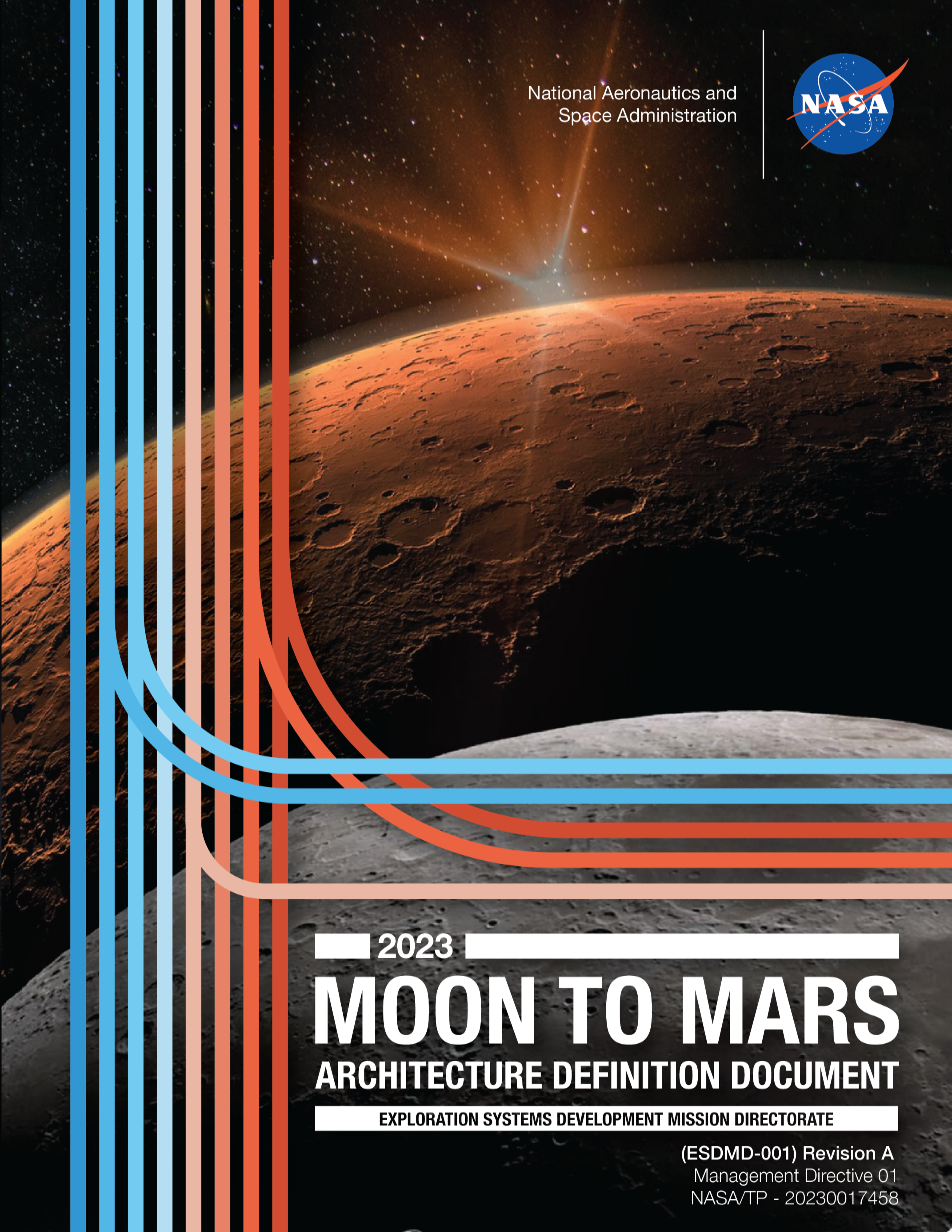

National Aeronautics and
Space Administration

2023

MOON TO MARS

ARCHITECTURE DEFINITION DOCUMENT

EXPLORATION SYSTEMS DEVELOPMENT MISSION DIRECTORATE

(ESDMD-001) Revision A

Management Directive 01

NASA/TP - 20230017458

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Exploration Systems Development Mission Directorate

Moon to Mars Architecture Definition Document (ESDMD-001) – Revision A – Management Directive 01

National Aeronautics and
Space Administration

Mary W. Jackson Headquarters
Washington, D.C.

March 2024

EXECUTIVE SUMMARY

The National Aeronautics and Space Administration's (NASA) mission is to explore the unknown in air and space, innovate for the benefit of humanity, and inspire the world through discovery. Key in this mission is extending the reach of humanity through the human exploration of the Moon, Mars, and beyond. To enable this effort, NASA's Moon to Mars Strategy and Objectives document establishes long-term goals and objectives; however, the practical management and execution to ensure objective satisfaction requires an innovative approach to the definition of NASA's Moon to Mars human exploration architecture. An architecture is the high-level unifying structure that defines a system. It provides a set of rules, guidelines, and constraints that defines a cohesive and coherent structure consisting of constituent parts, relationships, and connections that establish how those parts fit and work together. This Architecture Definition Document (ADD) establishes the process, framework, and decomposition of objectives to empower the executing systems', programs', and projects' success in achieving human exploration of the cosmos. The ADD will be updated annually to reflect the maturation of the architecture and the progress of NASA and partners toward achieving exploration objectives.

As established in the Moon to Mars Strategy and Objectives, "Why" we explore encompasses three pillars: Science, Inspiration, and National Posture. Ensuring success in all three areas requires an architectural approach that incorporates innovation, collaboration, and partnerships that can be sustained across a multi-decadal effort. This version of the ADD, developed to support NASA's 2023 Architecture Concept Review, incorporates several key updates to support the continued evolution of the architecture. Continuing the progress of Moon to Mars blueprint objective decomposition, characteristics and needs have been incorporated for the previously deferred Mars-focused objectives. These elements expand on the efforts needed to satisfy the objectives in the long term and provide additional traceability to Mars-forward lunar efforts for demonstrations and development. Based on both internal study and feedback across a range of stakeholders and partners, NASA has refined the lunar objective characteristics, needs, use cases, and functions. Many of these updates reflect inputs related to clarity in definitions or application, consistency, and additional definition for the Foundational Exploration segment. Iteration is essential for reflecting stakeholder needs, reflecting analysis and study results, and incorporating technology or innovations as they occur. These collective updates are reflected in a significant iteration to the complete objective decomposition contained in Appendix A.

The first Moon to Mars campaign segment, Human Lunar Return, establishes the initial capabilities, systems, and operations necessary to re-establish human presence on and around the Moon. Considerable effort was focused on the implementation of the supporting use cases and functions to this segment in the prior release, and updates reflect the refinements noted above. These use cases and functions include traceability to the established and emerging Foundational Exploration segment elements. Allocations and element definitions were developed for the Gateway Expanded Capability Configuration, which includes the Gateway External Robotic System and the European System Providing Refueling, Infrastructure and Telecommunications (ESPRIT) Refueling Module for the cislunar orbiting platform's architecture support. Additionally, the 2023 ADD includes the lunar surface element additions of the Human-class Delivery Lander, Lunar Terrain Vehicle, and the Pressurized Rover to enable greater exploration access across the lunar South Pole. Study of needs to support objectives and integration across the Foundational Exploration segment also led to the inclusion of four additional sub-architectures: Infrastructure, In-Situ Resource Utilization, Autonomous Systems & Robotics, and Data Systems and Management.

Throughout this architectural approach, the continual development and incremental progress will be measured, assessed, and matured to facilitate the Humans to Mars segment, including the

initial capabilities, systems, and operations necessary to support Mars missions and continued exploration beyond Mars. Assessment and analysis in support of this segment was a key focus for NASA architectural team efforts during this period. Content updates and discussion of drivers related to the Mars architectural efforts have been incorporated to increase the communication with partners relative to future studies necessary.

Finally, discussion of the recurring tenets (RT) and their application throughout the Moon to Mars Architecture were noted as deferred content during the prior ADD version development. These assessments are reflected in this revision throughout Section 4, including updates to RT-1 International Collaboration, which was addressed in the baseline version. This section provides significant additional context to NASA's efforts to ensure adherence to the principles by which we explore. Ultimately, this architectural approach was established to communicate and facilitate the expansion of humans into the universe according to the principles and tenets of NASA's Moon to Mars Strategy and Objectives. The NASA architecture team thanks the many stakeholders, participants, and partners for their efforts to review and provide feedback in support of the Moon to Mars Architecture process, which is a critical feature to the success of this approach.

REVISION AND HISTORY

The NASA Office of Primary Responsibility for this document is the Exploration Systems Development Mission Directorate Architecture Development Office. Please visit https://www.nasa.gov/MoonToMarsArchitecture for the latest version and updates to the Moon to Mars Architecture and exploration campaign.

Revision Identification	Description	Release Date
Initial	Initial Release (Reference NASA/TP-20230002706)	04/18/2023
Revision A	Updates for 2023 Architecture Concept Review • Refined sub-architectures and added the following: Data Systems and Management, Infrastructure, ISRU, Robotics (Section 1.3.2.1) • Refined and expanded objective decomposition into the characteristics and needs (Section 2.4 and Appendix A) • Added and updated use cases & functions (Appendix A) • Updated Human Lunar Return segment (Section 3.1) • Updated Foundational Exploration segment (Section 3.2) • Added the following elements with use cases & functions mapping: Gateway Expanded Capability Configuration, which includes Gateway External Robotic System (GERS), ESPRIT Refueling Module (ERM), and Gateway Airlock Module (ALM); Human-class Delivery Lander (HDL); Lunar Terrain Vehicle (LTV), and Pressurized Rover (PR) (Section 3.2) • Updated Humans to Mars segment (Section 3.4) • Added and updated assessments for all recurring tenets (Section 4.0)	01/22/2024
Revision A, Management Directive 1	Corrections of minor errata • Addition of FN-060-L and FN-062-L mapping to HLS in HLR and FE segments (Tables 3-10 and 3-23, respectively) • Updated definition of “cargo” • Updated definition of “consumables” • Removed “large cargo” from glossary	03/27/2024

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1.0 INTRODUCTION

An architecture is the high-level unifying structure that defines a system. It provides a set of rules, guidelines, and constraints that define a cohesive and coherent structure consisting of constituent parts, relationships, and connections that establish how those parts fit and work together. This definition, as found in the National Aeronautics and Space Administration (NASA) Systems Engineering Handbook,[1] is essential to capture the broad range of systems, programs, and projects supporting the human exploration of the Moon, Mars, and beyond. Although this definition is typically used for a single program construct rather than a multidecadal Moon to Mars human exploration architecture, the need for a unifying structure to address the magnitude of the endeavor remains. These goals represent the most complex systems engineering effort conducted by NASA to date. Ultimately, the programs, projects, and contributing systems will span decades, agencies, countries, cultures, and a variety of commercial, academic, and other types of contributors. Establishing a common architectural language, framework, and integration process to communicate and document the Moon to Mars system-of-systems is necessary, and this document is the first step in that process.

1.1 PURPOSE

An integrated architecture creates many opportunities to execute the ambitious Moon to Mars efforts. NASA addresses this in its Moon to Mars Strategy and Objectives Development[2] document (hereafter referred to as the Moon to Mars Strategy). Many of these opportunities involve establishing a systems engineering framework that can support the breadth of necessary program and system contributions. By applying these needs to nearer-term lunar development, NASA will be instituting the process, procedures, and techniques needed to enable longer-term Mars goals and more. Some of the challenges being addressed in the Moon to Mars Strategy are associated with the architecture definition, including broad/changing goals, funding, and external pressures/influences. This document and the methodology outlined for architecture definition have been crafted to contend with these challenges using an iterative and adaptable framework.

The primary purpose of the Architecture Definition Document (ADD) is to capture the methodology, organization, and decomposition necessary to translate the broad objectives outlined in the Moon to Mars Strategy into functions and use cases that can be allocated to implementable programs and projects. Inherent in this process will be the need to communicate the long-term vision, maintain traceability to responsible parties, and iterate on the architectural implementation as innovations and solutions develop. This document will be updated and improved in conjunction with the Architecture Concept Review (ACR), which will be held annually to get buy-in and input from across the Agency on the human exploration architecture. The annual nature of the process provides the opportunity to continually incorporate new developments in technologies and new partnerships, whether they are with industry, the U.S. Government, international entities, or academia.

1.2 SCOPE

The scope of this document is to capture the programs, projects, systems, and contributions that enable the human exploration of the Moon, Mars, and beyond. The Agency-level Moon to Mars Strategy encompasses the combined objectives that may be satisfied through human, robotic, or

[1] NASA System Engineering Handbook, SP-20170001761.
[2] NASA's Moon to Mars Strategy and Objectives Development, NP-2023-03-3115-HQ.

other efforts conducted across all Agency directorates. ESDMD has established this ADD, the methodology, and the decomposition of the objectives for the efforts applicable to the human exploration architecture and robotic systems interfacing with or supporting it. Agency blueprint goals and objectives will, in many cases, also decompose or be supported by independent robotic or other non-NASA systems that, in combination with the human architecture, contribute to complete objective satisfaction. Objective decompositions in the ADD identify objectives derived to support human exploration architecture and systems. They may also have other functions, features, or uses beyond those presented here. The Moon to Mars Architecture process will coordinate objective decomposition in conjunction with all NASA mission directorates.

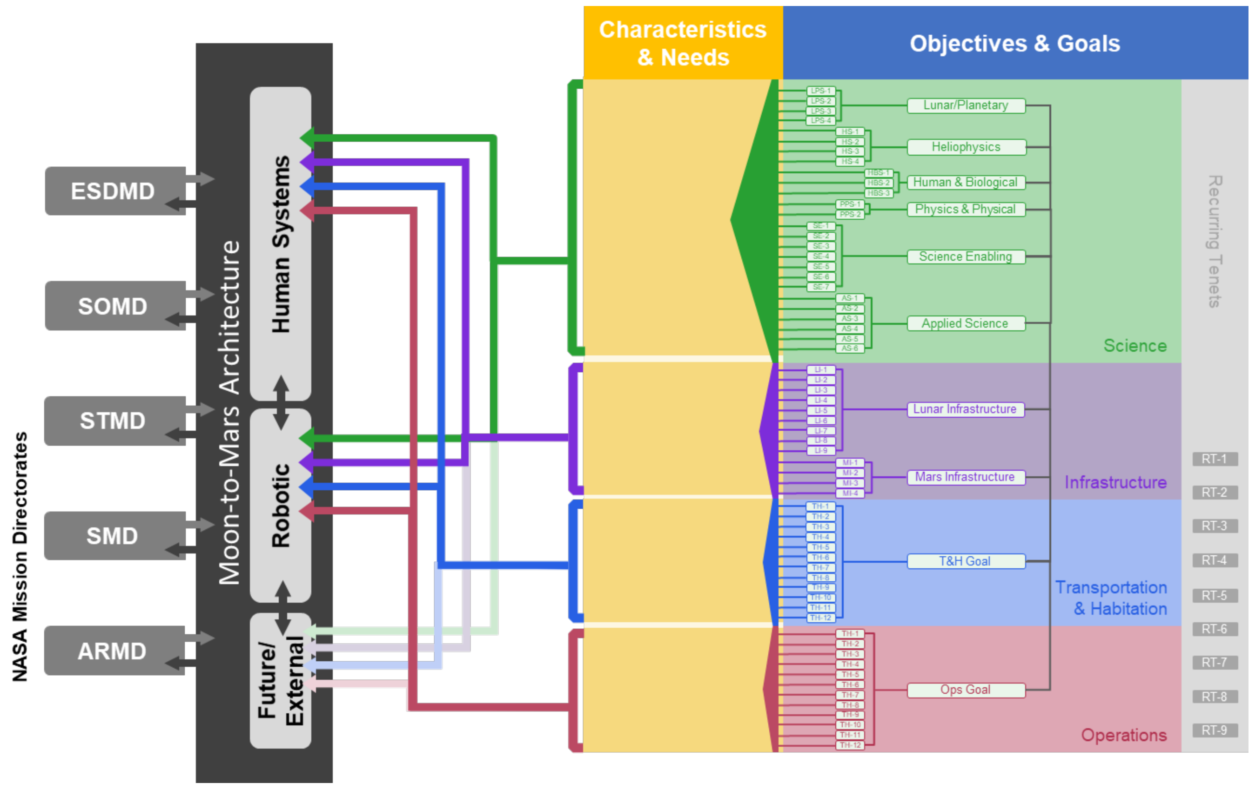


Figure 1-1. Human Exploration Moon to Mars Architecture Scope

1.2.1 ADD Content Structure

This ADD has been structured to reflect the architecture process and will be iterated on over time through subsequent analysis and integration efforts with partners. Section 1.0 describes the methodology and framework of the decomposition. This description includes definitions of the segments and sub-architectures used to describe the architecture and the process NASA will use to organize the decomposition through iterative cycles.

Section 2.0 Architecture Decomposition includes the rationale for the Lunar Architecture as viewed through a systems engineering lens. This describes the key drivers and questions that must be answered to arrive at the implemented architecture. Unique considerations for the Moon are also included. This section introduces the relationships between the architectural questions and how the order in which they are answered drives the Mars Architecture. In subsequent iterations of this document, this content will eventually be replaced by the Mars Architecture description as decisions are made and implemented. This section concludes with the decomposition of the objectives to the characteristics and needs the architecture must possess to support the Moon to Mars Strategy and Objectives.

Section 3.0 Moon to Mars Architecture describes the relationship of the characteristics and needs to assigned use cases and functions as applied to supporting architecture elements. These elements are organized by the architecture framework introduced in Section 1.0. In the scope of the ADD, one of the key drivers is to delineate between committed and funded elements and avoid premature inclusion of concept solutions. This approach is necessary to ensure the Moon to Mars Architecture reflects the open and evolutionary opportunities to support innovation, technology enhancements, and potential partnerships. As concepts are refined, the pre-formulation process develops elements into potential program/projects for implementation. These concepts are reviewed at NASA project management decision gates per the NASA Procedural Requirement 7120.5 NASA Space Flight Program and Project Management Requirements process. Following a successful NASA Mission Concept Review (MCR), an element will be approved as a candidate for inclusion into the architecture through the ACR process. NASA's project management decision gates, in combination with program/projects milestone reviews, will formally allocate architecture use cases and functions, key driving performance needs, and initial program/project concepts to the element. Additionally, following the successful completion of an MCR, the element concept also transitions to an implementing program/project phase. Through the ACR process, the ADD will be updated to capture the formal allocation of use cases and functions to the defined element in the appropriate segment. With respect to international partnerships, proposed cooperation will be included in the Moon to Mars Architecture and be reflected in the ADD upon the completion of internal NASA and partner reviews and conclusion of an appropriate international agreement. Section 3.0 also identifies open or unanswered questions in the architecture and the unallocated functions that are yet to be addressed by future systems or supporting elements. This section also includes descriptions of open trades or considerations for future architecture development are included, with an emphasis on the Mars Architecture.

Section 4.0 Assessment to the Recurring Tenets provides assessments of the architecture and reflects on the degree to which the architecture is adhering to the cross-cutting tenets of the strategy and objectives. These assessments are qualitative in nature to consider the state of the architecture and identify opportunities for revision. These will be living assessments updated on a recurring basis as the architecture adapts and develops. With respect to potential international partnerships, study agreements are developed to frame efforts. The ability to efficiently address gaps and needs in the architecture can be explored through strategic analysis, assessments of alternatives, and technology infusion studies. Results from these studies inform pre-formulation activities. Subsequent ADD revisions will be updated to reflect these efforts and potential areas of collaboration in the Section 4.0 RT-1 International Collaboration assessment.

The document content is followed by extensive decomposition and traceability tables in Appendix A. This appendix provides the complete traces from lunar objectives to the implementing element lunar use case and functions. Appendix B provides a list of acronyms and abbreviations and a glossary of terms for reference.

1.2.2 Content Outside of ADD Scope

During iteration of the ADD and communication of the architecture, it is important to what the ADD includes and intentionally excludes. This is necessary to capture the content that is within the scope of the architecture effort and delineate it from the existing process or other implementing organization areas of responsibility. To this end, the ADD is not…

… a replacement for existing processes or agreements.

Existing documented NASA mechanisms and processes for partnerships, procurements, etc., are unchanged and existing formal governmental processes remain in effect. The architecture approach is to engage and communicate in support of these processes and architecture products will be updated to reflect decisions from the formal processes.

… procurement direction.

As with existing processes and agreements, the NASA procurement process is a formally documented and highly managed activity. Architecture products, including the ADD, white papers, and other materials, are to communicate needs and not to presuppose solutions. Any indication of the procurement timing, requirements definition, and contract methods are defined within the procurement process. The ADD informs the procurement process by articulating the relationships for new elements in the context of the wider architecture.

… a manifest.

Actual flight manifests, sequences, or specific mission content or design are the responsibility of the Moon to Mars Program(s), partner planning, and contract mechanisms. Manifests are subject to the development, budget, schedule, and other pressures that are beyond the scope of the ADD. The architecture products reflect the content necessary to achieve the Moon to Mars goals and objectives and their effectiveness at doing so. The actual manifesting of flights or schedule to achieve the objectives are subject to the procurement, development, and implementation processes managed by the implementing programs.

… a budget request.

Decisions related to the creation of programs and elements occur in the context of the budget planning process and are not presupposed in the architecture documentation of needs. Ultimately, those needs may be fulfilled through various means coordinated through the existing processes and procedures including the budget analysis associated with them. Architecture products will inform those processes and reflect progress toward the objectives as decisions and content are approved, funded, or contributed.

1.3 Architecture Methodology

The Moon to Mars Strategy has developed two complementary principles to address the complex framework: architect from the right and execute from the left. Architecting from the right means beginning with the long-term goal (farthest to the right on a timeline) and working backwards from that goal to establish the complete set of elements that will be required for success. Derived from the decomposed plan, systems and elements execute from the left in a regular development process, integrating as systems move left to right within the architecture.

NASA developed an applied systems engineering method to facilitate applying these principles to the architecture definition. The first part of this method is an ordered process of objectives' decomposition to complete the process of architecting from the right. In this process, the characteristics and needs are identified to ensure objective satisfaction. These characteristics and needs are then traced to the functions and use cases that must be accomplished by elements and systems. The second supporting method is establishing an architectural framework to organize, integrate, and track the allocation of functions and use cases to the executing programs and projects. This structure will enable the integration of the system-of-systems development, identify gaps in the architecture, and adjust the architecture as left-to-right execution occurs, technologies mature, or objectives are satisfied. The architectural framework will be managed using sub-architectures and segments, which are discussed in Sections 1.3.2.1 and 1.3.2.2, respectively.

1.3.1 Objective Decomposition Process

As documented in the Moon to Mars Strategy, the broad top-level objectives of the Moon to Mars campaign have been identified with the help of stakeholders. These objectives establish desired results for NASA's exploration activities, with each objective defining a desired outcome of the Moon to Mars Architecture. Objectives were purposely drafted to be agnostic with respect to implementation, and thus do not specify architectural or operational solutions. Rather, they provide the goals to facilitate the development of an architecture and the means to measure progress.

To facilitate the objective decomposition process, several terms are defined as follows:

Table 1-1. Key Architecture Process Terms and Definitions

Architecture	The high-level unifying structure that defines a system. It provides a set of rules, guidelines, and constraints that define a cohesive and coherent structure consisting of constituent parts, relationships, and connections that establish how those parts fit and work together.[3]
Needs	Statements that drive architecture capability, are necessary to satisfy the Moon to Mars objectives, and identify a problem to be solved, but are not solutions.
Characteristics	Features or activities of exploration mission implementation necessary to satisfy the goals and objectives.
Use cases	Operations that would be executed to produce the desired needs and/or characteristics.
Functions	Actions that an architecture would perform to complete the desired use case.
Segments	Portions of the architecture, identified by one or more notional missions or integrated use cases, illustrating the interaction, relationships, and connections of the sub-architectures through progressively increasing operational complexity and objective satisfaction.
Sub-architecture	A group of tightly coupled elements, functions, and capabilities that perform together to accomplish architecture objectives.

[3] Definition from NASA System Engineering Handbook. SP-20170001761.

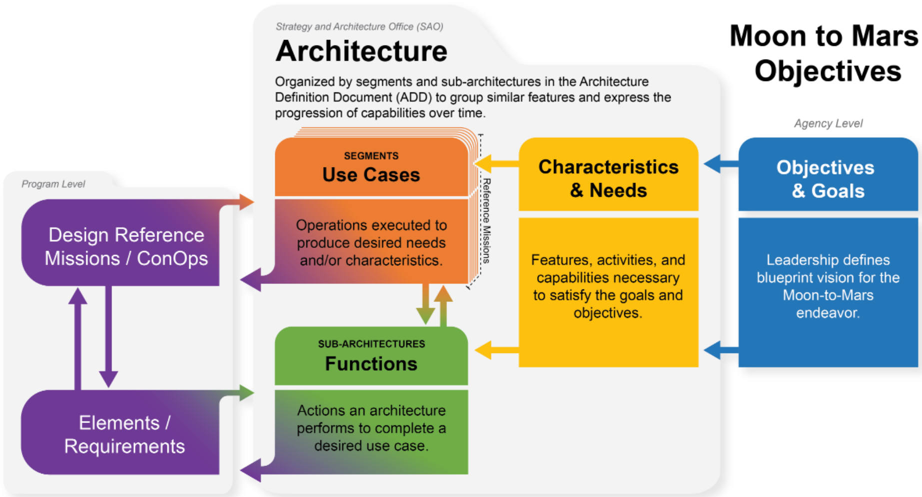


Figure 1-2. Objective Decomposition Process

The process that NASA will apply to define the exploration architecture, described in Figure 1-2, is rooted in the defined set of top-level objectives within the Moon to Mars Strategy. The process includes a series of discrete steps, each of which results in the progressive definition of needs with reduced abstraction in the architecture and increasing fidelity.

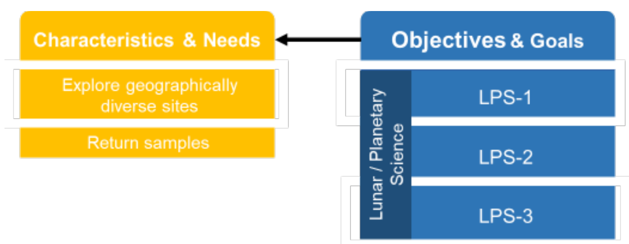


Figure 1-3. Notional Example Mapping of an Objective to Characteristics and Needs

The first step in this process is to define the characteristics and needs required to satisfy an objective or a group of objectives. While the objectives themselves focus on desired outcomes, the characteristics and needs translate those outcomes into the features or products of the exploration architecture necessary to produce those outcomes. Characteristics and needs are defined in a form that is still neutral regarding architectural implementation, not specifying a particular solution to produce the desired results, but rather focusing on what is produced or accomplished by the architecture. This step of the process is critical for converting generalized objectives into actionable exploration activities. Goal owners and stakeholders who are familiar with and helped to define the Moon to Mars Strategy top-level objectives contribute to the definition of the characteristics and needs, adding the detail needed to define the features and products. Figure 1-3 shows a partial and notional example of how one representative objective could be decomposed into a set of characteristics and needs.

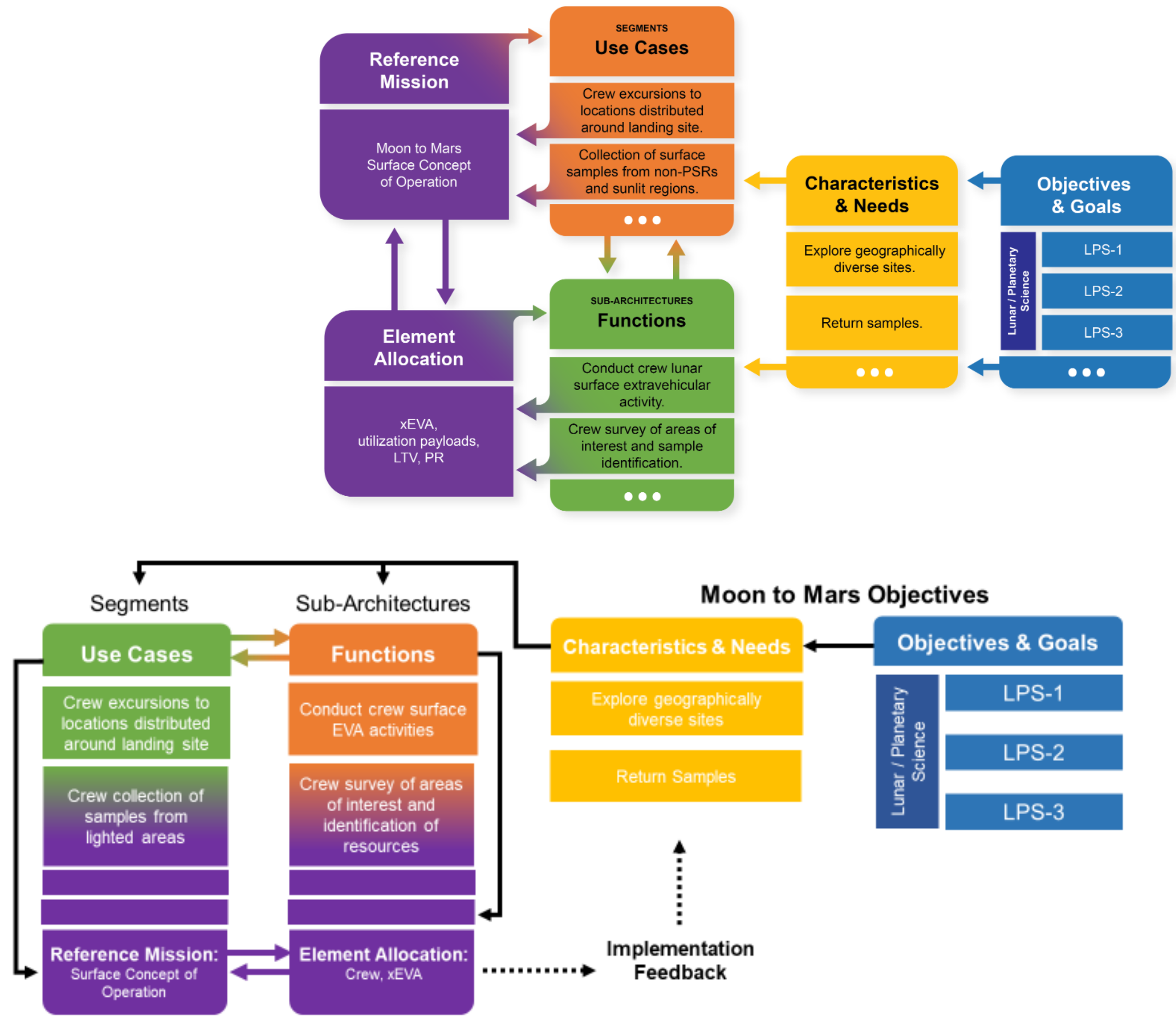


Figure 1-4. Notional Example Mapping of Characteristics and Needs to Functions and Use Cases

Once the characteristics and needs are defined, the next step in the process is to translate those statements into a more specific definition of implementable functions and use cases. This step adds further definition to the architectural needs and begins to define actionable features that could be included in the exploration architecture. Functions are the services or actions that would have to be produced by the exploration architecture to provide the desired characteristics and needs. Use cases describe how those functions are operationally employed to produce the desired characteristics and needs. Architecture teams formally decompose the characteristics and needs into functions and use cases, working with stakeholders to ensure that the defined functions and use cases would result in the desired outcomes.

In the last step in the decomposition process, the defined use cases and functions are organized to group similar features into representative reference missions, concepts of operations, and reference elements. Architecture teams, through trade studies and assessments, develop reference elements that can most effectively provide a subset, or group, of the desired functions within defined constraints. Similarly, teams develop reference missions and concepts of operations that employ those elements to fulfill the defined use cases. This step in the process is the first phase in the development of architectural solutions; it demonstrates the viability of the reference elements, reference missions, and concepts of operations in delivering the defined functions and use cases, providing the desired characteristics and needs, and satisfying the blueprint objectives. Figure 1-4 shows an example of how the notional characteristics and needs could be further decomposed into notional functions and use cases. The decomposition of blueprint objectives is provided in Appendix A and will continue to be refined during future process cycles.

The definitions of reference missions, concepts of operations, and system requirements can be traced from the use cases and functions. The allocated use cases and functions will be used throughout the program or project formulation process to address feasibility, definition, and scope. Programmatic assessments will identify the existence of feasible solutions to meet the assigned functions and use cases as requirements are instantiated. If adjustments are needed in formulation, functions/use cases may be descoped for allocation to a different system later in the architecture process. During design and development, assessments will be conducted to ensure the system is achieving the expected architectural functions or adjustments are made as needed. Groupings and definitions may change as designs progress and/or are better understood; however, the mapping of objectives to reference missions, concepts of operations, and systems should be continually revisited to assure objective satisfaction as intended.

1.3.2 Architecture Framework

Given the scale of the Moon to Mars Architecture, it is necessary to establish a framework for partitioning the effort into portions that are executable by NASA and its partners. Instituting a systems engineering process that empowers incremental advancements and the ability to infuse innovations in technologies and solutions provides the opportunity for economic benefit and the incorporation of partnerships while ensuring that objectives are systematically accomplished. In a typical systems engineering process, the architecture would be fully established up front, the requirements and concept of operations would be defined, and the programs would begin execution. This traditional method, if applied to the scale of Moon to Mars Architecture, would therefore have to “pick” the mission profile, technologies, and development schedule for an enormous number of projects up front and would be biased toward mature solutions and capabilities that exist today. This traditional “single pass through” architecture definition has been attempted for Moon and Mars systems many times in the past with limited success, as discussed in the Moon to Mars Strategy document.

To contend with this architecture breadth, NASA established an iterative framework process using two types of integration categories. The first type is to group tightly coupled systems, needs, and capabilities that function together to accomplish objectives as sub-architectures, similar to a system-to-sub-system relationship. More detail on the sub-architectures can be found in Table 1-2.

The second type is to establish segments defined as a portion of the architecture, identified by one or more notional missions or integrated use cases, illustrating the interaction, relationships, and connections of the sub-architectures through progressively increasing operational complexity and objective satisfaction. The specific segments are discussed in Section 3.0 and Table 3-1. Segments reflect the integration reference missions established to ensure elements can function together. Actual missions and segments operations may overlap; it is not necessary to complete one mission or segment before functions and projects in the next begin operations. Together, these provide horizontal (sub-architecture) and vertical (segment) integration to provide traceability in the Moon to Mars Architecture definition as illustrated in Figure 1-5.

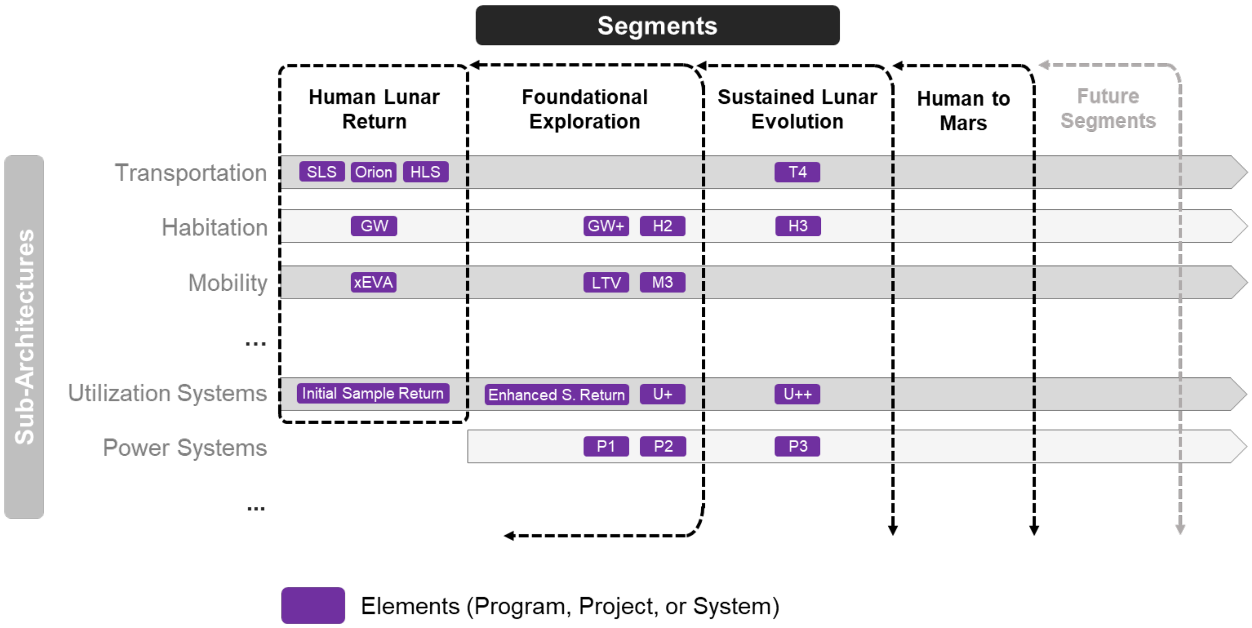


Figure 1-5. Illustration of the Moon to Mars Architecture Framework, (+/- denote added or reassigned functions)

In the Architecture Framework, the sub-architectures and segments will be used to ensure coherence in the elements, which may include various programs, projects, or systems, as represented by the lettered and numbered boxes. These programs and projects will be expanded or added to over time, plus additional elements with which they will need to interface within a sub-architecture. Segments will describe the relationship and cooperation across these elements. As systems mature, functions may be added or reassigned to reflect capabilities or implementations through the design or evolution of systems.

1.3.2.1 Sub-Architecture Definitions

The use of sub-architectures addresses the complexity of programs, projects, systems, and operations that span multiple sources or elements but must interact in a tightly coupled manner. By sub-dividing the architecture, functions and use cases can be assessed for consistency, gaps, or improvements. These sub-architectures will then evolve through the ADD iterations as functions and use cases are assigned to associated elements and systems to facilitate increasing capabilities toward the accomplishment of objectives. As shown in Figure 1-5, sub-architectures will add elements and systems through the progression of segments to achieve the associated characteristics and needs. These sub-architectures can facilitate and identify the areas where common standards and interoperability of associated elements are beneficial to ensure consistency in functions and allocations. Once identified, architecture-level interconnections can also be included in respective sub-architectures (e.g., Data Systems and Management) to ensure interoperability and application of common standards.

Table 1-2. Sub-Architecture Definitions

Communication, Positioning, Navigation, and Timing Systems	A group of services that enable the transmission and reception of end-to-end data flows such as commands, telemetry, video, files, and voice across all elements and all missions, the ability to accurately and precisely determine location and orientation, the capability to determine current and desired position, and the ability to acquire and maintain accurate and precise time from a standard.
Data Systems and Management	The group of capabilities that works together to transfer, distribute, receive, validate, secure, decode, format, compile, and/or process data and commands for use throughout the architecture. This includes future capabilities such as internet of things (IoT), cloud computing, servers, etc.
Habitation Systems	A group of capabilities that provide controlled environments to ensure crew health and performance.
Human Systems	The overall capabilities of the crew, ground personnel, and the supporting systems required to develop and execute safe and successful crewed and uncrewed missions.
Infrastructure Support	The group of support capabilities including facilities (e.g., structures, site improvements, manufacturing/fabrication shops, and other labs), systems (e.g., environmental monitoring, contamination control, food/crop management), operations planning and control, equipment (e.g., access, construction, heavy equipment & common tools), and services (e.g., commodity storage & handling; inspection, maintenance, and repair) needed across all domains (i.e., Earth, in space, and surfaces).
In-Situ Resource Utilization Systems	The group of capabilities dealing with estimating resource reserves and harvesting these resources to generate products (e.g., consumables, feedstocks for manufacturing and construction) on other planetary bodies (the Moon, Mars, etc.) or environments to further the goals of a project or mission while reducing the reliance on Earth-based resources and make space missions more sustainable and cost-effective.
Logistics Systems	Systems and capabilities needed for packaging, handling, transport, staging, storage, tracking, and transfer of logistics items and cargo, including equipment, spares required for anticipated repairs, materials, supplies, and consumables including capabilities for disposal.
Mobility Systems	A group of capabilities and functions that enable mobility of crew and/or cargo on and around the

	surface of the destination, including extravehicular activity systems.
Power Systems	Capabilities that support the function of providing electrical energy to architectural elements. These capabilities include components and hardware for power generation, power conditioning and distribution, and energy storage.
Autonomous Systems & Robotics	A group of capabilities which are accomplished with the use of software and hardware devices that can assist the crew and operate during uncrewed periods, either autonomously and/or via remote operator control (tele-robotics).
Transportation Systems	Capabilities that provide the transportation functions for all phases of the Moon and Mars missions for both crew and cargo, including in-space; entry, descent, and landing (EDL); and ascent for all Earth, Moon, and Mars phases.
Utilization Systems	A group of capabilities whose primary function is to accomplish utilization which enables science and technology demonstrations.

The initial set of identified sub-architectures reflects the current state of program and project development and current integration challenges. While the sub-architectures are defined independently, they will have interfaces and dependencies with other sub-architectures and will all work together to perform utilization activities supported by the architecture. The current sub-architectures will be refined and new sub-architectures will be identified during the Architecture Concept Review cycles. Table 1-2 identifies and provides rationale for the initial sub-architectures.

1.3.2.1.1 Communication, Positioning, Navigation, and Timing Systems

The Communication, Positioning, Navigation, and Timing (CPNT) sub-architecture is a group of services that enable the transmission and reception of end-to-end data flows such as commands, telemetry, video, files, and voice across all elements and provides all missions with the ability to accurately and precisely determine location and orientation, the capability to determine current and desired position, and the ability to acquire and maintain accurate and precise time from a standard. The regions in which service is available, the delivery mechanisms for those services to those areas, and the evolution of each aspect throughout the lifetime of the architecture are all key factors that will affect CPNT implementation. Another key consideration for a strong foundation is maximizing the interoperability of CPNT assets throughout an evolving architecture with many different providers and users (e.g., government, commercial, scientific, international). As the architecture evolves, the CPNT sub-architecture and concept of operations will scale based on the developing user needs and will evolve by collecting ground truth data as the campaign progresses. Services may expand (for example, with high-throughput optical links), and service regions may expand to include larger volumes of data on the South Pole and Far Side. Position, navigation, and timing services may expand to more Global Navigation Satellite System (GNSS)–like capabilities by providing services on a global or regional basis. Accurate positioning is essential for crew and asset applications like navigation, tracking, surveying, and geolocation-based capabilities and services. The evolution of lunar communications and navigation capabilities will close knowledge gaps to enable NASA and its partners to develop communications and navigation capabilities and concepts of operations for Mars missions.

1.3.2.1.2 Data Systems and Management

The Data Systems and Management sub-architecture includes capabilities that work together to move, manage, and secure/protect data within acceptable latency constraints for use throughout the architecture. This sub-architecture is tightly coupled with the CPNT and human system sub-architectures to ensure data is shared and made useful across the architecture. Future capabilities may include data fusion, internet of things (IoT), cloud computing, and servers. The implementation of this sub-architecture spans from Earth systems, space, and planetary surfaces. Not all capabilities are expected to reside in-situ; each domain will include a mixture of assets.

Data systems and management play a pivotal role in modern information-driven landscapes. This area encompasses the intricate framework of tools, processes, representations, and technologies designed to capture, store, process, and retrieve data efficiently and securely. From small-scale payloads to large, complex mission sequences, effective data management across the Moon to Mars Architecture ensures that valuable insights can be derived from raw data, driving informed decision making and providing broad access as allowed.

These systems can consist of databases, their management systems, data warehouses, and data lakes that collectively organize and maintain data integrity. With the advent of big data, cloud computing, and advanced analytics, modern data systems not only handle structured information, but also embrace unstructured and semi-structured data formats. A robust data management strategy considers data availability, quality, interoperability, security, privacy, compliance, and access to ensure that we can harness the full potential of the expansive amount of lunar data, fostering innovation across the architecture.

1.3.2.1.3 Habitation Systems

The Habitation sub-architecture is a group of capabilities that provide controlled environments to ensure crew health and performance over the course of missions. This functionality extends across multiple applications throughout the architecture and is tailored to suit the location and environment (e.g., deep space, lunar surface, Martian surface). Common habitation functions include environmental control and life support (ECLS), power, communications, thermal control, command and data handling, extravehicular activity (EVA) support (e.g., ingress/egress, suit services, worksite accommodations), crew habitability (e.g., hygiene, food and nutrition, waste management, sleep, crew exercise), crew health (e.g., health and medical care, human performance, psychological support), and crew survival (e.g. pressurized suits, safe haven), among others. These functions may scale in size and complexity based upon crew size, mission duration, operational environment, and the ability to share functionality through interfaces with other elements (e.g., consumables and power transfer). As such, the volume and structure supporting habitation can vary drastically and potentially include modular, connected, pressurized volumes of various materials (e.g., inflatable soft goods, metallic structure, in-situ constructed elements). While crew size and mission duration are primary factors in scaling the appropriate habitable volumes, other factors such as gravity environment, crew tasks, and required motions (e.g., supportability of on-board equipment; accommodation of science and technology utilization; and logistical stowage and resupply that require controlled, pressurized environments) also factor into overall volume. Some key trades to help scope such habitation elements include EVA ingress/egress methods, logistics resupply needs, and use of regenerable ECLS systems. To maximize the availability of crew time to perform science and technology utilization activities and to maintain nominal operation in each operational environment while uncrewed, habitation elements must use system autonomy (e.g., vehicle/element control and operation, including planning/scheduling/execution and fault management; identification/recovery; robotic assistance) while also enabling crew control (i.e., manual operations, software override) for critical functions and troubleshooting during unforeseen contingencies.

1.3.2.1.4 Human Systems

The Human Systems sub-architecture covers the collective capabilities of the flight crew, ground/mission teams, mission systems, and enabling architecture required to develop and execute safe and successful crewed and uncrewed missions that are not covered by sub-architectures like Habitation Systems, Mobility Systems, Logistics Systems, and others. However, the Human Systems sub-architecture is tightly coupled with all the other sub-architectures. Human Systems is unique from the other hardware sub-architectures; it significantly expands exploration beyond uncrewed mission capabilities. These systems ensure the safety and success of the mission and the well-being of the crew. They require a multidisciplinary approach, involving expertise in engineering, medicine, space science, human factors, safety and mission assurance, and operations. These systems are crucial for monitoring and maintaining crew health, enabling crew to accomplish the jobs required across the architecture, supporting the crew's physical and mental performance, and keeping the crew safe and comfortable during the mission.

The humans who embark on the exploration missions are the most critical component of the campaign to get humans to the Moon and, ultimately, to Mars. Vehicles, systems, training, and operations must be designed around the "human system." The success of ambitious lunar and Mars crewed missions will largely be determined by the degree to which the human system is strategically considered and integrated into the architecture. The architecture and implementation should allow the crew to move and operate seamlessly across elements to execute the mission. The Artemis Flight Control Team, consisting of the Mission Control Center – Houston (MCC-H) and other NASA/partner control centers, will monitor and control the crewed and uncrewed Artemis elements. This distributed operations model leverages decades of experience from International Space Station collaboration with international and commercial partners while advancing partner roles for Artemis. Standards for human-rated systems, design and construction, safety and mission assurance, crew health and performance, flight operations, crew and ground personnel training and certification, and system interoperability are necessary to conduct safe and successful missions. Mars missions will require NASA and its partners to fill key knowledge gaps and establish standards related to human performance after extended deconditioning beyond the ISS 6-to-12-month mission timeframe, with crew-Earth communication delays beyond a few seconds, and/or with total Earth autonomy for up to two weeks. Human capabilities and limitations within the context of mission-induced environments will drive the enabling architecture for element robustness, integrated capabilities, interoperable/consistent interfaces, human system integration (HSI), and crew health and performance (CHP).

1.3.2.1.5 Infrastructure Support

The Infrastructure Support sub-architecture describes the infrastructure associated with the operations of the Moon to Mars endeavor across the Earth (ground), in space, and in extraterrestrial surface domains. Several of the sub-architectures will have facilities, systems, equipment, and services in these domains that require supporting infrastructure. For example, ground processing of spaceflight elements and logistics items supports the transportation sub-architecture. Other examples include landing and recovery infrastructure on the ground for returning transportation vehicles and curation facilities for samples returned from the Moon and Mars. An in-space example is landers that require adapters to transfer stages. Surface examples include equipment needed for handling, accessing, and transferring dry goods and fluid commodities and common and portable lighting support equipment, both of which are likely to be shared across sub-architectures. Surface examples may also include prepared regolith surfaces or structures to minimize lofted dust, facilitate transfer of materials, and maximize crew mobility.

1.3.2.1.6 In-Situ Resource Utilization (ISRU) Systems

In-situ resource utilization (ISRU) is the concept of locating, mapping, and estimating extraterrestrial resource reserves and extracting and processing these local resources to generate products instead of delivering the products from Earth. As humans stay longer and go farther into space and the focus turns to more sustainable commercial operations and Earth independence, missions will incorporate ISRU practices. ISRU starts with identifying, characterizing, and mapping the resources at potential sites of exploration. ISRU identifies products that can significantly reduce mission cost and risk or enable new mission options, such as utilizing local resources (both natural resources, such as regolith, water, atmosphere, etc., as well as crew trash, waste, discarded hardware, etc.) to produce water, propellant, and other supplies, and capabilities to excavate and construct structures on an extraterrestrial body. ISRU pathways include commercial-scale water, oxygen, and metals; consumables for humans and food production; feedstock for construction, manufacturing, and energy; and commodities for reusable in-space and surface transportation and depots.

For successful implementation, ISRU systems and capabilities must obtain products and services from other lunar systems and infrastructure, and ISRU systems and operations require customers/users to utilize the products/commodities they produce. Lunar support services and infrastructure for ISRU systems include material transfer and asset movement between ISRU resource extraction, processing, waste tailing, product storage sites, handling and manipulation of resources and bulk regolith, local navigational aids, communications to/from and within ISRU operational sites, power transmission and management, crew and robotic logistics management, maintenance, and repair capabilities, and construction of roads and infrastructure to/from and on the ISRU operation sites. To achieve the full benefits of using in-situ derived products and to meet the intent of Moon to Mars Objective OP-11, customer/users need to design their systems and concepts of operation around the availability and location of these products and how they can be provided. To minimize the risk to the Artemis campaign and ISRU product customers, NASA and its partners must plan a transition of Earth-delivered to ISRU-derived products, along with adequate resource mapping and demonstration of the ISRU processes and product quality.

1.3.2.1.7 Logistics Systems

The Logistics Systems sub-architecture includes the systems and capabilities needed for packaging, handling, staging, and transferring logistics goods, including equipment, materials, supplies, and consumables needed to support use cases and meet architecture functional needs. This sub-architecture also includes approaches and capabilities for addressing trash and waste management. During the initial part of the campaign, the capability for logistics goods and consumables will be limited to those that arrive with the crew. As time advances, additional functions are introduced into the architecture. The logistics needs will broaden as the sub-architectures mature. Over time, the architecture will require solutions for increasing Mars mission duration. The need to deliver elements, payloads, cargo, experiments, and larger quantities of logistics and to better address inventory management, trash, and waste disposal functions necessary to support the missions and meet planetary protection requirements will increase. As the sub-architecture matures, the capabilities can continue to grow to take advantage of increased automation and/or in-situ resource sourcing of logistics to support increased mission durations.

1.3.2.1.8 Mobility Systems

The Mobility Systems sub-architecture is a group of capabilities and functions that enable the mobility of crew and/or cargo on and around the destination, including EVA systems. This sub-architecture extends the range of exploration and external operations in support of science. It spans robotic and crewed systems with both pressurized and unpressurized capabilities. Mobility systems will likely need to interface with other sub-architecture capabilities like power, CPNT, habitation, and logistics to accomplish the desired outcomes.

1.3.2.1.9 Power Systems

The Power Systems sub-architecture is a group of capabilities that support the function of providing electrical energy to architectural elements. These capabilities include components and hardware for power generation (e.g., solar arrays, fission surface power [FSP]), power distribution (e.g., electrical cables, induction), and energy storage (e.g., batteries, regenerative fuel cells). A primary aspect of the power sub-architecture is interoperability, including standardized power interfaces (either hard or inductive connections) and compatible power quality standards. The power sub-architecture will include the coordination of missions where elements are expected to provide their own power with the development of energy infrastructure to support future needs.

1.3.2.1.10 Autonomous Systems and Robotics Systems

The Autonomous Systems and Robotics (AS&R) sub-architecture aims to integrate the unique and complementary capabilities of humans and robotic systems to maximize the crew's efficiency, provide needed capabilities during uncrewed mission phases, and expand the range of possible exploration, science, and utilization activities across the architecture. Robots are well suited to not only tedious, highly repetitive, or hazardous tasks, but can also augment the abilities of human explorers through tailored suites of instruments or capabilities. This assistance enables the crew to focus on higher-priority activities while at the destination and improves safety without sacrificing operational effectiveness or mission reach. Robotics capable of efficient and effective mobility and manipulation improve remote access to areas of scientific interest; asset handling, repositioning, and utilization; logistics management; and infrastructure assembly, outfitting, and maintenance during crewed operations (and enable them in the absence of crew). During both crewed and uncrewed periods, robotic operations will be performed remotely via teleoperations of robotic systems or with increasing levels of autonomy, requiring minimal human interaction. The AS&R sub-architecture includes capabilities and systems that can (1) assist the crew (working in tandem or collaboratively with them), (2) perform operations at a distance from crew under their control or supervision, (3) operate remotely in the absence of crew, and (4) perform tasks in parallel to crew independent of crew timelines and requiring no oversight or intervention by the crew. The sub-architecture also includes support systems and equipment on Earth, such as simulations, planning and scheduling tools, and ground analog test beds. The sub-architecture spans the Earth (ground), cislunar space, and lunar surface environments, and eventually includes Mars.

1.3.2.1.11 Transportation Systems

The Transportation sub-architecture is the collection of capabilities that provide the transportation functions for all phases of the Moon and Mars missions for both crew and cargo, including in space; entry, descent, and landing (EDL); and ascent for all Earth, Moon, and Mars phases. The transportation systems will need to interface with or be incorporated into a variety of systems and payloads, including habitation and other human support systems, as well as refueling or recharging systems, all in diverse environments, including in-space and surface conditions. Initial lunar segments will include transportation capabilities for the transit of crew and cargo to cislunar space, the landing of crew and cargo on the surface, crew and limited cargo ascent to cislunar space, and return to Earth. As the architecture expands toward Mars, the transportation sub-architecture will evolve to include Mars transit, EDL, and ascent systems for cargo and crew.

1.3.2.1.12 Utilization Systems

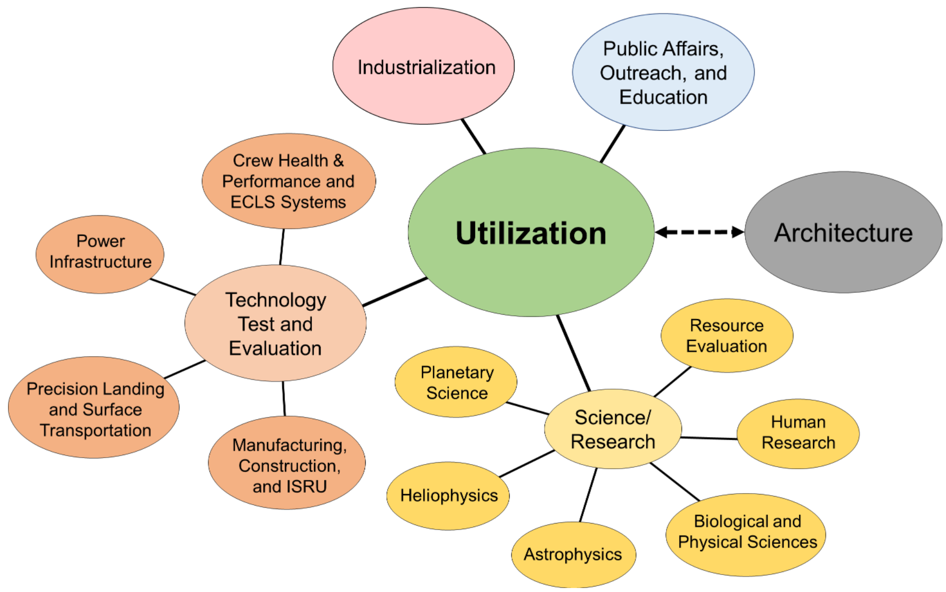


Figure 1-6. Visualization of Utilization Areas

The Moon to Mars Strategy document[4] defines *utilization* as the "use of the platform, campaign and/or mission to conduct science, research, test and evaluation, public outreach, education, and industrialization." In this document, the term *utilization* is used generically to encompass all areas of utilization; specific terms, such as "science or technology demonstration," are used where the meaning is more specific. The Utilization Systems sub-architecture is a group of capabilities whose primary function is to accomplish these science, technology, and other activities, including sample and utilization cargo return to Earth. In this sense, the Moon to Mars Architecture provides a platform of functions to a broad set of organizations in support of their needs. Inherent in the Moon to Mars Architecture is that all the sub-architectures ultimately support utilization; utilization systems will levy functions and use cases on all other sub-architectures. The major utilization areas of emphasis for the Moon to Mars Architecture are depicted in Figure 1-6.

Utilization is achieved through not just the capabilities in the Utilization Systems sub-architecture, but the entire architecture. For instance, a technology may be demonstrated under the umbrella of utilization on one mission and, through technology maturation, provide essential services as part of the exploration platform on subsequent missions. Similarly, some items may serve multiple functions (e.g., multi-purpose cameras used for both science and operations, equipment shared between human research and medical operations). However, systems whose primary purpose is to achieve utilization, and not just enable the mission, will be included in the utilization sub-architecture.

1.3.2.1.13 Future Sub-Architecture Development

As the focus of the Architecture Framework is to establish the process for recurrent architecture definition and refinement, the sub-architectures will continue evolve. The current sub-architectures were initially established based on knowledge gained from driving system requirements and included updates based on the revised use cases and functions. Future revisions will likely include additional sub-architectures.

[4] NASA's Moon to Mars Strategy and Objectives Development, NP-2023-03-3115-HQ.

1.3.2.2 Campaign Segment Definition

Segments capture the interaction, relationships, and connections of the sub-architectures at a specific phase. These would most commonly be typified by reference missions or operations use cases of the systems to illustrate how systems will work together to satisfy objectives. These examples provide the context for the allocation of functions to elements and systems in the sub-architectures, rather than prescriptive solutions. These segments will grow increasingly complex as systems are developed and added to the sub-architectures. The segments are crafted in a manner such that the knowledge gathered earlier in the campaign informs implementation later in the campaign. The segments integrate the exploration, utilization, and sustained development of the Moon, with preparation for the exploration of Mars. The segments integrate needs and capabilities over time but are not a defined launch manifest, as systems from a later segment may begin to appear as available. Further, in representing the context of the sub-architecture interactions, segments do not limit the types of missions that may be designed and flown. As systems are built, novel operations and uses are expected.

The segments, described in detail in Section 3, reflect the current Moon to Mars effort and provide open opportunities to refine and include use cases in the architecture as systems and technologies mature. The segments and their content will evolve through the annual ACR cycles to reflect the inputs, capabilities, and needs identified across the partners to achieve the Moon to Mars Strategy.

1.3.3 Architecture Definition Process

Having established the necessary components to decompose objectives (“architecting from the right”) and the framework to correlate the systems (“executing from the left”), the process by which these components and systems will be integrated remains. NASA and its partners established the process to enable an iterative allocation to programs and projects and infusion of solutions, technologies, and capabilities that emerge over time to address the strategy objectives. This process is managed by NASA’s Exploration Systems Development Mission Directorate through the coordination of Strategic Analysis Cycles (SAC). These cycles will occur annually to prioritize the work and studies needed to address open questions, identify potential architectural drivers to buy down mission risk, coordinate with partners, and identify and resolve gaps in the architecture. The cycles will conclude with study findings and/or updates and iteration to the Architecture Definition Document and supporting products, which are reviewed at the annual Architecture Concept Reviews.

These iterative cycles will need to both enable the definition of new elements or systems as they are added to the architecture by defining the allocated functions and needs and update and modify the architecture as existing elements and programs mature. The SAC process will also need to include assessments or studies of how emerging technologies or new solutions, whether from within NASA or from partners, could address architecture needs or modify the future segments. This complex analysis process will reflect a diversity of viewpoints, perspectives, and ideas from stakeholders and partners.

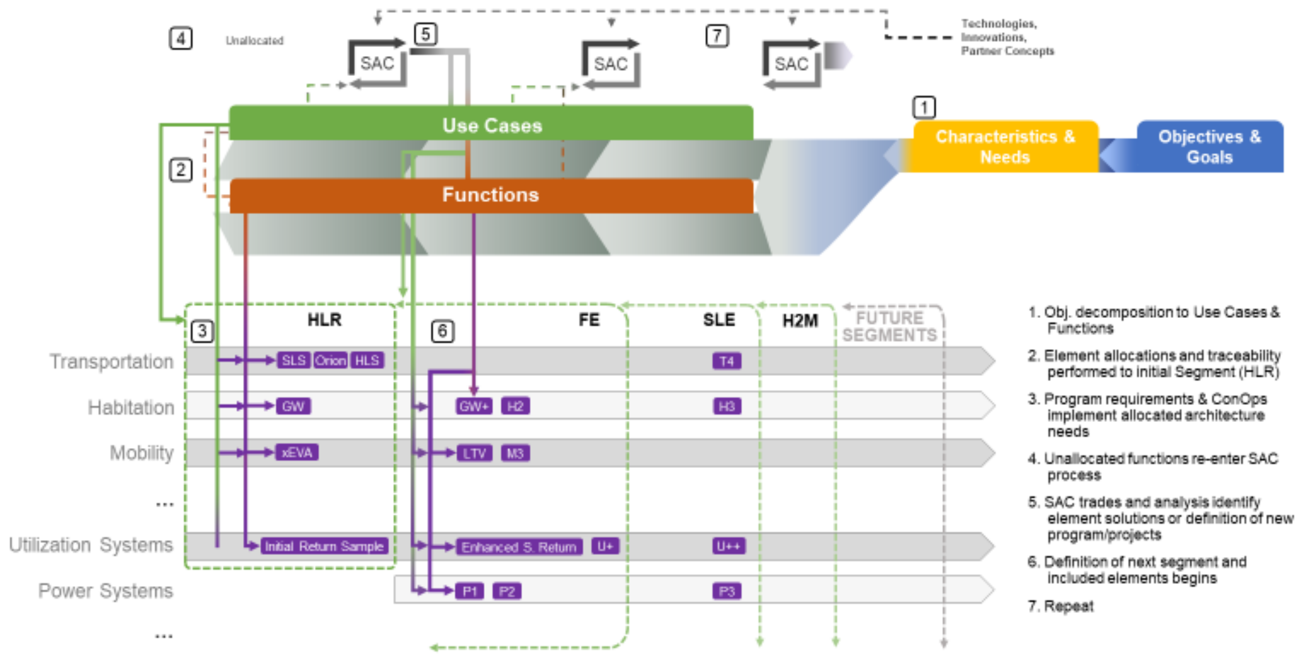


Figure 1-7. Illustration of the Architecture Definition Process

Table 1-3. Iterative Architecture Process Steps

1	Objectives decomposed to use cases and functions
2	Element allocations and traceability performed to segments
3	Program requirements and concepts of operation implementation allocated to architecture needs
4	Unallocated functions (gaps) re-enter SAC process w/ partner inputs/concepts
5	SAC trades and analysis identify element solutions or definition of new program/projects, including sub-architecture allocation and/or alignment
6	Definition of next segment and included elements begins
7	Repeat

Figure 1-7 shows the architecture definition process, which reflects the intersection of the architect from the right and execute from the left principles outlined in the Moon to Mars Strategy. Examples and representative systems using known sub-architectures, segments (discussed further in Section 3) and elements are used to illustrate this iterative process. This process reflects the reality the systems, functions, and needs of the most immediate segments are known and that significantly fewer allocations are made as the segments process to the right. Systems reflected in the current programs and projects are already executing their development and, in some cases, have conducted their first flights, such as the Space Launch System and Orion. Modifications to these existing systems should be limited or carefully traded in future segments. The SAC process will need to consider the programmatic trades in any allocation, whether existing or new systems are used, for cost, schedule, technical, and risk factors. The process steps are highlighted in Figure 1-7 are outlined in Table 1-3.

The SAC trade studies will continue to evaluate concepts and analysis to identify possible solutions to address unallocated functions and potential alternatives. Coordination with both internal NASA partners and external partner communities will be a key enabler to identify solutions that can most effectively satisfy objectives. Inputs of technological advancements, alternate concepts, and other innovations can be assessed for satisfaction to meet the integrated architecture needs during the SACs. These assessments will mature and refine allocations in partnership with the executing element or partner leadership to ensure traceability from the use cases and functions into the requirements and concepts of operations that formally establish the design process for execution. The SAC process will also consider technology advancements, alternative solutions, and different concepts to identify efficiencies or priorities for development in future segments. As program execution matures and actual missions are flown, the architecture will account for realized system performance and science discovery. These efforts will inform how future systems and elements are instantiated and developed as systems mature.

2.0 ARCHITECTURE DECOMPOSITION

A similar systems engineering process to the one applied at the strategic level in Section 1.0 can be used as a framework for the architecture by addressing the six key questions: Who, What, Where, When, How, and Why? (Figure 2-1.) Different stakeholders may find the answers to some of these questions more compelling than others: for example, engineers tend to focus on "How?," whereas technology developers may be more interested in "When?"; partners want to know "Who?," and scientists may be keen to discuss "Where?" and "What?" To reach consensus and move forward, an exploration architecture must address all six questions, but reiteration and negotiation may be required. The answer to any one question is less important than ensuring that the answers to all six fit together as an integrated whole.

Figure 2-1. Elements of a Compelling Architecture Story

2.1 Exploration Strategy: "Why Explore?"

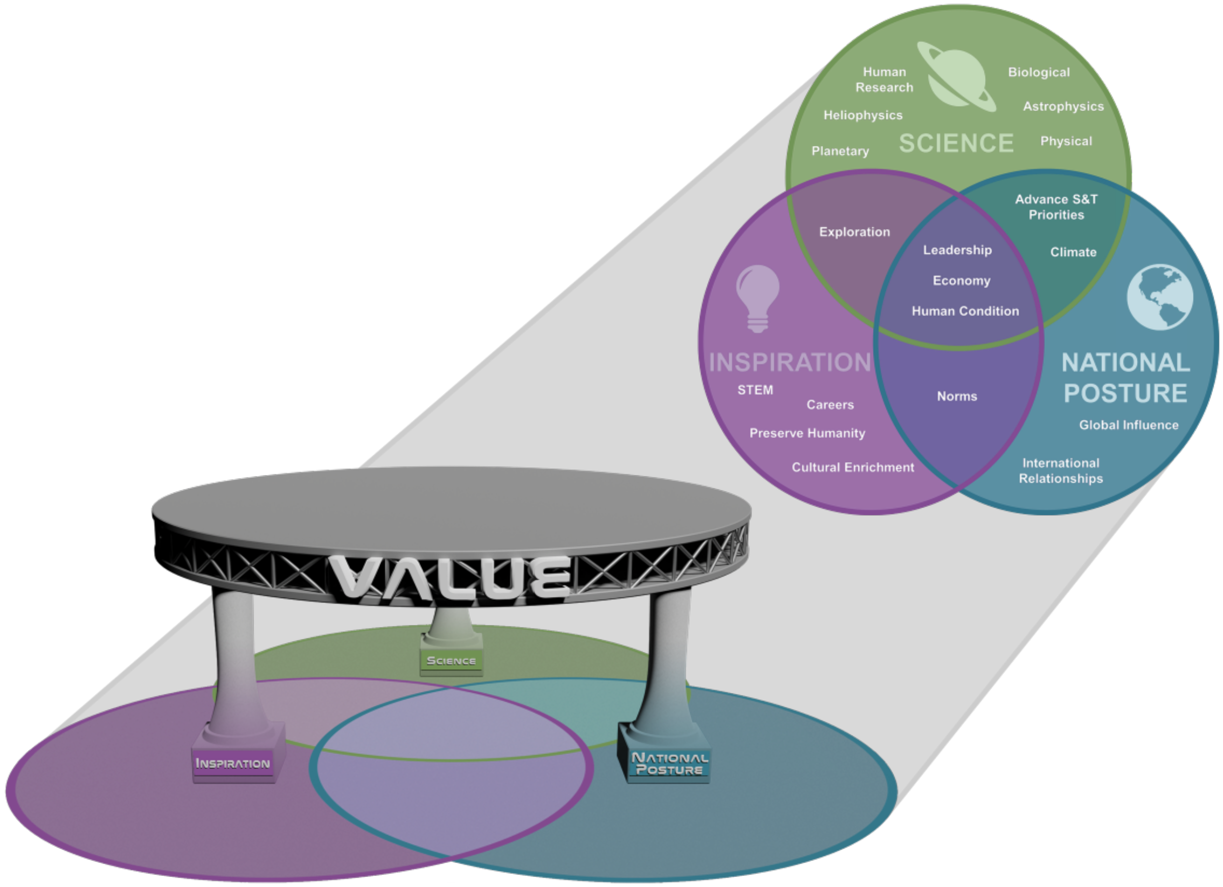


Figure 2-2. Three Pillars of Exploration from NASA's Moon to Mars Strategy and Objectives Development Document[5]

Systems engineering is predicated on the motivation, which is the fundamental goal. Why do this? For the blueprint vision and Moon to Mars endeavor, along with its goals, objectives, and subsequent architectural wireframe, the question is: Why send humans into space? Creating a blueprint for sustained human presence and exploration throughout the solar system provides a value proposition for humanity that is rooted across three balanced pillars: science, inspiration, and national posture. Each pillar contains both unique and intersecting stakeholder values that together form the value proposition for the blueprint vision, starting with the Moon to Mars endeavor (shown in Figure 2-2). While different individuals identify with different values, it is NASA's responsibility as a steward of taxpayer dollars to consider the entire landscape of motivating factors that underscore our society's answer to Why Go? Uniquely, by balancing all the factors, NASA positions the Moon to Mars strategy for longevity and success: it is not subject to whims or leadership overhauls. Instead, it is rooted deeply in a broadly relevant, largely unchanging value system. So, Why Go? These combined and intersecting three pillars, as illustrated in Figure 2-2, are why humans go into space.

[5] NASA's Moon to Mars Strategy and Objectives Development, NP-2023-03-3115-HQ.

2.1.1 Science

The pursuit of scientific knowledge—exploring and understanding the universe—is integral to the human space exploration endeavor. Just as the James Webb Space Telescope informs us about the history of time, answers gained on the Moon and Mars will build knowledge about the formation and evolution of the solar system and, more specifically, the Earth. From geology to solar, biological, and fundamental physics phenomena, exploration teaches us about the earliest solar system environment: whether and how the bombardments of nascent worlds influenced the emergence of life, how the Earth and Moon formed and evolved, and how volatiles (e.g., water) and other potential resources were distributed and transported throughout the solar system. Space exploration teaches us about human and plant physiology in extreme environments, how to mitigate engineering and health risks, and how to perform complex operations in harsh planetary environments. Space provides a unique vantage point to amplify learning on Earth. Biological and physical systems can be observed in partial gravity, bringing out second- and third-order effects that are otherwise overwhelmed in the gravity environment. The history of our Sun is preserved in lunar soil, examination of which enables solar activity predictions and space weather forecasts, which in turn support lunar and Martian exploration. Specific frequency ranges available for use only in space (because of interference by other Earth-based signals or the atmosphere) allow us to probe the universe's deepest space and time. While remote sensing is a great aid, robotic and human engagement with and visitation of other bodies in the solar system ultimately reap more data more effectively.

2.1.2 National Posture

By its very nature, achieving a vision of space exploration establishes national strength in science and technology innovation and competitiveness, which supports economic growth and global position. Hard technology problems solved in space have far-reaching implications for other Earth-based challenges and industries, and in many cases, spin off their own disciplines. For example, the term "software engineering" was crafted for the development of the guidance and navigation systems on Apollo spacecraft. Food safety standards and telemedicine likewise originated with NASA's effort to enable longer-duration human space flight. NASA technology, spin-offs, and investments fuel growth in American industry and support quality, high-paying jobs across the country. Specifically, NASA's contracts and partnership with domestic commercial space resulted in $15 billion in private investments in space start-up companies in a single year, most of which were with United States companies. Commercial space activity impacts other industries, such as agriculture, maritime, energy, and homeland security, producing ripple effects throughout the economy. Additionally, because there are no geographic bounds in space, exploration lends itself to international partnerships to achieve feats that might not otherwise be possible. Bolstering international partnerships, economic competitiveness, and global influence likewise reinforces national security interests.

2.1.3 Inspiration

The "Moonshots" of the Apollo Program became a metaphor for how we as a nation could take on an audacious challenge and succeed through hard work and determination. The "Moonshot" metaphor has since been applied to seemingly insurmountable challenges, from curing cancer to developing fusion power. Apollo inspired a new generation of engineers and scientists to pursue education and careers supporting visionary work. The International Space Station and other space partnerships model how people from many nations can live and work together toward a common purpose. The next steps in space exploration can likewise inspire a new generation—the Artemis Generation—in science, technology, engineering, and mathematics studies that support the great enterprises of voyaging into space and overcoming the most difficult challenges on Earth.

2.2 Lunar Architecture Strategic Assessments

The effort to return humans to the Moon has been addressed at a strategic level first by answering the "Why," as documented in NASA's Moon to Mars Strategy and Objectives Development document. This strategic plan ensures that the Lunar Architecture must consider a range of stakeholder needs, including the long-term goal of enabling Mars and other deep space exploration. Definition of the architecture and the methodology to achieve it is fundamental to the leadership needs reflected in the "Why." By implementing an architecture that can respond to innovation and developments and includes partners, the endeavor will enable benefits reflected in terms of both the economy and the human condition. Working from both the blueprint objectives and the array of available Mars studies, NASA has derived several key characteristics of the Lunar Architecture. Throughout all of these decisions, the Responsible Use (RT-6) Tenet is applied to ensure consistent application of policy, legal, and ethical frameworks. Areas of uncertainty about how policy or standards should be applied to the objectives or architecture are elevated to Agency leadership for resolution.

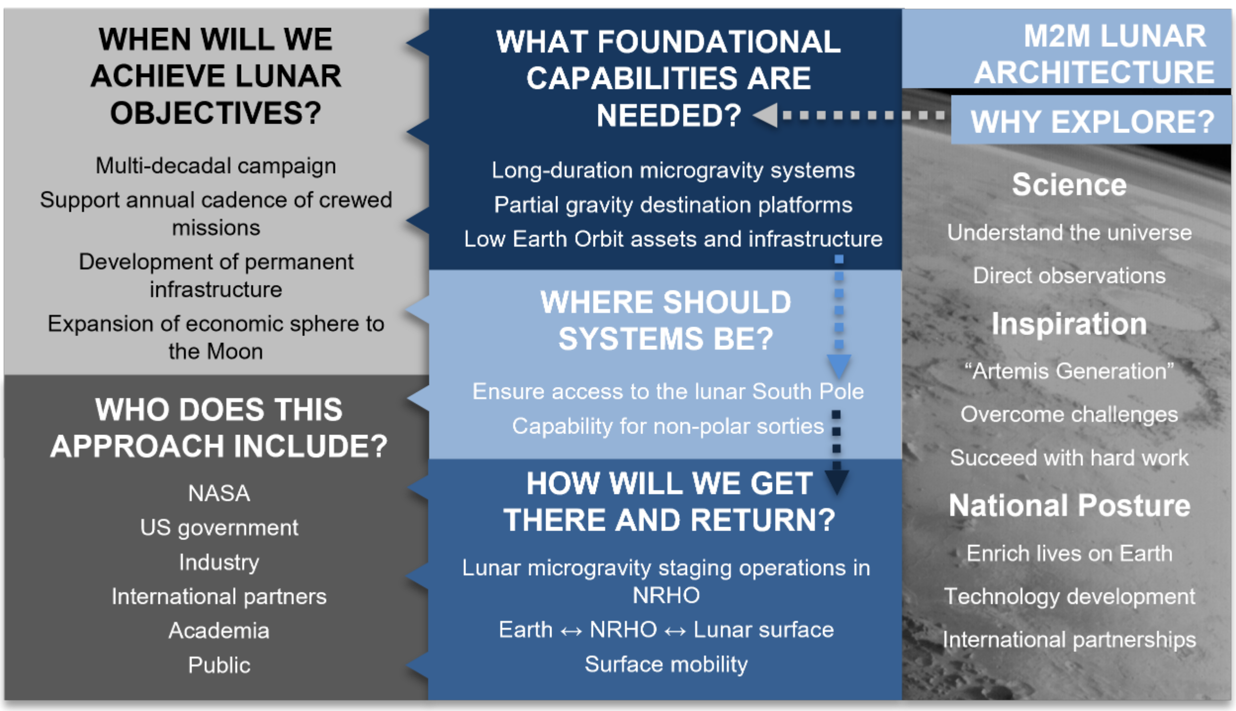


Figure 2-3. Lunar Architecture Decision Flow Starting with "Why?"

As illustrated in Figure 2-3, answering the "Why" for lunar exploration is only the first step in the decision process. Answering (or exploring the option space for) other big architecture questions ("Where," "What," "Who," "How," and "When") helps define the key characteristics of the lunar exploration campaign.

There are other questions that will be answered while developing programmatic solutions for architecture implementation, including "how much?," "how safe?," etc., that take the form of constraints as conditions to be met. These constraints inform an iterative design loop driven by the set of stakeholder expectations where an architecture, the associated concepts of operations, and the derived requirements and design solutions are developed and programmatic constraints such as cost and schedule are applied. The associated implementing organization works this iterative loop (sometimes referred to as “closure”), which is informed by the architecture in this document.

2.2.1 Key Lunar Decision Drivers

2.2.1.1 “What” Foundational Capabilities are Needed?

As decomposition of the objectives—captured in the Strategy and Objectives document—indicates, several technological, scientific, or human condition insights are needed to inform Mars architectural decisions. These multi-dimensional objectives across the science, technology, and infrastructure development goals will need to be supported by foundational platforms from which the crew will operate. These systems will enable the crew to retrieve and return samples, deploy instrumentation or technology demonstration, research in-situ resource utilization, understand the human condition in long-term deep space exploration, and much more. The ability to support these activities and the decomposition of the capabilities needed to accomplish science and infrastructure objectives will be key characteristics for cislunar and surface destination systems. Common across all architectural studies to date is the need to provide demonstration and test environments across dynamic space weather conditions, deep space microgravity, partial gravity, and the transitions between them. These environmental drivers must be paired with increasing operational durations to establish sufficient design, engineering, and demonstration drivers in the architectural approach.

From these assessments, two key destination systems and the ability to transition between them are derived as platforms for this development. First is the ability to stage long-duration microgravity systems in deep space or near–deep space–equivalent environmental conditions that analogues to the transit conditions to and from Mars. This platform will necessarily need to accommodate a human crew and function with reductions in the crew-managed reliability, maintenance, and ground intervention associated with near-Earth systems (RT-5 Maintainability and Reuse). Other characteristics beneficial for any microgravity platform include the ability to aggregate elements autonomously and to support incremental build-up to prepare for the eventual accumulation of systems necessary for Mars transit.

Second, the destination platform must provide human systems deployment and aggregation in partial gravity with what can be considered “hostile” atmospheric conditions (in the case of Mars) or no atmospheric environment (in the case of the Moon). This surface platform as an aggregation of elements will also provide the opportunity to demonstrate the necessary components for achieving Mars-forward systems for human-conducted surface exploration. These systems will need to support increasingly long crewed exploration periods and be expandable to accommodate the breadth of the objectives laid out towards the Mars goal.

The architectural approach will also leverage available low-Earth orbit (LEO) assets and infrastructure to accomplish lunar and Mars objectives. In this regard, exercising objective capabilities at the lowest energy state (whereas performance demand can be considered proportional to the resources and/or programmatic needs) will be applied throughout (RT-8 Leverage Low Earth Orbit).

2.2.1.2 “Where” Should the Systems Be?

From the definition of the “What,” it is necessary to support the architectural approach in the microgravity and surface platforms; “Where,” in relation to the Moon, became the next systems engineering driver. To ensure the platforms’ support of long-term objectives and the balanced-systems approach of the “Why,” NASA and other organizations have conducted numerous studies of lunar system locations. The primary consideration of "Where” is to ensure surface access to and optimization for the lunar South Pole; however, this approach ensures access to non-polar locations as well.

The lunar South Pole has several key driving characteristics to enable systems development for the Moon to Mars Architecture. First, from a flight performance perspective, the lunar South Pole provides a bounding condition for vehicle translation or delta-velocity costs. These performance drivers are one of the most significant conditions for transportation system design. Vehicles and reference missions designed to achieve landing at the South Pole can provide future flexibility to reach global locations through planning and certification. This approach differs from the Apollo vehicles and systems, which, when directed to reach the Moon at essentially the earliest possible time (answering the “When” question first), necessarily selected the “easiest” lunar landing sites on Earth-facing, near-equatorial regions and lacked the performance and systems capabilities for global and/or polar landings.

Second, lunar poles support multiple scientific and engineering values, and the South Pole provides more opportunity for these conditions in designing systems to ensure extensibility to other lunar locations and future Mars needs. One key enabling characteristic of the South Pole is the lighting conditions. At the lunar equator, solar illumination occurs in 14 days of continuous daylight and 14 days of continuous darkness (these are the lunar cycles we are so familiar with as viewed from Earth). However, at the South Pole, the Sun is seen very low on the horizon, as during the extreme summer nights at Earth’s poles. Unlike Earth, the extreme terrain on the lunar South Pole provides significant variation, resulting in “peaks” of light that can provide lit conditions for much of the year and “valleys” of darkness that never see the Sun. These peaks or ridges along craters provide advantageous locations to stage systems for longer-duration operations. However, while advantageous for illumination, the peaks and ridges are more challenging for navigation and placement of elements. These factors must be considered in the architectural approach and element designs. This lighting environment will be an enabling feature of the polar region to represent Mars-forward precursor missions and aggregation of surface elements for longer-duration test and demonstration.

Finally, the lighting conditions in the south polar region also contribute to unique scientific opportunities. Although the lunar surface was found to be void of volatiles, as they are stripped away by the solar wind, sites of permanent darkness in the polar regions could preserve volatiles collected throughout the Moon’s past. This region is among the oldest parts of the Moon—older than any explored during Apollo. The volatiles, likely trapped as ice, could reveal valuable knowledge about the history of the inner solar system, including when life gained a foothold on Earth. Just as ancient ices hold scientific value, lunar samples from this area will increase our knowledge of the history of the Moon itself. These ices could also serve as valuable resources for use during future exploration. Finally, the peaks of light at the South Pole are an enabling characteristic to support extended durations of human-tended surface operations to provide the infrastructure capabilities for sustainable and lasting development and research.

The lunar South Pole environment results in several architectural drivers. The power and thermal systems to operate in environmental extremes, provide surface mobility, and allow the aggregation of infrastructure are possible at the lunar South Pole. Given the necessary development of platforms and systems at these locations over time, the application of interoperability and commonality will be a key enabling characteristic (RT-7). The ability to deploy, upgrade, and develop systems across the platforms will be critical to the evolution and continued operations of the integrated architecture. These reasons ensure that the South Pole is a significant feature in the Moon to Mars Architecture definition, while also maintaining and supporting the ability to visit diverse non-polar sites.

2.2.1.3 "How" Will We Get There and Return?

The driving surface of the South Pole destination for long-term infrastructure, the need for global periodic access, and the development of a long-duration cislunar platform inform the architectural driver of "How" to place the lunar microgravity staging operations. Based on a variety of studies and alternatives, the Lunar Architecture will use the Near-Rectilinear Halo Orbit (NRHO). This orbit meets several key needs, including the long-duration staging through minimal propellent demand for orbit maintenance, accessibility to the lunar South Pole and other global access on a frequent and recurring basis, and consistent access for crew and cargo to and from Earth while still providing near–deep space environmental conditions with near-continuous illumination and limited lunar albedo (i.e., reflectivity of light and heat) to the orbiting platform.

Having established the NRHO architectural orbit, the ability to transport crew, cargo, and support systems to and from the destinations can be decomposed. These systems are driven by the sizing performance splits across the architectural destinations to traverse the regions from Earth to cislunar space and to the surface. Crewed transportation systems will be driven by the need to launch, transport, and safely mitigate potential contingencies and risks in two key transportation regimes: first, crew accessibility to and from Earth to NRHO platforms, and second, to and from NRHO to the surface destinations to support either South Pole or non-polar mission selection. The crew transportation access, in conjunction with destination systems, will necessarily need to ensure the safety and responsive planning for Crew Return (RT-3) for potential contingency scenarios.

Transportation objectives are some of the earliest objectives in the architecture and most established systems, given that they are necessary first steps for the human return to the Moon, enabling subsequent objectives. These systems are developed with several key characteristics applied, including the ability to achieve missions with sufficient frequency and opportunity. With the scope of objectives and the tightly coupled architectural aggregation approach, the ability to ensure timely and consistent launch and mission opportunities is a key characteristic. In addition to crew transportation, systems will also need to support the launch and delivery of cargo across a range of masses and volumes to support the element aggregation, logistics, and maintainability across the architectural lifetime and destinations (RT-5 Maintainability and Reuse). Systems capable of reuse offer significant benefits, reducing the number of launches required and continuing to enable long-term objectives across the architecture. Given the significant considerations in transportation objectives, the ability to support docking, deployment, and disposal—with minimal crew intervention when necessary—will be key. Increased crew time to support routine operations, maintenance, and services would compromise crew time (RT-4) to achieve utilization and other objectives.

Although the largest and most recognizable transportation systems are those that carry the crew through space, the ability to support mobile operations on the lunar surface is a key characteristic of many of the blueprint objectives. Mobility systems on the lunar surface are necessary to enable the myriad objectives that must be accomplished at points across the surface that would be impractical to reach or inaccessible to crew traveling on foot from the landing location. The ability to transport crew members safely and efficiently between surface locations is essential for maximizing crew time (RT-4) applied to the utilization objectives. This capability is also necessary for future Mars exploration and is essential to the exploration plans to enable the crew to travel to increasingly far points from the landing sites, explore regions where landing is not feasible, and carry and transport samples or utilization payloads.

A robust, secure communication, position, navigation, and timing system will also be critical to these complex operations. The volume of data required to safely monitor, command, and control active vehicles, both crewed and uncrewed, will be a key characteristic of the integrated architecture. The number of systems in both cislunar and surface operations will also generate the need to handle multiple simultaneous streams of data and telemetry. Management of these systems and functions across the distributed architecture through interoperable and expandable systems will be a key characteristic to accomplish lunar objectives.

2.2.1.4 “When” Will We Achieve Lunar Objectives?

As the lunar campaign has already begun, the key characteristics to address the “When” question are more appropriately addressed as the time frequency, or “how often”. Driving the systems to support an annual cadence of crewed lunar missions is a need that flows throughout the system development, from ground processing and launch facilities, to development and assembly timelines, to the assets necessary to support those missions. Turnaround and processing times will also be key characteristics for any system reuse driven by the transportation objectives. Further, the demand for logistics supply, repurposing, and disposal will be key considerations in the architecture’s opportunity frequency. Logistics demand is a significant derived capability necessary to support increasing mission durations to accomplish the blueprint objectives at both cislunar and surface platforms. Periods between crew flights will drive characteristics for the assets to provide ongoing value and benefit during tele-robotic or autonomous operations.

This diverse suite of frequent crewed and uncrewed operations using permanent infrastructure, will provide significant opportunity for commercial and space development. The Agency objectives can be addressed through a variety of approaches, innovations, and partners. One of the key recurring tenets applicable to addressing “When” is RT-9 Commerce and Space Development. NASA plans to foster the innovation among industry partners, expanding the economic sphere to the Moon, following the example of the commercial development of LEO. Creative solutions to meet multi-user needs, responsiveness to opportunities, and the shared support of lunar exploration across industry and partners will be necessary to keep the architecture durable and sustainable.

The planned campaign will spend several decades establishing permanent footholds in cislunar space and on the lunar surface, developing and deploying major human-rated transportation systems to the Moon and Mars, and developing and deploying lunar and Martian surface infrastructure to enable humans to live and explore once they arrive. The term “sustainable” can have different meanings, depending on the context. For the exploration campaign, several definitions apply. *Financial sustainability* is the ability to execute a program of work within spending levels that are realistic, managed effectively, and likely to be available. *Technical sustainability* requires that operations be conducted repeatedly at acceptable levels of risk. Proper management of the inherent risks of deep space exploration is the key to making those risks “acceptable.” Finally, *policy sustainability* means that the program’s financial and technical factors are supportive of long-term national interests, broadly and consistently, over time.

2.2.1.5 “Who” Does This Approach Include?

Having established all the component parts of the architecture, sizing for systems is designated to include up to four crew during an integrated mission. These crew members will thus be enabled to conduct the scientific, technological, and developmental objectives for which the human mind is most suited. Again, maximizing the time of the crew members to support these objectives is a recurring tenet (RT-4) in the architectural selection and decomposition. The ability to support four crew members provides the opportunity to assign various tasks ranging from piloting to utilization and operations. The crew operations will provide a gradual build-up approach to demonstrate the technologies and operations necessary to live and work on planetary surfaces and in extended deep space microgravity environments, including a safe return to Earth. Risk is inherent in any type of spaceflight, but it is an especially important consideration in the context of human spaceflight. As one of the recurring tenets, Crew Return (RT-3) is a key characteristic across all architectural domains. The application of risk management, fault tolerance, and integrated human-rating certification is necessary at the architectural level. Contingency capability, abort performance, and risk management are treated as an applied characteristic across the architecture.

The most critical components of the campaign to get humans to the Moon, and ultimately Mars, are the humans themselves. Vehicles, systems, training, and operations must be designed, developed, and certified to be safe and reliable for, compatible with, and in support of the "human system" as an integrated system to accomplish the mission with an acceptable level of human risk. Human-rating is the process of designing, evaluating, and ensuring that the total system can safely conduct the required human missions, as well as incorporating design features and capabilities that both accommodate human interaction with the system to enhance overall safety and mission success and enable safe recovery of the crew from hazardous situations. Human-rating applies standards for design and construction, safety and mission assurance, health and medical concerns, flight operations, and system interoperability. Human-rating is an integral part of all program activities throughout the life cycle of the system, including (but not limited to) design and development; test and verification; program management and control; flight readiness certification; mission operations; sustaining engineering; and maintenance, upgrades, disposal, and ground processing. NASA will lead/integrate the distributed team of government, commercial, and international partners that develop and implement hardware, software, and operations supporting exploration. Both nominal and contingency scenarios must be part of the overall development of the mission, hardware, software, and operations to arrive at a reasonable level of risk. The crew will require many years of Earth training across numerous vehicles and systems in a compressed timeframe to prepare for the mission.

In addition to the crew themselves, the development of the myriad systems, operations, and capabilities to meet objectives will require the support of international and industry collaborations (RT-1 and RT-2). The Moon to Mars Architecture approach enables a variety of support mechanisms and contributions to enable innovation, economic development, and the inspiration foundation to address Why We Explore (Section 2.1). Characteristics include architectural robustness to infuse innovative solutions and technological advancements over time. The iterative methodology, flexibility in design solutions, and ability to perform responsive mission planning for future developments will be key considerations.

NASA has a long, successful history of working with a diverse community of international partners to advance common space exploration and science objectives. NASA is committed to building on and broadening these global partnerships as part of the Moon to Mars objectives. NASA has numerous international partnerships already in place and is engaging in ongoing bilateral and multilateral dialogues with international space agencies to identify new, mutually beneficial opportunities for collaboration.

Building upon more than two decades of experience with the International Space Station in LEO, NASA and its partners will need operational flexibility to demonstrate the capability to integrate the multi-party contributions, aggregations of systems over time, and increasing complexity to address long-term Mars-forward development. The coordination of integrated ground, launch, and flight systems for both crewed and uncrewed regimes and multiple planetary bodies will require a significant leap forward in the complexity of mission operations.

2.2.2 Unique Considerations for the Moon

Although NASA has previously conducted human exploration on the lunar surface with the Apollo Program, there are still unique aspects to consider for the current Lunar Architecture. With the desire to seamlessly expand to long-term, sustainable exploration while preparing for human Mars exploration, the Moon to Mars Architecture must remain flexible to plan for the future campaign with current programs and elements in development, adjust to the actual flight systems as the elements mature and are deployed, and accommodate new contributions. This allows for an incremental increase in capabilities for lunar exploration, gradually building up functionality to achieve the Agency's objectives.

The most recent human spaceflight exploration and the majority of human spaceflight hours of experience have been conducted in LEO. There are several major differences in concepts of operations between LEO and cislunar missions. For one example, abort capabilities back to Earth vary in duration. With exploration interest in lunar South Pole locations and a cislunar platform in NRHO, aborts back to Earth are more complex and take days rather than hours (as is the case from the International Space Station). These durations significantly complicate or eliminate crew rescue options that may be available in LEO. In another example, crew will transition between micro- and partial-gravity environments, eventually doing so after extended durations in microgravity without the support that crew members experience upon their return to Earth after long missions on the International Space Station. Testing out the concept of operations for surface exploration with deconditioned crew will also help NASA prepare for Mars exploration. Further, the unique aspects of the South Pole, in term of lighting, terrain, and other environmental considerations, present unique challenges to the missions and strategic planning. These include the relatively constrained area of the South Pole, which is advantageous not only to NASA, but also to other commercial, scientific, international, or other lunar exploration plans.

2.3 Mars Architecture Strategic Assessments

In the five decades since Dr. Wernher von Braun proposed NASA's first human Mars architecture, NASA has pivoted from one exploration point design concept to another, many optimized around heritage programs or emerging technologies of particular interest. Indeed, half a century of architecture studies have filled our libraries with myriad architecture concepts that have maintained interests in Mars and contributed some progress toward the current Moon to Mars effort. However, none of these concepts found traction with stakeholders, many of whom had competing perspectives or needs. The Agency's new Moon to Mars objectives provide a comprehensive framework to ensure that human Mars architectures will meet—or can evolve to meet—more stakeholder needs. After mapping objectives to the required functional capabilities, the architecture team will coordinate with technology and element concept developers and identify the key architecture decisions that must be made. Because decisions in one part of the architecture will ripple through other parts of the architecture, it is critical that decision-makers understand the effect of each decision on the integrated architecture, including differences that depend on the order in which decisions are made. The strategic assessment and campaign segment description described in this document form the foundation for this Mars decision road-mapping process. Later revisions will document Mars Architecture decisions as they are made.

To build a compelling architecture that will gain traction with stakeholders, a similar systems engineering process applied at the strategic level can be used as a framework for the architecture by addressing the six key questions: "Who," "What," "Where," "When," "Why," and "How"? To reach consensus and move forward, an exploration architecture must address all six questions, but reiteration and negotiation may be required. The answer to any one question is less important than ensuring that the answers to all six fit together as an integrated whole.

2.3.1 Key Mars Decision Drivers

As noted in at the beginning of this section, the human Mars exploration architecture can be described as a six-sided trade space, shaped by the answers to six key questions: “Who,” “What,” “Where,” “When,” “How,” and “Why”? (As shown in Figure 2-1.) In laying out the Agency’s architecture decision roadmap, it is critical for decision-makers to understand how these key drivers relate to each other and how the architecture can vary depending on the order in which these decisions are made.

Figure 2-4. Mars Architecture Decision Flow Starting with “When?”

The Apollo Program was famously characterized by the mandate of “landing a man on the Moon and returning him safely to Earth before the end of the decade”. This prioritized “When?” (within the decade) over other considerations. NASA successfully achieved this goal, but because the resulting architecture was optimized to meet a tight implementation schedule, it was not particularly extensible, with implications for sustained human exploration of the Moon.

The Apollo Program serves as a cautionary tale for Mars exploration: if decision-makers focus on “When?” as an anchoring decision (Figure 2-4), and the answer is a date that does not give us enough time to develop new technologies, then the answer to “How?” would default to heritage or heritage-derived systems. If the specified date is too soon to develop and certify new transportation, descent, ascent, and surface systems, then the schedule compromise may be an orbital-only or fly-by first mission, followed by surface missions in later years. This affects not just “How?” but cascades to “What?” and “Why?” If, instead of a particular date, “When?” is indexed to another event—for example, the timeline of a particular technology development or an Agency funding profile—then certain technologies or assets from other programs may be prescribed, again influencing both “How?” and “What?” If the answer to “When?” specifies both a “boots on Mars” date and a “boots back on Earth” date (in other words, a total crewed mission duration), that restriction will define whether we require new high-tech, high-energy transportation systems capable of shorter mission durations. As shown in Figure 2-4, starting with “When?” can cause the answers to “Why?,” “Where?,” and “Who?” to rely on the answers to “How?” and “What?”.

Figure 2-5. Mars Architecture Decision Flow Starting with "Why?"

With few architecture decisions mandated thus far, human Mars exploration offers a unique opportunity to take an objectives-based approach to exploration architecture development. NASA's Moon to Mars Strategy provides such a framework. In contrast to a capabilities-based approach, an objectives-based approach focuses on the big picture, establishing the "What?" and "Why?" of deep space exploration before prescribing the "When?" or "How?"

As shown in Figure 2-5, NASA's blueprint identifies the answers to the question of "Why?" Any single answer is unlikely to satisfy all stakeholders, but each answer is important to one or more stakeholders. Starting with "Why?" will help anchor the development process, but architecture choices may still vary widely depending on how the many different answers to "Why?" are prioritized. Must the first human Mars mission check off *every* item in the "Why?" Venn diagram, or is it sufficient to establish a first-mission architecture that meets the highest-priority items, and is extensible to meet lower priorities during subsequent missions?

For example, prioritizing science on the first human Mars mission will influence "Where" we land if the specific science objective of interest requires access to a particular region or feature and may require other mission elements tailored to that particular science discipline. If that priority science location is difficult to reach or lacks the resources for sustained human presence, NASA could desire a lighter exploration footprint for the first mission, and crew selection may be heavily influenced by science expertise. Conversely, if inspiration, in the form of sustained human presence, is the priority goal, then NASA may desire a landing site offering abundant resources or ease of access, with the first mission elements laying the groundwork for a heavier, permanent infrastructure at a single location that is able to support a larger number of crew, possibly selected for their engineering expertise. As shown in Figure 2-5, different priorities within "Why?" will cascade through the other questions.

These sample decision structures illustrate an important point: the Mars Architecture will heavily depend on the decisions that are prioritized. In practice, the Mars Architecture decision flow is likely to be iterative rather than linear. To minimize disruption, rework, and cost or schedule changes, understanding the minimum goals and priorities for the first mission, as well as the longer-term goals for subsequent missions, can aid in establishing a flexible and sustainable architecture. The answer to any one of these questions is less important than whether the answers to all six complement one another as a set and can be balanced to establish an architecture that is achievable, affordable, and adaptable.

2.3.1.1 Key Mars Architecture Decision Roadmap

Developing a new exploration architecture will require hundreds of individual decisions made by dozens of decision authorities across the Agency. Every decision is important, but there is a class of decisions (i.e., “key” decisions) that can so profoundly influence the end-to-end architecture that they warrant a much higher level of scrutiny. For example, whether to launch round-trip propellant from Earth versus pre-deploying or manufacturing return propellant at the destination will significantly impact the surface infrastructure and ascent elements, which in turn will influence the number, cadence, and payload capacity of landers, which will in turn will influence transportation system cadence and capacity—all of which will influence the number, capacity, and cadence of rockets that must be launched from Earth. Though return propellant acquisition strategy might appear at first blush to be a straightforward engineering decision solely under the purview of the transportation element implementation authority, there are other, less obvious considerations: manufacturing propellant from in-situ Mars resources may involve forward or reverse planetary protection constraints, for which planetary protection and health and medical decision authorities must be involved. Establishing the infrastructure necessary for in-situ manufacturing has technology benefit implications that will be traded against development cost and schedule. Although a human spaceflight program office might prefer that subsequent missions return to the same landing site to take advantage of existing infrastructure (thus lowering campaign costs), constraining exploration to a single landing site might preclude the Agency’s ability to achieve important science objectives elsewhere on the planet.

By definition, a Key Architecture Decision Roadmap will only include “key” decisions whose outcomes profoundly influence the architecture and/or that require collaboration between multiple lower-level decision authorities, meaning that the decision authority for these “key” decisions resides with Agency leadership.

2.3.1.2 Key Architecture Decision Roadmap Value Proposition

As noted here and in ACR 2022 White Paper *Systems Analysis of Architecture Drivers*, making one key decision before fully understanding the cascading effects of that decision across the end-to-end architecture can limit the flexibility or utility of an architecture, rendering the enterprise unsustainable. At its core, an architecture decision roadmap is a path to orient the logical flow of decisions. The essential question is: of all the important decisions to be made, which should be decided first?

The practical utility of an architecture decision roadmap is to understand which decisions lay in the critical path of other decisions. An architecture roadmap developed early in an exploration campaign provides value in three ways:

1. **Minimizes later rework or disruption**
   Decomposing exploration objectives into characteristics and needs and their associated use cases and functions will identify key architecture decisions. To enhance the traceability and utility of this process, identifying linkages between those decisions—in particular, the effect that one decision has on others (if/then relationships and decision prerequisites)—will aid in identifying high-impact decisions that influence every aspect of the architecture. A roadmap

that prioritizes these high-impact decisions early in the overall decision flow will minimize implementation delays, rework, or relitigating decisions.

2. **Defines inter-organizational critical paths**
Most decision authority will reside within programs or projects, but because exploration architectures typically represent a collection of programs and projects, architecture decision authority will necessarily cross multiple organizational boundaries. A decision under one decision authority may be in the critical path of what might seem at first glance to be an unrelated decision under a different decision authority. By mapping out how decisions relate to each other—and under whose purview these decisions fall—programs, projects, or technical authorities will be aware of whose critical path they are in or who may be in their critical path.

3. **Informs investment strategies**
Where two or more investments could meet objectives, but budget or schedule realities cannot support multiple developments, a down-select decision must be made with input from all affected internal organizations. Making the decision too late will likely result in unwanted program/project consequences, including increased costs or schedule delays associated with development and testing schedules. However, as noted above, making the decision too early—such as before flow-down impacts are fully understood—may result in an architecture that is unable to meet exploration objectives. As an example, integrating important technology down-select decisions into the architecture decision roadmap will help technologists time their decision gates to optimize development resources.

2.3.1.3 Key Decision Roadmap Approach and Process

To ensure the impacts of these far-reaching decisions are carefully traced, assessed, and coordinated with those affected, a process is needed to define common terminology, establish roles and responsibilities, identify which decisions should be included on the roadmap, trace linkages between these decisions, and develop new tools to manage all the relevant information as decisions are made and the trade space narrows.

Although the premise of an architecture decision roadmap applies to Lunar and Mars Architecture development, there will be differences, given that some Lunar Architecture decisions have already been made, whereas the Mars Architecture decision process is beginning with a relatively clean slate. NASA is therefore using the *initial Humans to Mars segment* as a decision roadmap pathfinder, with an operating assumption that once the clean-slate approach, tools, and processes were established, they could be tailored to map remaining Lunar Architecture decisions in the context of decisions that have already been made. More importantly, this clean-slate approach also establishes a process baseline that could be applied to future exploration destinations beyond Mars.

As with all new processes, refinements and improvements will be made over time, so the process and the key architecture decision roadmap will be updated as needed. Note that key architecture decisions and overall decision roadmapping *is an internal Agency process*, though in many cases external input will be factored into decision making.

2.3.1.4 Key Architecture Decision Roadmap Terminology

New terms used in the decision roadmapping process include the following.

Key architecture decision – Defined as a decision (i.e., decision definitions and, when available, outcomes) that so profoundly influences the end-to-end architecture that it warrants elevated scrutiny. At one end of the spectrum, deciding how many crew members an architecture must accommodate is obviously a "key" decision because it influences virtually every aspect of the architecture and will involve collaboration between multiple decision authorities. At the other end of the spectrum, deciding handrail color or style—even though it will affect many elements—is best categorized as an engineering decision that does *not* rise to the same level of management scrutiny. But where to draw the line? For the purpose of sorting through thousands of decisions to determine which have a profound enough impact to be labeled as "key," NASA employs two criteria: high connectivity to other decisions, programs, and projects and high sensitivity of architecture-level and Agency values (such as cost, schedule, or risk) to the decision options. This sorting process is subjective but errs on the side of caution: if in doubt, a decision is considered key; it may be reclassified later if further analysis indicates—or a decision authority decides—that the decision could be made at a lower level or does not have a significant technical, cost, schedule, or risk impact.

Decision authority – Defined as the highest-ranking official or body (such as a control board or executive council) that will sign a formal decision outcome, thus indicating responsibility for—*and commitment to implementing*—that decision outcome. The instrument used to document each decision outcome will vary depending on the internal processes used by each decision authority. In the hierarchy of decision authorities, some decision outcomes will be determined by programs or projects, while other decision outcomes may be determined by technical authorities (crew health decisions, for example). Where the needs of multiple projects, programs, or technical authorities must be balanced, an architecture decision may require elevation to the applicable mission directorate's Associate Administrator, and where the needs of multiple mission directorates must be balanced, an architecture decision may require elevation to the NASA Administrator. In some cases, the decision may reside outside of NASA, such as with another government agency. For any given architecture decision definition, there may be multiple stakeholders, *but there can only be one decision authority*.

Stakeholders – In the context of architecture decision roadmapping, stakeholders are defined as those internal NASA organizations with an interest in a particular decision because they can either affect, or be affected by, the decision. For example, the stakeholder may affect the decision by contributing supporting data and analyses to the decision package, or the stakeholder may be affected by the decision if that decision results in a change to their implementation requirements, schedules, or resource requirements. Different architecture decisions may have different stakeholders. In some cases, stakeholders are decision authorities for prerequisite decisions that feed into another architecture decision.

Decision outcome – A formal judgement of the options as a result of deliberation, culminating in an approved forward path on which option(s) to implement.

Decision definition – Before a decision outcome is determined, there is a fully scoped decision definition. The decision definition is the set of inputs required to reach a decision outcome, which includes a question, options, context, dependencies, and a recommendation on which a decision authority will deliberate.

2.3.1.5 Identifying and Defining Key Architecture Decisions Needed

The first step of decision roadmapping is to identify and define each key decision that is needed. Decision definitions include the question that needs to be answered (i.e., the type of decision *outcome* needed), available options, the decision authority (if known), relevant stakeholders, architecture context, and dependencies (both prerequisites to making the decision and impacts of the decision on other decisions). This first step is crucial before analyses or decision package development can begin. Two methods are used to identify candidate key decisions: first, a bottom-up analysis will draw input from decades of heritage studies. Then, a top-down assessment will decompose NASA's exploration objectives into use cases and functions and map the use cases and functions to candidate key decisions. The two approaches together provide a more thorough key decision identification process.

2.3.1.6 Modeling the Key Architecture Decision Space

Once candidate key decisions are identified, the next step is to assess how these decisions relate to each other so that a logical order of decision making may be determined. For each candidate identified in the previous step, the dependencies on and of other decisions are cataloged. This step of the process is important for initiating collaboration and input for further decision definition. In some cases, the dependencies can be defined as prerequisites where one decision depends on the outcome of another decision. For example, a landing site selection decision may be highly dependent on the prioritization of utilization (technology demonstration or science) objectives, making that prioritization decision a prerequisite to the landing site decision. Additionally, there may be other types of prerequisites to a given decision, such as capability or knowledge gaps that must be filled before a decision can be made. Conversely, a given decision may have flow-down impacts to other decisions. For example, the decision to include a surface segment on a particular initial mission may have flow-down impacts to decisions concerning surface landing site selection, surface habitation strategy, surface infrastructure, or more. Flow-downs also include other known impacts, such as required new facilities, research, technology developments, or operations that would be required to enable one or more decision option. If these decision dependencies are predicated on specific assumptions (for example, that a partner provides a given capability or that a new high-temperature material will be developed) or constraints (for example, a particular payload shroud's diameter), those are also cataloged, particularly if changing the assumption or constraint would make that decision obsolete or change the comparison of the decision options.

Linkages between decisions are captured in an electronic decision space model. Crucial to the modeling effort is an ontology that sets the model's foundation and defines how data is structured—and input is captured—within the model. A decision space modeling ontology was developed to respond to the inadequacy of a traditional databasing approach at capturing the complex dependencies and impacts between key architecture decisions. The architecture model will capture the recommended relative order of each decision, and this visualization output from the model can aid in deconflicting schedule choke points to mitigate processing delays of one decision from disrupting subsequent architecture decisions. For this decision space model, candidate key decisions are instantiated as nodes, categorized as either an architecture characteristic decision or an architecture constraint decision. Note that these terms are used in the modeling environment for the purpose of linking decisions to one another.

Architecture characteristic decision – Decisions that define an architecture feature or characteristic, where the selection of an alternative option would be considered a different architecture. Options for these types of decisions fundamentally change the architecture trade space. Examples include number of crew to the surface, or power generation or propulsion technology selections.

Architecture constraint decision – Decisions that apply across all possible architecture variants but do not directly define an architecture characteristic. Options for these types of decisions do not narrow or expand the feasible architecture trade space; for example, establishing a loss of crew (LOC) threshold or payload allocations to meet “inspiration” goals.

The ontology also defines types of decision options—including simple and compound options—and how each decision’s set of options are captured in the model along with constraints, bounds, and units. Figure 2-6 depicts notionally how the decision ontology is used to build the decision space model, including nodes that are either decisions or decision options. Next, the dependencies for each decision are modeled as linkages (or edges) between the nodes. It is at this time that dependencies may be characterized as either prerequisites or flow-down impacts, but this may still be re-evaluated later during the process as the position of decisions on the architecture roadmap is assessed. The decision model is built in a modeling tool that supports team collaboration and is configuration controlled.

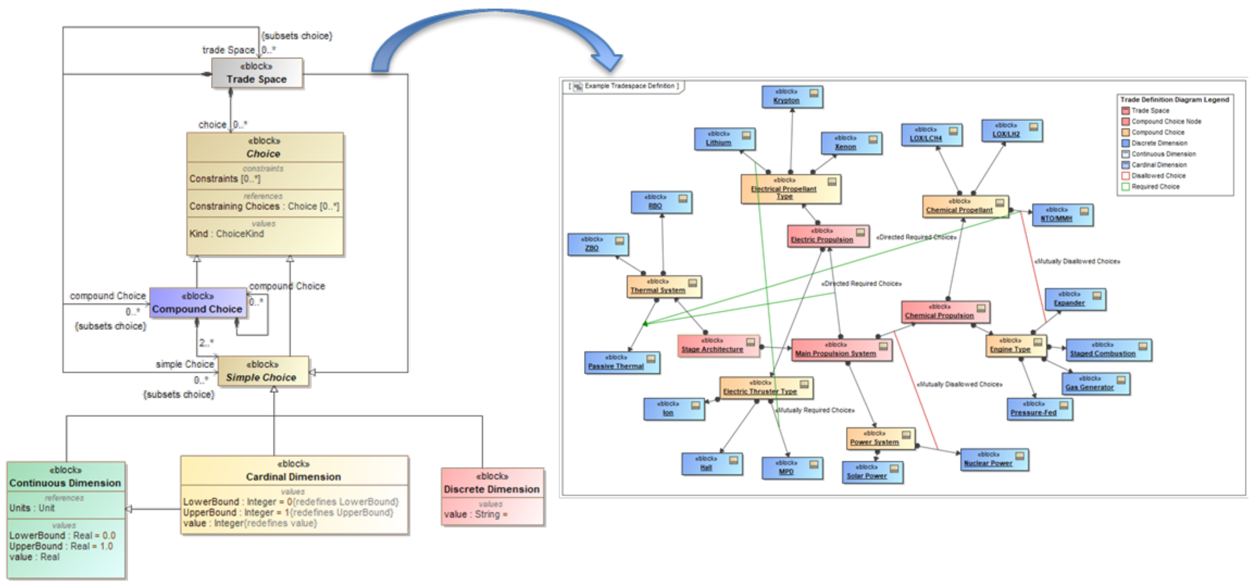


Figure 2-6. The Decision Space Ontology is Used to Build the Decision Space Model

Although the intent of the decision roadmap is to define a logical order of decision making, the reality is that—for various unforeseen reasons—key architecture decisions may not always be made in the preferred order. Therefore, the decision model is designed to accommodate updates.

2.3.1.7 Developing the Key Architecture Decision Roadmap

There are two important elements to the roadmap: the matrix of decision dependencies, and the logical organization of decisions into a decision flow that best fits those dependencies. It should also be noted that, although a logical order of decision making is recommended, that does not necessarily mean that the entire process is linear. It may take time to develop comprehensive decision packages for some decisions, and there is no reason that decision package *development* cannot proceed in parallel for many decisions, then finalized as prerequisite decision outcomes are available. This approach may compress the overall architecture decision timeline, though the decision timeline will of course be highly dependent on resource availability to develop decision packages, coordinate with stakeholders, and proceed to the relevant decision authority.

To be effective, the dependencies between decisions must be understood before placing decisions on the roadmap. For example, if the number of crew is decided *before* factoring in the top science and technology demonstration priorities, the crew complement decision may have to be changed later if the workload to meet mission priorities is greater than the selected number of crew can accomplish. If this disconnect does not surface until *after* crewed elements are well into development, either the architecture will be unable to meet mission objectives, or there will be significant cost and schedule penalties for redesign or replanning. Precise timing and schedules cannot be determined without detailed decision package development, but having a sense of the *relative* timing criticality of one decision versus others will help answer the question, "where to begin?"

To identify where to initially focus analysis resources, key decisions are bucketed into two broad categories: "driving" and "later." Driving and later decisions are sub-categories of the broader class of key decisions, representing different "time criticality" in the decision roadmapping process. Key decisions with many identified flow-down key decisions and other impacts—that is, key decisions that lay in the critical path of many other decisions need to be located near the beginning of the roadmap; therefore, they can be categorized as "driving" decisions, meaning these decisions will help set the pace of decision making. Decisions that require more prerequisite information or prerequisite decisions can be placed farther down the road and are categorized as "later" decisions. This does not imply that one category is more important than the other or that "later" decisions are optional; this is simply an acknowledgement that even critical decisions may not be practical, or even possible, until other decision outcomes are known first. More precise timing for each decision on the roadmap is determined through detailed decision package development and coordination, but having an initial sense of the *relative* time criticality of one key decision versus others will help answer the question, "where to begin?"

In addition to decisions that have significant flow-down impacts, the "driving" category may also include decisions with few or no prerequisites. If there is sufficient information in hand to make a decision sooner rather than later—even if that decision is not in the critical path of another key decision—and there is relatively little flow-down risk to making an early decision, it should be considered for near-term resolution because the sooner architecture decision outcomes are determined, the sooner investments can be focused and implementation can begin. One caution is that making a decision too early may mean that flow-down impacts are not yet fully understood, which presents a risk of cost or schedule impacts, or even invalidation of certain architecture decision options later. Therefore, the Agency should assess the potential impacts to cost, schedule, and risk for both waiting until later to make the decision or making this decision in the near term.

To reiterate: "Later" does *not* imply "not important"; it simply means the Agency can make a better decision after the driving decisions are made first. *Every decision must be made—but not every decision can be first.*

2.3.1.8 Initiating Key Architecture Decisions

Once a candidate architecture decision has been identified, defined, traced, and pre-coordinated with internal NASA organizations and relevant decision authorities, it is presented at ACR for consensus for Agency workload prioritization. This step provides rationale for relevant organizations to allocate resources for their individual contributions to decision package development, research or analysis, integration, decision making, and implementation.

2.3.1.9 Key Architecture Decision Outcomes

The actual decision-making process for each decision will vary depending on the decision authority, but in all cases, relevant internal organizations will participate in decision package development. Once supporting data has been collected and analyzed, input has been collected, options have been identified, flow-down impacts for each option have been traced, and recommendations have been developed, a decision package is presented to the relevant authority to make the decision. If an internal NASA organization does not concur with the decision outcome, an appeals process is invoked, in accordance with NASA Procedural Requirements (NPR) 7120.5F, NASA Space Flight Program and Project Management Requirements. Different decision authorities will have different technical courts of appeal and resolution processes, but in all cases, appeals and resolutions will be captured in the decision outcome documentation, which will also summarize all options considered, supporting data, rationale for the decision, flow-down impacts to the architecture and remaining decisions on the decision roadmap, and a high-level overview of the proposed implementation plan, including descope and fallback options.

Once an architecture decision has been made, the resulting impacts to the architecture are documented and reported at the next ACR and the internal decision roadmap is updated to reflect decision outcomes and changes to flow-down decisions.

2.3.2 Unique Considerations for Mars

2.3.2.1 Mars Architecture Frame of Reference

In Mars Architecture discussions, it is helpful to keep in mind that mission distances traveled will be at a scale far beyond the entirety of human spaceflight experience to date (Figure 2-7). A single round-trip journey between Earth and Mars will put about 1.8 to 2 billion kilometers on a Mars transportation system's odometer, regardless of departure opportunity or trajectory traveled—that is roughly equivalent to 950 round trips to the Moon. The distance between the Moon and Earth only varies by about 43,000 kilometers over time, so it always takes about the same amount of energy to travel to the Moon and back, no matter when we go. By contrast, the distance between Earth and Mars can vary by as much as 340 million kilometers as the two planets orbit the Sun. The closest Mars ever approaches Earth is 54.6 million kilometers; at their farthest, over 400 million kilometers of deep space separates the two planets. This means that much of the operational experience and many of the paradigms—such as mission control, sparing/resupply strategy, crew rescue, and mission abort contingency planning—will require a different approach than previously used on heritage programs (such as the International Space Station).

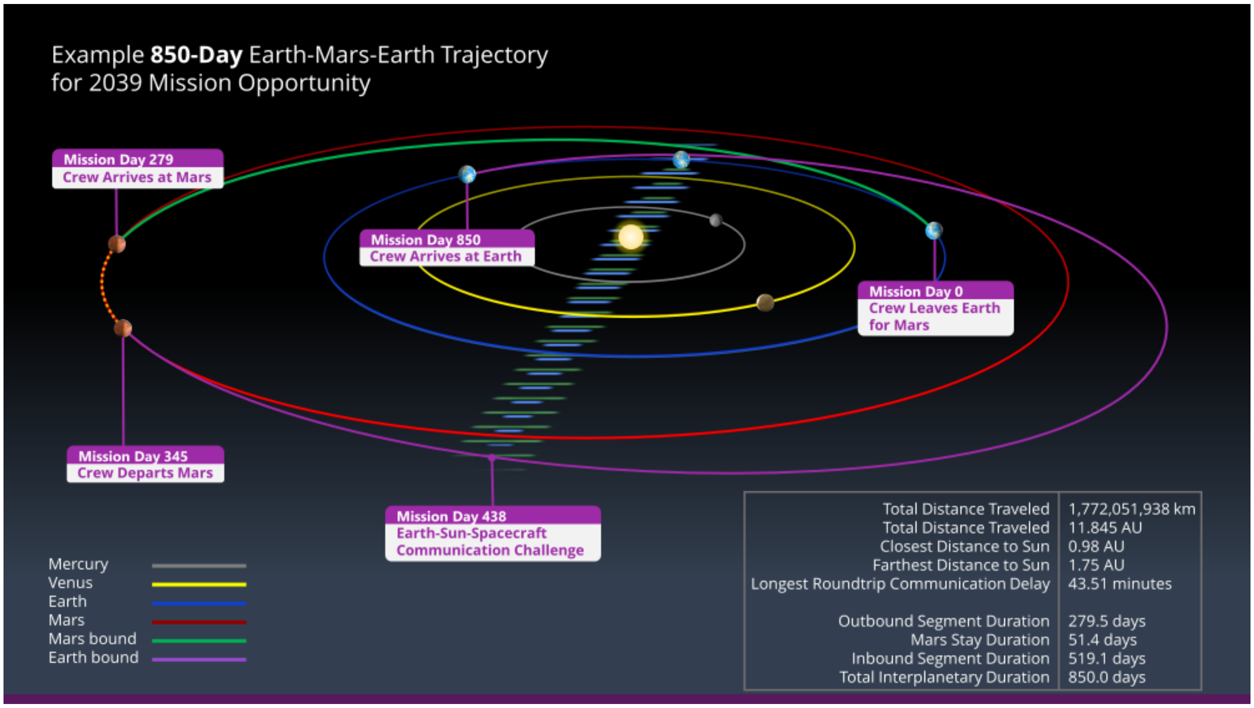


Figure 2-7. Roundtrip Mars Mission Distance in Perspective (AU, Astronomical Unit)

The energy required to achieve the roundtrip journey from Earth to Mars and back depends heavily on the timing. Because both planets orbit the Sun, both the distance and the relative velocity of the planets are constantly changing, cycling on a roughly 15- to 20-year cycle. It always takes about the same amount of energy to reach the Moon from Earth, but the amount of energy required to reach Mars varies considerably over this cycle. As part of the “When?” decision, a determination must be made on whether to optimize the transportation system for the easiest opportunities (more affordable, but limits us to one mission every 15 to 20 years), optimize for the most difficult opportunities (less affordable, but allows missions every 2 years), or aim for something in the middle.

Traditionally, to minimize the total energy required to achieve the roundtrip mission, mission planning has selected optimal planetary departure and arrival timing to maximize the benefit of the natural relative positions and velocity between the planets. This results in what is typically known as conjunction-class long-stay missions, where both the Earth-to-Mars and Mars-to-Earth trajectories are minimum-energy in nature, typically 180–300 days in duration (each way), depending on the mission opportunity. This approach requires a Mars stay time of 300–500 days to wait for the proper planetary alignment for the return trip and results in a roundtrip total mission duration of around three years.

Shorter duration roundtrip missions to Mars require less energy-efficient trajectories. The energy versus time tradeoff for a roundtrip mission to Mars is a continuum, but the relationship is exponential in nature: as the mission duration is shortened, the energy required to achieve the roundtrip mission increases exponentially. This translates to an exponential increase in the vehicle mass required, in terms of both propellant and propulsion system. The total energy required is also highly dependent on the Mars stay time. Unlike the minimum-energy conjunction-class mission, where the Mars stay time is dictated by the waiting period for the optimal return trajectory, shorter roundtrip missions do not have built-in constraints for Mars stay time. This design parameter becomes a key driving factor in interplanetary mission planning. Shorter mission duration also results in shorter stay time at Mars.

An example of these shorter roundtrip missions to Mars is an opposition-class short-stay mission. This class of roundtrip mission to Mars is optimized with one minimum-energy transit (either Earth-to-Mars or Mars-to-Earth), like the conjunction-class missions, and one high-energy transit that is timed to take advantage of a gravity assist swing-by of Venus during opportunities where Venus is in the correct location. This trajectory has typical transit time of 180–300 days each way, with a very short Mars stay time between 10 and 50 days, to achieve a roundtrip total mission duration as short as two years.

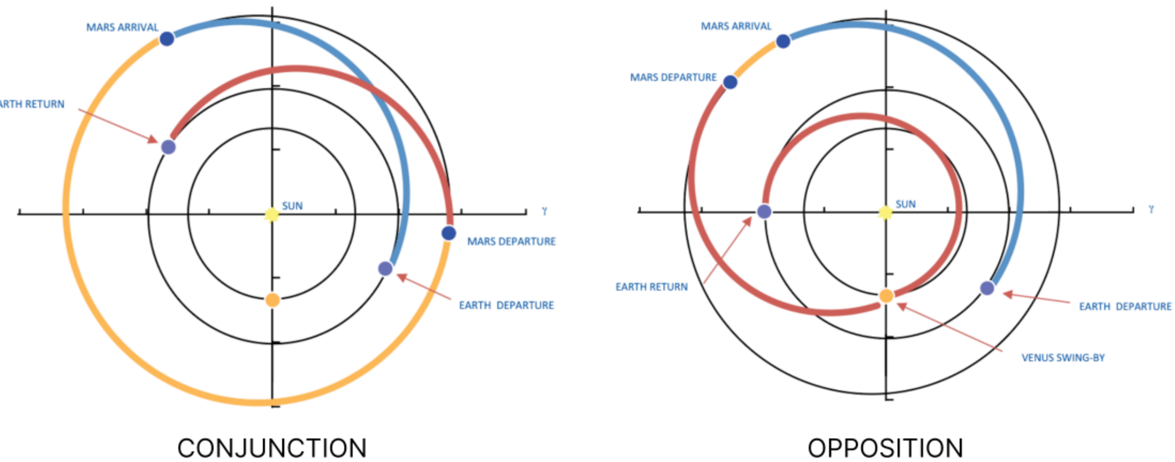


Figure 2-8. Illustration of Conjunction- and Opposition-Class Mars Trajectories

These two classes of mission have traditionally been the focus of Mars mission design and planning, but it is important to note that roundtrip missions to Mars are not limited to these two options, as evinced by the example trajectory shown in Figure 2-8. Mars mission design should not be a contest of "conjunction" versus "opposition," but rather an integrated, thoughtful analysis of all parameters of interest. Roundtrip transit time, Mars stay time, and departure dates are all important factors in determining the total energy required to achieve roundtrip missions. Analyzing the implications of each factor on all relevant systems will help us better understand the overall design trade space to support more informed decisions.

2.3.2.2 Aggregate Mars Mission Risk

Throughout the entire 60-year history of human spaceflight, astronauts have never been more than a few days (and rarely more than a few hours) from Earth. For missions to the International Space Station, or even to the Moon, aborting the mission and returning home is a relatively straightforward option. But on the transit to Mars, mission abort is complicated because of the sheer distance between Earth and Mars. Depending on when abort is initiated in the mission timeline, the heliocentric nature of the transit may require *months* to return to Earth, regardless of the transportation system selected. For transportation architectures that rely on Mars vicinity return fueling strategies, mission abort during the outbound transit leg may not be possible. In many cases, transit abort will not be a practical response to an emergency because the time to effect crew return will exceed the amount of time within which the crew must resolve the emergency. Early human Mars missions will also have limited Mars ascent/descent abort options. Mars's atmosphere and gravity make it difficult to carry sufficient on-board propellant to initiate human-scale payload descent and abort back to orbit during Mars descent, and Mars will initially lack the specialized infrastructure and staffing needed to aid crew after an ascent abort back to the Mars surface—even a successful abort to the surface may very well leave crew stranded away from assets necessary for a safe return to Mars orbit. These challenges will require an entirely new contingency operations paradigm for initial human Mars missions relative to NASA's Earth-centric flight experience. Given that crew survival has been key in meeting human-rating certification loss-of-crew requirements (as derived from Administrator-established safety risk thresholds), additional emphasis will need to be placed on hazard mitigation via other measures (e.g., incorporation of additional reliability and maintainability of hardware/software and a heavier reliance upon autonomy) to do the same for a Mars Architecture. Such measures will need to account for various other factors, including longer Earth-based communication delays and blackout periods, negative mental health and physiological impacts of transit and surface operations, and impacts upon human reliability.

The farther that humans travel from Earth, the more risk we must accept to achieve the goals of exploration. Mission durations, travel distances, and mass constraints increase the probabilities of something not performing as expected and decrease NASA's ability to respond in a timely manner to emergencies. Crew health, safety, and survival techniques will necessarily change as we move into Mars exploration. The definition of and acceptance of reasonable levels of risk will be a driving factor in determining architecture capabilities and use cases. The definition of acceptable risk is influenced heavily by both internal and external environments and, thus, must be explicitly defined and understood within the architecture so that it can influence decisions throughout the design and implementation process.

2.3.2.3 The Human System in the Mars Architecture

Mars Architecture discussions must consider the human system as part of the integrated mission architecture. Historically, emphasis on conjunction-class Mars missions on the order of three or more years duration was driven by a desire to lower Earth-launched transit propellant mass. While this may result in a "better" architecture from a transportation system point of view—with total stack mass serving as the measuring stick for "better"—the three-or-more-year conjunction-class mission duration is not necessarily better from a crew health and performance perspective. From a purely medical point of view, it would seem intuitively obvious that the two-year opposition-class mission should be "better" for the crew than the longer-duration conjunction-class mission because of the shorter time spent in the deep space environment, but that conclusion is premature without more insight into the integrated vehicle risks that will be layered on top of the medical risks, as well as considerations for crew performance. Beyond the transportation and habitation systems, crew support elements, such as a long-duration food system, remote medical care, laundry/clothing, on-demand training aids, communications, physical and psychological support, and utilization systems, must be included as part of the end-to-end human Mars Architecture.

To ensure the human system is well integrated into the overall architecture, NASA is exercising a process to develop more robust spaceflight systems and build a culture of interplanetary human exploration, guided by the Agency's new blueprint objectives for exploration. This process incorporates iterative steps building on lessons learned from NASA assets and operations—such as Earth analogs, International Space Station and commercial LEO missions, and the development of plans for Artemis—to mature plans for future human Mars missions and to use these plans to inform activities for ISS and future platforms in LEO, as well as Gateway and lunar surface mission analogs during upcoming Artemis missions. The knowledge gained from these will reduce uncertainty and risk for Mars.

2.3.2.4 Mars Architecture Development Approach

The light-footprint initial mission architecture that has been developed over the past several analysis cycles will serve as a starting point to define one corner of the trade space. This modest architecture concept, described in more detail below, will be expanded through a methodical process to develop the initial human Mars segment. The decomposition of the Agency objectives drives the specific functions and use cases that inform Mars Architecture strategy. NASA will coordinate with stakeholders to explore integrated architecture impacts, such as how infrastructure or science objectives influence mass, volume, power, and overall transportation and habitation design. This will be an iterative process, resulting in a catalog of key Mars Architecture decisions. Where additional research is required to inform a decision, NASA will coordinate activities across the Agency, which may include testing, analysis, or analog investigations on Earth, orbiting platforms, or the lunar surface. Objectives will be prioritized to align with anticipated resource availability timelines, opportunities, and partner agreements. As a roadmap of key architecture decisions emerges and the trade space is narrowed, this document will be updated to reflect the evolving Mars Architecture.

Since the Mars Architecture will be built up over time, interoperability is a vital aspect to ensure compatibility between elements and systems. With limited ground support, on-board autonomy (crew and systems) and interoperability in the Mars campaign will be crucial for crew safety and mission success. Lunar interoperability lessons will guide the development of interoperability for Mars Architecture systems. Compatible systems envisioned include deep space vehicles, surface vehicles, utilization/science, and logistics operations. The Mars Architecture team will work with lunar programs to evaluate best practices learned from the lunar campaign and define the future needs for specific system compatibility.

2.4 Decomposition of Objectives

2.4.1 Lunar/Planetary Science (LPS)

Goal: Address high priority planetary science questions that are best accomplished by on-site human explorers on and around the Moon and Mars, aided by surface and orbiting robotic systems.

Characteristics and Needs	ID	Objectives	ID
Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	CN-055-L	Uncover the record of solar system origin and early history, by determining how and when planetary bodies formed and differentiated, characterizing the impact chronology of the inner solar system as recorded on the Moon and Mars, and characterize how impact rates in the inner solar system have changed over time as recorded on the Moon and Mars.	LPS-01-LM
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	CN-056-L		
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar sub-surface.	CN-057-L		
Return a variety of samples from the lunar surface and subsurface, including regolith, pebbles, and rocks, back to curation facilities on Earth.	CN-058-L		
Return a variety of samples, including drill cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum, from the lunar subsurface back to curation facilities on Earth.	CN-059-L		
Deploy and operate utilization payload(s), related to understanding impact chronology, at distributed sites on the lunar surface.	CN-060-L		
Accurate location identification, tracking, and imagery of collected samples.	CN-061-LM		
Deploy utilization payloads outside the blast zone of the propulsive vehicles.	CN-062-LM		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM		
Deploy and operate utilization payload(s), related to understanding impact chronology, at distributed sites on the Martian surface.	CN-064-M		
Provide the ability for the Science Team to directly or indirectly communicate in real-time via either written or verbal means with the crew for EVA and IVA activities.	CN-065-L		
Visit one or more sites with access to multiple regions of interest on the Martian surface that can address high priority science goals.	CN-066-M		
Identify, collect, and document samples from the Martian surface from each region on interest.	CN-067-M		
Identify, collect, and document samples from the Martian sub-surface from each region on interest.	CN-068-M		

Characteristics and Needs	ID	Objectives	ID
Return a variety of samples from the Martian surface, including of dust, soil, sand, pebbles, volatiles, back to curation facilities on Earth.	**CN-069-M**		
Return a variety of samples from the Martian subsurface at multiple depths, including frozen samples in their pristine state, sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	**CN-070-M**		
Return all samples of dust, soil, sand, rock, and subsurface materials in containers sealed under Martian atmosphere or an inert gas.	**CN-071-M**		
Conduct borehole measurements at varying depths, including ionizing radiation and heat flow.	**CN-072-M**		
Provide the ability for the Science Team to directly or indirectly communicate in nonrealtime via either written or verbal means with the crew for EVA and IVA activities.	**CN-073-M**		
Provide capabilities for conducting sample science, including preliminary analysis for geochemistry, mineralogy, and organic content, and solution chemistry of the soluble component of solid samples as well as ice and/or liquid samples on the Martian surface.	**CN-074-M**		
Provide pre-crew landing reconnaissance of areas around the landing site to determine the highest priority areas for sample collection and deployment of utilization payloads, characterizing potential traverse paths for accessing regions of interest, and to establish baseline environmental conditions in advance of human presence.	**CN-075-M**		
Pre-landing deployment of utilization payloads to minimize the amount of time required to setup when humans are required.	**CN-076-M**		
Minimize environmental impacts on the Martian surface to preserve scientific integrity for future exploration.	**CN-077-M**		
Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	**CN-055-L**	Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.	**LPS-02-LM**
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	**CN-056-L**		
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar sub-surface.	**CN-057-L**		
Return a variety of samples from the lunar surface and subsurface, including regolith, pebbles, and rocks, back to curation facilities on Earth.	**CN-058-L**		
Return a variety of samples, including drill cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum, from the lunar subsurface back to curation facilities on Earth.	**CN-059-L**		
Accurate location identification, tracking, and imagery of collected samples.	**CN-061-LM**		
Deploy utilization payloads outside the blast zone of the propulsive vehicles.	**CN-062-LM**		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**		
Deploy and operate utilization payload(s), related to understanding impact chronology, at distributed sites on the Martian surface.	**CN-064-M**		

Characteristics and Needs	ID	Objectives	ID
Provide the ability for the Science Team to directly or indirectly communicate in real-time via either written or verbal means with the crew for EVA and IVA activities.	**CN-065-L**		
Visit one or more sites with access to multiple regions of interest on the Martian surface that can address high priority science goals.	**CN-066-M**		
Identify, collect, and document samples from the Martian surface from each region on interest.	**CN-067-M**		
Identify, collect, and document samples from the Martian sub-surface from each region on interest.	**CN-068-M**		
Return a variety of samples from the Martian surface, including of dust, soil, sand, pebbles, volatiles, back to curation facilities on Earth.	**CN-069-M**		
Return a variety of samples from the Martian subsurface at multiple depths, including frozen samples in their pristine state, sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	**CN-070-M**		
Return all samples of dust, soil, sand, rock, and subsurface materials in containers sealed under Martian atmosphere or an inert gas.	**CN-071-M**		
Conduct borehole measurements at varying depths, including ionizing radiation and heat flow.	**CN-072-M**		
Provide the ability for the Science Team to directly or indirectly communicate in nonrealtime via either written or verbal means with the crew for EVA and IVA activities.	**CN-073-M**		
Provide capabilities for conducting sample science, including preliminary analysis for geochemistry, mineralogy, and organic content, and solution chemistry of the soluble component of solid samples as well as ice and/or liquid samples on the Martian surface.	**CN-074-M**		
Provide pre-crew landing reconnaissance of areas around the landing site to determine the highest priority areas for sample collection and deployment of utilization payloads, characterizing potential traverse paths for accessing regions of interest, and to establish baseline environmental conditions in advance of human presence.	**CN-075-M**		
Pre-landing deployment of utilization payloads to minimize the amount of time required to setup when humans are required.	**CN-076-M**		
Minimize environmental impacts on the Martian surface to preserve scientific integrity for future exploration.	**CN-077-M**		
Deploy and operate utilization payload(s), related to geologic processes, at distributed sites on the lunar surface.	**CN-217-L**		
Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	**CN-055-L**	Reveal inner solar system volatile origin and delivery processes by determining the age, origin, distribution, abundance, composition, transport, and sequestration of lunar and Martian volatiles.	**LPS-03-LM**
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	**CN-056-L**		
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar sub-surface.	**CN-057-L**		
Return a variety of samples from the lunar surface and subsurface, including regolith, pebbles, and rocks, back to curation facilities on Earth.	**CN-058-L**		

Characteristics and Needs	ID	Objectives	ID
Return a variety of samples, including drill cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum, from the lunar subsurface back to curation facilities on Earth.	**CN-059-L**		
Accurate location identification, tracking, and imagery of collected samples.	**CN-061-LM**		
Deploy utilization payloads outside the blast zone of the propulsive vehicles.	**CN-062-LM**		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**		
Deploy and operate utilization payload(s), related to understanding impact chronology, at distributed sites on the Martian surface.	**CN-064-M**		
Provide the ability for the Science Team to directly or indirectly communicate in real-time via either written or verbal means with the crew for EVA and IVA activities.	**CN-065-L**		
Visit one or more sites with access to multiple regions of interest on the Martian surface that can address high priority science goals.	**CN-066-M**		
Identify, collect, and document samples from the Martian surface from each region on interest.	**CN-067-M**		
Identify, collect, and document samples from the Martian sub-surface from each region on interest.	**CN-068-M**		
Return a variety of samples from the Martian surface, including of dust, soil, sand, pebbles, volatiles, back to curation facilities on Earth.	**CN-069-M**		
Return a variety of samples from the Martian subsurface at multiple depths, including frozen samples in their pristine state, sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	**CN-070-M**		
Return all samples of dust, soil, sand, rock, and subsurface materials in containers sealed under Martian atmosphere or an inert gas.	**CN-071-M**		
Conduct borehole measurements at varying depths, including ionizing radiation and heat flow.	**CN-072-M**		
Provide the ability for the Science Team to directly or indirectly communicate in nonrealtime via either written or verbal means with the crew for EVA and IVA activities.	**CN-073-M**		
Provide capabilities for conducting sample science, including preliminary analysis for geochemistry, mineralogy, and organic content, and solution chemistry of the soluble component of solid samples as well as ice and/or liquid samples on the Martian surface.	**CN-074-M**		
Provide pre-crew landing reconnaissance of areas around the landing site to determine the highest priority areas for sample collection and deployment of utilization payloads, characterizing potential traverse paths for accessing regions of interest, and to establish baseline environmental conditions in advance of human presence.	**CN-075-M**		
Pre-landing deployment of utilization payloads to minimize the amount of time required to setup when humans are required.	**CN-076-M**		
Minimize environmental impacts on the Martian surface to preserve scientific integrity for future exploration.	**CN-077-M**		

Characteristics and Needs	ID	Objectives	ID
Monitor the pre-, during-, and post-mission presence of Earth life at various distances from the landing site to help determine the degree of terrestrial contamination caused by a human mission and the contamination lifetime on the surface.	**CN-078-M**		
Deploy and operate utilization payload(s), related to Solar System volatiles, at distributed sites on the lunar surface.	**CN-218-L**		
Accurate location identification, tracking, and imagery of collected samples.	**CN-061-LM**	Advance understanding of the origin of life in the solar system by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have co-evolved over time, and whether there is evidence of past or present life in the solar system beyond Earth.	**LPS-04-L**
Deploy utilization payloads outside the blast zone of the propulsive vehicles.	**CN-062-LM**		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**		
Visit one or more sites with access to multiple regions of interest on the Martian surface that can address high priority science goals.	**CN-066-M**		
Identify, collect, and document samples from the Martian surface from each region on interest.	**CN-067-M**		
Identify, collect, and document samples from the Martian sub-surface from each region on interest.	**CN-068-M**		
Return a variety of samples from the Martian surface, including of dust, soil, sand, pebbles, volatiles, back to curation facilities on Earth.	**CN-069-M**		
Return a variety of samples from the Martian subsurface at multiple depths, including frozen samples in their pristine state, sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	**CN-070-M**		
Return all samples of dust, soil, sand, rock, and subsurface materials in containers sealed under Martian atmosphere or an inert gas.	**CN-071-M**		
Conduct borehole measurements at varying depths, including ionizing radiation and heat flow.	**CN-072-M**		
Provide the ability for the Science Team to directly or indirectly communicate in nonrealtime via either written or verbal means with the crew for EVA and IVA activities.	**CN-073-M**		
Provide pre-crew landing reconnaissance of areas around the landing site to determine the highest priority areas for sample collection and deployment of utilization payloads, characterizing potential traverse paths for accessing regions of interest, and to establish baseline environmental conditions in advance of human presence.	**CN-075-M**		
Pre-landing deployment of utilization payloads to minimize the amount of time required to setup when humans are required.	**CN-076-M**		
Minimize environmental impacts on the Martian surface to preserve scientific integrity for future exploration.	**CN-077-M**		
Monitor the pre-, during-, and post-mission presence of Earth life at various distances from the landing site to help determine the degree of terrestrial contamination caused by a human mission and the contamination lifetime on the surface.	**CN-078-M**		
Provide capabilities for identification, collection, and return of samples that are geochemically and mineralogically diverse, with proven or potential organic molecules, including biosignatures.	**CN-079-M**		

2.4.2 Heliophysics Science (HS)

Goal: Address high priority Heliophysics science and space weather questions that are best accomplished using a combination of human explorers and robotic systems at the Moon, at Mars, and in deep space.

Characteristics and Needs	ID	Objectives	ID
Deploy and operate utilization payload(s) in a variety of lunar orbits relevant to addressing the associated science objectives.	**CN-080-L**	Improve understanding of space weather phenomena to enable enhanced observation and prediction of the dynamic environment from space to the surface at the Moon and Mars.	**HS-01-LM**
Deploy and operate utilization payload(s) for Solar monitoring off the Earth-Sun line.	**CN-081-LM**		
Deploy and Operate utilization payload(s), related to in-space weather, at distributed sites on the lunar surface.	**CN-082-L**		
Deploy and operate utilization payload(s) in deep space, during Mars transit, and in Martian orbit relevant to addressing the associated science objectives.	**CN-083-M**		
Deploy and Operate utilization payload(s), related to in-space weather, at distributed sites on the Martian surface.	**CN-084-M**		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	**CN-056-L**	Determine the history of the Sun and solar system as recorded in the lunar and Martian regolith.	**HS-02-LM**
Return a variety of samples, including drill cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum, from the lunar subsurface back to curation facilities on Earth.	**CN-059-L**		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**		
Visit one or more sites with access to multiple regions of interest on the Martian surface that can address high priority science goals.	**CN-066-M**		
Deploy and operate utilization payload(s), related to the history of the Sun and solar system, at distributed sites on the lunar surface.	**CN-085-L**		
Return samples, including drill cores, from a variety of depths, in containers sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	**CN-086-M**		
Deploy and operate science package(s), related to the history of the sun and solar system, at distributed sites on the Mars surface.	**CN-087-M**		
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	**CN-056-L**	Investigate and characterize fundamental plasma processes, including dust-plasma interactions, using the cislunar, near-Mars, and surface environments as laboratories.	**HS-03-LM**
Identify, collect, and document samples from the Martian surface from each region on interest.	**CN-067-M**		
Deploy and operate utilization payload(s) in a variety of lunar orbits relevant to addressing the associated science objectives.	**CN-080-L**		

Characteristics and Needs	ID	Objectives	ID
Deploy and operate utilization payload(s) in deep space, during Mars transit, and in Martian orbit relevant to addressing the associated science objectives.	CN-083-M		
Deploy and operate utilization payload(s) on the Martian surface at locations relevant to addressing associated science objectives.	CN-089-M		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	CN-112-L		
Deploy and operate utilization payload(s) related to fundamental plasma processes around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	CN-220-L		
Deploy and operate science package(s), related to the magnetotail and solar wind, in cislunar space.	CN-090-L	Improve understanding of magnetotail and pristine solar wind dynamics in the vicinity of the Moon and around Mars.	HS-04-LM
Deploy and operate science package(s), related to the magnetotail and solar wind, at distributed sites on the lunar surface.	CN-091-L		
Deploy and operate science package(s), related to the magnetotail and solar wind, in Martian obit.	CN-092-M		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	CN-112-L		

2.4.3 Human and Biological Science (HBS)

Goal: Advance understanding of how biology responds to the environments of the Moon, Mars, and deep space to advance fundamental knowledge, support safe, productive human space missions and reduce risks for future exploration.

Characteristics and Needs	ID	Objectives	ID
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**	Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants.	**HBS-01-LM**
Deploy and operate utilization payload(s) in deep space, during Mars transit, and in Martian orbit relevant to addressing the associated science objectives.	**CN-083-M**		
Deploy and operate utilization payload(s) on the Martian surface at locations relevant to addressing associated science objectives.	**CN-089-M**		
Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	**CN-093-L**		
Conduct mid-duration (month+) to extended-duration (year+) crew exploration mission(s) in cislunar space prior to lunar surface mission.	**CN-094-L**		
Transition crew from micro-gravity environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.	**CN-095-LM**		
Return biological and human research sample(s), including frozen samples, from the lunar surface back to Earth.	**CN-096-L**		
Return biological and human research sample(s), including frozen samples, from the cislunar space back to Earth.	**CN-097-L**		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the lunar surface to enable biological science analysis and human research.	**CN-098-L**		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) in cislunar space to enable biological science analysis and human research.	**CN-099-L**		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) during transits in cislunar and/or deep space to enable biological science analysis and human research.	**CN-100-LM**		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the Martian surface and/or in Martian orbit to enable biological science analysis and human research.	**CN-101-M**		
Return biological and human research sample(s), including frozen samples, from the Martian surface and Martian orbit back to Earth.	**CN-102-M**		
Return biological and human research sample(s), including frozen samples, from deep space back to Earth.	**CN-103-M**		
Conduct short-duration (days to weeks) crew exploration mission(s) on the Martian surface.	**CN-104-M**		
Transition crew from partial gravity environment to micro-gravity environment.	**CN-105-LM**		

Characteristics and Needs	ID	Objectives	ID
Provide capabilities to collect, document, and transmit data from human research and space biology experiment for investigating physiological responses to transitions between partial and micro-gravity environment.	CN-212-L		
	CN-212-M		
Deploy and operate utilization payload(s) related to understanding the environment around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	CN-219-L		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Evaluate and validate progressively Earth-independent crew health & performance systems and operations with mission durations representative of Mars-class missions.	HBS-02-LM
Deploy and operate utilization payload(s) in deep space, during Mars transit, and in Martian orbit relevant to addressing the associated science objectives.	CN-083-M		
Deploy and operate utilization payload(s) on the Martian surface at locations relevant to addressing associated science objectives.	CN-089-M		
Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	CN-093-L		
Transition crew from micro-gravity environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.	CN-095-LM		
Return biological and human research sample(s), including frozen samples, from the lunar surface back to Earth.	CN-096-L		
Return biological and human research sample(s), including frozen samples, from the cislunar space back to Earth.	CN-097-L		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the lunar surface to enable biological science analysis and human research.	CN-098-L		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) in cislunar space to enable biological science analysis and human research.	CN-099-L		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) during transits in cislunar and/or deep space to enable biological science analysis and human research.	CN-100-LM		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the Martian surface and/or in Martian orbit to enable biological science analysis and human research.	CN-101-M		
Return biological and human research sample(s), including frozen samples, from the Martian surface and Martian orbit back to Earth.	CN-102-M		
Return biological and human research sample(s), including frozen samples, from deep space back to Earth.	CN-103-M		
Conduct short-duration (days to weeks) crew exploration mission(s) on the Martian surface.	CN-104-M		
Transition crew from partial gravity environment to micro-gravity environment.	CN-105-LM		

Characteristics and Needs	ID	Objectives	ID
Conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	CN-106-LM		
Provide capabilities to collect, document, and transmit data from human research and space biology experiment for investigating physiological responses to transitions between partial and micro-gravity environment.	CN-212-L		
	CN-212-M		
Deploy and operate utilization payload(s) related to understanding the environment around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	CN-219-L		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Characterize and evaluate how the interaction of exploration systems and the deep space environment affect human health, performance, and space human factors to inform future exploration-class missions.	HBS-03-LM
Deploy and operate utilization payload(s) in deep space, during Mars transit, and in Martian orbit relevant to addressing the associated science objectives.	CN-083-M		
Deploy and operate utilization payload(s) on the Martian surface at locations relevant to addressing associated science objectives.	CN-089-M		
Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	CN-093-L		
Transition crew from micro-gravity environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.	CN-095-LM		
Return biological and human research sample(s), including frozen samples, from the lunar surface back to Earth.	CN-096-L		
Return biological and human research sample(s), including frozen samples, from the cislunar space back to Earth.	CN-097-L		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the lunar surface to enable biological science analysis and human research.	CN-098-L		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) in cislunar space to enable biological science analysis and human research.	CN-099-L		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) during transits in cislunar and/or deep space to enable biological science analysis and human research.	CN-100-LM		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the Martian surface and/or in Martian orbit to enable biological science analysis and human research.	CN-101-M		
Return biological and human research sample(s), including frozen samples, from the Martian surface and Martian orbit back to Earth.	CN-102-M		
Return biological and human research sample(s), including frozen samples, from deep space back to Earth.	CN-103-M		
Conduct short-duration (days to weeks) crew exploration mission(s) on the Martian surface.	CN-104-M		

Characteristics and Needs	ID	Objectives	ID
Transition crew from partial gravity environment to micro-gravity environment.	**CN-105-LM**		
Conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	**CN-106-LM**		
Provide capabilities to collect, document, and transmit data from human research and space biology experiment for investigating physiological responses to transitions between partial and micro-gravity environment.	**CN-212-L**		
Deploy and operate utilization payload(s) related to understanding the environment around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	**CN-219-L**		

2.4.4 Physics and Physical Science (PPS)

Goal: Address high priority physics and physical science questions that are best accomplished by using unique attributes of the lunar environment.

Characteristics and Needs	ID	Objectives	ID
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**	Conduct astrophysics and fundamental physics investigations of space and time from the radio quiet environment of the lunar far side.	**PPS-01-L**
Deploy and operate astrophysics utilization payload(s) on the far side of the lunar surface.	**CN-107-L**		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the lunar surface to enable fundamental physics experiments.	**CN-108-L**		
Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) in cislunar space to enable fundamental physics experiments.	**CN-109-L**		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Return science experiment result(s), including test sample(s), back to Earth.	**CN-113-LM**		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**	Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.	**PPS-02-LM**
Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, in cislunar space.	**CN-110-L**		
Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, at distributed and south polar region sites on the lunar surface.	**CN-111-L**		
Return science experiment result(s), including test sample(s), back to Earth.	**CN-113-LM**		
Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, in deep space and in Martian orbit.	**CN-114-M**		
Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, at distributed sites on the Martian surface.	**CN-115-M**		

2.4.5 Science-Enabling (SE)

Goal: Develop integrated human and robotic methods and advanced techniques that enable high-priority scientific questions to be addressed around and on the Moon and Mars.

Characteristics and Needs	ID	Objectives	ID
Train astronauts to be field scientists and to perform additional science tasks during crewed missions, through integrated geology, field and EVA ops and classroom training.	CN-116-LM	Provide in-depth, mission-specific science training for astronauts to enable crew to perform high-priority or transformational science on the surface of the Moon, and Mars, and in deep space.	SE-01-LM
Provide scalable communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, surface crew, and assets on the surface.	CN-117-LM	Enable Earth-based scientists to remotely support astronaut surface and deep space activities using advanced techniques and tools.	SE-02-LM
Provide scalable communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, in-space crew, and in-space assets.	CN-118-LM		
Train Earth-based scientists to support crew activities in real time.	CN-119-L		
Train Earth-based scientists to support crew activities asynchronously.	CN-120-M		
Provide capabilities to return samples, including frozen samples in their pristine state, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface, with supporting equipment, back to curation facilities on Earth.	CN-050-L	Develop the capability to retrieve core samples of frozen volatiles from permanently shadowed regions on the Moon and volatile-bearing sites on Mars and to deliver them in pristine states to modern curation facilities on Earth.	SE-03-LM
Provide capabilities to return samples, collected from the lunar surface, including regolith, pebbles, and rocks, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	CN-051-L		
Provide capabilities to return samples, including frozen samples in their pristine state, from a variety of depths, in containers sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	CN-053-M		
Provide capabilities to return samples, collected from the Martian surface, including regolith, pebbles, and rocks, in containers sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	CN-054-M		
Provide capabilities to return samples, including drill cores, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	CN-121-L		
Provide tools, including temperature sensors, to support acquisition of frozen samples, manufactured in accordance with science requirements to minimize sample contamination.	CN-122-LM		
Provide sample containers appropriate for the specimens collected and science needs (e.g. contamination considerations), including sealed containers and drill core tubes.	CN-123-LM		
Provide curation facilities on Earth equipped for preserving acquired samples in their pristine state.	CN-124-LM		
Provide capabilities to return samples, including drill cores, from a variety of depths, in containers sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	CN-125-M		
Provide capabilities to return samples, collected from the lunar surface, including regolith, pebbles, and rocks, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	CN-051-L	Return representative samples from multiple locations across the surface of the Moon and	SE-04-LM

Characteristics and Needs	ID	Objectives	ID
Provide capabilities to return samples, collected from the Martian surface, including regolith, pebbles, and rocks, in containers sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	CN-054-M	Mars, with sample mass commensurate with mission-specific science priorities.	
Provide capabilities for conducting sample science, including preliminary analysis for geochemistry, mineralogy, and organic content, and solution chemistry of the soluble component of solid samples as well as ice and/or liquid samples on the Martian surface.	CN-074-M		
Provide capabilities to return samples, including drill cores, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	CN-121-L		
Provide sample containers appropriate for the specimens collected and science needs (e.g. contamination considerations), including sealed containers and drill core tubes.	CN-123-LM		
Provide curation facilities on Earth equipped for preserving acquired samples in their pristine state.	CN-124-LM		
Provide capabilities to return samples, including drill cores, from a variety of depths, in containers sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	CN-125-M		
Provide capabilities to visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	CN-126-L		
Provide capabilities to identify, collect, and document samples from globally distributed and south polar region locations on the lunar surface.	CN-127-L		
Provide tools to support acquisition of samples, including dust, soil, pebbles, hand-sized rock samples, and drill cores, manufactured in accordance with science requirements to minimize sample contamination.	CN-128-L		
Provide tools to support acquisition of samples, including dust, soil, sand, hand-sized rock samples, and drill cores, manufactured in accordance with science requirements to minimize sample contamination.	CN-129-M		
Provide capabilities to visit one or more sites with access to multiple regions of interest on the Martian surface that can address high priority science goals.	CN-130-M		
Provide capabilities to identify, collect, and document samples from multiple locations on the Martian surface.	CN-131-M		
Provide sample containers appropriate for the specimens collected and science needs (e.g. contamination considerations), including sealed containers and drill core tubes.	CN-123-LM	Use robotic techniques to survey sites, conduct in-situ measurements, and identify/stockpile samples in advance of and concurrent with astronaut arrival, to optimize astronaut time on the lunar and Martian surface and maximize science return.	SE-05-LM
Conduct robotic surveys of potential landing sites, including video and in situ measurements.	CN-132-LM		
Provide appropriate robotic tools to support acquisition of samples, including dust, soil, pebbles, hand-sized rock samples, and drill cores, manufactured in accordance with science requirements to minimize sample contamination.	CN-133-L		
Provide appropriate robotic tools support acquisition of samples, including dust, soil, sand, hand-sized rock samples, and drill cores, manufactured in accordance with science requirements to minimize sample contamination.	CN-134-M		
Provide capabilities to deploy assets in advance of crew arrival to minimize crew setup time for operation.	CN-135-M		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Enable long-term, planet-wide research by delivering science instruments to multiple	SE-06-LM

Characteristics and Needs	ID	Objectives	ID
Deploy and operate utilization payload(s) in a variety of lunar orbits relevant to addressing the associated science objectives.	**CN-080-L**	science-relevant orbits and surface locations at the Moon and Mars.	
Deploy and operate utilization payload(s) in deep space, during Mars transit, and in Martian orbit relevant to addressing the associated science objectives.	**CN-083-M**		
Deploy and operate utilization payload(s) around globally distributed locations on the lunar surface relevant to addressing associated science objectives.	**CN-088-L**		
Deploy and operate utilization payload(s) on the Martian surface at locations relevant to addressing associated science objectives.	**CN-089-M**		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Coordinate delivery and deployment of utilization payloads in cislunar space and on the lunar surface to address associated science objectives.	**CN-136-L**		
Coordinate delivery and deployment of utilization payloads in Martian orbit and on the Martian surface to address associated science objectives.	**CN-147-M**		
Preserve radio free environment on the far side of the Moon.	**CN-137-L**	Preserve and protect representative features of special interest, including lunar permanently shadowed regions and the radio quiet far side as well as Martian recurring slope lineae, to enable future high-priority science investigations.	**SE-07-LM**
Limit contamination of PSRs.	**CN-138-L**		
Protect sites of historic significance.	**CN-139-LM**		
Abide by planetary protection protocols, policies, and guidelines.	**CN-140-M**		
Minimize environmental impacts on the Martian surface to preserve scientific integrity for future exploration.	**CN-141-M**		
Monitor the pre-, during-, and post-mission presence of Earth life around representative features of special interest to help determine the degree of terrestrial contamination caused by a human mission and the contamination lifetime on the surface.	**CN-142-M**		

2.4.6 Applied Sciences (AS)

Goal: Conduct science on the Moon, in cislunar space, and around and on Mars using integrated human and robotic methods and advanced techniques, to inform design and development of exploration systems and enable safe operations.

Characteristics and Needs	ID	Objectives	ID
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Characterize and monitor the contemporary environments of the lunar and Martian surfaces and orbits, including investigations of micrometeorite flux, atmospheric weather, space weather, space weathering, and dust, to plan, support, and monitor safety of crewed operations in these locations.	AS-01-LM
Deploy and operate utilization payload(s) on the Martian surface at locations relevant to addressing associated science objectives.	CN-089-M		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	CN-112-L		
Provide system(s) to monitor cislunar space and lunar surface natural environments, including space weather, meteoroids, cosmic weather, thermal conditions, and plasma environments, and provide early warnings to in-space and surface assets and crew.	CN-143-L		
Provide system(s) to monitor deep space, Martian orbit, and Martian surface natural environments, including space weather, meteoroids, cosmic weather, thermal conditions, and plasma environments, and provide Earth-independent early warnings to in-space and surface assets and crew.	CN-144-M		
Provide capabilities to enable strategic pointing, e.g., Sun-facing, for external utilization payloads on orbital and transit platforms.	CN-145-M		
Provide capabilities to enable on-board computational resources for Earth-independent data analyses, for example to support forecasting capability of space weather-related hazards for crew safety.	CN-146-M		
Deploy and operate utilization payload(s) related to understanding the environment around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	CN-219-L		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Coordinate on-going and future science measurements from orbital and surface platforms to optimize human-led science campaigns on the Moon and Mars.	AS-02-LM
Deploy and operate utilization payload(s) in a variety of lunar orbits relevant to addressing the associated science objectives.	CN-080-L		
Deploy and operate utilization payload(s) in deep space, during Mars transit, and in Martian orbit relevant to addressing the associated science objectives.	CN-083-M		
Deploy and operate utilization payload(s) around globally distributed locations on the lunar surface relevant to addressing associated science objectives.	CN-088-L		
Deploy and operate utilization payload(s) on the Martian surface at locations relevant to addressing associated science objectives.	CN-089-M		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	CN-112-L		
Coordinate delivery and deployment of utilization payloads in cislunar space and on the lunar surface to address associated science objectives.	CN-136-L		
Coordinate delivery and deployment of utilization payloads in Martian orbit and on the Martian surface to address associated science objectives.	CN-147-M		

Characteristics and Needs	ID	Objectives	ID
Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	CN-055-L	Characterize accessible lunar and Martian resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable In-Situ Resource Utilization (ISRU) on successive missions.	AS-03-LM
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	CN-056-L		
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar sub-surface.	CN-057-L		
Return a variety of samples from the lunar surface and subsurface, including regolith, pebbles, and rocks, back to curation facilities on Earth.	CN-058-L		
Return a variety of samples, including drill cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum, from the lunar subsurface back to curation facilities on Earth.	CN-059-L		
Accurate location identification, tracking, and imagery of collected samples.	CN-061-LM		
Deploy utilization payloads outside the blast zone of the propulsive vehicles.	CN-062-LM		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM		
Visit one or more sites with access to multiple regions of interest on the Martian surface that can address high priority science goals.	CN-066-M		
Identify, collect, and document samples from the Martian surface from each region on interest.	CN-067-M		
Identify, collect, and document samples from the Martian sub-surface from each region on interest.	CN-068-M		
Return a variety of samples from the Martian surface, including of dust, soil, sand, pebbles, volatiles, back to curation facilities on Earth.	CN-069-M		
Return a variety of samples from the Martian subsurface at multiple depths, including frozen samples in their pristine state, sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	CN-070-M		
Return samples, including drill cores, from a variety of depths, in containers sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	CN-086-M		
Return samples, including frozen samples in their pristine state, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface, with supporting equipment, back to curation facilities on Earth.	CN-148-L		
Provide mobility capabilities to conduct prospecting traverses with appropriate scientific instrumentation and drill capabilities over sites of interest.	CN-149-LM		
Deploy and operate utilization payload(s), related to available resources, at distributed and south polar region sites on the lunar surface.	CN-150-L		
Deploy and operate utilization payload(s), related to available resources, at distributed sites on the Martian surface.	CN-151-M		

Characteristics and Needs	ID	Objectives	ID
Demonstrate operation of bioregenerative ECLSS sub-systems in LEO and/or deep space.	**CN-152-LM**	Conduct applied scientific investigations essential for the development of bioregenerative-based, ecological life support systems.	**AS-04-LM**
Demonstrate operation of plant based ECLSS sub-systems in LEO and/or deep space.	**CN-153-LM**	Define crop plant species, including methods for their productive growth, capable of providing sustainable and nutritious food sources for lunar, Deep Space transit, and Mars habitation.	**AS-05-LM**
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**	Advance understanding of how physical systems and fundamental physical phenomena are affected by partial gravity, microgravity, and general environment of the Moon, Mars, and deep space transit.	**AS-06-LM**
Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, in cislunar space.	**CN-110-L**		
Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, at distributed and south polar region sites on the lunar surface.	**CN-111-L**		
Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, in deep space and in Martian orbit.	**CN-114-M**		
Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, at distributed sites on the Martian surface.	**CN-115-M**		

2.4.7 Lunar Infrastructure (LI)

Goal: Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.

Characteristics and Needs	ID	Objectives	ID
Provide scalable power generation, energy storage, and power distribution system(s) on the lunar surface to support large exploration assets.	**CN-154-L**	Develop an incremental lunar power generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels.	**LI-01-L**
Provide scalable power generation, energy storage, and power distribution system(s) on the lunar surface to allow power utilization to support assets at multiple distributed locations around exploration sites.	**CN-155-L**		
Provide power generation, energy storage, and power distribution system(s) on the lunar surface that are able to supply continuous power availability during crew safety critical mission operation and are able to support contingency operations.	**CN-156-L**		
Provide scalable communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, surface crew, and assets on the surface.	**CN-117-LM**	Develop a lunar surface, orbital, and Moon-to-Earth communications architecture capable of scaling to support long term science, exploration, and industrial needs.	**LI-02-L**
Provide scalable communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, in-space crew, and in-space assets.	**CN-118-LM**		
Provide scalable communication system(s) to enable high bandwidth, high availability communications between In-space personnel, surface crew, and assets on the surface.	**CN-157-LM**		
Provide communication capabilities to allow NASA to inspire and inform the general public, students, and teachers by enabling them to interact, learn about, and experience missions in a direct and tangible way.	**CN-158-L**		
Provide scalable navigation, positioning, and timing system(s) to enable high availability navigation and tracking in cislunar space.	**CN-159-L**	Develop a lunar position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.	**LI-03-L**
Provide scalable navigation, positioning, and timing system(s) to enable high availability navigation and tracking on the lunar surface.	**CN-160-L**		
Provide system(s) to enable accurate location identification, tracking, and documentation of collected surface samples.	**CN-161-L**		
Deploy and operate autonomous construction demonstration utilization payload(s) to the lunar surface, including partial-scale demonstrations of regolith management and construction of structures, to demonstrate scalable capabilities and applications.	**CN-162-L**	Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.	**LI-04-L**
Deploy and operate advanced manufacturing demonstration utilization payload(s) to the lunar surface, including scaled demonstration of additive/subtractive manufacturing techniques and inspection/certification processes, to demonstrate scalable capabilities and applications.	**CN-163-L**		
Demonstrate the capability for lunar landers to reliably and safely land within a defined radius around an intended location.	**CN-164-L**	Demonstrate precision landing capabilities in support of continuous human lunar presence and a robust lunar economy.	**LI-05-L**
Demonstrate the capability to allow crew to move locally around landing sites to visit multiple locations of interest.	**CN-165-L**	Demonstrate local, regional, and global surface transportation and mobility capabilities in support of continuous human lunar presence and a robust lunar economy.	**LI-06-L**
Demonstrate the capability to relocate large exploration assets to locations around the lunar south polar region during uncrewed phases of missions.	**CN-166-L**		

Characteristics and Needs	ID	Objectives	ID
Demonstrate the capability for crew to access surface assets at different potential locations distributed across the lunar globe.	**CN-167-L**		
Deploy and operate scalable demonstration ISRU utilization payload(s) to the lunar surface.	**CN-168-L**	Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy.	**LI-07-L**
Deploy and operate demonstration utilization payload(s) on the lunar surface to collect, produce, store, and transfer commodities, including water, oxygen, and/or construction feedstock, for potential use by system and/or crew.	**CN-169-L**		
Demonstrate the capability to identify and locate potential site(s) for resource utilization.	**CN-170-L**		
Demonstrate the capability to transfer propellant from one spacecraft to another in space (including interfaces for non-cryogenic propellants, cryogenic propellants, power, data, commands, and buffer gases).	**CN-171-L**	Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.	**LI-08-L**
Demonstrate the capability to transfer propellant from one asset to another on the lunar surface (including interfaces for non-cryogenic propellants, cryogenic propellants, power, data, commands, and buffer gases).	**CN-172-L**		
Demonstrate the capability to store propellant for extended-durations (year+) in space (including cryogenic propellant, leak management, and mass gauging).	**CN-173-L**		
Demonstrate the capability to store propellant for extended-durations (year+) on the lunar surface (including cryogenic propellant, leak management, and mass gauging).	**CN-174-L**		
Deploy and operate autonomous demonstration construction utilization payload(s) that are reliant on surface-borne feedstock to demonstrate scalable capabilities and applications, such as additive/subtractive manufacturing and construction of structures.	**CN-175-L**		
Provide system(s) to monitor cislunar space and lunar surface natural environments, including space weather, meteoroids, cosmic weather, thermal conditions, and plasma environments, and provide early warnings to in-space and surface assets and crew.	**CN-143-L**	Develop environmental monitoring, situational awareness, and early warning capabilities to support a resilient, continuous human/robotic lunar presence.	**LI-09-L**
Provide system(s) to monitor cislunar space and lunar surface induced environments, including radiation, thermal conditions, high-energy debris, contamination, electrostatics, and acoustics, and provide early warnings to in-space and surface assets and crew.	**CN-176-L**		

2.4.8 Mars Infrastructure (MI)

Goal: Create essential infrastructure to support initial human Mars exploration campaign.

Characteristics and Needs	ID	Objectives	ID
Provide power generation, energy storage, and power distribution system(s) on the Martian surface to support large exploration assets.	CN-177-M	Develop Mars surface power sufficient for an initial human Mars exploration campaign.	MI-01-M
Provide power generation, energy storage, and power distribution system(s) on the Martian surface to allow power utilization to support assets at multiple distributed locations around exploration sites.	CN-178-M		
Provide power generation, energy storage, and power distribution system(s) on the Martian surface that are able to supply continuous power availability during crew safety critical mission operations and are able to support contingency operations.	CN-179-M		
Provide communication capabilities to allow NASA to inspire and inform the general public, students, and teachers by enabling them to interact, learn about, and experience missions in a direct and tangible way.	CN-158-M	Develop Mars surface, orbital, and Mars-to-Earth communications to support an initial human Mars exploration campaign.	MI-02-M
Provide communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, surface crew, and assets on the surface.	CN-180-M		
Provide communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, in-space crew, and in-space assets.	CN-181-M		
Provide communication system(s) to enable high bandwidth, high availability communications between in-space crew, surface crew, and assets on the surface.	CN-182-M		
Provide system(s) to enable accurate location identification, tracking, and documentation of collected surface samples.	CN-161-M	Develop Mars position, navigation and timing capabilities to support an initial human Mars exploration campaign.	MI-03-M
Provide navigation, positioning, and timing system(s) to enable high availability navigation and tracking on the Martian surface.	CN-183-M		
Provide navigation, positioning, and timing system(s) to enable high availability navigation and tracking in deep space and in Mars orbit.	CN-184-M		
Demonstrate the capability for Mars landers to safely land within a defined radius around an intended location.	CN-185-M		
Demonstrate the capability to identify and locate potential site(s) for resource utilization.	CN-170-M	Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign.	MI-04-M
Deploy and operate scalable ISRU demonstration utilization payload(s) to the Martian surface.	CN-186-M		
Deploy and operate demonstration utilization payload(s) on the Martian surface to collect, produce, store, and transfer commodities, including water, oxygen and/or fuel, for potential use by system and/or crew.	CN-187-M		

2.4.9 Transportation and Habitation (TH)

Goal: Develop and demonstrate an integrated system of systems to conduct a campaign of human exploration missions to the Moon and Mars, while living and working on the lunar and Martian surface, with safe return to Earth.

Characteristics and Needs	ID	Objectives	ID
Provide capabilities to transport crew and crew system(s) from Earth to cislunar space.	**CN-001-L**	Develop cislunar systems that crew can routinely operate to and from lunar orbit and the lunar surface for extended durations.	**TH-01-L**
Provide capabilities to enable staging and/or assembly operations of crew and cargo system(s) in cislunar space with accessibility to both Earth and the lunar surface, including the lunar South Polar region.	**CN-002-L**		
Provide capabilities to transport crew between stable lunar orbit, including NRHO, and the lunar surface.	**CN-003-L**		
Provide capabilities to operate crew transportation system(s) in uncrewed mode for mid-durations (month+) to extended-durations (year+) in cislunar space and on the lunar surface.	**CN-004-L**		
Provide capabilities to safely return crew and system(s) to Earth from lunar surface and cislunar space.	**CN-005-L**		
Implement stable transportation capabilities, which minimize required upgrades over time, to support lunar missions.	**CN-006-L**		
Implement robust transportation capabilities, where systems can perform a variety of design reference missions, to support lunar missions.	**CN-007-L**		
Provide capabilities to deliver system(s) from Earth to the lunar surface.	**CN-008-L**	Develop system(s) that can routinely deliver a range of elements to the lunar surface.	**TH-02-L**
Provide capabilities to unload cargo from delivery system(s).	**CN-009-L**		
Implement end-of-life strategies for transportation systems to ensure future viable usage of exploration sites on the lunar surface.	**CN-010-L**		
Provide capabilities to conduct short-duration (days to weeks) crew exploration mission(s) on the lunar surface.	**CN-011-L**	Develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence; conducting scientific and industrial utilization as well as Mars analog activities.	**TH-03-L**
Provide capabilities to conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	**CN-012-L**		
Provide capabilities to conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	**CN-013-L**		
Provide capabilities to enable crew transition in/out of habitable space to conduct EVA activities.	**CN-014-L**		
Implement stable habitation capabilities, which minimize required upgrades over time, to support lunar missions.	**CN-015-L**		
Implement robust habitation capabilities, where systems can support all design reference missions, to support lunar missions.	**CN-016-L**		

Characteristics and Needs	ID	Objectives	ID
Provide capabilities to enable staging and/or assembly operations of crew and cargo system(s) in cislunar space with accessibility to both Earth and the lunar surface, including the lunar South Polar region.	**CN-002-L**	Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.	**TH-04-LM**
Provide capabilities to conduct short-duration (days to weeks) crew exploration mission(s) on the lunar surface.	**CN-011-L**		
Provide capabilities to conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	**CN-012-L**		
Provide capabilities to conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	**CN-013-L**		
Provide capabilities to enable staging and/or assembly operations of crew and cargo system(s) in cislunar or near-Earth space with accessibility to Earth and to support departure for Mars missions.	**CN-017-M**		
Provide capabilities to conduct mid-duration (month+) crew exploration mission(s) on the Martian surface.	**CN-018-M**		
Provide capabilities that allow crew to live in deep space for Mars duration mission(s).	**CN-019-M**		
Provide capabilities to transport crew and system(s) between Earth, cislunar space, and Mars orbit.	**CN-020-M**	Develop transportation systems that crew can routinely operate between the Earth-Moon vicinity and Mars vicinity, including the Martian surface.	**TH-05-M**
Provide capabilities to transport crew between Mars orbit and the Martian surface.	**CN-021-M**		
Provide capabilities to enable staging and/or assembly operations of crew and cargo system(s) in space to enable access to deep space and Mars.	**CN-022-M**		
Provide capabilities to operate system(s) in uncrewed mode for mid-duration (month+) to extended-duration (year+) in cislunar space, Martian orbit, and/or Martian surface.	**CN-023-M**		
Provide capabilities to safely return crew and system(s) to Earth from Mars.	**CN-024-M**		
Implement stable transportation capabilities, which minimize required upgrades over time, to support Mars missions.	**CN-025-M**		
Implement robust transportation capabilities, where systems can support all design reference missions, to support Mars missions.	**CN-026-M**		
Provide capabilities to unload cargo from delivery system(s).	**CN-009-M**	Develop transportation systems that can deliver a range of elements to the Martian surface.	**TH-06-M**
Implement stable transportation capabilities, which minimize required upgrades over time, to support Mars missions.	**CN-025-M**		
Implement robust transportation capabilities, where systems can support all design reference missions, to support Mars missions.	**CN-026-M**		
Provide capabilities to deliver system(s) from Earth and cislunar space to Mars orbit and Mars surface.	**CN-027-M**		

Characteristics and Needs	ID	Objectives	ID
Implement end-of-life strategies for transportation systems to ensure future viable usage of exploration sites on the Martian surface.	**CN-028-M**		
Provide capabilities to enable crew transition in/out of habitable space to conduct EVA activities.	**CN-014-M**	Develop systems for crew to explore, operate, and live on the Martian surface to address key questions with respect to science and resources.	**TH-07-M**
Provide capabilities to conduct mid-duration (month+) crew exploration mission(s) on the Martian surface.	**CN-018-M**		
Implement stable habitation capabilities, which minimize required upgrades over time, to support Mars missions.	**CN-029-M**		
Implement robust habitation capabilities, where systems can support all design reference missions, to support Mars missions.	**CN-030-M**		
Provide crew health and performance capabilities in cislunar space and in deep space, including demonstration of remote and autonomous healthcare and advanced diagnostics, to prepare for future Mars missions.	**CN-031-L**	Develop systems that monitor and maintain crew health and performance throughout all mission phases, including during communication delays to Earth, and in an environment that does not allow emergency evacuation or terrestrial medical assistance.	**TH-08-LM**
Provide crew health and performance capabilities on the lunar surface, including demonstration of remote and autonomous healthcare and advanced diagnostics, to prepare for future Mars missions.	**CN-032-L**		
Provide robust Integrated Data Architecture (IDA) to support Crew Health and Performance System(s).	**CN-033-LM**		
Provide countermeasures capabilities (e.g., exercise, nutrition, sensorimotor, cardiovascular, immune) that are commensurate in scope with the human system needs for the mission.	**CN-034-LM**		
Provide appropriate medical monitoring capabilities (including behavioral health) that enables inflight crew health diagnosis and decision making.	**CN-035-LM**		
Provide appropriate environmental monitoring capabilities (including acoustics, microbial, chemical, and radiation) that enables inflight crew health decision making and mitigation of relevant system/vehicle hazards.	**CN-036-LM**		
Provide comprehensive Earth-independent medical care capabilities that is scoped to support the mission and address relevant inflight medical conditions and long-term crew health considerations.	**CN-037-LM**		
Demonstrate crew survival capabilities in cislunar space and on the lunar surface, including safe havens, system supportability, and/or aborts, for nominal and off-nominal scenarios to prepare for future Mars missions.	**CN-038-L**		
Provide crew health and performance capabilities in deep space and Mars orbit, including demonstration of remote and autonomous healthcare and advanced diagnostics.	**CN-039-M**		
Provide crew health and performance capabilities on the Martian surface, including demonstration of remote and autonomous healthcare and advanced diagnostics.	**CN-040-M**		
Provide crew survival capabilities in deep space, Mars orbit, and on the Martian surface, including safe havens, system supportability, and/or aborts, for nominal and off-nominal scenarios.	**CN-041-M**		
Provide appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone on the lunar surface.	**CN-042-L**	Develop integrated human and robotic systems with inter-relationships that enable maximum science and exploration during lunar missions.	**TH-09-L**
Provide appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone in cislunar or deep space.	**CN-043-L**		

Characteristics and Needs	ID	Objectives	ID
Demonstrate the capability for safe and effective interactions between crew and automated/autonomous system(s).	**CN-044-L**		
Demonstrate capabilities to allow in-space and surface crew to control and command robotic system(s).	**CN-045-L**		
Minimize crew time required for inspection, commissioning, maintenance, and logistics operations to maximize crew time available for science and exploration activities.	**CN-046-L**		
Provide appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone in cislunar or deep space.	**CN-043-M**	Develop integrated human and robotic systems with inter-relationships that enable maximum science and exploration during Martian missions.	**TH-10-M**
Demonstrate the capability for safe and effective interactions between crew and automated/autonomous system(s).	**CN-044-M**		
Demonstrate capabilities to allow in-space and surface crew to control and command robotic system(s).	**CN-045-M**		
Minimize crew time required for inspection, commissioning, maintenance, and logistics operations to maximize crew time available for science and exploration activities.	**CN-046-M**		
Provide appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone on the Martian surface.	**CN-047-M**		
Provide capabilities to return cargo from the lunar surface back to cislunar space.	**CN-048-L**	Develop systems capable of returning a range of cargo mass from the lunar surface to Earth, including the capabilities necessary to meet scientific and utilization objectives.	**TH-11-L**
Provide capabilities to return cargo from cislunar space back to Earth-based facilities.	**CN-049-L**		
Provide capabilities to return samples, including frozen samples in their pristine state, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface, with supporting equipment, back to curation facilities on Earth.	**CN-050-L**		
Provide capabilities to return samples, collected from the lunar surface, including regolith, pebbles, and rocks, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	**CN-051-L**		
Provide capabilities to return cargo from cislunar space back to Earth-based facilities.	**CN-049-M**	Develop systems capable of returning a range of cargo mass from the Martian surface to Earth, including the capabilities necessary to meet scientific and utilization objectives.	**TH-12-M**
Provide capabilities to return cargo from the Martian surface back to Earth vicinity.	**CN-052-M**		
Provide capabilities to return samples, including frozen samples in their pristine state, from a variety of depths, in containers sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	**CN-053-M**		
Provide capabilities to return samples, collected from the Martian surface, including regolith, pebbles, and rocks, in containers sealed under Martian atmosphere or an inert gas, back to curation facilities on Earth.	**CN-054-M**		

2.4.10 Operations (OP)

Goal: Conduct human missions on the surface and around the Moon followed by missions to Mars. Using a gradual build-up approach, these missions will demonstrate technologies and operations to live and work on a planetary surface other than Earth, with a safe return to Earth at the completion of the missions.

Characteristics and Needs	ID	Objectives	ID
Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	**CN-093-L**	Conduct human research and technology demonstrations on the surface of Earth, low-Earth orbit platforms, cislunar platforms, and on the surface of the moon, to evaluate the effects of extended mission durations on the performance of crew and systems, reduce risk, and shorten the timeframe for system testing and readiness prior to the initial human Mars exploration campaign.	**OP-01-L**
Transition crew from micro-gravity environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.	**CN-095-LM**		
Transition crew from partial gravity environment to micro-gravity environment.	**CN-105-LM**		
Conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	**CN-106-LM**		
Conduct short-duration (days to weeks) crew exploration mission(s) on the lunar surface.	**CN-188-L**		
Conduct crewed and uncrewed testing of surface habitable system(s).	**CN-189-L**		
Conduct crewed and uncrewed testing of in-space habitable system(s).	**CN-190-L**		
Operate and gain experience with onboard autonomous system(s) and crew autonomy to train, plan, and execute safe mission(s) with reduced reliance on Earth based systems.	**CN-191-LM**	Optimize operations, training and interaction between the team on Earth, crew members on orbit, and a Martian surface team considering communication delays, autonomy level, and time required for an early return to the Earth.	**OP-02-LM**
Operate and gain experience with flight control and mission integration to ensure safety and mission success in nominal and off-nominal conditions.	**CN-192-LM**		
Operate and gain experience with remote & autonomous system(s) to reduce crew workload.	**CN-193-LM**		
Operate and gain experience with in-situ training and planning capabilities to ensure safety and mission success.	**CN-194-LM**		
Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	**CN-055-L**	Characterize accessible resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable use of resources on successive missions.	**OP-03-LM**
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	**CN-056-L**		
Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar sub-surface.	**CN-057-L**		
Visit one or more sites with access to multiple regions of interest on the Martian surface that can address high priority science goals.	**CN-066-M**		
Identify, collect, and document samples from the Martian surface from each region on interest.	**CN-067-M**		
Identify, collect, and document samples from the Martian sub-surface from each region on interest.	**CN-068-M**		

Characteristics and Needs	ID	Objectives	ID
Deploy and operate utilization payload(s), related to available resources, at distributed and south polar region sites on the lunar surface.	**CN-150-L**		
Deploy and operate utilization payload(s), related to available resources, at distributed sites on the Martian surface.	**CN-151-M**		
Demonstrate the capability to identify and locate potential site(s) for resource utilization.	**CN-170-L**		
	CN-170-M		
Provide capabilities to integrate networks and mission systems to exchange data between Earth-based systems, in-space exploration assets, and surface exploration assets.	**CN-195-LM**	Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.	**OP-04-LM**
Provide capabilities to utilize common data interface(s) for exchanges between Earth-based systems, in-space exploration assets, and surface exploration assets.	**CN-196-LM**		
Provide capabilities to store and protect data on exploration assets.	**CN-197-LM**		
Operate and gain experience with capabilities to transport crew and cargo between landing or base site and exploration sites at varying distances from fixed assets.	**CN-198-L**	Operate surface mobility systems, e.g., extra-vehicular activity (EVA) suits, tools and vehicles.	**OP-05-LM**
Operate and gain experience with capabilities to conduct extravehicular activities utilizing mobility assets and tools.	**CN-199-LM**		
Operate and gain experience with capabilities to remotely operate surface mobility system(s) from Earth, in-space assets, and/or other surface assets.	**CN-200-LM**		
Operate and gain experience with capabilities to transport crew and cargo between landing site and exploration sites at varying distances from fixed assets.	**CN-201-M**		
Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	**CN-093-L**	Evaluate, understand, and mitigate the impacts on crew health and performance of a long deep space orbital mission, followed by partial gravity surface operations on the Moon.	**OP-06-L**
Transition crew from micro-gravity environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.	**CN-095-LM**		
Transition crew from partial gravity environment to micro-gravity environment.	**CN-105-LM**		
Conduct short-duration (days to weeks) crew exploration mission(s) on the lunar surface.	**CN-188-L**		
Conduct numerous extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	**CN-202-L**		
Provide crew health and performance capabilities in cislunar space and in deep space, including demonstration of remote and autonomous healthcare and advanced diagnostics, to prepare for future Mars missions.	**CN-031-L**	Validate readiness of systems and operations to support crew health and performance for the initial human Mars exploration campaign.	**OP-07-LM**
Provide crew health and performance capabilities on the lunar surface, including demonstration of remote and autonomous healthcare and advanced diagnostics, to prepare for future Mars missions.	**CN-032-L**		

Characteristics and Needs	ID	Objectives	ID
Demonstrate crew survival capabilities in cislunar space and on the lunar surface, including safe havens, system supportability, and/or aborts, for nominal and off-nominal scenarios to prepare for future Mars missions.	**CN-038-L**		
Provide crew health and performance capabilities in deep space and Mars orbit, including demonstration of remote and autonomous healthcare and advanced diagnostics.	**CN-039-M**		
Provide crew health and performance capabilities on the Martian surface, including demonstration of remote and autonomous healthcare and advanced diagnostics.	**CN-040-M**		
Provide crew survival capabilities in deep space, Mars orbit, and on the Martian surface, including safe havens, system supportability, and/or aborts, for nominal and off-nominal scenarios.	**CN-041-M**		
Conduct crewed and uncrewed testing of surface habitable system(s).	**CN-189-L**		
Conduct crewed and uncrewed testing of in-space habitable system(s).	**CN-190-L**		
Demonstrate the capabilities to locate, access, and reuse surface assets from previous crewed and uncrewed missions.	**CN-203-LM**	Demonstrate the capability to find, service, upgrade, or utilize instruments and equipment from robotic landers or previous human missions on the surface of the Moon and Mars.	**OP-08-LM**
Demonstrate the capabilities to service and/or upgrade assets.	**CN-204-LM**		
Provide appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone on the lunar surface.	**CN-042-L**	Demonstrate the capability of integrated robotic systems to support and maximize the useful work performed by crewmembers on the surface, and in orbit.	**OP-09-LM**
Demonstrate the capability for safe and effective interactions between crew and automated/autonomous system(s).	**CN-044-L**		
Demonstrate capabilities to allow in-space and surface crew to control and command robotic system(s).	**CN-045-L**		
Demonstrate the capabilities to operate appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone on the lunar surface.	**CN-213-L**		
Demonstrate the capabilities to operate appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone in cislunar space.	**CN-214-L**		
Demonstrate the capabilities to operate appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone on the Martian surface.	**CN-215-M**		
Demonstrate the capabilities to operate appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone in deep space and/or Martian orbit.	**CN-216-M**		
Demonstrate the capability for safe and effective interactions between crew and automated/autonomous system(s).	**CN-044-L**	Demonstrate the capability to operate robotic systems that are used to support crew members on the lunar or Martian surface, autonomously or remotely from the Earth or from orbiting platforms.	**OP-10-LM**
Demonstrate autonomous and remote operations of surface systems from external systems, including Earth, orbital, and/or other surface locations.	**CN-205-LM**		
Demonstrate autonomous and remote operations of in-space systems from external systems, including Earth, orbital, and/or surface locations.	**CN-206-LM**		

Characteristics and Needs	ID	Objectives	ID
Deploy and operate demonstration utilization payload(s) on the lunar surface to collect, produce, store, and transfer commodities, including water, oxygen, and/or construction feedstock, for potential use by system and/or crew.	**CN-169-L**	Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.	**OP-11-LM**
Deploy and operate demonstration utilization payload(s) on the Martian surface to collect, produce, store, and transfer commodities, including water, oxygen and/or fuel, for potential use by system and/or crew.	**CN-187-M**		
Demonstrate the capability to use surface-borne resources for potential construction and/or manufacturing on the lunar surface.	**CN-207-L**		
Demonstrate the capability to use surface-borne resources for potential construction and/or manufacturing on the Martian surface.	**CN-208-M**		
Preserve radio free environment on the far side of the Moon.	**CN-137-L**	Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration.	**OP-12-LM**
Limit contamination of PSRs.	**CN-138-L**		
Abide by planetary protection protocols, policies, and guidelines.	**CN-140-M**		
Demonstrate the capabilities to recover useful equipment from surface assets, where valuable.	**CN-209-L**		
Demonstrate the capabilities to recovery of excess fluids and gases, including propellant residuals, from lunar landers and separation of products.	**CN-210-L**		
Demonstrate the capabilities to recovery of excess fluids and gases, including propellant residuals, from Mars landers and separation of products.	**CN-211-M**		

3.0 MOON TO MARS ARCHITECTURE

The architecture methodology process described in Section 1.3 has yielded a structured approach to objective decomposition and applicability to system definition to establish the architecture.

Return—The architecture starts with the development and demonstration of the systems that transport crew and exploration capabilities to target destinations. The successful Artemis I mission was the first step in this progressive expansion of the capability envelope over a series of missions where a minimum crew of four can support missions in deep space and on the lunar surface, and eventually future destinations.

Explore—Using an evolutionary approach, the architecture enables high-priority science, technology demonstrations, systems validation, and operations for crew to live and work on a non-terrestrial planetary surface, with a safe return to Earth at the completion of the mission(s). Key characteristics include operating and designing the lunar systems with Mars risk reduction in mind, from a systems, operations, and human perspective. The architecture accommodates this approach in the context of available capabilities and differences in the lunar and Mars environments. Initially, this is done at the element level, then through combined operations that eventually culminate in several precursor missions in the lunar vicinity where the crew experiences long durations in the deep space environment, coupled with rapid acclimation to partial gravity excursions using Mars-like systems and operations. The Mars-forward exploration systems also have the goal of maximizing crew efficiency for utilization, which will be tested by a continuum of excursions to a diverse set of sites driven by science needs. The balance between diverse site access and long-duration infrastructure objectives will inform the allocation of functions across systems.

Sustain—The Foundational Exploration capabilities serve as a basis to increase global access, industrial-scale ISRU, and crew durations beyond NASA's initial needs. Although evolution of the Lunar Architecture along the lines of these greater capabilities would seem to occur later in the architecture, the implications of the potential future lunar states are initiated at the very beginning of the architecture with the early reconnaissance missions, where factors like access to and purity of volatiles in several regions may dictate the role and level of ISRU.

The Lunar Architecture is developing, deploying, and operating systems for lunar vicinity exploration; performing science at diverse locations and returning lunar samples; preparing for further exploration with Mars-capable systems, operations, and precursor missions; and establishing a permanent lunar presence that could one day support a lunar economy. The Mars Architecture can follow the same basic approach as the Moon, to achieve a human presence, explore, and then sustain development.

The architecture has been structured to reflect the incremental buildup of capabilities and objective satisfaction. These campaign segments have been crafted along the return, explore, and sustain approach to further delineate the continuum of evolving capability and objective satisfaction. They are described in Table 3-1 below. Although the segments appear sequential in the table, they are not exclusively serialized, as the segments build upon each other and focus on how systems will work together to achieve objective satisfaction.

Table 3-1. Moon to Mars Campaign Segments

Human Lunar Return	Initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization (science, etc.) on and around the Moon.
Foundational Exploration	Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization (science, etc.) and Mars forward precursor missions.
Sustained Lunar Evolution	Enabling capabilities, systems, and operations to support regional and global utilization (science, etc.), economic opportunity, and a steady cadence of human presence on and around the Moon.
Humans to Mars	Initial capabilities, systems, and operations necessary to establish human presence and initial utilization (science, etc.) on Mars and continued exploration.
Future Segments	Additional segment(s) will be added to enable continued exploration for the Moon, Mars, or beyond as objectives are accomplished and/or added to in the future.

The initial segment is **Human Lunar Return**. This segment includes the initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization (science, etc.) on and around the Moon. This segment's primary focus is establishing the missions and supporting infrastructure to perform sortie crewed missions to the Moon. The systems and support span Earth, cislunar orbiting platforms, and the foothold capabilities on the lunar surface. The initial support of utilization focuses on the human-conducted science, sample collection, human research, and initial capabilities, among others, for the first time outside LEO in over 50 years.

The **Foundational Exploration** segment includes lunar excursions to diverse sites of interest with increasingly complex missions, enabling science and other utilization exploration. This segment also contributes to evaluating the systems, operations, human adaptation, or technologies required for Mars. These missions will enable increasingly extended time in deep space coupled with missions to the lunar surface of increasing duration and mobility that address identified research, testing, and demonstration objectives to enable Mars missions. Prior to the crewed Mars mission, these precursor missions would be performed in time to inform element design, testing, and operation. Foundational Exploration also starts the development of a sustainable human presence with the deployment of long-term infrastructure.

The third segment, **Sustained Lunar Evolution**, is the broad and undefined end state that builds on the foundation of the first two segments and enables capabilities, systems, and operations to support regional and global utilization (science, etc.), economic opportunity, and a steady cadence of human presence on and around the Moon. Here, we can envision various uses of the lunar surface and cislunar space to enable science, commerce, and further deep space exploration initiatives.

The fourth segment, **Humans to Mars**, captures the capabilities, systems, and operations necessary to enable the initial human exploration of the Red Planet. These systems will represent the transportation, logistics, utilization, and more required to enable the missions. This segment is an enabling capability of continued deep space exploration with additional efforts to be identified as architectural progress occurs.

As objectives are accomplished or added in the future, additional segments will be defined to enable continued exploration. These segments will be captured to reflect Agency objectives and continue the expansion of human/robotic exploration of the solar system. These efforts will enable NASA led efforts to go, explore, and sustain for continued discovery on the Moon, Mars, and beyond.

3.1 HUMAN LUNAR RETURN SEGMENT

The Human Lunar Return (HLR) segment of the exploration campaign includes the inaugural Artemis missions to enable returning humans to the Moon and demonstrate both crewed and uncrewed lunar systems, including the support to initial utilization (science, etc.) capabilities. This segment will be used to demonstrate initial systems to validate system performance and to establish a core capability for follow-on campaign segments. It captures the missions that test NASA's deep space crew and cargo transportation system(s), deploy the initial cislunar capabilities to support lunar missions, deploy and establish lunar orbital communication relays, and bring two crew members to the lunar surface and return them safely to Earth. Additionally, a variety of other efforts are working to support data-gathering and risk-reduction activities to help inform future decisions. These currently include, but are not limited to, the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE), Commercial Lunar Payload Services (CLPS) Provider Landers, and the Volatiles Investigating Polar Exploration Rover (VIPER).

3.1.1 Summary of Objectives

The objectives that drive the HLR segment include achieving science, inspiration, and national posture goals around and on the surface of the Moon. Initial missions will be used to deliver science value through operations in cislunar space and on the lunar surface, along with the return of samples to Earth. Key science objectives addressable during HLR include 1) exploring the lunar south polar region to understand chronology, composition, and structure of this region (e.g., LPS-1 and LPS-2); 2) understanding volatile composition and the environment of shallow permanently shadowed regions (PSRs) near the lunar South Pole (e.g., LPS-3); 3) assessing the history of the Sun as preserved in lunar regolith (e.g., HS-2); 4) characterizing space weather dynamics to enable future forecasting capabilities (e.g., HS-1); and 5) characterizing plant, model organism/systems, and human physiological responses in partial-gravity environments (e.g., HBS-1). These HLR science priorities were identified by the Science Mission Directorate (SMD).

To achieve these key science, inspiration, and national posture goals, the HLR segment is focused on demonstrating initial capabilities, systems, and operations necessary to re-establish human presence around and on the Moon. This segment began successfully with the Artemis I mission to systematically and progressively test areas such as crewed transportation to cislunar space (TH-1, TH-2), supporting ground infrastructure (OP-4), and deep space communications and tracking systems (OP-2). The next steps are crewed transportation to and from cislunar space, initial Gateway deployment (OP-6), rendezvous and docking, uncrewed Human Landing System demonstration, initial human landing (TH-2), and initial surface EVA capability, and uncrewed payload delivery. It encompasses the return of humans to the Moon for approximately six-day surface missions and establishes the foundational capabilities that will enable future campaign segments.

The objectives linked to the HLR segment will be a subset of the total, and even of those linked, some will be only partially satisfied; however, the segment serves as the starting point to define and validate capabilities and functions in later segments that will be driven by the objectives. The complete set of objectives can be found in Appendix A.

3.1.2 Use Cases and Functions

The objectives and mapping to the use cases and functions (shown in Appendix A) are used to drive the elements for this segment. Because many HLR elements are operational or in design/development stages, these elements form the basis of satisfying the functional needs. The mappings help identify functional gaps that must be addressed in the follow-on segments. Section 3.1.5 shows the mapping of the use cases and functions to the elements. Many of the use cases and functions will require additional elements or new functional capabilities that go beyond what is being assigned to the HLR elements described below. Key gaps between planned HLR capabilities and Moon to Mars objectives needs are noted later in this document and will continue to be expanded through the ACR process. Note that not all use cases (UC-#) and functions (FN-#) are sequential in this segment mapping. The numbering represents use cases and functions that have been identified through the overall objective decompositions process, but not all are applicable to the HLR segment.

The mapped elements in HLR segment and their corresponding descriptions are in the respective sub-sections of Section 3.1.3. While commercial launch vehicles will play a vital role in the architecture, they are not mapped here, as they are subject to future implementations and procurements.

3.1.3 Reference Missions and Concepts of Operations

As described in the objective decomposition methodology, use cases may be grouped into reference missions to provide examples of how several use cases may be accomplished with a particular concept of operations. Section 3.1.5 shows the full set of use cases in HLR, so only a representative subset is discussed below in two reference missions. While there is a certain temporal aspect to these reference missions, as the architecture capabilities are grown and enhanced, each individual reference mission simply represents an example of how architecture capabilities can be used; these are not planned missions to be flown.

3.1.3.1 Crewed Initial Lunar Surface Reference Mission

As the first crewed mission returning to the lunar surface, this reference mission encompasses many use cases that will be repeated throughout the Moon to Mars campaign. Starting with transportation, use cases include transporting crew and systems from Earth to cislunar space, staging crewed lunar surface missions from cislunar space, assembling integrated assets in cislunar space, transporting crew and systems between cislunar space and the lunar surface, and returning crew and systems from cislunar space to Earth. The surface portion includes use cases such as crew operations on the lunar surface, frequent crew EVAs on the surface, and crew-conducted utilization activities (including science, crew health and performance, and other operations) on the surface and in space.

3.1.3.2 Crewed Gateway and Lunar Surface Reference Mission

Building up from the initial return mission to the lunar surface, more capabilities in cislunar space address additional use cases, particularly for lunar orbital operations. As a habitable outpost located in NRHO, Gateway enables additional use cases in HLR beyond those in the initial crewed mission to the lunar surface. In particular, Gateway allows for crew to conduct utilization activities in cislunar space, allows for ground personnel and science teams to directly engage with astronauts on the surface and in lunar orbit, augmenting the crew’s effectiveness at conducting science activities, enables crew and/or robotic emplacement and set-up of science instrumentation in lunar orbit with long-term remote operation, and includes autonomous/semi-autonomous mission operations in cislunar space.

3.1.4 Sub-Architectures and Element Descriptions

Elements represent capabilities that are available in the HLR campaign segment that meet the designated Agency objectives and derived functions needed to support those objectives. The elements are described in the sub-architectures they support; they are not in chronological order.

3.1.4.1 Communication, Positioning, Navigation, and Timing Systems

During the HLR, CPNT services will be provided through a combination of assets on Earth, in lunar orbit, and on the lunar surface. Direct-to-Earth (DTE) service needs will be met through a combination of an upgraded Deep Space Network (DSN) and NASA's Near Space Network (NSN), with a new dedicated Lunar Exploration Ground System (LEGS) subnet. Three initial LEGS sites around Earth will provide almost continuous coverage of the near side of the Moon and NRHO, with the option for commercial services and international partner support to augment capacity and redundancy. Orbiting assets such as Gateway, the Lunar Communications Relay and Navigation System (LCRNS), and possible partner assets will provide service to users without line-of-sight to Earth and reduce the required size, weight, and power for a user's communications systems. The LCRNS will initially, in this segment, cover a service volume from -80° S to the South Pole of the Moon and up to 125 km altitude. Communication will support one S-band bidirectional link and one simultaneous Ka-band return link, as well as CPNT service through an Augmented Forward Signal (AFS). In the later part of the HLR segment, LCRNS service will expand to bidirectional Ka-band and multiple AFS links. Surface-to-surface communications may initially rely on legacy systems such as Ultra High Frequency (UHF) and WiFi, but will seek to leverage terrestrial standards such as 3GPP/5G within this segment of the architecture to increase mobility and capacity. Throughout this initial phase of the architecture, interoperability will be emphasized through the LunaNet Interoperability Specification (LNIS), the International Communication System Interoperability Standards (ICSIS),[6] and similar specifications. The growth of CPNT services throughout the HLR segment will enable the near-term exploration objectives of the HLR segment while providing a robust foundation upon which a scalable infrastructure can grow to support the needs of a sustained lunar presence, including precursor missions that will inform and validate a Martian architecture.

[6] International Deep Space Interoperability Standard. www.internationaldeepspacestandards.com

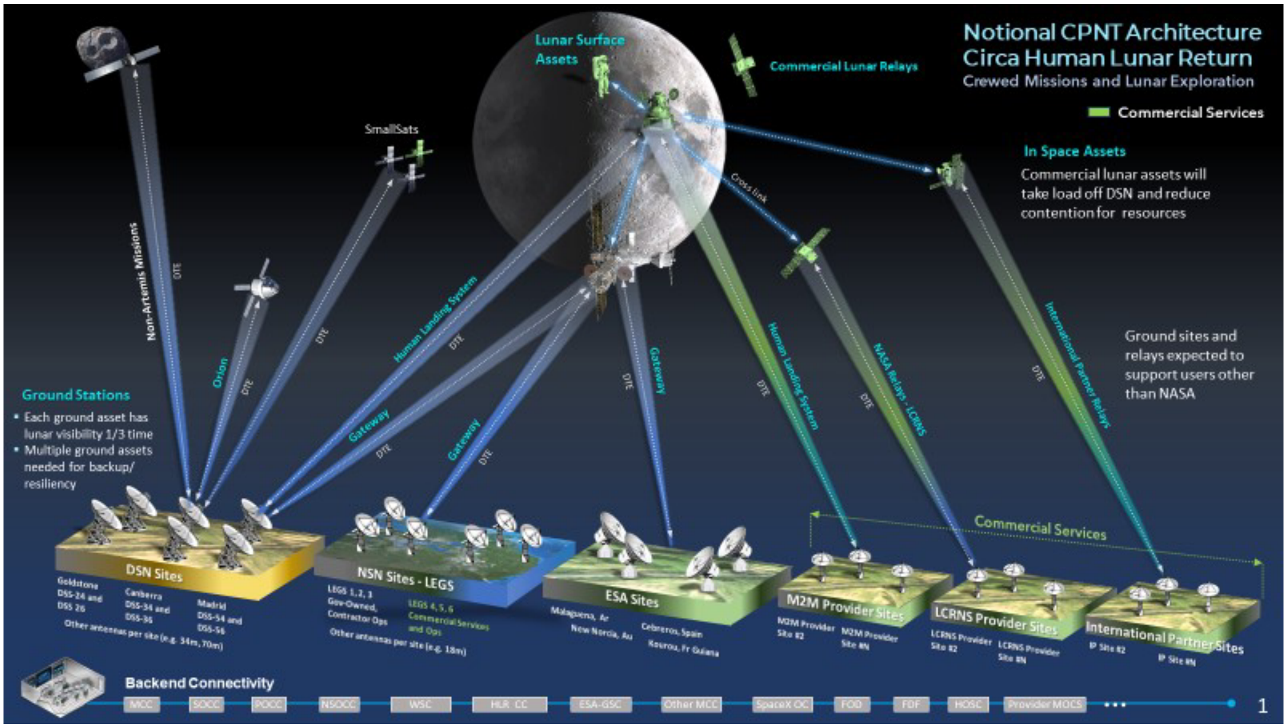


Figure 3-1. Notional CPNT Sub-architecture Circa HLR

The functions the LCRNS fulfills in the HLR campaign segment are shown in Table 3-2.

The functions the DSN and LEGS fulfill in the HLR campaign segment are shown in Table 3-3.

3.1.4.2 Habitation Systems

3.1.4.2.1 Gateway[7] Crew-Capable Configuration Overview

The Gateway architecture is composed of several modules incrementally launched and assembled in NRHO around the Moon in a system that provides for continuous architectural evolution. Individual Gateway modules are launched either as co-manifested payloads (CPL) on the Space Launch System (SLS) along with the Orion crew vehicle or on commercial launch vehicles. The modules combined in the Gateway architecture represent a meaningful series of demonstration steps in the direction of enabling the more extensive exploration effort in the future.

The HLR campaign segment comprises the Gateway Crew-Capable Configuration: Power and Propulsion Element (PPE), Habitation and Logistics Outpost (HALO), International Habitation Module (I-Hab), and Gateway Logistics Element. For this segment, Gateway capability represents a minimum functional core to support the initial human landing missions to the lunar surface. The I-Hab is being provided by ESA, with contributions from the Japan Aerospace Exploration Agency (JAXA). These modules provide pressurized volume for the crew to move between the docked vehicles, crew habitation activities (food and water consumption, sleep, hygiene), and internal and external utilization capabilities. They also provide initial life support services and docking ports for additional modules and visiting vehicles. The PPE is a commercially based spacecraft that provides electrical power, attitude and translational control, and communication for Gateway. The PPE maintains attitude using reaction wheels and a chemical propulsion system. When uncrewed, translation maneuvers and orbital maintenance are primarily performed using a solar

[7] For more information, please visit: www.nasa.gov/gateway

electric propulsion (SEP) system. The PPE has power storage and the systems necessary to convert and distribute power to the rest of Gateway. It provides internal avionics systems and is one part of an integrated command and control architecture for Gateway.

Figure 3-2. Gateway Crew-Capable Configuration

The integrated PPE/HALO configuration also provides communication via PPE and the ESA HALO Lunar Communications Systems (HLCS) for space-to-Earth and space element–to–space element; with visiting vehicles during rendezvous, proximity operations, and docking/undocking; and between lunar surface systems and Earth. NASA utilizes deep space logistics (see Section 3.1.4.6) to deliver cargo and other supplies to Gateway, including critical spares and outfitting for HALO and I-Hab, cargo stowage, and trash disposal. Gateway will launch with an initial suite of internal and external science utilization payloads, provided by NASA, ESA, and JAXA, that will operate and collect data in transit and in NRHO during crewed and uncrewed operations. External payload sites and future robotic attach points will be provided by CSA on PPE, HALO, and I-Hab. The Gateway Crew-Capable Configuration is shown in Figure 3-2. Expansion of Gateway is planned to include additional capabilities and systems as part of the Foundational Exploration segment.

The functions Gateway Crew-Capable Configuration fulfills in the HLR campaign segment are shown in Table 3-4.

3.1.4.3 Human Systems

The humans who embark on the exploration missions are the most critical component of the campaign to get humans to the Moon, to Mars, and beyond. Proper vehicle and mission design for the crew encompasses a complex and extensive list of human system integration (HSI) and crew health and performance (CHP) needs that must be considered. If inadequately addressed, these can translate into negative crew health and performance outcomes both during and after the mission. The HLR campaign is the first step in deep space exploration and presents a human systems challenge that is different from Apollo and the International Space Station. These challenges and experiences will build with each successive mission across the campaign segments. Figure 3-3 shows a crewmember working in a pressurized volume in space.

Figure 3-3. Crewmember Working in Space

To emphasize the unique capability and impact to exploration of the crew, they are represented in the Moon to Mars Architecture as both a sub-architecture and an element. As such, crew are required to achieve several of the functions and use cases driven by the Moon to Mars objectives. Humans are a unique exploration resource, capable of flexibility and adaptation, real-time analysis and independent decision making, and fine motor-skill operations. Humans also have unique sensory and perceptive capabilities that are often difficult to reproduce in hardware. As such, humans are irreplaceable in their ability to perform highly varied and complex tasks in space and on planetary bodies. There will be unanticipated non-conformances that humans are best qualified to detect and resolve. And working toward increasing Earth-independent operations, the humans onboard will be the most adaptive, inductive problem-solving systems available to address emergent, unforeseen time-critical vehicle/habitat issues. Vehicle systems must be designed to enable crew to execute these operations with reduced ground support.

Complex and highly varied tasks will be necessary to accomplish mission objectives such as surface infrastructure installation, geological site analysis and sample collection, planetary science payload deployment, and in-space biological experiments. Without human presence, each of these goals would require highly specialized robotic systems and remote human input. Human assets also present the opportunity to study and assess human-rated systems, human operations, human factors, and other aspects of human research in an environment similar to future Artemis or Mars missions. These studies will provide critical data related to performance, efficiency, and safety, which will inform future technology development, operational planning, and risk assessment for Artemis and Mars missions. Ultimately, humans are critical as operators, subjects, and inspirational figures throughout the Artemis missions and are intrinsic to the Moon to Mars and Agency strategic goals of furthering human presence on the Moon and beyond.

3.1.4.4 Infrastructure Support

3.1.4.4.1 Exploration Ground Systems[8] Overview

Figure 3-4. Exploration Ground Systems

The Exploration Ground Systems (EGS) Program was established to develop and operate systems and facilities necessary to process, launch, and recover vehicles. EGS provides the ground infrastructure for launch and landing in support of processing and launch of the SLS and Orion. EGS also provides recovery capabilities for the Orion spacecraft. EGS utilizes the Vehicle Assembly Building (VAB) for integration and testing and vertical stacking on the Mobile Launcher (ML). The ML with the fully stacked SLS and Orion secured is moved to Launch Pad 39B by the crawler-transporter. Vehicle testing, vehicle final propellant servicing, launch countdown, and launch take place at Launch Pad 39B. Additional capabilities, such as the Mobile Launcher 2 (ML2) will be included in the infrastructure of EGS to support the SLS Block 1B missions. The VAB is shown in Figure 3-4.

The functions EGS fulfills in the HLR campaign segment are shown in Table 3-5.

3.1.4.5 In-Situ Resource Utilization Systems

3.1.4.5.1 ISRU Demonstrations

Permanently shadowed region classification and environmental characterization are aided by current orbital missions, such as the Lunar Reconnaissance Orbiter, and planned near-term technology demonstrations. PRIME-1 and VIPER are two examples of planned near-term demonstrations to assist in understanding lunar resources, especially water in PSRs at the lunar poles, and determining viable pathways for ISRU, which will help to fulfil the function “Collect water/ice from the polar region of the lunar surface (demonstration)”.

[8] For more information, please visit: www.nasa.gov/exploration/systems/ground/index.html

Scheduled to launch in 2024, the Polar Resources Ice Mining Experiment-1 (PRIME-1) will be the first in-situ resource utilization demonstration on the lunar surface. For the first time, NASA will robotically sample and analyze sub-surface material for ice below the surface. PRIME-1 includes two components, both of which will be mounted to a commercial lunar lander. The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) will drill up to one meter deep, extracting lunar regolith, or soil, up to the surface. The instrument can drill in multiple segments, pausing and retracting to deposit cuttings on the surface after each depth increment. Mass Spectrometer observing lunar operations (MSolo), a modified-for-spaceflight, commercial-off-the-shelf mass spectrometer, will evaluate the drill cuttings from multiple depths for water and other chemical compounds. The data from PRIME-1 will help us understand in-situ resources on the Moon, including resource location mapping, and demonstrate the performance and operation of these important instruments before use in the subsequent VIPER mission.

The VIPER mission will explore the relatively nearby but more extreme environment of the lunar South Pole region around Nobile crater in search of ice and other potential resources. VIPER is targeted to land at the South Pole in late 2024 for a 100-day mission. VIPER will characterize the distribution and physical state of lunar polar water and volatiles and minerals outside, near, and inside small permanently shadowed regions. VIPER will help evaluate the resource potential for ISRU at the lunar polar regions and help determine how to harvest the Moon's resources for future human space exploration. VIPER has three instruments and a 3.28-foot (1-meter) drill to detect and analyze various lunar soil environments at a range of depths and temperatures. VIPER’s instruments will also make important science measurements. Determining the distribution, physical state and composition of these ice deposits will aid in understanding the sources of the lunar polar water, giving insight into distribution and origin of water and other volatiles across the solar system.

To advance the technologies and operations associated with extracting and processing lunar resources into usable products as well as demonstrating other lunar infrastructure–related capabilities for sustained lunar presence, NASA, in partnership with industry, is planning one or more demonstrations (designated Lunar Infrastructure Foundational Technology-1 [LIFT-1] for the first demonstration). The purpose of these demonstrations is to evaluate the performance of critical technologies and capabilities with actual lunar regolith and under lunar environmental conditions, instead of simulants and terrestrial environmental simulation facilities, to reduce the risk associated with incorporating them into subsequent lunar systems and missions. Following subscale demonstration missions, NASA, in partnership with industry, is planning to demonstrate the end-to-end system and operations associated with resource extraction to product generation and storage to reduce the risk of missions relying on ISRU products for mission success. Referred to as the ISRU Pilot Plant, this demonstration will be performed for a duration and at a scale that will significantly reduce the risks associated with deployment and the commercial life of a full-scale system and demonstrate the quality of the product produced. Several pilot plant concepts are under consideration, including liquefaction and storage of oxygen extracted from regolith, oxygen and hydrogen liquefaction and storage from water extracted from within a permanently shadowed region, and metal and silicon extraction from regolith to produce solar cells and wires for future in-situ production of solar arrays and electrical power transmission cables.

Figure 3-5. VIPER Egress from Lander Test

3.1.4.6 Logistics Systems

3.1.4.6.1 Gateway Logistics Element

Exploration activities will need logistics deliveries to satisfy objectives. Logistics items represent all equipment and supplies that are needed to support mission activities that are not installed as part of the vehicle. Logistics typically includes consumables (e.g., food, water, oxygen), maintenance items (planned replacement items), spares (for unexpected/unplanned failures), utilization (e.g., science and technology demonstrations), and outfitting (additional systems/sub-systems for the elements), as well as the associated packaging. Logistics deliveries of critical pressurized and unpressurized cargo and payloads will be needed to support activities with and without crew. In the HLR segment of the exploration campaign, logistics delivery to cislunar space will be provided by the Gateway Logistics Element (GLE).

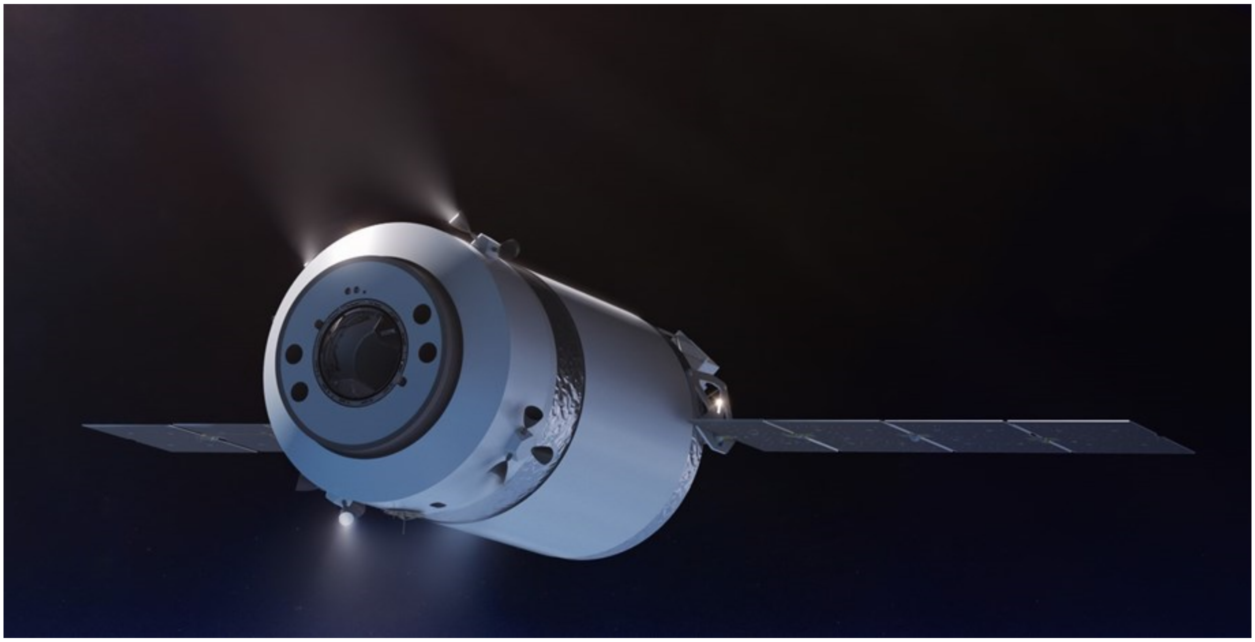


Figure 3-6. Gateway Logistics Element (Image credit: SpaceX)

During HLR, GLE will be used for transporting cargo, payloads, equipment, and consumables to enable exploration of the Moon and Mars. Logistics flights are necessary to supply Gateway with critical cargo deliveries and maximize the length of crew stays on Gateway. The Gateway Logistics Services contract and technical capability are extensible to deliver unique payload configurations and supply cargo deliveries to other destinations. Additional capabilities may be added in future segments. At least one logistics services delivery is anticipated for each Artemis mission to Gateway of 30 days. Dragon XL is shown in Figure 3-6 as one of the providers of Gateway logistics.

The functions the GLE fulfills in the HLR campaign segment are shown in Table 3-6.

3.1.4.7 Mobility Systems

3.1.4.7.1 Exploration Extravehicular Activity System Overview

Figure 3-7. Exploration Extravehicular Activity System

The Exploration Extravehicular Activity (xEVA) System allows crew members to perform extravehicular exploration, research, construction, servicing, repair operations, and utilization and science in cislunar orbit and on the lunar surface. EVA transverse and tasks may be augmented by robotics and rovers. The xEVA System includes the EVA suit, EVA tools, and vehicle interface equipment. Through Exploration Extravehicular Activity Services, Axiom Space and Collins Aerospace have been selected to build the next generation of spacesuit and spacewalk systems.

The functions the xEVA fulfills in the HLR campaign segment are shown in Table 3-7.

3.1.4.8 Transportation Systems

3.1.4.8.1 Space Launch System (SLS)[9] Overview

Figure 3-8. Space Launch System

The SLS is a super-heavy-lift launch vehicle that provides the foundation for human exploration beyond Earth orbit (BEO). With its unprecedented power and capabilities, SLS is the only launch vehicle that can send Orion, astronauts, and payloads directly to the Moon on a single launch. The SLS is designed to be evolvable, which makes it possible to conduct more types of missions, including human missions to Mars; assembly of large structures; and robotic, scientific, and exploration missions to destinations such as the Moon, Mars, Saturn, and Jupiter. Humans will be transported safely, and different payloads will be delivered efficiently and effectively, to enable a variety of complex missions in cislunar and deep space. The first SLS crew transportation system, called Block 1, uses an Interim Cryogenic Propulsion Stage (iCPS) to send the Orion spacecraft on towards the Moon. Block 1 was used for Artemis I and is planned for use for Artemis II and III. The Block 1B variant will use an Exploration Upper Stage (EUS) to enable more ambitious missions, such as carrying the Orion crew vehicle along with large cargo (co-manifested payload) in a single launch. SLS also enables free-flyer science payloads in cislunar space and beyond as secondary payloads. Although Block 1 and Block 1B Crew are the only two variants in HLR, Block 1B Cargo and Block 2 Crew and Cargo variants are key capabilities for future campaign segments. Figure 3 exhibits the SLS in the Block 1 configuration for Artemis I.

The functions the SLS fulfills in the HLR campaign segment are shown in Table 3-8.

[9] For more information, please visit: www.nasa.gov/exploration/systems/sls/index.html

3.1.4.8.2 Orion[10] Overview

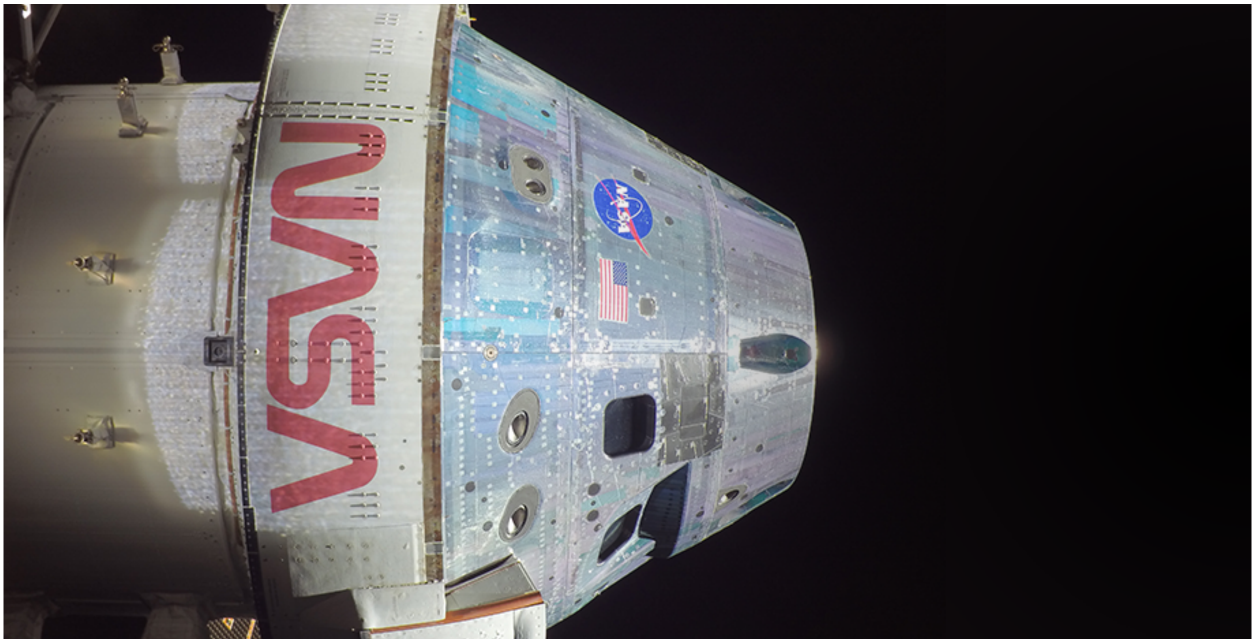


Figure 3-9. Orion Spacecraft

The Orion spacecraft, NASA's next-generation spacecraft to take astronauts on a journey of exploration to the Moon and on to Mars, is shown in Figure 3-9. The Orion spacecraft serves as the primary crew vehicle for Artemis missions for transporting crew between Earth and lunar orbit. The vehicle can conduct regular in-space operations in conjunction with payloads delivered by the SLS. The Orion spacecraft includes the Crew Module (CM), Service Module (SM), and Launch Abort System (LAS). The CM is capable of transporting four crew members beyond the Moon, providing a safe habitat from launch through landing and recovery. The SM, made up of the NASA-provided Crew Module Adapter (CMA) and the ESA-provided European Service Module (ESM), provides support to the crew module from launch through separation prior to entry. The SM provides in-space propulsion for orbital transfer, power and thermal control, attitude control, and high-altitude ascent aborts. While mated with the crew module, the SM also provides water and air to support the crew. The LAS, positioned on a tower atop the CM, can activate within milliseconds to propel the vehicle to safety and position the CM for a safe landing.

The functions the Orion spacecraft fulfills in the HLR campaign segment are shown in Table 3-9.

[10] For more information, please visit: www.nasa.gov/exploration/systems/orion/index.html

3.1.4.8.3 Human Landing System—Initial and Integrated Lander Configurations Overview

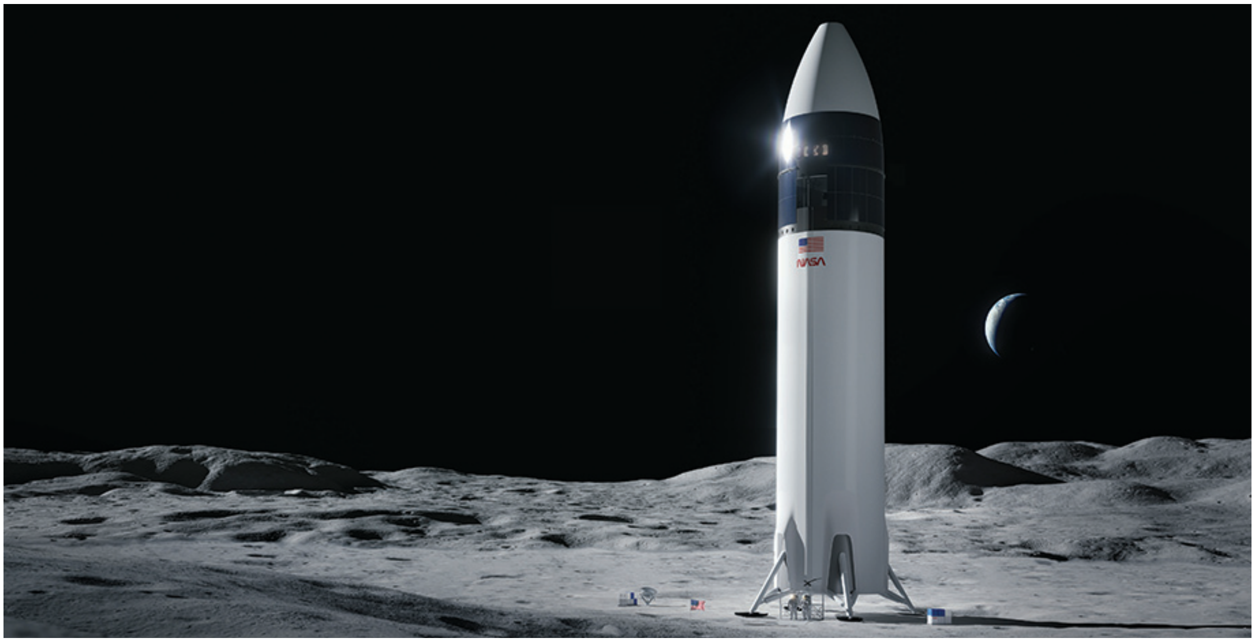


Figure 3-10. Human Landing System—Initial and one of the Integrated Lander Configurations as Awarded (Image credit: SpaceX)

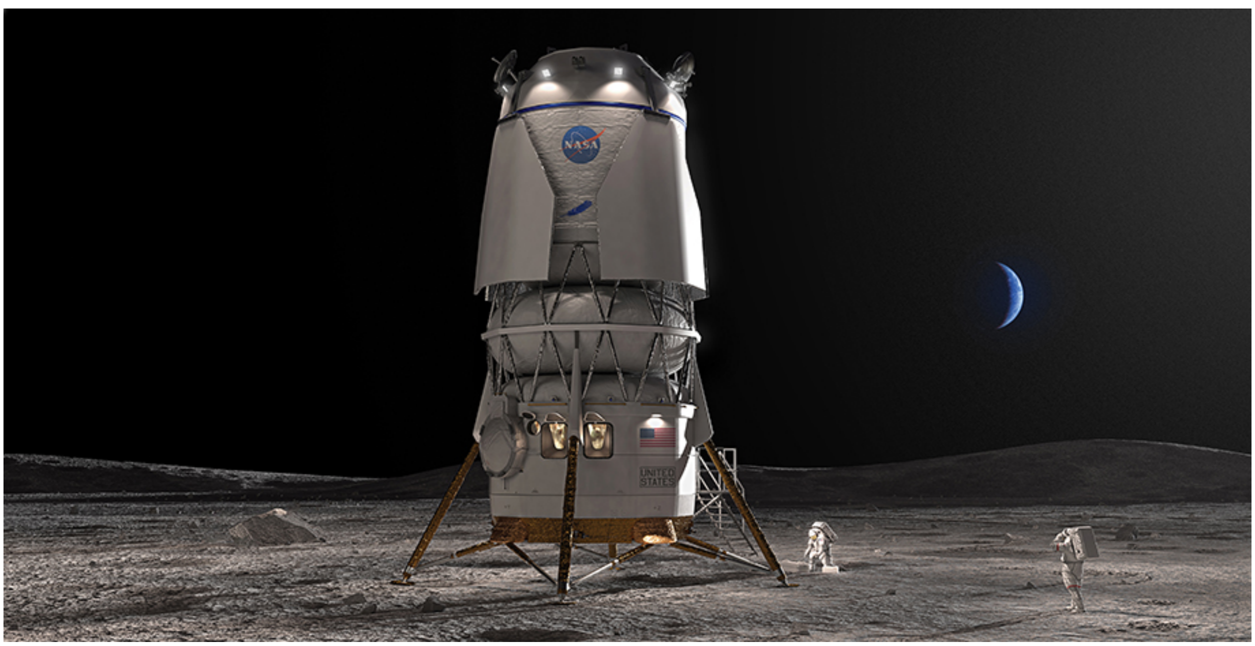


Figure 3-11. Human Landing System—One of the Integrated Lander Configurations as Awarded (Image credit: Blue Origin)

The Human Landing System (HLS) will transport crew members, support payloads, cargo, and logistics between a crew staging vehicle (either Orion or Gateway) orbiting the Moon in NRHO and the lunar surface. On the lunar surface, HLS provides the habitable volume, consumables, and design features, enabling crew surface stay and execution of lunar surface EVAs, along with utilization accommodations inside the cabin as well as external attached payloads. The specific HLS architecture is subject to commercial provider design implementation approach.

The initial HLS configuration supports a crew of two and will operate between Orion in NRHO and a landing site in the vicinity of the lunar South Pole. Additionally, in this configuration HLS will deliver the cargo and support logistics to NRHO from Earth prior to the start of the crewed phase of the mission. The initial human landing mission will be a demonstration of this initial HLS configuration and of the minimum basic technologies and innovation required to safely transport crew and utilization cargo to and from the lunar surface.

The HLS integrated lander will build on the initial configuration's base capabilities to enable the full range of crewed lunar mission objectives, including accommodating additional internal and external payloads. More ambitious missions will also be pursued as lunar surface exploration evolves toward the Foundational Exploration segment. Missions with the HLS integrated lander will require HLS to support landing a crew of up to four, leveraging additional habitable surface assets to support the larger crew for the duration of the lunar stay. These missions may include the capability to land and operate at non-polar landing sites or for extended durations at the lunar South Pole. This HLS configuration has increased performance capabilities allowing for enhanced up and down mass and increased darkness survivability. These missions will also seek sustainable HLS designs that may include reusable elements or interactions with other systems in the lunar vicinity. All missions with the HLS integrated lander will begin and end at Gateway—enabling extended missions on the lunar surface, as Orion will be able to remain in lunar orbit longer docked with Gateway. The initial HLS and HLS integrated lander configurations are shown in Figures 3-10 and 3-11.

The functions the HLS fulfills in the HLR campaign segment are shown in Table 3-10.

3.1.4.8.4 Cargo Landers—Commercial Lunar Payload Services (CLPS)[11] Provider Landers

Lunar surface exploration will require the delivery of assets, equipment, and supplies to the lunar surface. While some supplies and equipment may be delivered with crew on HLS, cargo landers provide additional flexibility and capability for robust exploration. In the HLR segment of the exploration campaign, additional cargo delivery can be provided through NASA's CLPS Provider Landers.

NASA's CLPS initiative allows rapid acquisition of lunar delivery services from American companies for payloads that advance capabilities for science, technology, exploration, or commercial development of the Moon. Investigations and demonstrations launched on commercial Moon flights will help the Agency study Earth's nearest neighbor under the Artemis approach. Companies are encouraged to fly commercial and other partner payloads in addition to the NASA payloads. NASA has awarded 9 task orders to CLPS lander providers for delivery of more than 40 payloads to the lunar surface during the HLR exploration segment. Additional task orders will be awarded as mission and payload definition continues. Current CLPS Provider Landers deliveries are sending science and technology payloads. SMD is planning annual calls for new payload suites, called the Payload and Research Investigations from the Surface of the Moon (PRISM). PRISM will enable high-priority science and will be complemented by other NASA-sponsored payloads.

The functions CLPS Provider Landers fulfill in the HLR campaign segment are shown in Table 3-11.

[11] For more information, please visit: www.nasa.gov/clps

3.1.4.9 Utilization Systems

3.1.4.9.1 Payloads Overview

The transportation, delivery, deployment, and operation of utilization payloads to cislunar space and the lunar surface, as well as the return to Earth of samples and other cargo, is a key service provided by the Moon to Mars Architecture and a critical enabler of every NASA utilization objective. Utilization payload is broadly characterized here to encompass any item transported and supported by the Moon to Mars Architecture that is primarily in support of and attributed to utilization objectives, as distinct from other components in the baseline platform of services provided by the Architecture. A utilization payload is defined as an instrument, data or sample collection, investigation, or hardware/software item that accomplishes utilization before, during and/or after Artemis missions. This includes dedicated or shared internal and external equipment, scientific experiments, technology demonstrators, instruments, tools, supplies, sample containers, and samples. This definition excludes a spacecraft, vehicle, element, or asset launched by a rocket. Examples include:

- Secondary SLS payloads, including CubeSats
- Externally mounted scientific sensors on Gateway, HLS, logistics modules, and other surface elements
- Science experiments and technology demonstrators deployed to the lunar surface by the crew or by robotic landers
- Internally operated experiments and other equipment in every crew volume, including Orion, Gateway, and HLS
- Tools and containers used to collect geological samples from the lunar surface, as well as samples collected from other science experiments and human research activities
- Portable equipment used to make scientific observations of the lunar surface, including cameras and other instruments
- The HLR segment will include a freezer that will be capable of conditioning geology, human research, space biology, and other samples at near −85 °C

Note that some equipment, including some multi-purpose cameras and medical equipment, is dual use, supporting both utilization and operations, and may be considered a utilization payload or a part of the platform depending on the context.

The functions the payloads fulfill in the HLR campaign segment are shown in Table 3-12.

3.1.5 Element Mapping

The following tables map elements to the functions they fulfill.

Table 3-2. Functions Fulfilled by LCRNS During the HLR Segment

		ID	Functions	ID	Use Cases
EM-006-HLR	Lunar Communications Relay and Navigation Systems	**FN-009-L**	Provide high availability position, navigation, and timing capability in cislunar space	**UC-002-L**	Stage crewed lunar surface missions from cislunar space
				UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-024-L	Provide high availability position, navigation, and timing capability on the lunar surface	**UC-011-L**	Support crew extravehicular operations on the lunar surface
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples

		ID	Functions	ID	Use Cases
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-107-L	Document sample details prior to collection on the lunar surface
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking
		FN-071-L	Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	UC-002-L	Stage crewed lunar surface missions from cislunar space
				UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-032-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-082-L	Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	UC-019-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-093-L	Demonstrate in-situ crew command and control of robotic system(s)
		FN-226-L	Provide accurate location tracking and position data in cislunar space	UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-227-L	Provide accurate location tracking and position data on the lunar surface	UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-107-L	Document sample details prior to collection on the lunar surface
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking

		ID	Functions	ID	Use Cases
		FN-229-L	Provide reference time/frequency generation in cislunar space	**UC-068-L**	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-230-L	Provide reference time/frequency distribution in cislunar space	**UC-068-L**	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-231-L	Format and transmit data to Earth from the lunar surface	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-234-L	Format, transmit, and receive data between assets on the lunar surface	**UC-067-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-235-L	Store and distribute data between assets on the lunar surface	**UC-067-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-236-L	Format and transit data to Earth from cislunar space	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-237-L	Store and distribute data between assets in cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
		FN-238-L	Format, transmit, and receive data from cislunar space to the lunar surface	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-239-L	Format, transmit, and receive data from the lunar surface to cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-240-L	Provide tracking and analysis of orbital/trajectory parameters for assets in cislunar space	**UC-068-L**	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-241-L	Provide planning, tracking, and analysis of traverse paths for assets on the lunar surface	**UC-075-L**	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region

		ID	Functions	ID	Use Cases
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
		FN-242-L	Provide reference time/frequency generation on the lunar surface	**UC-126-L**	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking
		FN-243-L	Provide reference time/frequency distribution on the lunar surface	**UC-126-L**	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
		FN-244-L	Protect and/or secure data for storage and transmission	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received

Table 3-3. Functions Fulfilled by DSN/LEGS During the HLR Segment

		ID	Functions	ID	Use Cases
EM-010-HLR	LEGS/DSN	FN-015-L	Operate crew system(s) from Earth on the lunar surface during crewed missions	UC-005-L	Operate transportation assets(s) from Earth during crew surface missions
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-071-L	Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	UC-002-L	Stage crewed lunar surface missions from cislunar space
				UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-032-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges

		ID	Functions	ID	Use Cases
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-081-L	Provide Earth based ground stations for exploration communications	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-140-L	Monitor operating asset(s)	**UC-031-L**	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-042-L	Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation
				UC-053-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-062-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-165-L	Deploy assets to monitor natural environments in cislunar space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-157-L	Operate assets in cislunar space in uncrewed mode for extended (year+) durations	**UC-120-L**	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
				UC-148-L	Habitation capabilities for extended-duration (year+) missions in cislunar space
		FN-226-L	Provide accurate location tracking and position data in cislunar space	**UC-068-L**	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-231-L	Format and transmit data to Earth from the lunar surface	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-232-L	Receive and format data on Earth	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth

		ID	Functions	ID	Use Cases
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-233-L	Store and distribute data to user(s) on Earth	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-236-L	Format and transit data to Earth from cislunar space	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-240-L	Provide tracking and analysis of orbital/trajectory parameters for assets in cislunar space	**UC-068-L**	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-244-L	Protect and/or secure data for storage and transmission	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received

Table 3-4. Functions Fulfilled by Gateway Crew-Capable Configuration During the HLR Segment

		ID	Functions	ID	Use Cases
EM-004-HLR	Gateway	FN-008-L	Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	UC-003-L	Aggregate and physically assemble spacecraft components in cislunar space
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-034-L	Provide pressurized, habitable environment in cislunar space	UC-002-L	Stage crewed lunar surface missions from cislunar space
		FN-035-L	Transfer cargo into habitable asset(s) in cislunar space	UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-036-L	Manage waste from habitable asset(s) in cislunar space	UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space

		ID	Functions	ID	Use Cases
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-038-L	Provide crew health maintenance capabilities in microgravity environment	**UC-162-L**	Crew health maintenance with countermeasure activities in microgravity environment
		FN-039-L	Provide remote crew medical systems in cislunar space	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
				UC-103-L	In-situ diagnosis and treatment of crew in cislunar space
		FN-057-L	Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	**UC-031-L**	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-053-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-062-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-165-L	Deploy assets to monitor natural environments in cislunar space
				UC-167-L	Deploy asset(s) to monitor induced environment in cislunar space
		FN-062-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) in cislunar space	**UC-037-L**	Crew conduct biological science and human research activities while in habitable volume in cislunar space
				UC-044-L	Crew conduct fundamental physics experiments while in habitable volume in cislunar space
		FN-071-L	Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**UC-002-L**	Stage crewed lunar surface missions from cislunar space
				UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-032-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation

		ID	Functions	ID	Use Cases
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-125-L	Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**UC-106-L**	Utilize common interface(s) for power transfers and distribution in cislunar space
				UC-110-L	Deliver power to asset(s) in cislunar space
		FN-134-L	Distribute power to utilization payloads in cislunar space	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
				UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-110-L	Deliver power to asset(s) in cislunar space
		FN-138-L	Docking/berthing between pressurized assets in cislunar space	**UC-192-L**	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-147-L	Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**UC-178-L**	Transport conditioned cargo from cislunar space to Earth
				UC-179-L	Transport cargo from the lunar surface to cislunar space
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-151-L	Collect and store medical data and health information	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
		FN-155-L	Operate habitation system(s) in dormancy/remote mode between crewed missions in cislunar space	**UC-149-L**	Reuse habitation systems(s) in cislunar space
		FN-157-L	Operate assets in cislunar space in uncrewed mode for extended (year+) durations	**UC-120-L**	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
				UC-148-L	Habitation capabilities for extended-duration (year+) missions in cislunar space
		FN-160-L	Provide crew health care in cislunar space	**UC-016-L**	Crew health care, diagnosis, and treatment in space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
		FN-176-L	Provide intravehicular maintenance, upgrade, and/or repair accommodations (demonstration)	**UC-139-L**	Demonstrate maintenance, modification, and/or upgrades of asset(s)

		ID	Functions	ID	Use Cases
		FN-181-L	Provide food system(s) in cislunar space	**UC-161-L**	Nutrition monitoring for crew during mission
		FN-182-L	Provide crew exercise system(s) in cislunar space	**UC-162-L**	Crew health maintenance with countermeasure activities in microgravity environment
		FN-203-L	Provide common data interface in cislunar space	**UC-085-L**	Utilize common interface(s) for data transfer and distribution
		FN-224-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**UC-002-L**	Stage crewed lunar surface missions from cislunar space
				UC-093-L	Demonstrate in-situ crew command and control of robotic system(s)
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-236-L	Format and transit data to Earth from cislunar space	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-237-L	Store and distribute data between assets in cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
		FN-238-L	Format, transmit, and receive data from cislunar space to the lunar surface	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-239-L	Format, transmit, and receive data from the lunar surface to cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-244-L	Protect and/or secure data for storage and transmission	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth

		ID	Functions	ID	Use Cases
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received

Table 3-5. Functions Fulfilled by EGS During the HLR Segment

		ID	Functions	ID	Use Cases
EM-002-HLR	Exploration Ground Systems	**FN-001-L**	Provide ground services on Earth	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-002-L	Stack and integrate system(s) on Earth	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-003-L	Manage consumables and propellant	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-004-L	Enable vehicle launch(es)	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-005-L	Allow multiple launch attempts	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-017-L	Recover crew, crew system(s), and cargo after Earth landing	**UC-006-L**	Return crew and systems from cislunar space to Earth
				UC-181-L	Transport conditioned cargo to appropriate facilities on Earth
				UC-182-L	Transport collected samples to appropriate curation facilities on Earth
		FN-043-L	Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**UC-020-L**	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-181-L	Transport conditioned cargo to appropriate facilities on Earth
				UC-182-L	Transport collected samples to appropriate curation facilities on Earth
		FN-121-L	Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**UC-181-L**	Transport conditioned cargo to appropriate facilities on Earth
		FN-204-L	Provide common data interface on Earth	**UC-085-L**	Utilize common interface(s) for data transfer and distribution

Table 3-6. Functions Fulfilled by Gateway Logistics Element During the HLR Segment

		ID	Functions	ID	Use Cases
EM-009-HLR	Gateway Logistics Element	FN-008-L	Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	UC-003-L	Aggregate and physically assemble spacecraft components in cislunar space
		FN-035-L	Transfer cargo into habitable asset(s) in cislunar space	UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-056-L	Deliver utilization payload(s) to cislunar space	UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-053-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-062-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-165-L	Deploy assets to monitor natural environments in cislunar space
				UC-167-L	Deploy asset(s) to monitor induced environment in cislunar space
		FN-138-L	Docking/berthing between pressurized assets in cislunar space	UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions

Table 3-7. Functions Fulfilled by xEVA System During the HLR Segment

		ID	Functions	ID	Use Cases
EM-007-HLR	xEVA System	FN-028-L	Conduct crew lunar surface extravehicular activity	UC-011-L	Support crew extravehicular operations on the lunar surface
				UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-111-L	Collect sub-surface samples from PSRs
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-029-L	Crew ingress/egress from habitable asset(s) to lunar surface vacuum	UC-011-L	Support crew extravehicular operations on the lunar surface

		ID	Functions	ID	Use Cases
		FN-032-L	Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
		FN-046-L	Conduct crew survey of areas of interests and sample identification	**UC-024-L**	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs
				UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-111-L	Collect sub-surface samples from PSRs
		FN-047-L	Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
		FN-048-L	Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
		FN-105-L	Utilize tools to collect surface samples from non-PSRs and sunlit regions on the lunar surface	**UC-089-L**	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning
		FN-106-L	Utilize tools for equipment cleaning and maintenance	**UC-089-L**	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning
		FN-114-L	Control robotic system(s) on the lunar surface by crew on the lunar surface	**UC-093-L**	Demonstrate in-situ crew command and control of robotic system(s)
				UC-105-L	Perform lunar surface activities with surface robotic system(s) assistance
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
				UC-121-L	Robotic system(s) support of logistic operations on the lunar surface as required
		FN-139-L	Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-039-L	Deploy and set up astrophysics utilization payload(s) on the far side of the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation

		ID	Functions	ID	Use Cases
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-143-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-117-L	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples
		FN-179-L	Ready and transition crew to transportation asset for return to orbit	UC-129-L	Prepare crew for transition and transport from the lunar surface to cislunar space
		FN-202-L	Provide common data interface on the lunar surface	UC-085-L	Utilize common interface(s) for data transfer and distribution
		FN-269-L	Capture imagery on the lunar surface	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-107-L	Document sample details prior to collection on the lunar surface

Table 3-8. Functions Fulfilled by SLS During the HLR Segment

		ID	Functions	ID	Use Cases
EM-001-HLR	Space Launch System	**FN-002-L**	Stack and integrate system(s) on Earth	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-004-L	Enable vehicle launch(es)	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-005-L	Allow multiple launch attempts	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-006-L	Enable abort(s) to safety	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-007-L	Transport crew and associated cargo from Earth to cislunar space to support short-duration (days to weeks) missions	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
		FN-058-L	Deliver free flying asset(s) to cislunar space	**UC-032-L**	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-042-L	Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation
				UC-058-L	Deploy and operate free-flying assets in a variety of lunar and heliocentric orbits long-term
		FN-203-L	Provide common data interface in cislunar space	**UC-085-L**	Utilize common interface(s) for data transfer and distribution
		FN-204-L	Provide common data interface on Earth	**UC-085-L**	Utilize common interface(s) for data transfer and distribution
		FN-225-L	Deliver free-flying asset(s) to heliocentric and deep space	**UC-058-L**	Deploy and operate free-flying assets in a variety of lunar and heliocentric orbits long-term

Table 3-9. Functions Fulfilled by Orion During the HLR Segment

		ID	Functions	ID	Use Cases
EM-003-HLR	Orion	**FN-006-L**	Enable abort(s) to safety	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-007-L	Transport crew and associated cargo from Earth to cislunar space to support short-duration (days to weeks) missions	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
		FN-008-L	Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	**UC-003-L**	Aggregate and physically assemble spacecraft components in cislunar space
		FN-016-L	Transport crew and associated cargo from cislunar space to Earth	**UC-006-L**	Return crew and systems from cislunar space to Earth
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-120-L	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space
		FN-034-L	Provide pressurized, habitable environment in cislunar space	**UC-002-L**	Stage crewed lunar surface missions from cislunar space
		FN-036-L	Manage waste from habitable asset(s) in cislunar space	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-039-L	Provide remote crew medical systems in cislunar space	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
				UC-103-L	In-situ diagnosis and treatment of crew in cislunar space
		FN-133-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces), in transit assets	**UC-112-L**	Crew conduct biological science and human research activities in habitable volume while in transit
		FN-138-L	Docking/berthing between pressurized assets in cislunar space	**UC-192-L**	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-145-L	Transport cargo from cislunar space to Earth	**UC-020-L**	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth

		ID	Functions	ID	Use Cases
				UC-178-L	Transport conditioned cargo from cislunar space to Earth
				UC-186-L	Transport cargo from the lunar surface or cislunar space back to Earth
		FN-147-L	Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	UC-178-L	Transport conditioned cargo from cislunar space to Earth
				UC-179-L	Transport cargo from the lunar surface to cislunar space
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-150-L	Provide crew health care during transit	UC-016-L	Crew health care, diagnosis, and treatment in space
		FN-151-L	Collect and store medical data and health information	UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
		FN-160-L	Provide crew health care in cislunar space	UC-016-L	Crew health care, diagnosis, and treatment in space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
		FN-181-L	Provide food system(s) in cislunar space	UC-161-L	Nutrition monitoring for crew during mission
		FN-182-L	Provide crew exercise system(s) in cislunar space	UC-162-L	Crew health maintenance with countermeasure activities in microgravity environment
		FN-203-L	Provide common data interface in cislunar space	UC-085-L	Utilize common interface(s) for data transfer and distribution
		FN-208-L	Monitor electrostatic charging in space	UC-140-L	Monitor environmental factors in habitation systems in space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-168-L	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-236-L	Format and transit data to Earth from cislunar space	UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-244-L	Protect and/or secure data for storage and transmission	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth

		ID	Functions	ID	Use Cases
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received

Table 3-10. Functions Fulfilled by HLS During the HLR Segment

		ID	Functions	ID	Use Cases
EM-005-HLR	Human Landing System	FN-008-L	Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	UC-003-L	Aggregate and physically assemble spacecraft components in cislunar space
		FN-013-L	Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	UC-004-L	Transport crew and supporting system(s) between cislunar space and the lunar surface
				UC-021-L	Crewed mission(s) to landing sites in the lunar south polar regions
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-056-L	Land exploration missions at sites removed from sites of historic significance
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-131-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to the lunar south polar region
				UC-132-L	Cislunar space to lunar surface transportation supporting mid-duration (month+) missions to the lunar south polar region
		FN-014-L	Transport crew and associated cargo from the lunar surface to cislunar space	UC-004-L	Transport crew and supporting system(s) between cislunar space and the lunar surface
				UC-099-L	Return crew and associated cargo from the lunar surface to cislunar space
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-129-L	Prepare crew for transition and transport from the lunar surface to cislunar space
				UC-131-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to the lunar south polar region
				UC-132-L	Cislunar space to lunar surface transportation supporting mid-duration (month+) missions to the lunar south polar region
				UC-133-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to distributed landing sited on the lunar surface
		FN-018-L	Transport cargo from Earth to the lunar surface	UC-010-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation

		ID	Functions	ID	Use Cases
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-072-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
				UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-019-L	Unload cargo on the lunar surface	UC-008-L	Deploy utilization payloads and equipment on the lunar surface
				UC-100-L	Deploy cargo to the lunar surface
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples

		ID	Functions	ID	Use Cases
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-026-L	Provide remote crew medical systems on the lunar surface	UC-018-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface
				UC-104-L	In-situ diagnosis and treatment of crew on the lunar surface
				UC-152-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface
		FN-029-L	Crew ingress/egress from habitable asset(s) to lunar surface vacuum	UC-011-L	Support crew extravehicular operations on the lunar surface
		FN-034-L	Provide pressurized, habitable environment in cislunar space	UC-002-L	Stage crewed lunar surface missions from cislunar space
		FN-035-L	Transfer cargo into habitable asset(s) in cislunar space	UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-036-L	Manage waste from habitable asset(s) in cislunar space	UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-037-L	Manage waste from habitable asset(s) on the lunar surface	UC-010-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface

		ID	Functions	ID	Use Cases
				UC-136-L	Manage disposal of hardware and waste products
				UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-038-L	Provide crew health maintenance capabilities in microgravity environment	**UC-162-L**	Crew health maintenance with countermeasure activities in microgravity environment
		FN-039-L	Provide remote crew medical systems in cislunar space	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
				UC-103-L	In-situ diagnosis and treatment of crew in cislunar space
		FN-040-L	Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-094-L	Remotely manage robotic system(s) during surface operation as required
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
		FN-041-L	Control robotic system(s) in cislunar space from Earth and/or cislunar space	**UC-109-L**	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations in cislunar space
				UC-184-L	Remotely manage robotic system(s) during in space operation as required
		FN-060-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	**UC-036-L**	Crew conduct biological science and human research activities on the lunar surface
				UC-040-L	Crew conduct fundamental physics experiments while in habitable volume on the lunar surface
				UC-043-L	Conduct intravehicular science and utilization activities on the lunar surface
		FN-062-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) in cislunar space	**UC-037-L**	Crew conduct biological science and human research activities while in habitable volume in cislunar space
				UC-044-L	Crew conduct fundamental physics experiments while in habitable volume in cislunar space
		FN-087-L	Provide precision landing for crew transport to the lunar surface	**UC-071-L**	Land crew lander(s) at specific pre-defined locations
		FN-114-L	Control robotic system(s) on the lunar surface by crew on the lunar surface	**UC-093-L**	Demonstrate in-situ crew command and control of robotic system(s)

		ID	Functions	ID	Use Cases
				UC-105-L	Perform lunar surface activities with surface robotic system(s) assistance
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
				UC-121-L	Robotic system(s) support of logistic operations on the lunar surface as required
		FN-126-L	Reduce blast ejecta	UC-056-L	Land exploration missions at sites removed from sites of historic significance
				UC-114-L	Reduce blast ejecta to limit the migration of ejecta across the lunar surface
		FN-138-L	Docking/berthing between pressurized assets in cislunar space	UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-141-L	Deliver cargo(s) to distributed sites on the lunar surface	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-146-L	Transport cargo from the lunar surface to cislunar space	UC-020-L	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-179-L	Transport cargo from the lunar surface to cislunar space
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-147-L	Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	UC-178-L	Transport conditioned cargo from cislunar space to Earth

		ID	Functions	ID	Use Cases
				UC-179-L	Transport cargo from the lunar surface to cislunar space
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-149-L	Provide crew health care on the lunar surface	UC-018-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface
				UC-154-L	Crew emergency health care, diagnosis, and treatment on the lunar surface
		FN-150-L	Provide crew health care during transit	UC-016-L	Crew health care, diagnosis, and treatment in space
		FN-151-L	Collect and store medical data and health information	UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
		FN-152-L	Transfer equipment from extravehicular to intravehicular environment (demonstration)	UC-139-L	Demonstrate maintenance, modification, and/or upgrades of asset(s)
		FN-158-L	Access from habitable volume to lunar surface exterior vacuum	UC-011-L	Support crew extravehicular operations on the lunar surface
		FN-160-L	Provide crew health care in cislunar space	UC-016-L	Crew health care, diagnosis, and treatment in space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
		FN-176-L	Provide intravehicular maintenance, upgrade, and/or repair accommodations (demonstration)	UC-139-L	Demonstrate maintenance, modification, and/or upgrades of asset(s)
		FN-180-L	Provide food system(s) on the lunar surface	UC-161-L	Nutrition monitoring for crew during mission
		FN-181-L	Provide food system(s) in cislunar space	UC-161-L	Nutrition monitoring for crew during mission
		FN-183-L	Provide crew exercise system(s) on the lunar surface	UC-163-L	Crew health maintenance with countermeasure activities in partial gravity environment
		FN-201-L	Provide advanced warning of threats from induced environmental hazards on the lunar surface	UC-172-L	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-202-L	Provide common data interface on the lunar surface	UC-085-L	Utilize common interface(s) for data transfer and distribution
		FN-203-L	Provide common data interface in cislunar space	UC-085-L	Utilize common interface(s) for data transfer and distribution
		FN-208-L	Monitor electrostatic charging in space	UC-140-L	Monitor environmental factors in habitation systems in space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges

		ID	Functions	ID	Use Cases
				UC-168-L	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-209-L	Monitor natural radiation levels in space	**UC-140-L**	Monitor environmental factors in habitation systems in space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-228-L	Provide crew health maintenance capabilities in partial gravity environment	**UC-018-L**	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-152-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface
				UC-163-L	Crew health maintenance with countermeasure activities in partial gravity environment
		FN-231-L	Format and transmit data to Earth from the lunar surface	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-236-L	Format and transit data to Earth from cislunar space	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-237-L	Store and distribute data between assets in cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
		FN-239-L	Format, transmit, and receive data from the lunar surface to cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-244-L	Protect and/or secure data for storage and transmission	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth

		ID	Functions	ID	Use Cases
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-269-L	Capture imagery on the lunar surface	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-107-L	Document sample details prior to collection on the lunar surface
		FN-275-L	Monitor crew health on the lunar surface	**UC-104-L**	In-situ diagnosis and treatment of crew on the lunar surface

Table 3-11. Functions Fulfilled by CLPS Provider Landers During the HLR Segment

		ID	Functions	ID	Use Cases
EM-008-HLR	CLPS Provider Landers	FN-018-L	Transport cargo from Earth to the lunar surface	UC-010-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-072-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
				UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-088-L	Provide precision landing for cargo transport to the lunar surface	UC-072-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface
				UC-098-L	Transport large exploration asset(s) to the lunar surface

		ID	Functions	ID	Use Cases
		FN-122-L	Decommission surface delivery system(s) and/or surface asset(s)	**UC-101-L**	Conduct end-of-life operations
		FN-141-L	Deliver cargo(s) to distributed sites on the lunar surface	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-164-L	Deliver cargo(s) to south polar region sites on the lunar surface	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface

Table 3-12. Functions Fulfilled by Payloads During the HLR Segment

		ID	Functions	ID	Use Cases
EM-011-HLR	Payloads	**FN-032-L**	Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
		FN-043-L	Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**UC-020-L**	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-181-L	Transport conditioned cargo to appropriate facilities on Earth
				UC-182-L	Transport collected samples to appropriate curation facilities on Earth
		FN-046-L	Conduct crew survey of areas of interests and sample identification	**UC-024-L**	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs
				UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-111-L	Collect sub-surface samples from PSRs
		FN-047-L	Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
		FN-048-L	Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
		FN-050-L	Orbital observations and sensing of the lunar surface	**UC-027-L**	Orbital survey(s) before, during, and after crew mission
		FN-054-L	Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	**UC-030-L**	Collect surface samples from PSRs
		FN-055-L	Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state	**UC-034-L**	Collect sub-surface samples from non-PSRs and sunlit regions
		FN-069-L	Provide in-mission crew training in cislunar space	**UC-046-L**	Provide in-situ training to astronauts for science tasks during mission(s)

		ID	Functions	ID	Use Cases
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
		FN-070-L	Provide in-mission crew training on the lunar surface	UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
		FN-118-L	Collect water/ice from the polar region of the lunar surface (demonstration)	UC-077-L	Demonstrate operational techniques to recover water from the lunar regolith in the polar regions
		FN-121-L	Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	UC-181-L	Transport conditioned cargo to appropriate facilities on Earth
		FN-143-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-117-L	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples
		FN-151-L	Collect and store medical data and health information	UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
		FN-153-L	Prepare unconditioned cargo or samples for Earth return	UC-020-L	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-179-L	Transport cargo from the lunar surface to cislunar space
		FN-154-L	Prepare conditioned cargo or samples for return to Earth	UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-178-L	Transport conditioned cargo from cislunar space to Earth
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-157-L	Operate assets in cislunar space in uncrewed mode for extended (year+) durations	UC-120-L	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
				UC-148-L	Habitation capabilities for extended-duration (year+) missions in cislunar space
		FN-185-L	Collect regolith at scale and subscale (demonstration)	UC-076-L	Demonstrate operational techniques to recover oxygen from lunar regolith

		ID	Functions	ID	Use Cases
				UC-143-L	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction
				UC-145-L	Demonstrate regolith based additive/subtractive manufacturing techniques
				UC-150-L	Demonstrate operational techniques to recover and refine metals from the lunar regolith
		FN-194-L	Monitor environmental conditions within habitable volume in space	UC-168-L	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-195-L	Detect and monitor high energy debris in cislunar space	UC-168-L	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-197-L	Monitor environmental conditions within habitable volume on the lunar surface	UC-172-L	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-198-L	Detect and monitor high energy debris on the lunar surface	UC-172-L	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-208-L	Monitor electrostatic charging in space	UC-140-L	Monitor environmental factors in habitation systems in space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-168-L	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-209-L	Monitor natural radiation levels in space	UC-140-L	Monitor environmental factors in habitation systems in space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-210-L	Monitor radiation on the lunar surface	UC-141-L	Monitor environmental factors in habitation systems on the lunar surface
				UC-170-L	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-211-L	Monitor electrostatic charging on the lunar surface	UC-141-L	Monitor environmental factors in habitation systems on the lunar surface
				UC-170-L	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-172-L	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics

		ID	Functions	ID	Use Cases
		FN-212-L	Monitor plasma environment in space	**UC-166-L**	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-213-L	Monitor meteoroid activities in cislunar space	**UC-166-L**	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-214-L	Monitor plasma environment on the lunar surface	**UC-170-L**	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-215-L	Monitor meteoroid activities on the lunar surface	**UC-170-L**	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-218-L	Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	**UC-030-L**	Collect surface samples from PSRs
		FN-219-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**UC-111-L**	Collect sub-surface samples from PSRs
				UC-117-L	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples
		FN-220-L	Stow collected surface samples from PSRs on the lunar surface	**UC-030-L**	Collect surface samples from PSRs
		FN-221-L	Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state	**UC-111-L**	Collect sub-surface samples from PSRs
		FN-248-L	Robotic surveys of potential exploration sites on the lunar surface with assets on surface	**UC-023-L**	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
		FN-249-L	Robotic identification of potential samples and resources on the lunar surface	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-250-L	Robotic collection of lunar surface samples	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-251-L	Robotic collection, containment, and documentation of lunar surface samples from PSRs	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-261-L	Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**UC-111-L**	Collect sub-surface samples from PSRs
		FN-262-L	Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-034-L**	Collect sub-surface samples from non-PSRs and sunlit regions
		FN-263-L	Provide containers to package sub-surface samples	**UC-118-L**	Package sub-surface samples for return
		FN-269-L	Capture imagery on the lunar surface	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-107-L	Document sample details prior to collection on the lunar surface

		ID	Functions	ID	Use Cases
		FN-270-L	Operate assets on the lunar surface in uncrewed mode for extended (year+) durations	**UC-005-L**	Operate transportation assets(s) from Earth during crew surface missions
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
		FN-274-L	Stow collected surface samples on the lunar surface from PSRs in conditioned state	**UC-030-L**	Collect surface samples from PSRs

3.1.6 Unallocated Use Cases and Functions

Use case and functional decomposition focused on near-term achievability of the lunar objectives has been completed. Once the Mars objectives decomposition is complete, there may be additional lunar use cases and functions to be included in the HLR segment.

The current list of functions that are unallocated for HLR are listed below.

Table 3-13. Unallocated Use Cases and Functions for the HLR Segment

		ID	Functions	ID	Use Cases
EM-012-HLR	Unallocated	**FN-068-L**	Provide crew training prior to mission	**UC-045-L**	Provide advanced geology training, integrated geology and EVA ops training, as well as detailed objective-specific training to astronauts for science activities
		FN-196-L	Survey potential exploration sites on the lunar surface from lunar orbit	**UC-023-L**	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
		FN-199-L	Capture imagery in cislunar space	**UC-175-L**	Communications and data exchange between assets in cislunar space and Earth
		FN-200-L	Provide advanced warning of threats from natural environmental hazards on the lunar surface	**UC-170-L**	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-265-L	Provide power for conditioning to sample containers during transit from the lunar surface to Earth	**UC-097-L**	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
		FN-266-L	Provide power for conditioning to sample containers on the lunar surface	**UC-030-L**	Collect surface samples from PSRs
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
		FN-267-L	Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	**UC-097-L**	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-268-L	Provide power for conditioning to sample containers during transit from cislunar space to Earth	**UC-097-L**	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-178-L	Transport conditioned cargo from cislunar space to Earth

		FN-278-L	Transport collected sub-surface samples on the lunar surface in conditioned state	**UC-034-L**	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-111-L	Collect sub-surface samples from PSRs

3.1.7 Open Questions, Ongoing Assessments, and Future Work

Open questions, ongoing assessments, and future work for HLR segment include:

- What options are available to increase sample return and conditioned cargo from the lunar surface to Earth?
- What options are available to increase down-mass to the lunar surface to support utilization?
- What implications to the current systems are required to support non-polar sorties in the HLR segment?
- What elements need to provide in-situ training of crew in cislunar space?
- What options are available to maximize the allowable crew EVA walking distance (up to 2 km)?
- What options are available to provide power to deployed utilization payloads, enabling payloads to survive extended lunar nights on the lunar surface?
- What functions and use cases should be added to address public affairs and outreach?

3.2 FOUNDATIONAL EXPLORATION SEGMENT

The Foundational Exploration (FE) segment builds on the initial capabilities of Human Lunar Return (HLR) and prepares for future segments through the lunar expansion of operations, capabilities, and systems supporting complex orbital and surface missions to conduct utilization and Mars-forward precursor missions. With the continued use of the elements in HLR and the deployment of new capabilities, surface missions will feature increased duration, expanded mobility, and regional exploration of the lunar South Pole. Orbital operations will also increase in duration and, when coupled with the surface mission phases, will serve as Mars mission analogs, validating both the systems and the exploration concepts of operations for future Mars mission profiles. FE will have to initiate activities and capabilities that will be influenced by the future needs in the Sustained Lunar Evolution (SLE) and Humans to Mars segments. Such activities include reconnaissance, Mars risk reduction, and initial infrastructure supporting the long-term SLE evolution.

3.2.1 Use Cases and Functions

As seen in the HLR segment, by starting with the Agency objectives and their associated characteristics and needs, particular use cases and functions may be defined. As the FE segment continues to be matured, so will the functional breakdown from the objectives. The complete set of objectives can be found in Appendix A.

As a representative example, objective TH-3 (develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence; conducting scientific and industrial utilization as well as Mars analog activities) drives several characteristics and needs. These include demonstration of capabilities to allow crew to live, to work inside habitable spaces, and to exit them to conduct EVA activities in both cislunar space and on the lunar surface. Sample use cases that contribute to fulfilling those characteristics and needs include crew operations, habitation, EVA, collection of samples, and crew emplacement and set-up of science and utilization packages. Some of the functions that map to these use cases include transportation, crew health and human performance, habitation, and integrated human-robotic operations.

For FE, several elements are in design/development stages and these elements form the basis of satisfying some of the functional needs. Element mappings for elements that have passed NASA's Mission Concept Review[12] are provided in Section 3.2.5. As additional elements are added to the architecture for FE, updates to the element mapping will be provided. Many of the use cases and functions will require additional elements or new functional capabilities that go beyond what is being assigned to the current FE elements described below. Key gaps between planned FE capabilities and Moon to Mars objectives needs are noted later in this document and will continue to be expanded through the ACR process. Note that not all use cases (UC-#) and functions (FN-#) are sequential in this segment mapping. The numbering represents use cases and functions that have been identified through the overall objective decompositions process but not all are applicable to the FE segment.

3.2.2 Summary of Objectives

Increased mission durations, expanded capabilities, and the ability to access various regions of the lunar surface enable a growth in utilization during both crewed and uncrewed mission phases. A variety of science objectives may be addressed during the FE segment, ranging from lunar and planetary science to human and biological science and science-enabling and applied science goals. During the FE campaign segment, enhanced architecture capabilities would further enhance the ability to address and achieve science objectives, including 1) expanding accessible regions of exploration from the south polar region to key locations across the Moon to further advance understanding of the chronology, composition, and internal structure of the Moon (LPS-1 and LPS-2), 2) characterizing the distribution, source, and composition of volatile-bearing materials across the lunar south polar region, including within larger PSRs (LPS-3) and determine their viability for ISRU, 3) generating forecasting capabilities for space weather monitoring off the Earth-Sun line (HS-1), 4) characterizing plant, model organisms/systems, and human physiological responses to long-term exposure to extreme environments with microgravity or partial gravity (HBS-1, HBS-3), 5) characterizing physical systems in partial-gravity environments and associated models (HBS-2), and 6) conducting relativity and quantum physics experiments tin the lunar environment (PPS-1, PPS2). These FE science priorities were identified by NASA's SMD, Human Research Program (HRP), Science Technology Mission Directorate (STMD), and other stakeholders in FE execution.

All of the lunar infrastructure (LI) objectives help define FE. Expansion of the power (LI-1), communications/position/navigation/timing (LI-2, LI-3), transportation (LI-5, LI-6), mobility (LI-6), ISRU (LI-7), infrastructure (LI-4, LI-8), and utilization (LI-9) sub-architectures builds toward the LI goal of "[creating] an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while also accomplishing science objectives and forward testing for Mars."

The transportation and habitation (TH) objectives drive the additional capabilities in mobility, habitation, and transportation systems during FE. For example, TH-1, TH-2, and TH-11 all address a need for transportation systems to transfer crew and cargo to and- rom Earth, through cislunar space, and between lunar orbit and the surface, enabling scientific and utilization objectives. TH-3 (develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence; conducting scientific and industrial utilization as well as Mars analog activities) and TH-4 (develop in-space and surface

[12] Mission Concept Review as defined in NASA Procedural Requirement 7120.5F, https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5F

habitation system(s) for crew to live in deep space for extended duration, enabling future missions to Mars) define FE as a campaign segment.

A number of operations (OP) objectives drive the capabilities needed for FE. The overall operations goal is to “conduct human missions on the surface and around the Moon followed by missions to Mars. Using a gradual build-up approach, these missions will demonstrate technologies and operations to live and work on a planetary surface other than Earth, with a safe return to Earth at the completion of the missions.” These objectives encompass the need for extended-duration missions in deep space and partial-gravity environments to test systems and crew concepts of operations in preparation for the initial human Mars exploration campaign (OP-1, OP-2, OP-4, OP-5, OP-6, OP-7). Additionally, the need to develop methods to work with robotic systems (OP-9, OP-10) and characterize in-situ resources (OP-3) defines other aspects of FE.

3.2.3 Reference Missions and Concepts of Operations

As described in the Objective Decomposition section, use cases may be grouped into reference missions to show examples of how several use cases may be accomplished with a particular concept of operations. Expanding on the types of mission phases expected in HLR, several notional reference mission phases are presented, showing progress toward the FE objectives. Reference missions represent how architecture capabilities can be used; these are not planned missions to be flown.

3.2.3.1 Sortie Reference Mission with Unpressurized Mobility

The FE segment will build on the types of lunar surface exploration conducted in the HLR segment, which includes crew habitation in an EVA-capable crew lander. Additional FE use cases may be implemented with the addition of an unpressurized mobility platform to extend EVA range and scientific exploration. This enables the use case for crew excursions to locations distributed around the landing site and has the potential to enable others, such as robotic assistance of crew exploration, the locating of samples and resources, and retrieval of samples; crewed/robotic collection of samples from PSRs; and deployment of power generation, storage, and distribution systems at multiple locations around the lunar South Pole, among others.

3.2.3.2 Reference Mission with Pressurized Mobility

Working toward the objectives to expand exploration for longer durations while conducting scientific and industrial utilization, developing surface habitation systems, and performing Mars risk reduction activities prompts the inclusion of additional functional capabilities. With initial surface crew sizes, one method to accomplish these objectives is by adding functionality for pressurized mobility systems. This function may enable use cases such as crew intra-vehicular activity (IVA) research, additional robotic assistance of crew exploration beyond the unpressurized mobility function, expanded durations for crew operations on the lunar surface (including additional habitation functions), logistics and waste management, crew excursions to locations distributed around the landing site, EVA egress/ingress, crew/robotic collection of samples, and crew relocation and exploration in a shirt-sleeve environment.

With the addition of pressurized habitation and mobility, as well as potentially increased number of crew, mission durations, and sites, other needs will arise, such as logistics transport and stowage, trash disposal, maintenance, and other infrastructure services and support. Challenges with the lunar environment, such as dust, plasma interactions, radiation, etc., will become increasingly complex and will need to be mitigated.

3.2.3.3 Robotic Uncrewed Operations

Even with the opportunity to extend surface mission durations from those in HLR, the surface of the Moon is currently planned to be uncrewed for the majority of each year in the FE segment. Functions regarding autonomous, local tele-operations, or Earth-based remote operations enabled by the CPNT sub-architecture provide additional exploration and utilization opportunities during the uncrewed portions of the year. Assuming a main function of autonomous and/or tele-operations, these robotic functions could include cargo unloading, logistics transfers, surface and/or sub-surface sample collection, and infrastructure development (e.g., landing site scouting or preparation). These functions contribute to use cases like robotic survey of potential crewed landing sites to identify locations of interest (including nearby PSRs), uncrewed relocation of mobility elements to landing sites around the lunar South Pole, and autonomous deployment of science and utilization packages.

3.2.3.4 Extended Cislunar Operations at Gateway

A key aspect of FE is preparing for crewed exploration of Mars through lunar precursor missions. In addition to an extension in duration for surface mission segments from HLR, other main characteristics are to provide numerous long-duration crew increments in cislunar space to compliment crewed surface mission segments and to support crew transitions from microgravity to partial gravity. Extended mission segments in cislunar space at Gateway and accompanying visiting vehicles also allow for increased time for IVA science and utilization. A main use case to accomplish these characteristics and needs is to utilize precursor Mars mission profiles with extended durations in NRHO, followed by lunar surface missions. Although these missions are not identical, they allow for long-term physiological, psychological, team performance, and operational assessments of crew and systems as a precursor to Mars missions.

Other use cases applicable to Gateway reference missions include crew delivery and transfer to crewed landing systems in cislunar space, utilization equipment delivery to/from landing systems and return to Earth, remote diagnosis and treatment of crew health issues during extended increments in cislunar space, crew emplacement and setup of science and utilization packages in cislunar space (with long-term remote operation as applicable), and crew IVA research in dedicated science workspaces in cislunar space.

3.2.3.5 Extended Surface Habitation Operations

The addition of dedicated surface habitation enables longer-duration missions, increased crew size, and enhanced surface utilization and exploration to help meet objectives that lead to continuous presence. With dedicated habitation capability, additional use cases to support science and utilization are achievable, enhancing crew EVA exploration, sample collection, and emplacement of science and/or utilization packages. Performing in-situ science through allocated workspaces and demonstrating progressively regenerative and self-sustaining ECLS systems are example use cases that might be addressed with additional surface habitation capability. Increased functional capabilities that support longer-duration deep space and partial-gravity crew habitation include robust crew medical systems and health kits; space-based manufacturing techniques allowing repairs and replacement; enhancing surface EVAs; and providing interfaces for logistics transfers (e.g., solid and fluid consumables, maintenance, utilization, and waste), all further contribute towards fulfilling Moon to Mars objectives focused on building a sustained lunar presence. Systems that were originally sized to maintain elements during extended uncrewed periods and early FE missions will need augmentation to permit increased objective satisfaction and longer-duration human presence.

3.2.3.6 Non-Polar Lunar Sortie Reference Mission

Although the focus for lunar surface exploration is the South Pole, several objectives, particularly those related to science and utilization, motivate looking at landing sites beyond the South Pole. The use case of crewed missions to non-polar landing sites would allow for exploration of alternative locations with enabling functions like crew descent, landing, and ascent at non-polar sites. Each area presents its own challenges and points of interests. This allows for sample collection and/or return from various locations of interest across the lunar surface via EVA without surface mobility.

3.2.3.7 Cislunar Orbit Only

During the FE segment, there may be periods where strategic objectives or mission implementation necessitate crew missions to orbit only without a subsequent landing on the lunar surface. This exploration strategy would require capabilities to not only perform crew missions in cislunar orbit (i.e., NRHO), but also the ability to control lunar surface assets from Earth and lunar orbit. This would allow faster control response by the crew (near–real time), which could include cargo unloading, logistics transfer, surface and/or sub-surface sample collection, and infrastructure development (e.g., landing site scouting or preparation).

3.2.4 Sub-Architectures and Element and Functional Descriptions

Elements introduced in HLR will continue to be utilized, as additional capabilities will become available, flowing from the Agency objectives. As element concepts mature, they have been added to the FE segment. Other concepts can be grouped into general functional categories and/or associated sub-architectures. As the architecture matures and the Artemis Program advances, new elements will be conceptualized to meet these needs. Other important aspects to consider include interoperability between elements, the associated functions necessary to achieve interoperability, and the impacts of functional groupings on the overall architecture.

Forward work remains to further define the sub-architectures and their expansion for FE. In addition to integrating with particular elements, the sub-architectures bridge elements and operations, necessitating high levels of long-term planning and coordination across the overall exploration architecture. For other sub-architectures, notional, non-comprehensive functions are included here. Images shown are examples of concepts that may meet (or partially meet) the capabilities in these functional descriptions; they should not be taken as recommendations for design solutions or treated as the only concept(s) under consideration.

3.2.4.1 Communications, Position, Timing, and Navigation Systems

Building upon the HLR segment, the CPNT capabilities expand in the FE segment to include greater coverage, availability, and more capable system capacity. Greater CPNT coverage and availability involves expanding the orbital relay service to increase coverage and availability over the South Pole and other lunar regions of interest. A surface wireless networking infrastructure enables direct surface/local communication and aggregates data for backhaul transmission to Earth and offers supplemental local PNT. An increasingly capable orbital relay network will provide additional communication and navigation services to the expected increase in number of surface users/assets and support increased data volume and growth, while improving accurate and timely PNT services over the global lunar surface volume. As more elements are deployed to the surface, many will be telerobotically controlled or operate autonomously under remote supervision, including the commanding of rovers and control and monitoring of science payloads. Each of these elements and users will have a variety of communication and navigation needs to accurately land, move, localize, time-stamp, and navigate about the surface; travel to and record locations of interest and samples; communicate and exchange data with other elements on the surface, with Gateway, and with operations on Earth; and collect and return telemetry, video, and other science data. As the number of simultaneous users increases, the PNT architecture for global coverage would not require a parallel increase in orbital nodes. NASA's current spectrum plans incorporate the Interagency Operations Advisory Group (IOAG) Architecture, the International Communication System Interoperability Standards (ICSIS), the International Telecommunications Union (ITU), and the Space Frequency Coordination Group (SFCG). As future elements are defined, example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment for this sub-architecture include:

- Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface
- Provide high availability position, navigation, and timing capability on the lunar surface
- Simulate up to Mars distance communication latency or disruptions during operations in cislunar space
- Simulate up to Mars distance communication latency or disruptions during operations on the lunar surface
- Provide accurate location tracking and position data on the lunar surface
- Implement communication methods to coordinate and preserve the radio environment on the lunar far side

3.2.4.2 Data Management and Systems Sub-Architecture

The data management and systems (DMS) sub-architecture will leverage initial capabilities put in place in HLR for managing and moving data across the architecture; it is highly dependent on the CPNT and human system sub-architectures. Capabilities to be added in FE focus on a more robust data management strategy that considers data quality, interoperability, security, privacy, latency, and compliance to ensure that the full potential of the expansive amount of lunar data can be harnessed. This sub-architecture, like many others, spans not only the lunar surface and cislunar space, but also includes the data obtained, needed, stored, or shared on Earth. With elements yet to be defined, example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment for this sub-architecture include:

- Format, transmit, and receive data between assets on the lunar surface
- Store and distribute data between assets on the lunar surface
- Store and distribute data between assets in cislunar space
- Provide common data interface on the lunar surface

3.2.4.3 Habitation Systems

Building upon the initial Gateway capability described in HLR, both cislunar and surface habitation are expanded during FE. Concepts for such expanded functionality are under assessment and may support Mars analogs in the lunar vicinity. For such analogs, long-duration habitation system operations in a relevant environment will support risk reduction and crew preparation for Mars transit. For the lunar surface, extending durations and crew size beyond HLR durations of more than seven days on the surface with two crew will afford opportunities to achieve several Moon to Mars objectives. Examples of expanded functional capabilities in the FE segment (from the current function list in Appendix A) for this sub-architecture include:

- Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations
- Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)
- Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use
- Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface
- Provide capability to restore and stabilize the habitable environment after off-nominal scenario

3.2.4.3.1 Gateway Expanded Capability Configuration

The FE segment includes planned upgrades from the Gateway Crew-Capable configuration, described in HLR, to the Gateway Expanded Capability configuration. These upgrades include the previously described Gateway External Robotic System (GERS) to be provided by the CSA, the ESPRIT Refueling Module (ERM) to be provided by ESA, logistics resupply to be provided by JAXA, and the Gateway Airlock Module (ALM). ALM is a multipurpose element that provides the capability for EVAs while supporting scientific research and day-to-day Gateway operations with a specialized Science Airlock. By leveraging the capabilities provided by GERS/Canadarm3, the Science Airlock will allow scientific experiments and Gateway hardware to move between the pressurized cabin and unpressurized destinations outside of Gateway. The ALM is also planned to provide an additional docking port for visiting vehicles, supplementary storage, and the capability for unattended robotic maintenance of Gateway. NASA expands on the flexible deep space logistics capabilities (see Section 3.1.4.3) to deliver elements (i.e., GERS), payloads, cargo, experiments, and other supplies to Gateway, to extend the duration of crewed missions. The ERM enables the refueling capability of the Gateway Power and Propulsion Element and provides the capability for external viewing of the Moon and cislunar space. The ERM will include a docking port for the logistics module and supports expanded cargo stowage for Gateway. The Gateway Expanded Capability Configuration is shown in Figure 3-12.

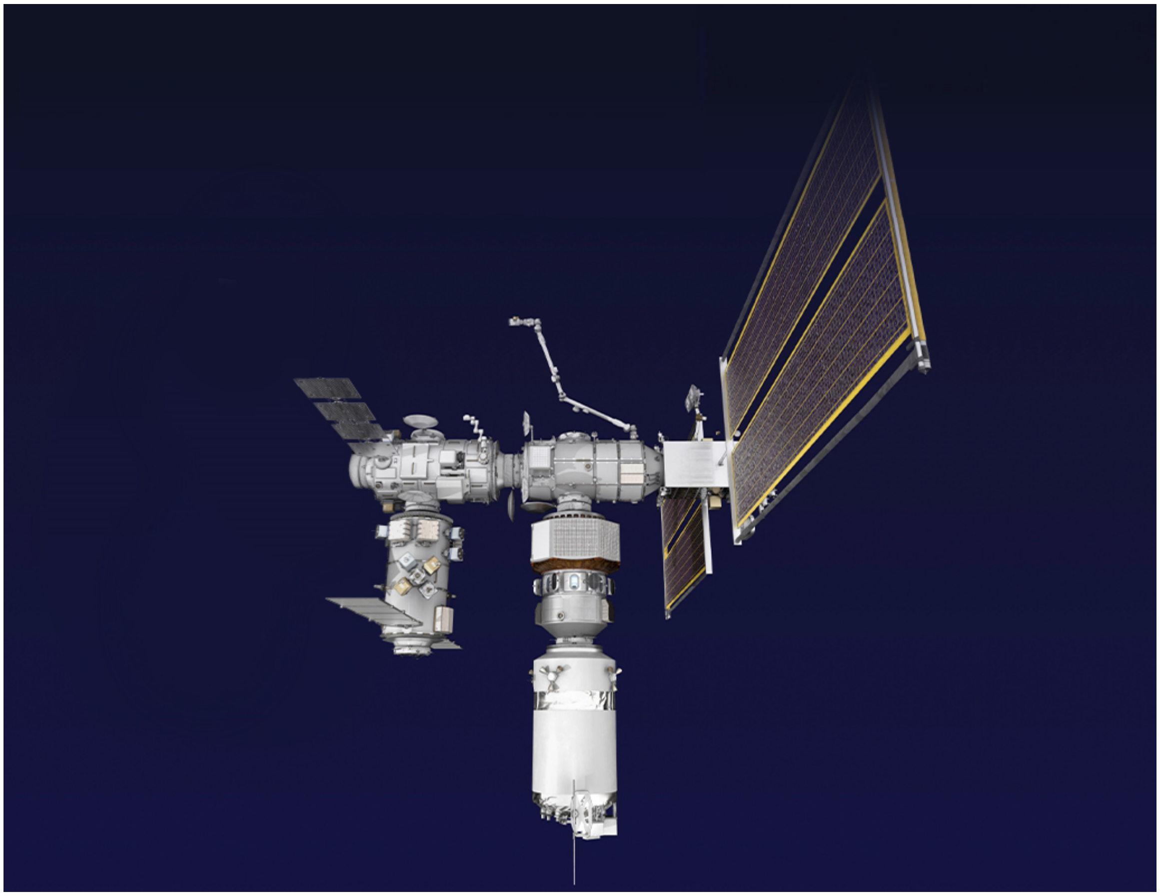


Figure 3-12. Gateway Expanded Capability Configuration

3.2.4.3.2 Habitation Concepts

FE emphasizes extended duration and preparing for crewed Mars mission profiles through analog missions in lunar vicinity. An important aspect is long-duration mission segments in the deep space microgravity environment, which mimics the transit phases between Earth and Mars. To that end, a growth in cislunar orbital operations will occur as Gateway's capabilities expand (as shown in Figure 3-13) and visiting vehicles, such as a Mars transit habitat, can be deployed. This expansion will support extended mission durations in preparation for Mars missions (e.g., objectives TH-3, TH-4, TH-8, HBS-1, HBS-2, HBS-3, OP-1, OP-4).

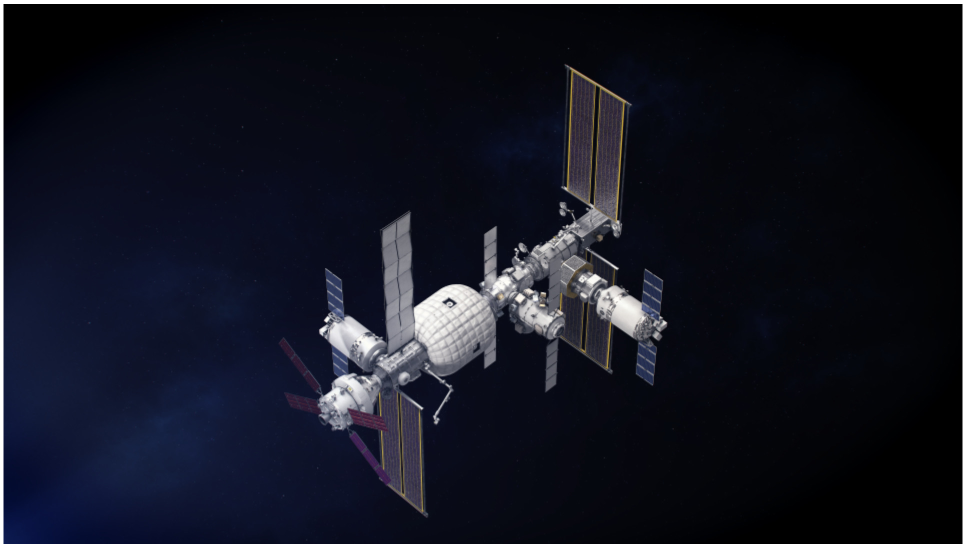


Figure 3-13. Gateway Expanded Capability Configuration with Visiting Expanded Habitation Example Concept

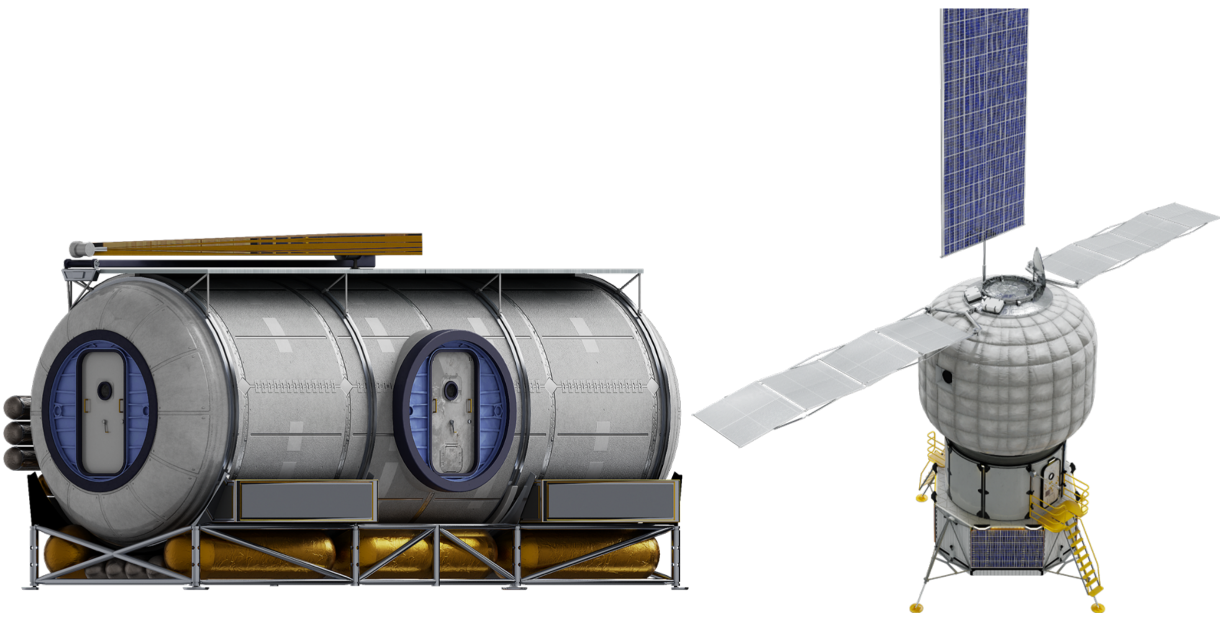


Figure 3-14. Example Concepts for Surface Habitation

With objectives aiming for long-term surface exploration, additional capabilities for surface habitation allows progressive advancement toward sustained human lunar operations. General habitation functions may be common across surface habitation elements and can include providing remote medical systems; providing IVA workspaces; supporting internal and external utilization; supplying environmental control and life support system (ECLSS) capabilities; enabling EVAs; and supporting logistics transfer. Such functions may be shared between several elements of varying designs and levels of capability. Other unique functions that may be implemented include support and storage of ISRU-produced materials and/or consumables, demonstration of bioregenerative ECLS systems, and demonstration of plant growth sub-systems. Some notional surface habitation concepts are shown in Figure 3-14.

3.2.4.4 Human Systems

In HLR, FE, and other campaign segments, vehicles, systems, training, and operations all must be designed for the "human system"—the crew, the crew support systems, and supporting mission systems and ground teams. Knowledge and lessons learned from missions accomplished in HLR will be incorporated and advanced to support longer-duration missions in space and on the lunar surface. Activities in FE will be more complex, involve crew moving between more elements when compared to HLR, and will incrementally utilize increasing Earth-independent operations. Therefore, additional capabilities will be necessary. Example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment for this sub-architecture include:

- Provide crew training prior to mission
- Provide in-mission crew training on the lunar surface
- Conduct crew training in simulation of increasingly Earth-independent operations
- Perform regular training and drills to simulate off-nominal scenarios
- Provide remote crew medical systems on the lunar surface
- Provide crew health maintenance capabilities in partial gravity environment
- Provide crew health care on the lunar surface
- Collect and store medical data and health information

3.2.4.5 Infrastructure Support

EGS is a key pillar of the infrastructure sub-architecture in HLR and throughout the follow-on campaign segments, established to develop and operate systems and facilities necessary to process, launch, and recover vehicles. As human exploration expands into cislunar space, the Moon, Mars, and beyond, capabilities and lessons learned from Earth infrastructure will be applied to the exploration destinations and expanded capabilities on Earth. The infrastructure sub-architecture supports the other sub-architectures in terms of facilities, systems, equipment, and services on the ground (Earth), in space, and while on the surface. The infrastructure sub-architecture will expand to support other sub-architectures as they mature. As elements are yet to be defined, example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment for this sub-architecture include:

- Provide intravehicular maintenance, upgrade, and/or repair accommodations (demonstration)
- Utilize tools for equipment cleaning and maintenance

3.2.4.6 In-Situ Resource Utilization Systems

Knowledge and lessons learned from the demonstration activities in HLR will be applied to the next steps in the in-situ resource utilization (ISRU) sub-architecture for FE. The shift from reconnaissance, initial resource assessment, and sampling to resource reserve estimation, acquisition, and processing occurs in this segment. Because of the significant differences in resource understanding and characteristics, terrain, environments, extraction, and processing technologies, and ISRU products, a dual path that includes both water mining in PSRs and oxygen and/or metal extraction from regolith is being pursued. Demonstrations to prove out technologies to enable both pathways are envisioned. Both pathways support surface construction activities that occur in this segment. In addition, the ISRU sub-architecture is directly tied to the power sub-architecture given the significant power demands of supporting large scale ISRU, and tied to the CPNT sub-architecture for command, control, and monitoring, for ISRU operations and navigating about the lunar surface to locations of interest. Example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment for this sub-architecture include:

- Produce scalable quantities of water from in-situ materials (demonstration)
- Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)
- Form scalable quantities of structures from lunar regolith (demonstration)
- Manufacture (additive or subtractive) scalable quantities of item(s) from lunar regolith (demonstration)
- Produce scalable quantities of metal from lunar regolith (demonstration)
- Testing of product(s) from additive/subtractive manufacturing (demonstration)
- Testing of product(s) from metal production/refinement (demonstration)

3.2.4.7 Logistics Systems

For the HLR segment, logistics deliveries include logistics modules to Gateway and what can be transported with the crew to the lunar surface in the HLS. Additionally, during HLR, any trash or waste generated that remains on the lunar surface will be positioned so as not to impact operations. As capabilities expand for the FE segment, dedicated lunar surface delivery platforms are needed to support more crew and longer durations on the lunar surface. To align with the reoccurring tenet of maximizing crew time for exploration, a strategy is needed that minimizes crew-time needed for logistics operations while also maximizing delivery efficiency. The first step is to understand the amount and types of logistics items needed, which, along with the interfaces of the planned surface elements, drive the type and quantity of the logistics carriers needed. Carrier types would include those suitable for EVA transfer and sized to be carriable through a hatch or an airlock while accommodating various logistics items including dry goods and water. While other carrier types, such as tanks, would be used to transport gases unless there is an umbilical transfer capability. Additionally, pressurized carriers that use a berthing/docking-type interface will be used, when possible, to replace or house the smaller, carriable carriers to allow for shirt-sleeve transfer of the logistics items. Finally, certain unpressurized items (e.g., oversized items or those for external utilization) may require specialized carriers that account for operational considerations. Once these carriers have been used for logistics delivery, they will be used for long-term storage of trash and waste. As capabilities to recover or process trash and waste become available, they may be incorporated into the sub-architecture. Example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment this sub-architecture include:

- Robotic system(s) interaction with logistics carriers on lunar surface
- Manage waste from habitable elements on the lunar surface
- Transfer of gases and water to habitable assets on the lunar surface

3.2.4.8 Mobility Systems

Mobility capabilities are necessary to enable exploration in the FE segment beyond the EVA walking range of the crew described in the HLR segment. The lunar terrain vehicle (LTV) and the pressurized rover (PR) are elements in development to meet several of the mobility-related Moon to Mars objectives. Functions that typically fall into this category include providing local unpressurized and pressurized crew and uncrewed surface mobility, as well as autonomous and/or tele-operations, and enabling additional science and utilization. Additional capabilities beyond the LTV and PR are currently under assessment. Example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment of this sub-architecture include:

- Transport scalable quantities of oxygen produced exploration elements (demonstration)
- Transport scalable quantities of water produced to exploration elements (demonstration)
- Robotic survey of potential exploration sites on lunar surface with assets on surface
- Reposition cargo on the lunar surface
- Conduct crew surface extravehicular activities at the lunar far side
- Transport of cargo on lunar surface between landing location and surface assets

3.2.4.8.1 Lunar Terrain Vehicle

The LTV is an unpressurized rover with the primary role of transporting two suited crewmembers and secondary role of supporting science, exploration, and operations objectives. The LTV provides reliable and safe transportation between waypoints for two suited crew members and cargo. The LTV can carry cargo, including various payloads, work packages, logistics supplies, science tools, samples, and associated stowage containers, etc., across the lunar surface. The LTV can extend the wireless surface CPNT network, enhancing coverage and range for exploration. It can also be used for landing site reconnaissance and payload utilization. It can be operated manually by a single suited crew member, remotely by teleoperators, or via some autonomous operations. Another of its primary functions will be to provide the crew a companion platform in the event of another mobile asset’s failure to return to the habitation asset. Two mobility platforms operating together allows for farther crewed traverses than would be possible utilizing a single mobility platform.

Figure 3-15. Lunar Terrain Vehicle (Artist Rendition)

3.2.4.8.2 Pressurized Rover

The PR is a mobile habitable vehicle whose primary purpose is to support crew, utilization, operations, and Mars analog objectives. The PR provides reliable and safe transportation of two crew members inside a pressurized cabin. It can support various payloads, work packages, logistics, science tools, samples, and associated stowage containers. The PR can be operated manually by a single IVA crew member from the cabin, remotely by teleoperators on Earth, or via some autonomous operations. The PR will travel distances compatible with exploration traverses, as well as uncrewed traverses. The PR can perform extended exploration missions lasting up to 30 days, performing multiple two-crew EVAs, and allowing for some servicing as needed, with logistics resupply necessary for missions longer than 14 days. When operated in conjunction with the LTV, the traverse distance could be increased over the limitations of the PR alone, since the LTV can be used as a backup mobility asset in the event of a failure.

Figure 3-16. Pressurized Rover (Artist Rendition)

3.2.4.9 Power Systems

The baseline power strategy for HLR is element self-sufficiency, which presumes that every element can provide its own power and energy storage needed to perform the intended mission for a given time span. The HLR approach is to locate elements at lunar South Pole sites with favorable solar illumination and short eclipse periods. Lunar missions beyond a few specific South Pole locations will require power production through the approximately 360-hour lunar night, which significantly impacts the power system mass and volume. As the lunar surface architecture expands and likely becomes more integrated, the power sub-architecture will likely expand to include internal augmentation (e.g., power added after delivery of an asset to the surface), external augmentation (e.g., a surface asset can connect to a single independent power element to charge/recharge) and/or a power grid (e.g., multiple independent power elements that form a power network for elements and other surface assets to utilize). These capabilities will be further refined through future assessments. In addition, transitioning samples and other utilization packages from the lunar surface, through cislunar space, and back to Earth will require interoperability and resources (e.g., power). A key objective is to develop an incremental lunar power generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels. Example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment this sub-architecture include:

- Generate power on the lunar surface
- Store energy on the lunar surface

- Provide power for deployed surface asset(s)
- Distribute power on the lunar surface
- Provide power through common power distribution interface(s) on the lunar surface
- Provide capability for bi-directional power exchange
- Provide power for conditioning to sample containers on the lunar surface
- Provide power for conditioning to sample containers during transit from lunar surface to cislunar space
- Provide power for conditioning to sample containers during transit from cislunar space to Earth
- Provide power during crew critical mission events

3.2.4.10 Autonomous Systems & Robotics Systems

As the number of astronauts and the availability of the surface crew to perform tasks could be limited, a balance of crewed and uncrewed operations will maximize crew exploration time. Robots are well suited to performing tasks that are tedious, highly repetitive, or dangerous. In addition, uncrewed operations can continue throughout the year while crew are not present on the surface or in space. Robots may be operated autonomously with or without human supervision, remotely by nearby crew, or by mission controllers on Earth, with progressive reductions in situational awareness and response time. Although the Autonomous Systems and Robotics (AS&R) sub-architecture is apparent during HLR with the use of rovers, such as PRIME-1 and VIPER, to perform various objectives, the human-robotic partnership is embraced starting in the FE segment. Robotic and autonomous systems are being used as precursor explorers preceding crewed missions to inform scientific investigations, mission planning, identification and availability of usable resources, and ISRU technologies. Robots can serve as crew assistants in space and on the lunar surface and as caretakers for conducting utilization and science activities. Robotic reconnaissance (e.g., scouting, surveying, mapping, collecting samples), site preparation ahead of human exploration missions, and robotic and autonomous systems capable of offloading, handling, staging, and prepositioning cargo and logistics supplies can save valuable crew time. The first of many capabilities is the Gateway External Robotic System (GERS). GERS provides the capability to deploy and retrieve external utilization payloads; inspect the Gateway system; capture, berth, and relocate robotic spacecraft or modules; support contingency maintenance; support self-maintenance of robotic components; and support crew EVAs. As there are comparable needs for robotic manipulation on the lunar surface (among other robotic use cases), synergistic opportunities will continue to be assessed to identify additional capabilities and elements needed to achieve Moon to Mars objectives. Example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment of this sub-architecture include:

- Control robotic system(s) in cislunar space by in-situ crew
- Control robotic system(s) on the lunar surface by crew on the lunar surface
- Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space
- Robotic collection, containment, and documentation of lunar surface samples from PSRs
- Robotic system(s) interaction with logistics carriers on the lunar surface
- Perform robotic manipulation of payloads, logistics, and/or equipment at multiple scales

- Docking/berthing of spacecraft components
- Docking/berthing between pressurized assets on the lunar surface

3.2.4.11 Transportation Systems

The Transportation Systems sub-architecture builds upon the SLS, Orion, HLS, and CLPS Provider Landers accomplishments planned during HLR and continues to emphasize these elements in the FE segment. As the Moon to Mars objectives point to expansion of crew size and longer durations on the surface, cargo landers become a necessity. The Human-class Delivery Lander (HDL) and small-to-medium class payload landers are needed to deliver cargo to the lunar surface, ranging from utilization payloads and logistics to additional surface elements like the Pressurized Rover and surface habitation. An increase in capabilities for the HLS Integrated Lander is also planned to accommodate four crew and longer durations on the lunar surface. Additional capabilities that may be grouped into this sub-architecture include spacecraft aggregation in cislunar space, cargo delivery (e.g., science, utilization, technology, crew logistics) from Earth and unloading on the lunar surface, logistics transfer (e.g., fluids and gasses), cargo return (e.g., cryogenic samples) from the lunar surface to Earth, and in-space and/or surface cryogenic storage of propellant. Additional example functions (from the current function list in Appendix A) that that are new or significantly enhanced in the FE segment for this sub-architecture include:

- Transport cargo from lunar surface to Earth
- Provide precision landing for cargo transport to the lunar surface
- Transport crew to lunar surface in proximity of deployed exploration asset(s)
- Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface
- Transport cargo from Earth to the far side of the lunar surface

3.2.4.11.1 Human Landing System Integrated Lander

Additional capabilities planned for the HLS Integrated Lander will be exercised in the FE segment. Missions with the HLS Integrated Lander will use the HLS land a crew of up to four and will leverage additional habitable surface assets to support the larger crew for the duration of the lunar stay. These missions may include the capability to land and operate at non-polar landing sites or to operate for extended durations at the lunar South Pole. This HLS configuration has increased performance capabilities, allowing for enhanced up and down mass to and from the lunar surface and increased darkness survivability. These missions will also seek sustainable HLS designs that may include reusable elements or interactions with other systems in the lunar vicinity.

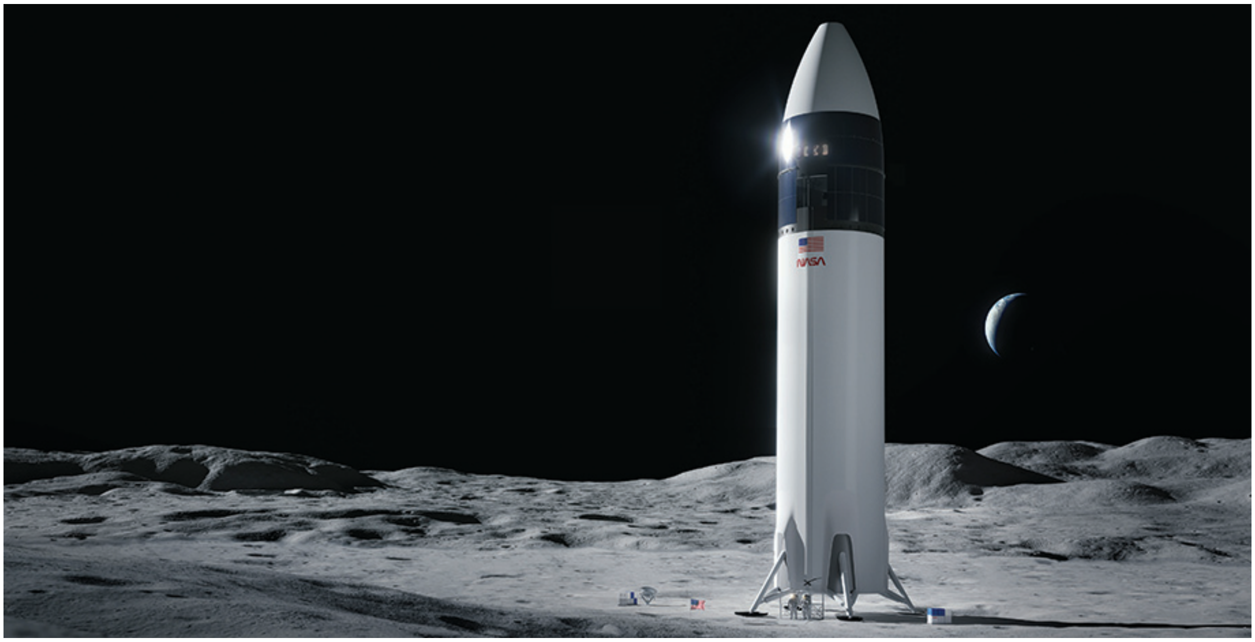


Figure 3-17. Human Landing System—One of the Integrated Lander Configurations as Awarded (Image credit: SpaceX)

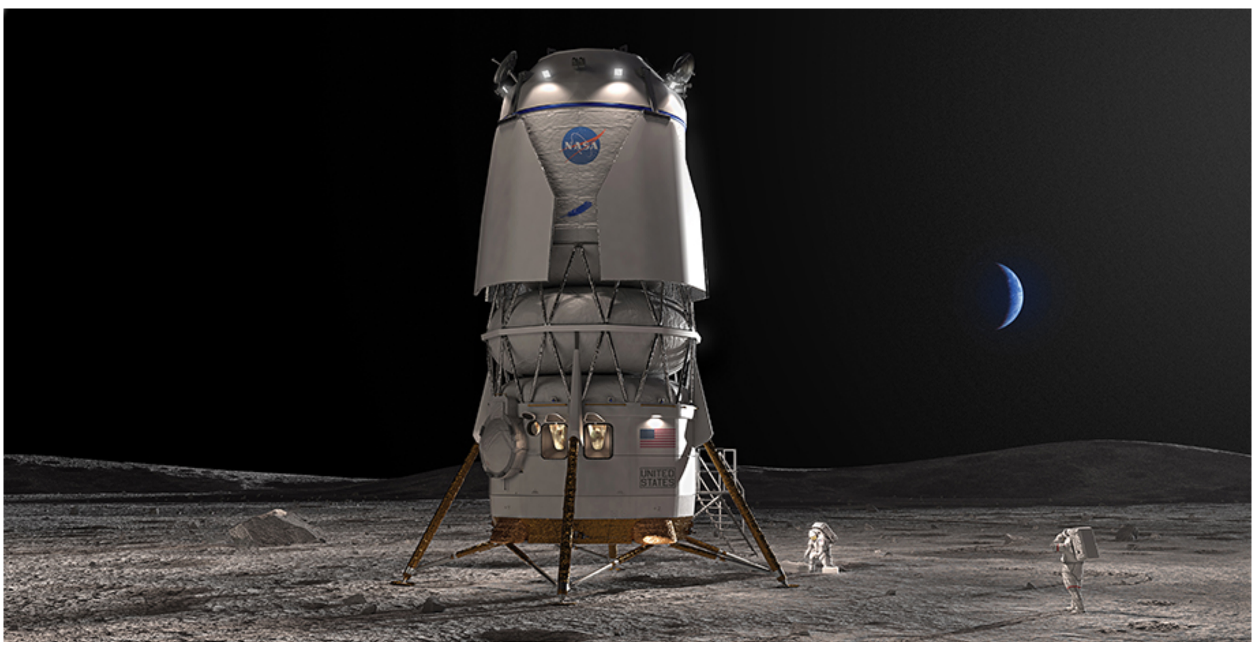


Figure 3-18. Human Landing System—One of the Integrated Lander Configurations as Awarded (Image credit: Blue Origin)

3.2.4.11.2 Human-class Delivery Lander

A large cargo lander will support delivery missions to the lunar South Pole region and will be capable of delivering a wide range of small to large lunar surface assets as cargo. The large cargo lander can support cargo that remains integrated with the lander on the lunar surface and can provide offloading capability to deliver cargo such as a rover directly to the lunar surface. Examples of large cargo that may be delivered are the PR, surface habitation elements, and surface power elements. Smaller cargo items can also be delivered co-manifested with the larger items or as several small items that are grouped together or individually. The large cargo lander is not intended to deliver crew. Crew interaction with the large cargo lander occurs primarily through EVA access to cargo. For cargo that remains integrated with the lander, such as a surface habitat, this includes EVA ingress/egress capability. During transit from the Earth and while on the lunar surface, the large cargo lander will support the cargo with services until the cargo is ready to operate independently. Once the large cargo lander completes its operations and enables the cargo to operate independently, it will transition to a safe condition/state.

3.2.4.11.3 Cargo Lander Concepts

In addition to the large surface elements delivered by the HDL landers, the longer duration, larger crew sizes, and more extensive lunar surface operations possible in the FE segment will require the routine delivery of equipment and supplies to the lunar surface. The FE segment will also require continued delivery of utilization payloads for reconnaissance and scientific observations across many potential exploration regions. Additionally, there is the need for delivery of technology demonstration payloads, mobility systems, and logistics to support longer-duration surface missions and resupply of a variety of surface assets. While some of these items may be delivered with crew on HLS or co-manifested with larger elements on HDL, additional cargo landers will provide flexibility and capability for robust exploration. Options for cargo landers to deliver these assets include those under NASA's Commercial Lunar Payload Services (CLPS) described in previous sections and other cargo landers still in formulation.

3.2.4.12 Utilization Systems

The utilization sub-architecture will continue to expand on the accomplishments of HLR to take advantage of new architecture capabilities, including extended traverse capability with mobility platforms; enhancement of the end-to-end sampling capability, including returning of conditioned samples from PSRs; extended-duration mission capability on the lunar surface and in cislunar orbit; and increased facilities for IVA and EVA research. A common enabler of utilization accomplishments is the capability to deliver to and return from the lunar surface larger quantities of cargo. Each of these aspects is currently being assessed to drive conceptual elements that can aid in achieving the capabilities needed to accomplish NASA's utilization objectives. Example functions (from the current function list in Appendix A) that are new or significantly enhanced in the FE segment for this sub-architecture include:

- Provide intravehicular activity facilities and utilization accommodation, including resources (e.g. power, data, and physical interfaces) on the lunar surface
- Recover and package surface samples from PSRs
- Recover and package sub-surface samples from non-PSRs and sunlit regions
- Recover and package sub-surface samples from PSRs
- Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions
- Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs
- Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state
- Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state
- Stow collected surface samples on the lunar surface from PSRs in conditioned state

3.2.5 Element Mapping

Table 3-14. Functions Fulfilled by LCRNS During the FE Segment

		ID	Functions	ID	Use Cases
EM-006-FE	Lunar Communications Relay and Navigation Systems	**FN-009-L**	Provide high availability position, navigation, and timing capability in cislunar space	**UC-002-L**	Stage crewed lunar surface missions from cislunar space
				UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-024-L	Provide high availability position, navigation, and timing capability on the lunar surface	**UC-011-L**	Support crew extravehicular operations on the lunar surface
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region

		ID	Functions	ID	Use Cases
				UC-107-L	Document sample details prior to collection on the lunar surface
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking
		FN-071-L	Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	UC-002-L	Stage crewed lunar surface missions from cislunar space
				UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-032-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-082-L	Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	UC-019-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-093-L	Demonstrate in-situ crew command and control of robotic system(s)
		FN-100-L	Command and control uncrewed asset(s) in cislunar space from Earth	UC-082-L	Conduct autonomous/semi-autonomous mission operations in cislunar space
		FN-226-L	Provide accurate location tracking and position data in cislunar space	UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-227-L	Provide accurate location tracking and position data on the lunar surface	UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-107-L	Document sample details prior to collection on the lunar surface
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking

		ID	Functions	ID	Use Cases
		FN-229-L	Provide reference time/frequency generation in cislunar space	**UC-068-L**	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-230-L	Provide reference time/frequency distribution in cislunar space	**UC-068-L**	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-231-L	Format and transmit data to Earth from the lunar surface	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-234-L	Format, transmit, and receive data between assets on the lunar surface	**UC-067-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-235-L	Store and distribute data between assets on the lunar surface	**UC-067-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-236-L	Format and transit data to Earth from cislunar space	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-237-L	Store and distribute data between assets in cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
		FN-238-L	Format, transmit, and receive data from cislunar space to the lunar surface	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-239-L	Format, transmit, and receive data from the lunar surface to cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-240-L	Provide tracking and analysis of orbital/trajectory parameters for assets in cislunar space	**UC-068-L**	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-241-L	Provide planning, tracking, and analysis of traverse paths for assets on the lunar surface	**UC-075-L**	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region

		ID	Functions	ID	Use Cases
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
		FN-242-L	Provide reference time/frequency generation on the lunar surface	**UC-126-L**	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking
		FN-243-L	Provide reference time/frequency distribution on the lunar surface	**UC-126-L**	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
		FN-244-L	Protect and/or secure data for storage and transmission	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received

Table 3-15. Functions Fulfilled by DSN/LEGS During the FE Segment

		ID	Functions	ID	Use Cases
EM-010-FE	LEGS/DSN	FN-015-L	Operate crew system(s) from Earth on the lunar surface during crewed missions	UC-005-L	Operate transportation assets(s) from Earth during crew surface missions
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-045-L	Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	UC-019-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-094-L	Remotely manage robotic system(s) during surface operation as required
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
		FN-071-L	Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	UC-002-L	Stage crewed lunar surface missions from cislunar space
				UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation

		ID	Functions	ID	Use Cases
				UC-032-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-081-L	Provide Earth based ground stations for exploration communications	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-100-L	Command and control uncrewed asset(s) in cislunar space from Earth	**UC-082-L**	Conduct autonomous/semi-autonomous mission operations in cislunar space
		FN-140-L	Monitor operating asset(s)	**UC-031-L**	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-042-L	Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation
				UC-053-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-062-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-165-L	Deploy assets to monitor natural environments in cislunar space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-157-L	Operate assets in cislunar space in uncrewed mode for extended (year+) durations	**UC-120-L**	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
				UC-148-L	Habitation capabilities for extended-duration (year+) missions in cislunar space
		FN-226-L	Provide accurate location tracking and position data in cislunar space	**UC-068-L**	Position, navigation, and timing for crew and robotic assets in cislunar space

		ID	Functions	ID	Use Cases
		FN-231-L	Format and transmit data to Earth from the lunar surface	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-232-L	Receive and format data on Earth	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-233-L	Store and distribute data to user(s) on Earth	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-236-L	Format and transit data to Earth from cislunar space	UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-240-L	Provide tracking and analysis of orbital/trajectory parameters for assets in cislunar space	UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
		FN-244-L	Protect and/or secure data for storage and transmission	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth

		ID	Functions	ID	Use Cases
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received

Table 3-16. Functions Fulfilled by Gateway Expanded Capability During the FE Segment

		ID	Functions	ID	Use Cases
EM-004-FE	Gateway Expanded Capability	FN-008-L	Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	UC-003-L	Aggregate and physically assemble spacecraft components in cislunar space
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-033-L	Transport cargo from Earth to assets in cislunar space	UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-034-L	Provide pressurized, habitable environment in cislunar space	UC-002-L	Stage crewed lunar surface missions from cislunar space
		FN-035-L	Transfer cargo into habitable asset(s) in cislunar space	UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions

		ID	Functions	ID	Use Cases
		FN-036-L	Manage waste from habitable asset(s) in cislunar space	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-038-L	Provide crew health maintenance capabilities in microgravity environment	**UC-162-L**	Crew health maintenance with countermeasure activities in microgravity environment
		FN-039-L	Provide remote crew medical systems in cislunar space	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
				UC-103-L	In-situ diagnosis and treatment of crew in cislunar space
		FN-041-L	Control robotic system(s) in cislunar space from Earth and/or cislunar space	**UC-109-L**	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations in cislunar space
				UC-184-L	Remotely manage robotic system(s) during in space operation as required
		FN-056-L	Deliver utilization payload(s) to cislunar space	**UC-031-L**	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-053-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-062-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-165-L	Deploy assets to monitor natural environments in cislunar space
				UC-167-L	Deploy asset(s) to monitor induced environment in cislunar space
		FN-057-L	Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	**UC-031-L**	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-053-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-062-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-165-L	Deploy assets to monitor natural environments in cislunar space
				UC-167-L	Deploy asset(s) to monitor induced environment in cislunar space

		ID	Functions	ID	Use Cases
		FN-058-L	Deliver free flying asset(s) to cislunar space	**UC-032-L**	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-042-L	Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation
				UC-058-L	Deploy and operate free-flying assets in a variety of lunar and heliocentric orbits long-term
		FN-062-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) in cislunar space	**UC-037-L**	Crew conduct biological science and human research activities while in habitable volume in cislunar space
				UC-044-L	Crew conduct fundamental physics experiments while in habitable volume in cislunar space
		FN-071-L	Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**UC-002-L**	Stage crewed lunar surface missions from cislunar space
				UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-032-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-094-L	Transfer propellant/fluids between assets in space (demonstration)	**UC-078-L**	Demonstrate operational techniques to transfer fluid and/or propellant in space
		FN-100-L	Command and control uncrewed asset(s) in cislunar space from Earth	**UC-082-L**	Conduct autonomous/semi-autonomous mission operations in cislunar space
		FN-125-L	Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**UC-106-L**	Utilize common interface(s) for power transfers and distribution in cislunar space
				UC-110-L	Deliver power to asset(s) in cislunar space
		FN-134-L	Distribute power to utilization payloads in cislunar space	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
				UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-110-L	Deliver power to asset(s) in cislunar space

		ID	Functions	ID	Use Cases
		FN-138-L	Docking/berthing between pressurized assets in cislunar space	**UC-192-L**	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-147-L	Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**UC-178-L**	Transport conditioned cargo from cislunar space to Earth
				UC-179-L	Transport cargo from the lunar surface to cislunar space
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-148-L	Perform robotic manipulation of payloads, logistics, and/or equipment at multiple scales	**UC-105-L**	Perform lunar surface activities with surface robotic system(s) assistance
		FN-151-L	Collect and store medical data and health information	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
		FN-155-L	Operate habitation system(s) in dormancy/remote mode between crewed missions in cislunar space	**UC-149-L**	Reuse habitation systems(s) in cislunar space
		FN-157-L	Operate assets in cislunar space in uncrewed mode for extended (year+) durations	**UC-120-L**	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
				UC-148-L	Habitation capabilities for extended-duration (year+) missions in cislunar space
		FN-160-L	Provide crew health care in cislunar space	**UC-016-L**	Crew health care, diagnosis, and treatment in space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
		FN-173-L	Repurpose and/or recycle equipment that is no longer useful in its primary function	**UC-101-L**	Conduct end-of-life operations
				UC-135-L	Repurpose hardware and materials brought to the surface for subsequent missions
		FN-175-L	Conduct crew cislunar extravehicular activity	**UC-190-L**	Support crew extravehicular operations in cislunar space
		FN-176-L	Provide intravehicular maintenance, upgrade, and/or repair accommodations (demonstration)	**UC-139-L**	Demonstrate maintenance, modification, and/or upgrades of asset(s)
		FN-181-L	Provide food system(s) in cislunar space	**UC-161-L**	Nutrition monitoring for crew during mission
		FN-182-L	Provide crew exercise system(s) in cislunar space	**UC-162-L**	Crew health maintenance with countermeasure activities in microgravity environment
		FN-187-L	Crew ingress/egress from habitable asset(s) to cis lunar vacuum	**UC-190-L**	Support crew extravehicular operations in cislunar space
		FN-191-L	Access from habitable volume to cislunar exterior vacuum	**UC-190-L**	Support crew extravehicular operations in cislunar space

		ID	Functions	ID	Use Cases
		FN-199-L	Capture imagery in cislunar space	**UC-175-L**	Communications and data exchange between assets in cislunar space and Earth
		FN-203-L	Provide common data interface in cislunar space	**UC-085-L**	Utilize common interface(s) for data transfer and distribution
		FN-224-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**UC-002-L**	Stage crewed lunar surface missions from cislunar space
				UC-093-L	Demonstrate in-situ crew command and control of robotic system(s)
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-236-L	Format and transit data to Earth from cislunar space	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-237-L	Store and distribute data between assets in cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
		FN-238-L	Format, transmit, and receive data from cislunar space to the lunar surface	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-239-L	Format, transmit, and receive data from the lunar surface to cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-244-L	Protect and/or secure data for storage and transmission	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-253-L	Control robotic system(s) in cislunar space by in-situ crew	**UC-093-L**	Demonstrate in-situ crew command and control of robotic system(s)

		ID	Functions	ID	Use Cases
				UC-109-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations in cislunar space
				UC-122-L	Robotic system(s) support of maintenance and repair operations as appropriate
				UC-185-L	Perform activities in space with robotic system(s) assistance
		FN-276-L	Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	**UC-031-L**	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-032-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-042-L	Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation
				UC-053-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-062-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-165-L	Deploy assets to monitor natural environments in cislunar space
				UC-167-L	Deploy asset(s) to monitor induced environment in cislunar space

Table 3-17. Functions Fulfilled by EGS During the FE Segment

		ID	Functions	ID	Use Cases
EM-002-FE	Exploration Ground Systems	**FN-001-L**	Provide ground services on Earth	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-002-L	Stack and integrate system(s) on Earth	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-003-L	Manage consumables and propellant	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-004-L	Enable vehicle launch(es)	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-005-L	Allow multiple launch attempts	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-017-L	Recover crew, crew system(s), and cargo after Earth landing	**UC-006-L**	Return crew and systems from cislunar space to Earth
				UC-181-L	Transport conditioned cargo to appropriate facilities on Earth
				UC-182-L	Transport collected samples to appropriate curation facilities on Earth
		FN-043-L	Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**UC-020-L**	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-181-L	Transport conditioned cargo to appropriate facilities on Earth
				UC-182-L	Transport collected samples to appropriate curation facilities on Earth
		FN-121-L	Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**UC-181-L**	Transport conditioned cargo to appropriate facilities on Earth
		FN-204-L	Provide common data interface on Earth	**UC-085-L**	Utilize common interface(s) for data transfer and distribution

Table 3-18. Functions Fulfilled by Gateway Logistics During the FE Segment

		ID	Functions	ID	Use Cases
EM-009-FE	Gateway Logistics Element	FN-008-L	Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	UC-003-L	Aggregate and physically assemble spacecraft components in cislunar space
		FN-033-L	Transport cargo from Earth to assets in cislunar space	UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-035-L	Transfer cargo into habitable asset(s) in cislunar space	UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-056-L	Deliver utilization payload(s) to cislunar space	UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-053-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation
				UC-062-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
				UC-165-L	Deploy assets to monitor natural environments in cislunar space
				UC-167-L	Deploy asset(s) to monitor induced environment in cislunar space
		FN-138-L	Docking/berthing between pressurized assets in cislunar space	UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions

Table 3-19. Functions Fulfilled by xEVA System During the FE Segment

		ID	Functions	ID	Use Cases
EM-007-FE	xEVA System	FN-028-L	Conduct crew lunar surface extravehicular activity	UC-011-L	Support crew extravehicular operations on the lunar surface
				UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-111-L	Collect sub-surface samples from PSRs
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-029-L	Crew ingress/egress from habitable asset(s) to lunar surface vacuum	UC-011-L	Support crew extravehicular operations on the lunar surface

		ID	Functions	ID	Use Cases
		FN-032-L	Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
		FN-046-L	Conduct crew survey of areas of interests and sample identification	**UC-024-L**	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs
				UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-111-L	Collect sub-surface samples from PSRs
		FN-047-L	Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
		FN-048-L	Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
		FN-105-L	Utilize tools to collect surface samples from non-PSRs and sunlit regions on the lunar surface	**UC-089-L**	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning
		FN-106-L	Utilize tools for equipment cleaning and maintenance	**UC-089-L**	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning
		FN-114-L	Control robotic system(s) on the lunar surface by crew on the lunar surface	**UC-093-L**	Demonstrate in-situ crew command and control of robotic system(s)
				UC-105-L	Perform lunar surface activities with surface robotic system(s) assistance
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
				UC-121-L	Robotic system(s) support of logistic operations on the lunar surface as required
		FN-139-L	Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-039-L	Deploy and set up astrophysics utilization payload(s) on the far side of the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation

		ID	Functions	ID	Use Cases
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-143-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-117-L	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples
		FN-179-L	Ready and transition crew to transportation asset for return to orbit	UC-129-L	Prepare crew for transition and transport from the lunar surface to cislunar space
		FN-202-L	Provide common data interface on the lunar surface	UC-085-L	Utilize common interface(s) for data transfer and distribution
		FN-220-L	Stow collected surface samples from PSRs on the lunar surface	UC-030-L	Collect surface samples from PSRs
		FN-221-L	Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state	UC-111-L	Collect sub-surface samples from PSRs
		FN-259-L	Utilize tools to collect sub-surface samples from non-PSRs and sunlit regions on the lunar surface	UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-089-L	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning
		FN-262-L	Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
		FN-269-L	Capture imagery on the lunar surface	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-107-L	Document sample details prior to collection on the lunar surface
		FN-274-L	Stow collected surface samples on the lunar surface from PSRs in conditioned state	UC-030-L	Collect surface samples from PSRs

Table 3-20. Functions Fulfilled by Lunar Terrain Vehicle During the FE Segment

		ID	Functions	ID	Use Cases
EM-014-FE	Lunar Terrain Vehicle	FN-015-L	Operate crew system(s) from Earth on the lunar surface during crewed missions	UC-005-L	Operate transportation assets(s) from Earth during crew surface missions
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-024-L	Provide high availability position, navigation, and timing capability on the lunar surface	UC-011-L	Support crew extravehicular operations on the lunar surface
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-107-L	Document sample details prior to collection on the lunar surface
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface

		ID	Functions	ID	Use Cases
				UC-127-L	Position, navigation, and timing for accurate sample tracking
		FN-030-L	Provide local unpressurized crew surface mobility	**UC-024-L**	Crew excursions to locations distributed around landing site
				UC-030-L	Collect surface samples from PSRs
		FN-040-L	Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-094-L	Remotely manage robotic system(s) during surface operation as required
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
		FN-045-L	Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-094-L	Remotely manage robotic system(s) during surface operation as required
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
		FN-046-L	Conduct crew survey of areas of interests and sample identification	**UC-024-L**	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs
				UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-111-L	Collect sub-surface samples from PSRs
		FN-048-L	Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
		FN-054-L	Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	**UC-030-L**	Collect surface samples from PSRs
		FN-082-L	Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval

		ID	Functions	ID	Use Cases
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-093-L	Demonstrate in-situ crew command and control of robotic system(s)
		FN-089-L	Operate mobility systems semi-autonomously on the lunar surface (demonstration)	UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
		FN-101-L	Command and control uncrewed asset(s) on the lunar surface from Earth	UC-083-L	Conduct autonomous/semi-autonomous mission operations on the lunar surface
		FN-111-L	Operate mobility system(s) in dormancy/remote mode between crew surface missions (demonstration)	UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
		FN-114-L	Control robotic system(s) on the lunar surface by crew on the lunar surface	UC-093-L	Demonstrate in-situ crew command and control of robotic system(s)
				UC-105-L	Perform lunar surface activities with surface robotic system(s) assistance
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
				UC-121-L	Robotic system(s) support of logistic operations on the lunar surface as required
		FN-132-L	Record sample position, orientation, context and time prior to collection on the lunar surface	UC-107-L	Document sample details prior to collection on the lunar surface
		FN-135-L	Command and control autonomous asset(s) on the lunar surface from cislunar space	UC-083-L	Conduct autonomous/semi-autonomous mission operations on the lunar surface
		FN-139-L	Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-039-L	Deploy and set up astrophysics utilization payload(s) on the far side of the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation

		ID	Functions	ID	Use Cases
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-143-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-117-L	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples
		FN-178-L	Transport cargo on the lunar surface between landing location and surface assets	UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-179-L	Ready and transition crew to transportation asset for return to orbit	UC-129-L	Prepare crew for transition and transport from the lunar surface to cislunar space
		FN-201-L	Provide advanced warning of threats from induced environmental hazards on the lunar surface	UC-172-L	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-202-L	Provide common data interface on the lunar surface	UC-085-L	Utilize common interface(s) for data transfer and distribution
		FN-227-L	Provide accurate location tracking and position data on the lunar surface	UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-107-L	Document sample details prior to collection on the lunar surface
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking
		FN-234-L	Format, transmit, and receive data between assets on the lunar surface	UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-235-L	Store and distribute data between assets on the lunar surface	UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-238-L	Format, transmit, and receive data from cislunar space to the lunar surface	UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface

		ID	Functions	ID	Use Cases
		FN-239-L	Format, transmit, and receive data from the lunar surface to cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-242-L	Provide reference time/frequency generation on the lunar surface	**UC-126-L**	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking
		FN-243-L	Provide reference time/frequency distribution on the lunar surface	**UC-126-L**	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
		FN-244-L	Protect and/or secure data for storage and transmission	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-249-L	Robotic identification of potential samples and resources on the lunar surface	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-250-L	Robotic collection of lunar surface samples	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-251-L	Robotic collection, containment, and documentation of lunar surface samples from PSRs	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-255-L	Interface robotic system(s) with logistics carriers on the lunar surface	**UC-121-L**	Robotic system(s) support of logistic operations on the lunar surface as required
		FN-263-L	Provide containers to package sub-surface samples	**UC-118-L**	Package sub-surface samples for return
		FN-269-L	Capture imagery on the lunar surface	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-107-L	Document sample details prior to collection on the lunar surface
		FN-270-L	Operate assets on the lunar surface in uncrewed mode for extended (year+) durations	**UC-005-L**	Operate transportation assets(s) from Earth during crew surface missions

		ID	Functions	ID	Use Cases
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
		FN-277-L	Transport collected surface samples on the lunar surface	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs

Table 3-21. Functions Fulfilled by Pressurized Rover During the FE Segment

		ID	Functions	ID	Use Cases
EM-015-FE	Pressurized Rover	FN-015-L	Operate crew system(s) from Earth on the lunar surface during crewed missions	UC-005-L	Operate transportation assets(s) from Earth during crew surface missions
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-024-L	Provide high availability position, navigation, and timing capability on the lunar surface	UC-011-L	Support crew extravehicular operations on the lunar surface
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-107-L	Document sample details prior to collection on the lunar surface
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface

		ID	Functions	ID	Use Cases
				UC-127-L	Position, navigation, and timing for accurate sample tracking
		FN-025-L	Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)	**UC-010-L**	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-146-L	Habitation capabilities for short-duration (days to weeks) missions on the lunar surface
		FN-026-L	Provide remote crew medical systems on the lunar surface	**UC-018-L**	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface
				UC-104-L	In-situ diagnosis and treatment of crew on the lunar surface
				UC-152-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface
		FN-027-L	Transfer pressurized cargo into habitable assets on the lunar surface	**UC-010-L**	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-121-L	Robotic system(s) support of logistic operations on the lunar surface as required
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-029-L	Crew ingress/egress from habitable asset(s) to lunar surface vacuum	**UC-011-L**	Support crew extravehicular operations on the lunar surface
		FN-031-L	Provide pressurized crew surface mobility	**UC-024-L**	Crew excursions to locations distributed around landing site
		FN-037-L	Manage waste from habitable asset(s) on the lunar surface	**UC-010-L**	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-136-L	Manage disposal of hardware and waste products
				UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-040-L	Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-094-L	Remotely manage robotic system(s) during surface operation as required
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface

		ID	Functions	ID	Use Cases
		FN-046-L	Conduct crew survey of areas of interests and sample identification	**UC-024-L**	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs
				UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-111-L	Collect sub-surface samples from PSRs
		FN-047-L	Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
		FN-048-L	Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
		FN-055-L	Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state	**UC-034-L**	Collect sub-surface samples from non-PSRs and sunlit regions
		FN-060-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	**UC-036-L**	Crew conduct biological science and human research activities on the lunar surface
				UC-040-L	Crew conduct fundamental physics experiments while in habitable volume on the lunar surface
				UC-043-L	Conduct intravehicular science and utilization activities on the lunar surface
		FN-070-L	Provide in-mission crew training on the lunar surface	**UC-046-L**	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
		FN-082-L	Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-093-L	Demonstrate in-situ crew command and control of robotic system(s)
		FN-089-L	Operate mobility systems semi-autonomously on the lunar surface (demonstration)	**UC-075-L**	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region

		ID	Functions	ID	Use Cases
		FN-101-L	Command and control uncrewed asset(s) on the lunar surface from Earth	**UC-083-L**	Conduct autonomous/semi-autonomous mission operations on the lunar surface
		FN-111-L	Operate mobility system(s) in dormancy/remote mode between crew surface missions (demonstration)	**UC-075-L**	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
		FN-113-L	Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	**UC-092-L**	Reuse habitation system(s) on the lunar surface
				UC-102-L	Operate habitation system(s) on the lunar surface while uncrewed
		FN-114-L	Control robotic system(s) on the lunar surface by crew on the lunar surface	**UC-093-L**	Demonstrate in-situ crew command and control of robotic system(s)
				UC-105-L	Perform lunar surface activities with surface robotic system(s) assistance
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
				UC-121-L	Robotic system(s) support of logistic operations on the lunar surface as required
		FN-127-L	Inhibit dust migration and impacts	**UC-115-L**	Reduce path erosion, dust lofting, and sample contamination
				UC-125-L	Limit spread of dust raised by lunar surface operations
		FN-132-L	Record sample position, orientation, context and time prior to collection on the lunar surface	**UC-107-L**	Document sample details prior to collection on the lunar surface
		FN-135-L	Command and control autonomous asset(s) on the lunar surface from cislunar space	**UC-083-L**	Conduct autonomous/semi-autonomous mission operations on the lunar surface
		FN-139-L	Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-039-L	Deploy and set up astrophysics utilization payload(s) on the far side of the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation

		ID	Functions	ID	Use Cases
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-143-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-117-L	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples
		FN-149-L	Provide crew health care on the lunar surface	UC-018-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface
				UC-154-L	Crew emergency health care, diagnosis, and treatment on the lunar surface
		FN-151-L	Collect and store medical data and health information	UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
		FN-152-L	Transfer equipment from extravehicular to intravehicular environment (demonstration)	UC-139-L	Demonstrate maintenance, modification, and/or upgrades of asset(s)
		FN-158-L	Access from habitable volume to lunar surface exterior vacuum	UC-011-L	Support crew extravehicular operations on the lunar surface
		FN-176-L	Provide intravehicular maintenance, upgrade, and/or repair accommodations (demonstration)	UC-139-L	Demonstrate maintenance, modification, and/or upgrades of asset(s)
		FN-178-L	Transport cargo on the lunar surface between landing location and surface assets	UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-179-L	Ready and transition crew to transportation asset for return to orbit	UC-129-L	Prepare crew for transition and transport from the lunar surface to cislunar space
		FN-180-L	Provide food system(s) on the lunar surface	UC-161-L	Nutrition monitoring for crew during mission
		FN-183-L	Provide crew exercise system(s) on the lunar surface	UC-163-L	Crew health maintenance with countermeasure activities in partial gravity environment
		FN-197-L	Monitor environmental conditions within habitable volume on the lunar surface	UC-172-L	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-200-L	Provide advanced warning of threats from natural environmental hazards on the lunar surface	UC-170-L	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-201-L	Provide advanced warning of threats from induced environmental hazards on the lunar surface	UC-172-L	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics

		ID	Functions	ID	Use Cases
		FN-202-L	Provide common data interface on the lunar surface	**UC-085-L**	Utilize common interface(s) for data transfer and distribution
		FN-227-L	Provide accurate location tracking and position data on the lunar surface	**UC-075-L**	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-107-L	Document sample details prior to collection on the lunar surface
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking
		FN-228-L	Provide crew health maintenance capabilities in partial gravity environment	**UC-018-L**	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-152-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface
				UC-163-L	Crew health maintenance with countermeasure activities in partial gravity environment
		FN-234-L	Format, transmit, and receive data between assets on the lunar surface	**UC-067-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-235-L	Store and distribute data between assets on the lunar surface	**UC-067-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-238-L	Format, transmit, and receive data from cislunar space to the lunar surface	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-239-L	Format, transmit, and receive data from the lunar surface to cislunar space	**UC-173-L**	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-242-L	Provide reference time/frequency generation on the lunar surface	**UC-126-L**	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking

		ID	Functions	ID	Use Cases
		FN-243-L	Provide reference time/frequency distribution on the lunar surface	**UC-126-L**	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
		FN-244-L	Protect and/or secure data for storage and transmission	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-249-L	Robotic identification of potential samples and resources on the lunar surface	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-250-L	Robotic collection of lunar surface samples	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-255-L	Interface robotic system(s) with logistics carriers on the lunar surface	**UC-121-L**	Robotic system(s) support of logistic operations on the lunar surface as required
		FN-263-L	Provide containers to package sub-surface samples	**UC-118-L**	Package sub-surface samples for return
		FN-266-L	Provide power for conditioning to sample containers on the lunar surface	**UC-030-L**	Collect surface samples from PSRs
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
		FN-269-L	Capture imagery on the lunar surface	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-107-L	Document sample details prior to collection on the lunar surface
		FN-270-L	Operate assets on the lunar surface in uncrewed mode for extended (year+) durations	**UC-005-L**	Operate transportation assets(s) from Earth during crew surface missions
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface

		ID	Functions	ID	Use Cases
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
		FN-275-L	Monitor crew health on the lunar surface	**UC-104-L**	In-situ diagnosis and treatment of crew on the lunar surface
		FN-277-L	Transport collected surface samples on the lunar surface	**UC-026-L**	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs
		FN-278-L	Transport collected sub-surface samples on the lunar surface in conditioned state	**UC-034-L**	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-111-L	Collect sub-surface samples from PSRs

Table 3-22. Functions Fulfilled by SLS During the FE Segment

		ID	Functions	ID	Use Cases
EM-001-FE	Space Launch System	**FN-002-L**	Stack and integrate system(s) on Earth	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-004-L	Enable vehicle launch(es)	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-005-L	Allow multiple launch attempts	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-006-L	Enable abort(s) to safety	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
		FN-007-L	Transport crew and associated cargo from Earth to cislunar space to support short-duration (days to weeks) missions	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
		FN-058-L	Deliver free flying asset(s) to cislunar space	**UC-032-L**	Deploy and operate free-flying assets in a variety of lunar orbits long-term
				UC-042-L	Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation
				UC-058-L	Deploy and operate free-flying assets in a variety of lunar and heliocentric orbits long-term
		FN-203-L	Provide common data interface in cislunar space	**UC-085-L**	Utilize common interface(s) for data transfer and distribution
		FN-204-L	Provide common data interface on Earth	**UC-085-L**	Utilize common interface(s) for data transfer and distribution
		FN-225-L	Deliver free-flying asset(s) to heliocentric and deep space	**UC-058-L**	Deploy and operate free-flying assets in a variety of lunar and heliocentric orbits long-term
		FN-272-L	Transport crew and associated cargo from Earth to cislunar space to support mid-duration (month+) to extended (year+) durations	**UC-001-L**	Transport crew and supporting system(s) from Earth to cislunar space
				UC-120-L	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space

Table 3-23. Functions Fulfilled by HLS Integrated Lander During the FE Segment

		ID	Functions	ID	Use Cases
EM-005-FE	Human Landing System	FN-008-L	Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	UC-003-L	Aggregate and physically assemble spacecraft components in cislunar space
		FN-013-L	Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	UC-004-L	Transport crew and supporting system(s) between cislunar space and the lunar surface
				UC-021-L	Crewed mission(s) to landing sites in the lunar south polar regions
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-056-L	Land exploration missions at sites removed from sites of historic significance
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-131-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to the lunar south polar region
				UC-132-L	Cislunar space to lunar surface transportation supporting mid-duration (month+) missions to the lunar south polar region
		FN-014-L	Transport crew and associated cargo from the lunar surface to cislunar space	UC-004-L	Transport crew and supporting system(s) between cislunar space and the lunar surface
				UC-099-L	Return crew and associated cargo from the lunar surface to cislunar space
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-129-L	Prepare crew for transition and transport from the lunar surface to cislunar space
				UC-131-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to the lunar south polar region
				UC-132-L	Cislunar space to lunar surface transportation supporting mid-duration (month+) missions to the lunar south polar region
				UC-133-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to distributed landing sited on the lunar surface
		FN-018-L	Transport cargo from Earth to the lunar surface	UC-010-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation

		ID	Functions	ID	Use Cases
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-072-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
				UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-019-L	Unload cargo on the lunar surface	UC-008-L	Deploy utilization payloads and equipment on the lunar surface
				UC-100-L	Deploy cargo to the lunar surface
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site

		ID	Functions	ID	Use Cases
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-026-L	Provide remote crew medical systems on the lunar surface	**UC-018-L**	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface
				UC-104-L	In-situ diagnosis and treatment of crew on the lunar surface
				UC-152-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface
		FN-029-L	Crew ingress/egress from habitable asset(s) to lunar surface vacuum	**UC-011-L**	Support crew extravehicular operations on the lunar surface
		FN-034-L	Provide pressurized, habitable environment in cislunar space	**UC-002-L**	Stage crewed lunar surface missions from cislunar space
		FN-035-L	Transfer cargo into habitable asset(s) in cislunar space	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-036-L	Manage waste from habitable asset(s) in cislunar space	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions

		ID	Functions	ID	Use Cases
		FN-037-L	Manage waste from habitable asset(s) on the lunar surface	**UC-010-L**	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-136-L	Manage disposal of hardware and waste products
				UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-038-L	Provide crew health maintenance capabilities in microgravity environment	**UC-162-L**	Crew health maintenance with countermeasure activities in microgravity environment
		FN-039-L	Provide remote crew medical systems in cislunar space	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
				UC-103-L	In-situ diagnosis and treatment of crew in cislunar space
		FN-040-L	Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-094-L	Remotely manage robotic system(s) during surface operation as required
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
		FN-041-L	Control robotic system(s) in cislunar space from Earth and/or cislunar space	**UC-109-L**	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations in cislunar space
				UC-184-L	Remotely manage robotic system(s) during in space operation as required
		FN-044-L	Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	**UC-004-L**	Transport crew and supporting system(s) between cislunar space and the lunar surface
				UC-022-L	Crewed mission(s) to distributed landing sites on the lunar surface
				UC-056-L	Land exploration missions at sites removed from sites of historic significance
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-133-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to distributed landing sited on the lunar surface

		ID	Functions	ID	Use Cases
		FN-045-L	Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-094-L	Remotely manage robotic system(s) during surface operation as required
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
		FN-060-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	**UC-036-L**	Crew conduct biological science and human research activities on the lunar surface
				UC-040-L	Crew conduct fundamental physics experiments while in habitable volume on the lunar surface
				UC-043-L	Conduct intravehicular science and utilization activities on the lunar surface
		FN-062-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) in cislunar space	**UC-037-L**	Crew conduct biological science and human research activities while in habitable volume in cislunar space
				UC-044-L	Crew conduct fundamental physics experiments while in habitable volume in cislunar space
		FN-087-L	Provide precision landing for crew transport to the lunar surface	**UC-071-L**	Land crew lander(s) at specific pre-defined locations
		FN-100-L	Command and control uncrewed asset(s) in cislunar space from Earth	**UC-082-L**	Conduct autonomous/semi-autonomous mission operations in cislunar space
		FN-107-L	Transport crew to the lunar surface in proximity of deployed exploration asset(s)	**UC-092-L**	Reuse habitation system(s) on the lunar surface
				UC-137-L	Land crew on the lunar surface in proximity to previously positioned surface assets
				UC-153-L	Demonstrate equipment recovery from surface asset(s)
		FN-114-L	Control robotic system(s) on the lunar surface by crew on the lunar surface	**UC-093-L**	Demonstrate in-situ crew command and control of robotic system(s)
				UC-105-L	Perform lunar surface activities with surface robotic system(s) assistance
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
				UC-121-L	Robotic system(s) support of logistic operations on the lunar surface as required
		FN-126-L	Reduce blast ejecta	**UC-056-L**	Land exploration missions at sites removed from sites of historic significance

		ID	Functions	ID	Use Cases
				UC-114-L	Reduce blast ejecta to limit the migration of ejecta across the lunar surface
		FN-138-L	Docking/berthing between pressurized assets in cislunar space	UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions
		FN-141-L	Deliver cargo(s) to distributed sites on the lunar surface	UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-146-L	Transport cargo from the lunar surface to cislunar space	UC-020-L	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-179-L	Transport cargo from the lunar surface to cislunar space
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-147-L	Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	UC-178-L	Transport conditioned cargo from cislunar space to Earth
				UC-179-L	Transport cargo from the lunar surface to cislunar space
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-149-L	Provide crew health care on the lunar surface	UC-018-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface

		ID	Functions	ID	Use Cases
				UC-154-L	Crew emergency health care, diagnosis, and treatment on the lunar surface
		FN-150-L	Provide crew health care during transit	**UC-016-L**	Crew health care, diagnosis, and treatment in space
		FN-151-L	Collect and store medical data and health information	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
		FN-152-L	Transfer equipment from extravehicular to intravehicular environment (demonstration)	**UC-139-L**	Demonstrate maintenance, modification, and/or upgrades of asset(s)
		FN-158-L	Access from habitable volume to lunar surface exterior vacuum	**UC-011-L**	Support crew extravehicular operations on the lunar surface
		FN-160-L	Provide crew health care in cislunar space	**UC-016-L**	Crew health care, diagnosis, and treatment in space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
		FN-176-L	Provide intravehicular maintenance, upgrade, and/or repair accommodations (demonstration)	**UC-139-L**	Demonstrate maintenance, modification, and/or upgrades of asset(s)
		FN-180-L	Provide food system(s) on the lunar surface	**UC-161-L**	Nutrition monitoring for crew during mission
		FN-181-L	Provide food system(s) in cislunar space	**UC-161-L**	Nutrition monitoring for crew during mission
		FN-183-L	Provide crew exercise system(s) on the lunar surface	**UC-163-L**	Crew health maintenance with countermeasure activities in partial gravity environment
		FN-201-L	Provide advanced warning of threats from induced environmental hazards on the lunar surface	**UC-172-L**	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-202-L	Provide common data interface on the lunar surface	**UC-085-L**	Utilize common interface(s) for data transfer and distribution
		FN-203-L	Provide common data interface in cislunar space	**UC-085-L**	Utilize common interface(s) for data transfer and distribution
		FN-208-L	Monitor electrostatic charging in space	**UC-140-L**	Monitor environmental factors in habitation systems in space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-168-L	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-209-L	Monitor natural radiation levels in space	**UC-140-L**	Monitor environmental factors in habitation systems in space

		ID	Functions	ID	Use Cases
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-228-L	Provide crew health maintenance capabilities in partial gravity environment	UC-018-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-152-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface
				UC-163-L	Crew health maintenance with countermeasure activities in partial gravity environment
		FN-231-L	Format and transmit data to Earth from the lunar surface	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-236-L	Format and transit data to Earth from cislunar space	UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
		FN-237-L	Store and distribute data between assets in cislunar space	UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
		FN-239-L	Format, transmit, and receive data from the lunar surface to cislunar space	UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
		FN-244-L	Protect and/or secure data for storage and transmission	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface

		ID	Functions	ID	Use Cases
				UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
				UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface
				UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
				UC-175-L	Communications and data exchange between assets in cislunar space and Earth
				UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
		FN-253-L	Control robotic system(s) in cislunar space by in-situ crew	UC-093-L	Demonstrate in-situ crew command and control of robotic system(s)
				UC-109-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations in cislunar space
				UC-122-L	Robotic system(s) support of maintenance and repair operations as appropriate
				UC-185-L	Perform activities in space with robotic system(s) assistance
		FN-266-L	Provide power for conditioning to sample containers on the lunar surface	UC-030-L	Collect surface samples from PSRs
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
		FN-267-L	Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-269-L	Capture imagery on the lunar surface	UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-107-L	Document sample details prior to collection on the lunar surface
		FN-275-L	Monitor crew health on the lunar surface	UC-104-L	In-situ diagnosis and treatment of crew on the lunar surface

Table 3-24. Functions Fulfilled by HDL During the FE Segment

		ID	Functions	ID	Use Cases
EM-013-FE	Human-Class Delivery System	FN-008-L	Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	UC-003-L	Aggregate and physically assemble spacecraft components in cislunar space
		FN-018-L	Transport cargo from Earth to the lunar surface	UC-010-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-072-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
				UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-019-L	Unload cargo on the lunar surface	UC-008-L	Deploy utilization payloads and equipment on the lunar surface

		ID	Functions	ID	Use Cases
				UC-100-L	Deploy cargo to the lunar surface
		FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
				UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-040-L	Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-094-L	Remotely manage robotic system(s) during surface operation as required
				UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
		FN-088-L	Provide precision landing for cargo transport to the lunar surface	**UC-072-L**	Transport cargo to specific pre-defined location within exploration area on the lunar surface
				UC-098-L	Transport large exploration asset(s) to the lunar surface
		FN-101-L	Command and control uncrewed asset(s) on the lunar surface from Earth	**UC-083-L**	Conduct autonomous/semi-autonomous mission operations on the lunar surface

		ID	Functions	ID	Use Cases
		FN-122-L	Decommission surface delivery system(s) and/or surface asset(s)	**UC-101-L**	Conduct end-of-life operations
		FN-141-L	Deliver cargo(s) to distributed sites on the lunar surface	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-144-L	Transport large exploration asset(s) from Earth to the lunar surface	**UC-098-L**	Transport large exploration asset(s) to the lunar surface
		FN-159-L	Unload large utilization assets on the lunar surface	**UC-007-L**	Unload large exploration assets on the lunar surface
		FN-164-L	Deliver cargo(s) to south polar region sites on the lunar surface	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation

		ID	Functions	ID	Use Cases
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-227-L	Provide accurate location tracking and position data on the lunar surface	**UC-075-L**	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
				UC-107-L	Document sample details prior to collection on the lunar surface
				UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
				UC-127-L	Position, navigation, and timing for accurate sample tracking

Table 3-25. Functions Fulfilled by CLPS Provider Landers During the FE Segment

		ID	Functions	ID	Use Cases
EM-008-FE	CLPS Provider Landers	FN-018-L	Transport cargo from Earth to the lunar surface	UC-010-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
				UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-072-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
				UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-088-L	Provide precision landing for cargo transport to the lunar surface	UC-072-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface
				UC-098-L	Transport large exploration asset(s) to the lunar surface

		ID	Functions	ID	Use Cases
		FN-122-L	Decommission surface delivery system(s) and/or surface asset(s)	**UC-101-L**	Conduct end-of-life operations
		FN-141-L	Deliver cargo(s) to distributed sites on the lunar surface	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-164-L	Deliver cargo(s) to south polar region sites on the lunar surface	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface

Table 3-26. Functions Fulfilled by Payloads

		ID	Functions	ID	Use Cases
EM-011-FE	Payloads	FN-032-L	Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	UC-026-L	Collect surface samples from non-PSRs and sunlit regions
		FN-043-L	Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	UC-020-L	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-181-L	Transport conditioned cargo to appropriate facilities on Earth
				UC-182-L	Transport collected samples to appropriate curation facilities on Earth
		FN-046-L	Conduct crew survey of areas of interests and sample identification	UC-024-L	Crew excursions to locations distributed around landing site
				UC-025-L	Crew extravehicular explorations and identification of surface samples
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
				UC-030-L	Collect surface samples from PSRs
				UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-111-L	Collect sub-surface samples from PSRs
		FN-047-L	Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	UC-019-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
				UC-026-L	Collect surface samples from non-PSRs and sunlit regions
		FN-048-L	Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	UC-026-L	Collect surface samples from non-PSRs and sunlit regions
		FN-050-L	Orbital observations and sensing of the lunar surface	UC-027-L	Orbital survey(s) before, during, and after crew mission
		FN-054-L	Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	UC-030-L	Collect surface samples from PSRs
		FN-055-L	Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state	UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
		FN-069-L	Provide in-mission crew training in cislunar space	UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)

		ID	Functions	ID	Use Cases
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
		FN-070-L	Provide in-mission crew training on the lunar surface	**UC-046-L**	Provide in-situ training to astronauts for science tasks during mission(s)
				UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
		FN-076-L	Operate utilization payloads related to bio-regenerative ECLSS (demonstration) in space	**UC-060-L**	Demonstrate utilization payload(s) related to bio-regenerative oxygen and water recovery in cislunar space
		FN-077-L	Operate utilization payloads related to plant growth (demonstration) in space	**UC-061-L**	Demonstrate plant growth in cislunar asset(s)
		FN-090-L	Produce scalable quantities of oxygen from lunar regolith (demonstration)	**UC-076-L**	Demonstrate operational techniques to recover oxygen from lunar regolith
		FN-093-L	Produce scalable quantities of water from in-situ materials (demonstration)	**UC-077-L**	Demonstrate operational techniques to recover water from the lunar regolith in the polar regions
		FN-118-L	Collect water/ice from the polar region of the lunar surface (demonstration)	**UC-077-L**	Demonstrate operational techniques to recover water from the lunar regolith in the polar regions
		FN-119-L	Store collected water/ice on the lunar surface (demonstration)	**UC-077-L**	Demonstrate operational techniques to recover water from the lunar regolith in the polar regions
		FN-121-L	Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**UC-181-L**	Transport conditioned cargo to appropriate facilities on Earth
		FN-143-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-034-L**	Collect sub-surface samples from non-PSRs and sunlit regions
				UC-117-L	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples
		FN-151-L	Collect and store medical data and health information	**UC-158-L**	Transmit data from in-space and surface asset(s) to medical personnel on Earth
		FN-153-L	Prepare unconditioned cargo or samples for Earth return	**UC-020-L**	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-179-L	Transport cargo from the lunar surface to cislunar space
		FN-154-L	Prepare conditioned cargo or samples for return to Earth	**UC-097-L**	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-178-L	Transport conditioned cargo from cislunar space to Earth

		ID	Functions	ID	Use Cases
				UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
		FN-157-L	Operate assets in cislunar space in uncrewed mode for extended (year+) durations	**UC-120-L**	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
				UC-148-L	Habitation capabilities for extended-duration (year+) missions in cislunar space
		FN-163-L	Conduct crew training in simulation of increasingly Earth-independent operations	**UC-130-L**	Test, analyze, and evaluate responses to range of communication latency expected of Mars-class missions
				UC-157-L	Conduct in-situ crew training in cislunar space
		FN-184-L	Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	**UC-076-L**	Demonstrate operational techniques to recover oxygen from lunar regolith
				UC-077-L	Demonstrate operational techniques to recover water from the lunar regolith in the polar regions
				UC-143-L	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction
				UC-145-L	Demonstrate regolith based additive/subtractive manufacturing techniques
				UC-150-L	Demonstrate operational techniques to recover and refine metals from the lunar regolith
		FN-185-L	Collect regolith at scale and subscale (demonstration)	**UC-076-L**	Demonstrate operational techniques to recover oxygen from lunar regolith
				UC-143-L	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction
				UC-145-L	Demonstrate regolith based additive/subtractive manufacturing techniques
				UC-150-L	Demonstrate operational techniques to recover and refine metals from the lunar regolith
		FN-188-L	Compact scalable quantities of lunar regolith (demonstration)	**UC-143-L**	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction
		FN-189-L	Form scalable quantities of structures from lunar regolith (demonstration)	**UC-143-L**	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction
		FN-190-L	Manufacture (additive or subtractive) scalable quantities of item(s) from lunar regolith (demonstration)	**UC-145-L**	Demonstrate regolith based additive/subtractive manufacturing techniques
		FN-194-L	Monitor environmental conditions within habitable volume in space	**UC-168-L**	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics

		ID	Functions	ID	Use Cases
		FN-195-L	Detect and monitor high energy debris in cislunar space	**UC-168-L**	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-197-L	Monitor environmental conditions within habitable volume on the lunar surface	**UC-172-L**	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-198-L	Detect and monitor high energy debris on the lunar surface	**UC-172-L**	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-200-L	Provide advanced warning of threats from natural environmental hazards on the lunar surface	**UC-170-L**	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-205-L	Test product(s) from regolith processing (demonstration)	**UC-143-L**	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction
		FN-206-L	Test product(s) from additive/subtractive manufacturing (demonstration)	**UC-145-L**	Demonstrate regolith based additive/subtractive manufacturing techniques
		FN-207-L	Test product(s) from metal production/refinement (demonstration)	**UC-150-L**	Demonstrate operational techniques to recover and refine metals from the lunar regolith
		FN-208-L	Monitor electrostatic charging in space	**UC-140-L**	Monitor environmental factors in habitation systems in space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-168-L	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-209-L	Monitor natural radiation levels in space	**UC-140-L**	Monitor environmental factors in habitation systems in space
				UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-210-L	Monitor radiation on the lunar surface	**UC-141-L**	Monitor environmental factors in habitation systems on the lunar surface
				UC-170-L	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-211-L	Monitor electrostatic charging on the lunar surface	**UC-141-L**	Monitor environmental factors in habitation systems on the lunar surface
				UC-170-L	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
				UC-172-L	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics

		ID	Functions	ID	Use Cases
		FN-212-L	Monitor plasma environment in space	**UC-166-L**	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-213-L	Monitor meteoroid activities in cislunar space	**UC-166-L**	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-214-L	Monitor plasma environment on the lunar surface	**UC-170-L**	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-215-L	Monitor meteoroid activities on the lunar surface	**UC-170-L**	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-218-L	Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	**UC-030-L**	Collect surface samples from PSRs
		FN-219-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**UC-111-L**	Collect sub-surface samples from PSRs
				UC-117-L	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples
		FN-220-L	Stow collected surface samples from PSRs on the lunar surface	**UC-030-L**	Collect surface samples from PSRs
		FN-221-L	Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state	**UC-111-L**	Collect sub-surface samples from PSRs
		FN-222-L	Operate utilization payloads related to advanced ECLSS in space (demonstration)	**UC-156-L**	Conduct experiments that can be used to gather data to inform the advanced ECLSS analysis/trade study in cislunar space
		FN-223-L	Operate utilization payloads related to bioregenerative ECLSS in space (demonstration)	**UC-155-L**	Conduct reduced gravity materials and processes science experiments, other extreme environments-related research, and associated modeling to support in-space technologies related to support bioregenerative ECLSS
		FN-246-L	Produce scalable quantities of metal from lunar regolith (demonstration)	**UC-150-L**	Demonstrate operational techniques to recover and refine metals from the lunar regolith
		FN-248-L	Robotic surveys of potential exploration sites on the lunar surface with assets on surface	**UC-023-L**	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
		FN-249-L	Robotic identification of potential samples and resources on the lunar surface	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-250-L	Robotic collection of lunar surface samples	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-251-L	Robotic collection, containment, and documentation of lunar surface samples from PSRs	**UC-019-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
		FN-261-L	Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**UC-111-L**	Collect sub-surface samples from PSRs

		ID	Functions	ID	Use Cases
		FN-262-L	Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**UC-034-L**	Collect sub-surface samples from non-PSRs and sunlit regions
		FN-263-L	Provide containers to package sub-surface samples	**UC-118-L**	Package sub-surface samples for return
		FN-269-L	Capture imagery on the lunar surface	**UC-066-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
				UC-107-L	Document sample details prior to collection on the lunar surface
		FN-270-L	Operate assets on the lunar surface in uncrewed mode for extended (year+) durations	**UC-005-L**	Operate transportation assets(s) from Earth during crew surface missions
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
		FN-274-L	Stow collected surface samples on the lunar surface from PSRs in conditioned state	**UC-030-L**	Collect surface samples from PSRs

3.2.6 Unallocated Use Cases and Functions

As the FE segment has been further matured and refined, use cases and functions have been mapped to FE elements has been completed. The complete list of unallocated functions appears below. The following is an abbreviated list of topics areas for those functions:

- Moderate (month+) to extended (year+) durations
- Docking/berthing
- Unloading cargo
- Repositioning cargo
- Dedicated power
- Far side activities
- Most ISRU functions
- Off-nominal/contingency for Mars missions and testing at the Moon
- Mars distance communications latency
- Crew working with autonomous systems
- Operations in PSRs
- Logistics strategy

Table 3-27. Unallocated Use Cases and Functions for the FE Segment

		ID	Functions	ID	Use Cases
EM-012-FE	Unallocated	FN-010-L	Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	UC-002-L	Stage crewed lunar surface missions from cislunar space
				UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
				UC-148-L	Habitation capabilities for extended-duration (year+) missions in cislunar space
				UC-190-L	Support crew extravehicular operations in cislunar space

		ID	Functions	ID	Use Cases
		FN-012-L	Docking/berthing of spacecraft components	**UC-003-L**	Aggregate and physically assemble spacecraft components in cislunar space
		FN-020-L	Reposition cargo on the lunar surface	**UC-008-L**	Deploy utilization payloads and equipment on the lunar surface
				UC-100-L	Deploy cargo to the lunar surface
		FN-021-L	Generate power on the lunar surface	**UC-064-L**	Deploy power generation and energy storage system(s) on the lunar surface
		FN-022-L	Store energy on the lunar surface	**UC-064-L**	Deploy power generation and energy storage system(s) on the lunar surface
				UC-188-L	Provide continuous power availability during mission critical activities
				UC-189-L	Provide continuous power availability in off-nominal conditions
		FN-042-L	Transport cargo from the lunar surface to Earth	**UC-020-L**	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
				UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth
				UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
				UC-186-L	Transport cargo from the lunar surface or cislunar space back to Earth
		FN-051-L	Provide power for deployed surface asset(s)	**UC-014-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
				UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
				UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
				UC-123-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs
				UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
				UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
				UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation

		ID	Functions	ID	Use Cases
				UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
				UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
				UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
				UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
		FN-066-L	Transport cargo from Earth to the far side of the lunar surface	UC-039-L	Deploy and set up astrophysics utilization payload(s) on the far side of the lunar surface with long-term remote operation
		FN-067-L	Conduct crew surface extravehicular activities at the lunar far side region	UC-039-L	Deploy and set up astrophysics utilization payload(s) on the far side of the lunar surface with long-term remote operation
		FN-068-L	Provide crew training prior to mission	UC-045-L	Provide advanced geology training, integrated geology and EVA ops training, as well as detailed objective-specific training to astronauts for science activities
		FN-080-L	Distribute power on the lunar surface	UC-065-L	Deploy power distribution capabilities around power generation and energy storage system(s) on the lunar surface
				UC-187-L	Deliver power to assets on the lunar surface
				UC-188-L	Provide continuous power availability during mission critical activities
				UC-189-L	Provide continuous power availability in off-nominal conditions
		FN-095-L	Provide storage of cryogenic propellant in space (demonstration)	UC-079-L	Demonstrate propellant storage for extended-duration (year+) in space
		FN-096-L	Provide storage of cryogenic propellant on the lunar surface (demonstration)	UC-080-L	Demonstrate propellant storage for extended-duration (year+) on the lunar surface
		FN-102-L	Provide power through common power distribution interface(s) on the lunar surface	UC-065-L	Deploy power distribution capabilities around power generation and energy storage system(s) on the lunar surface
				UC-084-L	Utilize common interface(s) for power transfers and distribution on the lunar surface
				UC-187-L	Deliver power to assets on the lunar surface
		FN-103-L	Provide propellant/fluid transfer through common interface(s) between assets in space (demonstration)	UC-078-L	Demonstrate operational techniques to transfer fluid and/or propellant in space
		FN-108-L	Access residual propellant from surface assets (demonstration)	UC-090-L	Demonstrate recovery of excess propellant from surface asset(s)
		FN-109-L	Provide storage of non-cryogenic propellant on the lunar surface (demonstration)	UC-080-L	Demonstrate propellant storage for extended-duration (year+) on the lunar surface
		FN-116-L	Store oxygen on the lunar surface (demonstration)	UC-076-L	Demonstrate operational techniques to recover oxygen from lunar regolith

		ID	Functions	ID	Use Cases
		FN-117-L	Transport scalable quantities of oxygen produced to exploration elements (demonstration)	**UC-076-L**	Demonstrate operational techniques to recover oxygen from lunar regolith
		FN-120-L	Transport scalable quantities of water produced to exploration elements (demonstration)	**UC-077-L**	Demonstrate operational techniques to recover water from the lunar regolith in the polar regions
		FN-123-L	Provide propellant/fluid transfer through common interface(s) between assets on the lunar surface (demonstration)	**UC-090-L**	Demonstrate recovery of excess propellant from surface asset(s)
				UC-151-L	Demonstrate operational techniques to transfer fluid and/or propellant on the lunar surface
		FN-124-L	Docking/berthing between pressurized assets on the lunar surface	**UC-191-L**	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-128-L	Provide storage of non-cryogenic propellant in space (demonstration)	**UC-079-L**	Demonstrate propellant storage for extended-duration (year+) in space
		FN-129-L	Transfer propellant/fluids between assets on the lunar surface (demonstration)	**UC-090-L**	Demonstrate recovery of excess propellant from surface asset(s)
				UC-151-L	Demonstrate operational techniques to transfer fluid and/or propellant on the lunar surface
		FN-130-L	Implement supportability to correct system failures	**UC-160-L**	Crew survival during off-nominal situations
		FN-131-L	Transport crew and crew system(s) from cislunar space to Earth in off-nominal situation	**UC-164-L**	Crew abort to Earth in off-nominal situations
		FN-136-L	Transport crew from cislunar space to the lunar surface after extended duration (year+) in space	**UC-035-L**	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
		FN-137-L	Utilize tools to assist in contingency scenarios	**UC-089-L**	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning
		FN-142-L	Rendezvous, proximity operations, docking, and undocking of the assets on the lunar surface (demonstration)	**UC-113-L**	Demonstrate aggregation and physical assembly of assets on the lunar surface
		FN-156-L	Manage undesired samples and investigation items	**UC-135-L**	Repurpose hardware and materials brought to the surface for subsequent missions
				UC-136-L	Manage disposal of hardware and waste products
		FN-161-L	Simulate up to Mars distance communication latency or disruptions during operations in cislunar space	**UC-130-L**	Test, analyze, and evaluate responses to range of communication latency expected of Mars-class missions
		FN-162-L	Simulate up to Mars distance communication latency or disruptions during operations on the lunar surface	**UC-130-L**	Test, analyze, and evaluate responses to range of communication latency expected of Mars-class missions
		FN-165-L	Provide safe haven capability for crew to shelter during off-nominal scenario	**UC-160-L**	Crew survival during off-nominal situations
		FN-166-L	Provide hazard remediation capabilities	**UC-160-L**	Crew survival during off-nominal situations

		ID	Functions	ID	Use Cases
		FN-167-L	Provide capability to restore and stabilize the habitable environment after off-nominal scenario	**UC-160-L**	Crew survival during off-nominal situations
		FN-168-L	Provide power during crew critical mission events	**UC-189-L**	Provide continuous power availability in off-nominal conditions
		FN-169-L	Provide capability for crew loiter until return window	**UC-164-L**	Crew abort to Earth in off-nominal situations
		FN-170-L	Transport crew from the lunar surface to cislunar space in off-nominal scenario	**UC-164-L**	Crew abort to Earth in off-nominal situations
		FN-171-L	Perform repairs and/or replacement of subsystems	**UC-183-L**	Crew repair and/or replacement of failed or off-nominal systems
		FN-172-L	Provide storage for necessary spares and repair equipment	**UC-183-L**	Crew repair and/or replacement of failed or off-nominal systems
		FN-174-L	Implement communication methods to coordinate and preserve the radio environment on the lunar far side	**UC-055-L**	Preserve lunar far side environment to ensure scientific data integrity
		FN-177-L	Transfer gases and water to habitable assets on the lunar surface	**UC-191-L**	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
		FN-186-L	Provide storage for collected regolith (demonstration)	**UC-076-L**	Demonstrate operational techniques to recover oxygen from lunar regolith
				UC-143-L	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction
				UC-145-L	Demonstrate regolith based additive/subtractive manufacturing techniques
				UC-150-L	Demonstrate operational techniques to recover and refine metals from the lunar regolith
		FN-192-L	Provide remote propellant management system(s) in microgravity environment (demonstration)	**UC-079-L**	Demonstrate propellant storage for extended-duration (year+) in space
		FN-193-L	Provide remote propellant management system(s) in partial gravity environment (demonstration)	**UC-080-L**	Demonstrate propellant storage for extended-duration (year+) on the lunar surface
		FN-196-L	Survey potential exploration sites on the lunar surface from lunar orbit	**UC-023-L**	Robotically survey potential crewed landing and exploration sites to identify locations of interest
				UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
		FN-216-L	Provide advanced warning of threats from natural environmental hazards in cislunar space	**UC-166-L**	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
		FN-217-L	Provide advanced warning of threats from induced environmental hazards in cislunar space	**UC-168-L**	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
		FN-245-L	Perform regular training and drills to simulate off-nominal scenarios	**UC-177-L**	Conduct testing, contingency planning, and run edge-case analyses of flight systems

		ID	Functions	ID	Use Cases
		FN-247-L	Access equipment from other assets (demonstration)	**UC-153-L**	Demonstrate equipment recovery from surface asset(s)
		FN-252-L	Monitor robotic system(s) performance and health	**UC-093-L**	Demonstrate in-situ crew command and control of robotic system(s)
				UC-094-L	Remotely manage robotic system(s) during surface operation as required
				UC-184-L	Remotely manage robotic system(s) during in space operation as required
		FN-254-L	Provide safety features on robotic and/or autonomous system(s)	**UC-093-L**	Demonstrate in-situ crew command and control of robotic system(s)
				UC-122-L	Robotic system(s) support of maintenance and repair operations as appropriate
				UC-138-L	Ensure safe and effective interaction between crew and autonomous asset(s)
		FN-256-L	Provide physical and electronic safeguards for automated asset(s) operating near crew	**UC-138-L**	Ensure safe and effective interaction between crew and autonomous asset(s)
		FN-257-L	Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	**UC-071-L**	Land crew lander(s) at specific pre-defined locations
				UC-072-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface
				UC-098-L	Transport large exploration asset(s) to the lunar surface
		FN-258-L	Utilize tools to collect surface samples from PSRs on the lunar surface	**UC-030-L**	Collect surface samples from PSRs
				UC-089-L	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning
		FN-260-L	Utilize tools to collect sub-surface samples from PSRs on the lunar surface	**UC-089-L**	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning
				UC-111-L	Collect sub-surface samples from PSRs
		FN-264-L	Provide capability for bi-directional power exchange	**UC-065-L**	Deploy power distribution capabilities around power generation and energy storage system(s) on the lunar surface
				UC-188-L	Provide continuous power availability during mission critical activities
				UC-189-L	Provide continuous power availability in off-nominal conditions
		FN-265-L	Provide power for conditioning to sample containers during transit from the lunar surface to Earth	**UC-097-L**	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
				UC-116-L	Return physical artifacts from experiments to Earth

		ID	Functions	ID	Use Cases
		FN-271-L	Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	**UC-128-L**	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
				UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
		FN-273-L	Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	**UC-015-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space
				UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
				UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.

3.2.7 Open Questions, Ongoing Assessments, and Future Work

With forward work remaining to define the FE segment, there are open questions on the segment, from the architectural approach(es) to accomplish the objectives to specific element and sub-architecture planning and design. The open questions here are non-comprehensive examples of the types of areas that will be addressed in future work; they are only notionally binned for FE. This section will be updated in future revisions of the ADD.

- What is an attainable balance in mission types and locations to address infrastructure buildup objectives and scientific exploration of diverse sites objectives?
- What is the most effective way to utilize lunar missions as preparation for crewed Mars exploration?
- With the expansion of mission types and durations, what are the options for logistics resupply, both for delivery to cislunar space and the lunar surface and for transfer to the necessary location(s)?
- What waste management and element repurposing, recycling, or disposal approaches should be utilized for sustainable exploration?
- What assets should be available to support non-polar sorties?
- What benefits do various levels of ISRU provide for the lunar surface activities?
- How can the architecture expansion in FE enable key science and technology needs (e.g., polar volatiles, ISRU, biological, environments)?
- What options are available to significantly enhance sample return and conditioned/cryogenic cargo from the lunar surface to Earth?
- What assets should be available to support sustained scientific activity in the south polar region? How should they be distributed, and what are the supporting infrastructure dependencies?
- What strategies should be considered for maintaining asset health through uncrewed periods?
- When should ISRU strategies be applied to the architecture?

Even as FE expands on what was accomplished in HLR, the FE missions set the stage for Sustained Lunar Evolution and make progress toward Humans to Mars.

3.3 Sustained Lunar Evolution Segment

3.3.1 Summary of Objectives

In the Sustained Lunar Evolution (SLE) campaign segment, NASA aims to build, together with its partners, a future of economic opportunity, expanded utilization (including science), and greater participation on and around the Moon. The focus of SLE is the growth beyond the FE segment to accommodate objectives of increased global science capability, long-duration/increased population, and the large-scale production of goods and services derived from lunar resources. This segment is an “open canvas,” embracing new ideas, systems, and partners to grow to a true sustained lunar presence. The steps for obtaining use cases for the SLE segment will involve broad coordination. Given the maturity of this segment, there is insufficient depth to allocate functions at this time beyond the high-level capabilities associated with the objectives. However, for context, notional examples of the future use case and the sub-architecture dependencies over time are discussed as a placeholder for the initial work that needs to be completed.

Sustained lunar presence represents responsible long-term exploration of the surface and the establishment of a robust lunar economy. This segment is driven by RT-9 (Commerce and Space Development: foster the expansion of the economic sphere beyond Earth orbit to support U.S. industry and innovation), TH-3 (Develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence conducting scientific and industrial utilization as well as Mars analog activities), and the infrastructure objectives with the overarching goal of: “Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.” A sustained architecture at the lunar surface would further enable achievement of key science objectives in lunar/planetary science, heliophysics, human and biological science, and physics and physical science and facilitate addressing new science objectives identified as a result of discoveries made during the previous campaign segments.

3.3.2 Use Cases and Functions

Architecting from the right requires the development of use cases that are coordinated with NASA’s partners and based in economic plausibility to derive the functional needs. Table 3-28 is an example set of interconnected notional paths worked in parallel to incrementally achieve sustained states of increased duration and population, increased economic opportunity, and increased science capability as guided by the objectives and recurring tenets. Future work will involve developing uses cases in coordination with NASA’s partners.

Table 3-28. Example Sub-Architectures and Use Case Evolution for SLE Segment

Foundational Exploration Segment	**Sub-Architecture and Use Case Evolution**			**Notional SLE Use Cases**
Foundational Capabilities for: • **Lunar Surface Access** • **Mobility** • **Habitation** • **Logistics** • **Power** • **Manufacturing** • **Construction** • **In-Situ Resource Utilization & Production**	<u>Expanded Power for Expanded Missions</u> *More mission opportunities further from the South Pole for longer durations*	<u>Increased Crew Size & Duration</u> *Replicated surface habitats, laboratories and increased logistics*	<u>Permanent Lunar Outpost</u> *Crew/cargo access to and from the lunar surface enabled by ISRU, scores of crew*	Increased Duration & Population
	<u>Minimal ISRU & Regolith Utilization</u> *100s of kg of water/propellant produced*	<u>ISRU Derived Propellants</u> *1,000s of kg of water/propellant produced, minor civil engineering*	*<u>Industrial-Scale ISRU & Mining</u>* *10,000s of kg of ISRU propellant with regolith used for raw materials, 3D printing, propellant manufacturing, and mining*	Increased Economic Opportunity
	<u>Expanded Mobility & Range</u> *10s of km to 100s of km range from South Pole*	<u>Increased Sample Return</u> *100s of kg from non-polar regions cached and returned to Earth in addition to FE capabilities*	<u>Lunar Global Access (Crew & Cargo)</u> *1,000s of kg from global locations returned to central location, then returned to Earth*	Increased Science Capability

3.3.2.1 Increased Science Capability

The science objectives are supported by the ability to deliver science instruments to various locations in cislunar space and the lunar surface and return the acquired data or samples to Earth. In addition, providing real-time human interaction where science activities are being performed increases the ability to rapidly react to discoveries and to determine optimal areas and samples to explore. When coupled with the ability to update, replace, and repair the systems for performing the science, human presence is extremely beneficial. Prior to this segment, science capability is governed by the initial orbital platforms, landers, and regional exploration infrastructure, coupled with the HLS's ability to support global lunar sorties, including to the lunar far side. Although the FE segment will include the function to return the required science samples gathered during a 30-day–class mission, approaches to increase the science capability as mission duration and available power grow beyond the previous segment's limits will have to be addressed. A notional path working across the sub-architectures to increase science abilities beyond the previous segment is discussed next, in the context of the objectives and key characteristics.

Increasing science capability is enabled by enhancing multiple sub-architectures, with trades within those architectures to understand the best approach. If global concurrent lunar science activities represent the desired end state, then the lunar communications and navigation sub-architecture will need to evolve via interoperability, scalability, and reconfigurability to allow concurrent science missions distributed across the lunar globe to send back data via high-speed links. This would represent a continued evolution beyond the initial communications/navigation infrastructure that features direct-to-Earth for the lunar near side, relay service for the South Pole region and limited relay services for non–South Pole regions. NASA and its partners can trade different approaches for satellite constellations, surface relay infrastructure and technologies such as optical links to enable high-data-rate communications.

Working backwards from and forward to the notional use cases across the segments informs key sub-architecture questions like what access and purity for viable ISRU are needed; what power interface and standards can enable a power grid that evolves to industrial scale; and what communications, navigation, and positioning architecture features will be required to scale to an evolved lunar future.

3.3.2.2 Increased Economic Opportunity

Economic opportunity on and around the Moon in the context of this discussion means that governments are no longer the sole source of support for the funding of the lunar activities and that non-governmental entities would like to invest in, and profit from, activities at the Moon. NASA aims to reduce the barriers of entry for activities on and around the Moon and to provide capabilities others can leverage. Artemis is making the foundational investments for access to the Moon from a transportation, exploration, and science perspective. The opportunity for industry at this point is to leverage that investment to enable lunar access (both robotic and human) to additional governmental entities, scientific institutions, international entities, and industry partners. Additional investments in communications, navigation, ISRU, power, and transportation sub-architectures will be needed to enhance access and return, facilitating the beginning of new supporting service economic opportunities in those areas.

Economic opportunity/profitability could progress along the lines of 1) information transfer, 2) delivering goods, 3) providing services at the Moon to enable others, and 4) bringing resources from the Moon to other destinations. Larger-scale economic opportunity begins to emerge when lunar reach and access are expanded, small-scale ISRU propellant grows to industrial scale, aggregate power grows from kilowatts to megawatts, and the use of in-situ material and manufacturing become more economical than importing everything from Earth. Once ISRU production is of sufficient scale, exporting propellant and material beyond the lunar surface manifests as an economic opportunity.

3.3.2.3 Increased Duration and Population

Increased science capability influences economic opportunity, which overlaps both with the need to increase the population of humans at the lunar South Pole region and the need for them to stay there longer. However, humans currently require a significant quantity of resources imported from Earth to survive, along with large amounts of pressurized volume in which to live safely. To significantly increase the size and duration of the lunar population, local resources will eventually be required to provide water, support food growth, and build out infrastructure, with commercial or internationally provided crew transportation systems infused to increase mission frequency and crew population. As an interim step, small modular systems could be supplied by multiple partners to act as a bridge between the initial FE capabilities and the full-up ISRU systems to provide additional habitation and logistics. Fission power augmentation will also be required to achieve a year-round population at the lunar South Pole region, as available sunlight oscillates by month and season. At some point in this evolution, the possibility of lunar tourism appears, possibly at first with Earth-provided modular systems at a higher cost, then later at a larger, more affordable scale once lunar resources can be fully leveraged.

3.3.3 Reference Missions and Concepts of Operations

Given the maturity of this segment, future work will include defining reference missions and detailed concepts of operations as the architecture matures.

3.3.4 Elements and Sub-Architectures

Although the notional use cases discuss the implications of sub-architecture evolution across those use cases and time, actual element functional allocation and sub-architecture evolution will require the development of the use cases by the appropriate stakeholders before further decomposition can be performed.

3.3.5 Open Questions, Ongoing Assessments, and Future Work

Increased science capability, economic opportunity, and duration/population at the lunar South Pole region have the potential to evolve and merge in the future to form the first sustained human civilization beyond Earth. The capabilities put in place during the initial Artemis segments feed forward and enable the future enhancements, and the partnerships forged grow to incorporate a broader community. As Artemis solidifies its implementation of the previous segments, planning for the SLE segment needs to begin in earnest, as the ideation of both the future lunar state and the path(s) for getting there will impact what comes before it. Given the objective decomposition process as described in Section 1.3.1, the notional use cases and functions described in this section need to be replaced with ones developed by the segment stakeholders in future revisions of the ADD.

Input from across the Moon to Mars workshops this cycle has indicated the need to identify “demand signals” for services that would begin in the Foundational Exploration segment and grow in the SLE segment. These services include logistics, ISRU propellant, power/energy, crew habitation, exploration/science systems, and communications/data/navigation systems. An important trade that is currently being performed is the size of logistics carriers and the need for pressurized surface docking. The SLE segment will benefit from larger logistics carriers (which create the potential for longer surface stays) and the ability to transfer logistics without requiring EVA (more EVA time available for science). Not only do the logistics carriers become a potential service demand for the Moon, but the logistics carriers themselves can become a mechanism for infrastructure growth if they can be repurposed for habitation or utilization. Other ongoing assessments involving the infusion of ISRU and the level of mobility across the infrastructure will both be influenced by SLE-related objectives as the path from the FE segment to the SLE segment matures.

3.4 HUMANS TO MARS SEGMENT

3.4.1 Summary of Objectives

The Agency’s Moon to Mars Strategy laid out specific tenets and goals to guide the development of an integrated Moon to Mars Architecture. In addition to the cross-cutting science and operations goals, Mars-specific goals both in infrastructure and in transportation and habitation provide further architecture implementation guidance.

3.4.2 Use Cases and Functions

The decomposition of objectives into characteristics and needs and use cases and functions is still in progress for the Humans to Mars segment. The decomposition follows a similar philosophy to the HLR, FE, and SLE segments, whereby beginning with Agency objectives, use cases and functions necessary to accomplish objectives are identified. As the use cases and functions for this segment are still in flux and elements have not been defined, mapping to elements has not begun yet and remains as forward work.

As a representative example of decomposition, TH-10 (Develop integrated human and robotic systems with inter-relationships that enable maximum science and exploration during Martian missions) drives several characteristics and needs. These include providing robotic systems that can assist the crew on the Martian surface and in space, demonstrating safe interactions between automated systems and the crew and the capability for crew to command robotic systems, and maximizing crew time available for science and exploration activities. Sample use cases that contribute to fulfilling those characteristics and needs include unloading and deployment of elements, robotic exploration operations, implementation of safety procedures, and remote control of exploration elements. Some of the functions that map to these use cases include receiving distributed energy, navigation, and timing, monitoring of elements, and transmission and reception of signals.

3.4.2.1 Humans to Mars Example Use Cases and Functions

Although decomposition of use cases and functions is not yet complete, a representative, non-comprehensive list of notional use cases and functions is provided here, which are specific to the Humans to Mars segment. These use cases and functions outline the expected means for achieving the Agency objectives and should not be taken as a complete set of comprehensive plans or requirements. Additionally, high-level functions needed for each of the systems are described in subsequent sections, serving as a starting point to lay the foundation for a Mars Architecture decision roadmap.

3.4.2.1.1 Humans to Mars Example Use Cases

- Identification, collection, and storage of geological samples from sites on the Martian surface
- Robotic systems perform utilization and/or exploration operations
- Crew use of EVA suits and tools to conduct exploration and utilization activities
- Transport elements, crew, and/or cargo between Martian orbit and Martian surface
- Transport collected samples and supporting packages from Martian surface to Earth vicinity
- Return crew and systems from cislunar space/Earth vicinity to Earth surface
- Recovery of excess propellant from tanks of previous lander elements
- Unloading and/or deployment of payloads on the Martian surface
- Operation of ISRU production, storage, and/or transfer demonstration packages in a relevant environment
- Crew live and operate for long-duration increments in deep space
- Operation of crew health and performance countermeasures systems (e.g., exercise, nutrition, sensorimotor, cardiovascular, immune, radiation) for Mars duration missions
- Remote diagnosis and treatment of crew health during long-duration increments
- System operations and emergency response capabilities to enable crew survival
- On-demand, in-situ training and planning for nominal and contingency procedures

- Execution of procedures and operation of technologies to ensure safe interactions between crew and automated/autonomous systems
- Continuous operation of power systems in environmental conditions during crew safety critical mission operation
- Communications between Earth and Martian surface
- Provide high-availability position, navigation, and timing at exploration locations on the Martian surface

3.4.2.1.2 Humans to Mars Example Functions

- Conduct utilization activities, such as collecting samples, collecting science data, and/or conducting experiments
- Detect crew healthcare conditions
- Transmit signals
- Identify and monitor current position and orientation
- Receive stored or distributed energy
- Use EVA tools to clean EVA suits and equipment
- Manage temperature and humidity
- Provide fail-safes and override capabilities for automated/autonomous systems
- Perform atmospheric entry, descent, and landing
- Manage solid and liquid waste from crew and life support systems
- Recover and package geological samples
- Recover and package biological and human research samples
- Store collected geological samples in stable environmental conditions
- Store collected biological and human research samples in stable environmental conditions
- Distribute energy

3.4.2.1.3 Humans to Mars Example Support Functions

In addition to the functions established during decomposition of each objective, there are “support functions” that are inherent to almost all spaceflight elements and therefore need not be explicitly mapped within objectives. However, it is still necessary to document these support functions; some notional examples of support functions for the Humans to Mars segment are listed below:

- Manage and condition power
- Receive signals
- Condition signals
- Identify and monitor current position and orientation *(Note: for mobility and transportation systems)*
- Provide data and computer security (e.g., encryption)

- Collect operational data (e.g., telemetry, housekeeping, fault monitoring)
- Detect and diagnose a servicing need in an element/system/payload
- Command and control elements

3.4.3 Mars Trade Space, Reference Missions, and Concepts of Operations

For the purpose of initial analysis, a technically feasible early practical Mars mission was used. For example, a Mars surface mission would be too challenging for a solo explorer, so two crew to the surface is the current practical minimum working assumption. However, the trade space remains wide open. Definition of the full trade space, along with updated reference missions and concepts of operations, are being developed in the context of the Moon to Mars objectives and will aid in developing the Mars Architecture decision roadmap.

3.4.3.1 "How" to Get to Mars and Back?

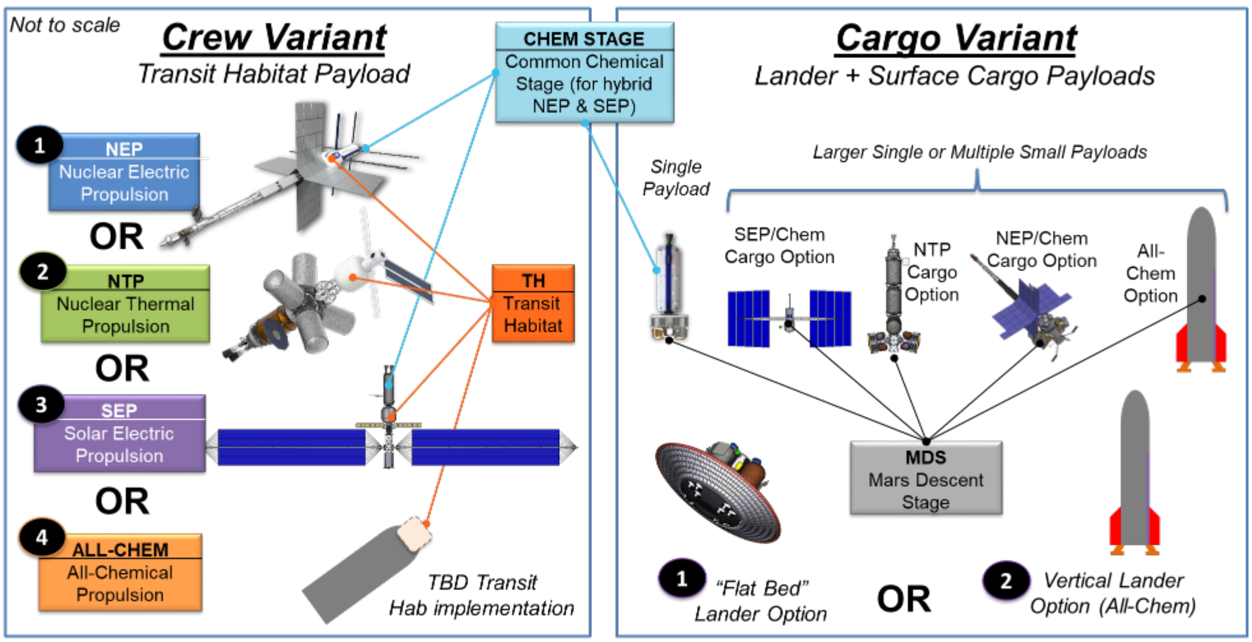


Figure 3-19. Major Mars Architecture Transportation Options Trade Space

Because the first challenge of any Mars mission is simply to get to Mars safely and return to Earth, the Earth-Mars transportation system elicits a substantial amount of discussion relative to the "How?" trade space. To that end, recent analysis was designed to explore the pros and cons of different transportation system options across a wider range of mission profiles than previously considered. The initial metric of interest for recent assessments was total roundtrip mission duration, due to the significant duration-related flow-down impacts to crew health and performance, technology investment, development timelines, and cost. Historically, Mars mission duration has been treated as a binary choice: either an approximately two-year opposition-class mission characterized by at least one high-energy transit leg and a very short Mars stay (measured in days), or a three-or-more-year conjunction-class mission characterized by low-energy transits with at least a year-long loiter period at Mars. In truth, mission duration can be thought of as a continuum: the architecture can be optimized for any given duration for a particular opportunity year or a range of durations over different opportunities.

To inform the total mission duration decision, which in turn will inform a host of other decisions (including transportation propulsion technology investments), stakeholders will need several pieces of information: an understanding of system-by-system performance sensitivity over the entire duration trade space and an integrated campaign and risk assessment for the various possible implementations, including integrated risks to the human system. To that end, the Mars Architecture concepts presented here are intended to populate a broad swath of the "how" trade space, allowing decision-makers to see how different implementations of four different transportation systems fare in the context of different reference missions (the "Why," "What," and "Where").

As shown in Figure 3-19, transportation system concepts currently under evaluation include hybrid nuclear electric propulsion/chemical (NEP/Chem), nuclear thermal propulsion (NTP), hybrid solar electric propulsion/chemical (SEP/Chem), and all-chemical (All-Chem). For comparison purposes, a common transit habitat (TH) is assumed for all crew transportation systems in the crewed variant; cargo variants of each concept are also available. Two different Mars Descent System (MDS) concepts have also been developed: a relatively small 25 metric ton (t) payload capacity "flat-bed" lander and a larger vertical lander capable of landing the minimum total surface payload cumulative mass of 75 t. For comparison purposes, a common set of surface systems is assumed for all architectures, as is a common Mars Ascent Vehicle (MAV) concept. To bound the trade space, recent analysis has focused on a minimal two-crew MAV concept that relies on Earth-delivered ascent propellant, but more complex options capable of ferrying larger crew complements using ISRU propellants have been studied and will be revisited for later sustained exploration missions as the Mars Architecture evolves. Details of these concepts are provided in subsequent sections of this document.

3.4.3.2 Mars Initial Analysis Assumptions

Human Mars mission requirements will be developed under an eventual human Mars exploration program. In lieu of requirements, guidance provided by NASA leadership heavily influenced the architecture concepts used for human Mars mission architecture development.

Recent analysis assumptions used to assess impacts for the Mars exploration campaign's architecture development include the following:

- A light initial exploration footprint: as few as two or as many as six crew members to Mars orbit, and a minimum of two crew members descending and living on the surface for a minimum 30-sol surface stay
- Multiple Mars landers, with the first lander(s) pre-deploying cargo to prepare for a later crew landing
- Modest initial surface infrastructure: a 10 kWe minimum FSP system and communications infrastructure, but no surface habitat, and no return-mission-critical ISRU propellant production
- "All-up mission" approach: crew depart Earth with all the transit propellant they need for the round-trip journey, a consequence if there is no ISRU for early missions

Note that these assumptions are considered for a basis of comparison only. More complex mission scenarios will be addressed in subsequent analysis cycles, but the initial step is to define a practical architecture for the first human Mars mission campaign, from which subsequent missions can expand. It is important to note that none of these assumptions are fixed; they provide a framework for direct architecture comparisons, and all decisions will be made with architecture evolution in mind.

3.4.3.3 Reference Missions for Assessments

To provide stakeholders with a sense for how the Mars Architecture changes as just a single constraint is varied, three reference missions of different total durations—but all with the same surface and transit operational constraints, such as environmental exposure, communication delays, and blackout periods—are defined to enable assessment of the architecture to inform the eventual decision roadmap (Figure 3-20): Reference Mission 0, with an Earth-Mars-Earth transit duration not to exceed 760 days; Reference Mission 1, with a moderate transit duration of 850 days; and Reference Mission 2, with a more relaxed transit duration of up to 1,100 days.

Reference Mission 0 is an opposition-class mission where at least one leg of the transit requires substantial energy to close the distance gap between Earth and Mars rather than loitering in Mars orbit to take advantage of planetary motion, as in Reference Mission 2. Reference Mission 0 reflects the desire to shorten the roundtrip mission duration in an attempt to reduce long-duration spaceflight risk to the crew.

Reference Mission 2 represents the traditional conjunction-class corner of the trade space, taking advantage of minimum-energy trajectories by loitering in Mars' vicinity for up to a year, which in turn reduces overall propellant mass and launch costs. This reference mission represents the desire to minimize the total mass of the transportation system by minimizing the energy required for the roundtrip journey.

Mission Duration Knob	WHO We Send	WHAT We Do	WHERE We Go	WHEN We Go	WHY We Go	HOW We Get There & Back
Fast Roundtrip High Energy **Reference Mission 0**	**Analysis Assumption: Number of Crew Range of 2 – 6**	**Analysis Assumption: 75t Total Landed Payload** Light footprint: Minimal surface infrastructure, crew live in rover, 10 kWe Fission Surface Power (no return propellant ISRU)	**Analysis Assumption: Single Mars Surface Site +35° N Latitude**	**Analysis Assumption: 2039 crew departure to meet "by 2040" boots on Mars**	**Science** **Inspiration** **National Posture**	**Mission Time:** **760d or less** in Deep Space, **fixed 50 sols** in Mars Orbit, w/30 sols on Mars Surface (**870-900 days total** crew time off Earth)
Moderate Duration Moderate Energy **Reference Mission 1**						**Mission Time:** **850d** in Deep Space, **fixed 50 sols** in Mars Orbit, w/30 sols on Mars Surface (**960-1020 days total** crew time off Earth)
Long Duration Minimum Energy **Reference Mission 2**		**>75t Total Landed Payload** Light Footprint: Plus leverage additional capacity if available				**Mission Time:** **950-1100d** in Deep Space, **no less than 50 sols** in Mars Orbit, w/30 sols on Mars Surface (**1090-1250 days total** crew time off Earth)

Figure 3-20. SAC22 Humans to Mars Reference Missions for Transportation System Assessments

Reference Mission 1, though accelerated, is not strictly an opposition-class mission; rather, it is on the continuum between traditional opposition-class and conjunction-class missions. This reference mission represents a compromise between Reference Mission 0 and Reference Mission 2 in an attempt to understand the middle ground of this particular trade space.

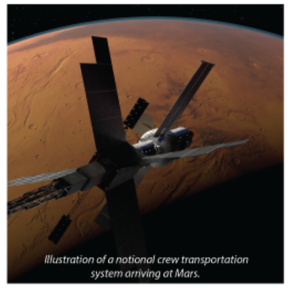
The rationale for multiple reference missions is twofold: first, to assess candidate transportation propulsion system performance across the continuum from opposition-class to conjunction-class missions, and second, to answer the question, "Is nuclear propulsion needed to enable crewed Mars missions?" A given propulsion concept may perform well for one mission class type but not others; by considering different mission class types, decision-makers can better compare these architectures and understand how constraints such as total mission duration influence performance.

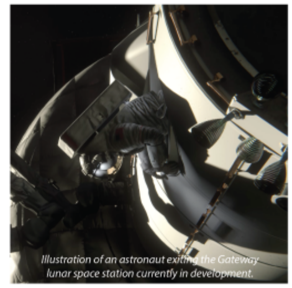
3.4.3.4 Mars Architecture Decision Categories

To aid in assessing extensibility of Mars elements to other destinations or programs and vice versa, the Mars Architecture elements can be bucketed into four major categories: 1) Mars surface systems that enable crew to live and work on the planetary surface; 2) entry, descent, landing, and ascent (EDLA) systems that are able to move crew and surface systems from Mars orbit to the Mars surface and return crew and cargo back to Mars orbit; 3) transportation systems that are able to move crew and cargo from Earth to Mars orbit and back again; and 4) crew support systems that cross multiple missions, phases, and destinations, such as EVA spacesuits, distributed communications networks, or crew healthcare systems. These categories, and the key architecture decisions required within each category, are outlined in Figure 3-21.

Key Mars Architecture Decisions

(full list under analysis)





Surface Systems

Surface Objective Priorities
science, technology demonstrations, and vision for initial human segment infrastructure

Habitation Strategy
(linked to duration and number of crew)

Mobility Strategy
including exploration radius

Surface Power
generation technology, sizing, and distribution

Entry, Descent, Landing, and Ascent (ELDA) Systems

Propulsion Technology and Propellant Type
ascent and descent

Payload Mass
descended, ascended, and largest individual payloads

Orbital Crew Operations
split crew versus all to surface

Landing Site
one site versus multiple sites; number of missions to each site

Landing Accuracy

Transportation Systems

Mission Mode

Mars Parking Orbit

Habitation Strategy
integrated with propulsion system or separable; single or multiple modules

Transportation Propulsion Technology
including nuclear and non-nuclear options

Stack Aggregation Strategy and Location

Crew Support

EVA Strategy

Logistics Strategy

Human Health and Performance Strategy
including health care, radiation mitigation, hygene, food system shelf life, etc.

Number of Crew
(to vicinity and surface per mission)

Planetary Protection Strategy
(surface and Mars orbit)

Mission Cadence and Crew Duration per Mission

Return Propellant Acquisition Strategy
(both ascent and descent)

Crew Ingress and Egress Strategy and Cabin Atmosphere

Element Life and Re-Use Strategy

Communications Strategy

Test and Verification Strategy
(including analogs)

Figure 3-21. Sample of the Major Mars Architecture Categories and Decisions

As noted above, major decisions (the "Why" or "When," for example) will heavily influence subsequent decisions within each architecture category. Because decisions in one architecture category will ripple across the other categories as mass, cost, or complexity, NASA will study the effects of options across the end-to-end architecture under various decision structures. This process will enable NASA to develop a roadmap of key architecture decisions. It is important to note that Figure 3-21 and the description provided in this document are not intended to provide an exhaustive list of decisions and categories, but rather to begin development of the integrated Mars Architecture decision roadmap for eventual implementation. Key decisions that will affect all four Mars Architecture elements are establishment and approval of the Agency loss of crew (LOC) Safety Reporting Thresholds (SRTs) and directorate loss of mission (LOM) requirements. The LOC SRTs and LOM requirements specify the minimum tolerable/allowable levels of crew safety (maximum tolerable level of risk) and mission loss, respectively, for the design in the context of the proposed design reference mission(s). These are key early steps in the human-rating certification process that will aid in allocating reliability requirements and identifying safety/risk technological areas that require further development, prioritization, and/or demonstration.

3.4.4 Mars Surface Systems

The initial focus for Mars exploration is the development of a modest first exploration mission, framed as a first step to a sustained human exploration campaign. For the sake of comparison, initial analysis assumes the same surface system elements, regardless of how those systems are transported or deployed to the Martian surface. Long-duration crew stays at Mars will be assessed as future work related to sustained human exploration analysis.

3.4.4.1 Functions

The primary function of human Mars surface systems is to protect crew and utilization payloads from the Mars environment for the duration of the Mars surface mission. Mars surface systems will also be critical to enabling science investigations before the crew arrives, while they are on the surface, and after they depart. For utilization payloads, this includes the pre-deployed cargo phase prior to crew arrival and an extended robotic operations phase following crew departure. Capabilities required to perform this function include utilities such as power and communications, surface mobility assets, and habitable volumes.

3.4.4.2 Key Decisions and Drivers

Virtually every other surface system decision will hinge on the desired number of crew members on the surface ("Who?") and their purpose ("Why?"). Other decisions could be made first, but these two decisions may be considered anchoring decisions for a logical flow of subsequent surface architecture decisions. Understanding the relationships between these decisions is vital to developing an integrated surface architecture.

3.4.4.2.1 Surface Mission Purpose

The Mars surface systems architecture will vary significantly depending on whether the surface mission purpose is confined to a narrow set of specific human-assisted science objectives, a set of tasks intended to lay the groundwork for sustained human presence, or some combination of the two. Key considerations will be high-priority science objectives, technology demonstrations, and long-term exploration plans.

Note that decisions involving the surface mission purpose will have impacts beyond the surface systems architecture. For example, surface mission purpose will inform landing site selection, which will drive the EDLA and transportation architectures. Also note that science, technology demonstration objectives, and utilization strategy are key factors in the surface mission purpose decision, with flow-down impacts to landed utilization mass, volume, and power. These decisions also potentially influence the payload capacity and/or number of landers required.

3.4.4.2.2 Number of Crew Members to the Surface

The minimum practical number of crew members to be sent to the surface is assumed to be two, given NASA's long-standing "buddy rule" for critical spaceflight operations. Initial crew complements as high as six have been analyzed, but ultimately the number of crew members required will be tied to the surface mission purpose, with more crew members needed for more elaborate mission plans and managing critical operations in an environment where communication delay precludes Earth-based ground support. Technology autonomy may support reducing the number of crew; however, architecture design supportive of effective human system integration will be a necessity, especially if the number of crew is minimized. Whether to split crew (with some remaining in orbit while others descend to the surface) will depend on orbital and surface tasks, technology autonomy, and risk to crew and mission during critical operations. Iterative analyses may be required to assess different architectures and concepts of operations.

Designs for systems such ECLSS (and associated maintenance and spares logistics) are driven by the number of crew, as are logistics consumables such as oxygen, food, water, medicine, clothing, and hygiene supplies. The number and type of science objectives that can be addressed is also contingent on the number of crew available to perform utilization tasks.

3.4.4.2.3 Surface Stay Duration

Minimum surface stay duration will be a function of the surface mission purpose and how many crew are available to accomplish the mission. Depending on the architecture, there may be logical stay duration break points, beyond which additional elements may be required to complete the mission.

3.4.4.2.4 Habitation Options

The multiple habitation options are largely based on architecture decisions about crew size, surface mobility strategy, EDLA and transportation capability, utilization needs, and the location of initial and subsequent crewed Mars missions. Numerous studies have analyzed the necessary habitable volumes for a surface crew for various mission scenarios, as well as the EDLA and transportation architectures that must deliver these elements. Habitat reuse or repurpose from previous missions must also be considered as part of the surface habitation strategy.

3.4.4.2.5 Crew and Logistics Ingress/Egress

Habitation decisions will, in turn, inform crew ingress/egress options, with key considerations being dust mitigation, planetary protection, logistics management, contingency access, system maintenance needs, and operational efficiency. Crew and logistics ingress/egress strategy is expected to be substantially informed by Artemis experience on and around the Moon, along with mission-specific constraints such as schedule, mass, and cost. Options include ingress/egress via airlocks, hatches directly into the habitable volume, and/or use of a (suit) port that allows crew to directly don a spacesuit via a detachable hatch mounted directly to the exterior of the habitable volume.

3.4.4.2.6 Surface Mobility Options

Surface mobility decisions will be derived from the mission purpose (where do we need to go to meet the objectives and what do we need to do there?), stay duration (how long do we have to get there and back to the MAV?), cargo movement (what payload elements need to be moved from one location [e.g., the lander deck] to other locations?), and habitation decisions (are the habitable volumes moveable? what are the traverse distances to/from habitat, landing site, and ascent stage?). Each of these individual considerations will influence the overall exploration radius. Because mobility includes EVA systems, crew ingress/egress must also be considered, as it will influence EVA suit design and operation. Mobility systems may also be required to support autonomous or remotely commanded operations before the crew arrives or after they depart, which may influence the communications architecture. Vehicle mobility systems, such as a pressurized rover, tend to be large, so mobility decisions will impact the EDLA and transportation architectures that must deliver these elements.

3.4.4.2.7 Surface Communication Options

Surface communications decisions will ultimately depend on how many surface assets are deployed; their relative proximity to each other and whether there are potential line-of-sight obstructions between them; the mobilization plan as assets move around the surface; which assets need to communicate with each other, with orbiting assets, and/or with Earth; data rates required between various assets; and power available to each asset. Surface communications decisions are expected to be substantially informed by Artemis experience on and around the Moon, and there is likely to be iteration across the elements as mass, power, complexity, or other constraints are balanced.

3.4.4.2.8 Surface Power Options

Fission surface power (FSP) is the leading candidate for primary Mars surface power because of the prevalence of dust storms that have proven difficult for solar-powered Mars surface systems. Although solar-powered short-duration surface missions might have acceptable risk, longer stay missions or missions pre-deploying powered cargo will likely require surface power technologies, such as FSP, that are resistant to environmental disruption. Initial analysis has identified a minimum power level needed to achieve a 30-sol, light-footprint exploration mission, but assessing and integrating power needs for science and technology demonstration remains as forward work. Therefore, the power level, number of units, and operations plan (e.g., leave surface power system on the lander it arrives on or deploy elsewhere) also remain as forward work.

3.4.4.2.9 Surface Architecture Life and Reuse

Operating life limits, including reuse for subsequent missions, will depend on total surface mission duration (including the pre-deployed cargo and post-crew departure robotic science mission phases) and whether subsequent human missions will return to the first mission landing site.

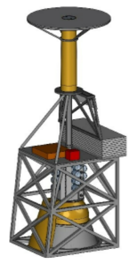
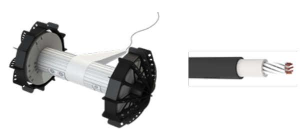
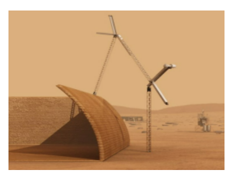
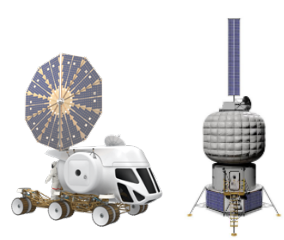
3.4.4.2.10 Return Propellant Strategy

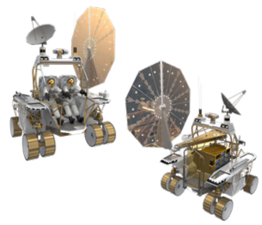
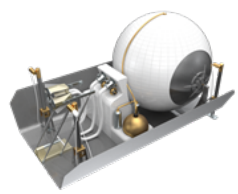
Return propellant strategy—whether manufacturing propellant in-situ on Mars, using Martian-derived resources or Earth-delivered resources—drives surface system mass, power, operational timelines, and potentially landing site selection. The Martian atmosphere is a readily accessible feedstock anywhere on the planet from which oxygen, carbon, and other commodities can be acquired. Water is known to exist in various forms and in discrete locations on the surface or in the near sub-surface across the planet, from which hydrogen and oxygen can be derived. Acquiring these feedstocks and the choice of propellants to manufacture drive surface system mass, power, operational timelines, and potentially landing site selection.

3.4.4.3 System Concepts

Table 3-29 summarizes the minimum set of surface concepts based on functional needs currently being evaluated in the Mars surface architecture. Note that these are in the conceptual design phase; subsequent publications will contain additional surface concept reference detail as they mature, and more concepts may be added as additional functions are defined.

Table 3-29. Mars Surface System Functions and Example Concepts

Functions	Example Concept(s)		Heritage and Status
Provide power for all surface elements	Surface Power		FSP derivative of the Kilopower concept is in formulation for a lunar demonstration mission. Other options have been evaluated but may not meet constraints.
Provide power storage and distribution from the source to surface end-users or distribution points			Derivative of cables used in Earth applications (e.g., solar farms, offshore wind farms, undersea cabling). Various deployment concepts are being evaluated.
Enable automated cargo handling	Robotics		Robotic cargo handler: simple design and components. Should be scalable to multiple cargo types or sizes. Various concepts have been studied; lunar analogs may offer new insights.
Enable autonomous or remoted-controlled fine motor-control manipulation of mechanisms and other components, such as cables, hoses, etc.			Robotic manipulator heritage from ISS robotics, Robonaut, etc.
Provide aerial exploration and contingency support			Advanced generation of Ingenuity, a robotic helicopter landed with Perseverance and currently in use on Mars
Provide ability for crew Extravehicular Activity	Refer to Mars Crew Support Architecture, Section 3.4.7		
Provide habitable volume for shirt-sleeve crew for surface activities	Habitation		Lunar habitation and mobility derivative concept

Functions	Example Concept(s)		Heritage and Status
Provide ability to transport crew utilization payloads, and other cargo across the Mars surface. Note: Utilization payloads can include science equipment.	Surface Mobility		Mars terrain vehicle Derivatives of lunar mobility concepts
Provide ability to store, condition, and transfer ascent propellant through Earth launch, transit, and Mars landing, as well as the Mars surface environment	Propellant Storage and Transfer		Same design and fluid-compatibility as conceptual ascent vehicle propellant tanks
Provide means to transfer propellant to the ascent vehicle	Propellant Delivery		Potential concept leverages technology developed in support of the satellite servicing mission previously called Restore-L (now OSAM-1) and its predecessor Restore-G
Science: Provide equipment needed to meet Mars transit and surface-based science objectives			To be coordinated with the Science Mission Directorate, the Space Operations Mission Directorate, and possibly the Science and Technology Mission Directorate, or other research stakeholders if new technologies are required
Technology Demonstration: Provide equipment needed to meet Mars surface infrastructure technology demonstration objectives			To be coordinated with the Space Technology Mission Directorate
Return Cargo: Provide containment and environmental control for Mars-origin or Mars-contaminated materials			To be determined based on mission objectives
Communication between crew, surface assets, orbital assets, and Earth	Refer to Mars Crew Support Architecture, Section 3.4.7		
Provide logistics	Refer to Mars Crew Support Architecture, Section 3.4.7		

3.4.4.4 Concepts of Operations

HEOMD-415, *Reference Surface Activities for Crewed Mars Mission Systems and Utilization,*[13] provides detailed information on initial surface mission concepts of operations. As noted above, no decisions have been made, and significant forward work remains to define science and

[13] *Reference Surface Activities for Crewed Mars Mission Systems and Utilizations,* National Aeronautics and Space Administration (2022), HEOMD-415.

technology demonstration objective implementation options and integrate with crew systems and operations.

3.4.5 Mars Entry, Descent, Landing, and Ascent Systems

All surface system assets, plus the crew's ascent system, must descend and land on Mars. The landed mass required for a human mission exceeds the practical limits of heritage robotic mission EDL systems such as parachutes, airbags, or sky cranes. Two different types of landing systems are currently being assessed: a "flat bed" lander where the payload is mounted on a cargo deck relatively close to the surface and a "vertical lander" that could accommodate higher-mass payloads. The number of landers needed for a particular mission will depend on the lander's payload capacity (both mass and volume) and any pre-deployment timing constraints. For the sake of comparison, it is assumed that both types of landers could deliver the same surface cargo, including the same surface and ascent system with Earth-origin propellants. There are alternative ascent system schemes employing in-situ propellant manufacturing, but because these options stray from the first mission's "light exploration footprint" assumption, those options are deferred to subsequent analysis cycles.

3.4.5.1 Functions

Regardless of design, all Mars EDLA systems must provide a minimum set of functional capabilities to support the integrated Mars Architecture.

3.4.5.1.1 Protect Crew and Cargo During Mars Entry, Descent, and Landing

The Mars EDL system must accommodate rapid changes in temperature, pressure, and gravity while decelerating from orbital velocities without transmitting damaging loads to crew or cargo. Because of a combination of potential crew deconditioning, lengthy communications delays with Earth, and the rapid pace of dynamic events during EDL, Mars EDL systems must be designed for autonomous operation with limited real-time crew input.

3.4.5.1.2 Protect Crew and Cargo During Mars Ascent

The Mars ascent system must accommodate rapid changes in temperature, pressure, and gravity without transmitting damaging loads to crew or cargo. The ascent vehicle will also be responsible for providing a habitable environment to support the crew during ascent from the Martian surface.

3.4.5.1.3 Protect Against Cross-Contamination of Martian and Earth Environments

Descent systems will need to minimize the transfer of uncontained Earth material to prevent forward contaminating the Martian environment to maintain pristine scientific samples to the maximum extent possible. Similarly, ascent systems will need to minimize the transfer of uncontained Martian material to prevent backward contaminating Earth return vehicles.

3.4.5.1.4 Provide Integration Interfaces to Mars Transportation and Surface Systems

Mars EDLA elements must receive services (such as power, data, or thermal control) from the Mars transportation system during transit and must provide similar services to the cargo payloads they carry during transit, entry, descent, landing, and surface operations prior to accessing power from surface infrastructure (i.e., from the FSP).

3.4.5.1.5 Provide Precision Landing Capability to Enable Multi-Lander Surface Operations

Lunar landing systems will be insufficient to meet precision landing requirements on Mars. Technologies developed for the Moon may be applicable but insufficient because of differences in EDL on Mars, primarily because of the presence of the Martian atmosphere. Architectural decisions, such as Mars parking orbit, can also impact the required precision landing technology development because of differences in flight path angles and relative velocities during key phases of EDL. Additionally, there may be constraints on landing precision technology imposed by the need to land multiple landers in close proximity for operational purposes while simultaneously maintaining safe distances from previously landed assets to mitigate the potential damage caused by ejecta lofted by terminal descent rocket engines.

3.4.5.2 Key Decisions and Drivers

EDLA design will be heavily influenced by two human Mars mission requirements and two constraints. Total required payload mass to the surface and return to Mars orbit is informed by “Why” we are going to Mars and “What” we will do there, which in turn drives the number of crew members we need to land on the surface and return to orbit, the equipment we need to land, and the number of crew members and cargo we need to return to orbit. Whether these systems need to be extensible to larger future payloads may also influence EDLA design. EDLA design will also be constrained by the largest indivisible payload item (mass and volume) and whether the EDLA system is required to support all crew to surface and back to orbit together, and split crew operations, in which some crew members land while others remain in orbit. EDLA design may also be constrained by potential human system risks associated with physical deconditioning from the lack of gravity during the transit phase. This deconditioning can also impact crew readiness timelines for Mars surface EVA. EDLA design may also be influenced by requirements on payload protection from entry environments and orbital debris.

3.4.5.2.1 Payload Mass Landed on the Mars Surface

The largest payload landed to date on Mars is about 1 t, but even the most modest human Mars mission is estimated to require at least 75 t of total landed payload for even a short-duration surface stay. Longer, more ambitious missions will require more landed mass. Total landed payload mass, in combination with EDL technology availability, will determine how many landers are needed to complete the mission, which in turn will inform lander production, launch, and delivery cadence, with flow-down impacts to the Earth-Mars transportation architecture. The number of landers will also inform surface system concepts of operations, depending on how far apart landers are deployed, which payloads need to move between landers, and the power and communications strategy between them.

3.4.5.2.2 Payload Mass Ascended to Mars Orbit

Ascent from the Mars surface has never been attempted. The Mars Sample Return Program’s Mars Ascent Vehicle is the first planned ascent from another planet. Mars atmosphere and gravity make this a high “gear ratio” operation, meaning several kilograms of ascent propulsion mass are required for every kilogram lofted back to orbit. At a minimum, ascending just two crew members—even without any return cargo—is estimated to require more than 30 t of propellant to a 5-sol Earth transportation vehicle parking orbit. Each additional kilogram of cargo mass further increases ascent propellant mass; either this mass must be added to the landed payload allocation noted above or propellant production mass and additional power must be added to the landed payload mass, with flow-down impacts to the surface operations timeline.

3.4.5.2.3 Largest Indivisible Payload

Total landed payload mass can be distributed across smaller landers, which could minimize the EDL technology development burden, but the limiting factor will be the largest indivisible payload. For modest missions, this is likely to be the MAV. Propellant can be off-loaded onto other landers or manufactured on the surface to reduce landed mass. MAV hardware (e.g., tanks, engines) assembly is possible, but extremely risky, especially for initial missions. For more ambitious, longer-duration missions, a large surface habitat might be the pacing payload mass item, depending on how much/how fast outfitting could be installed after landing. Note that payload volume will be constrained by the payload shroud of Earth launch systems, potentially requiring additional Earth launches or Mars landers for large items that can be modularized, or larger launch and lander vehicles for those items that cannot be segmented and exceed current payload shroud size.

3.4.5.2.4 Orbital Crew Operations

If all crew members are to land on the surface, then direct entry options are possible, but if the architecture is required to support "split crew" operations (where some crew members remain in Mars orbit), then both the transportation and EDL systems may need to support orbital operations. The parking orbit has a significant impact on vehicle design, orbital operations, and timelines. Landing and ascent durations and time required to accommodate multiple launch/landing opportunities are highly dependent on the parking orbit. Additionally, mass of the MAV, which is already identified as a "high gear ratio" element impacting the design of several other architecture elements, is highly sensitive to parking orbit altitude. In general, EDLA systems favor lower parking orbits. However, in-space transportation systems tend to favor high parking orbits. Therefore, the optimal parking orbit is an integrated problem between EDLA systems, in-space transportation systems, and crew operations.

3.4.5.2.5 Landing Site Selection

The terrain of a selected Mars landing site location will obviously influence EDLA design, with landing site latitude and elevation affecting both ascent and descent propellant mass, creating flow-down impacts to landed payload mass and surface operations related to MAV fueling strategy. Terrain and whether subsequent missions will return to a given landing site can also influence landing precision requirements. Key reconnaissance parameters (e.g., high-resolution imaging or surface properties assessments) may be needed to inform EDLA design. In addition, the landing site's lighting constraints during the descent phase of the mission could have integrated impacts to the in-space transportation system.

3.4.5.2.6 Ascent Propellant Acquisition Strategy

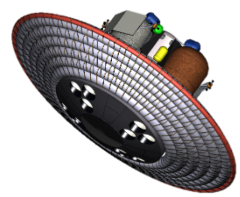
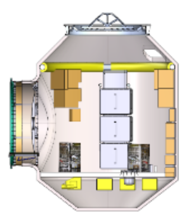
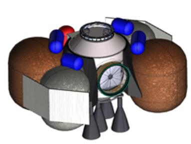
Options include landing a fully fueled MAV on Mars or landing an empty or partially fueled MAV on Mars and either transferring propellant from another lander or manufacturing propellant from in-situ resources. All of these options result in flow-down impacts to other systems: a fully fueled MAV drives MDS payload capacity and Earth launch capacity; a partially fueled MAV drives surface propellant transfer mass and complexity; and in-situ propellant manufacturing drives surface system mass, power, and operational timelines. Constraints such as Earth launch fairing diameter and Mars parking orbit can also have significant constraints on ascent vehicle design choices and propellant acquisition strategy. For example, cryogenic propellant-based MAV to a five-sol orbit challenges the geometry of an 8.4 m diameter Earth launch system fairing due to low density propellants combined with increased propellant loads for higher parking orbits. Workarounds to the Earth launch shroud constraint in turn impact the transportation system by potentially driving it to a lower Mars orbit (at a higher propellant penalty) or require the addition of a “taxi” element to bridge the gap between how low the transportation system can dip into the Mars gravity well and how high the MAV can ascend on a lighter propellant load.

3.4.5.2.7 Element Reuse

Reuse cannot be an afterthought for EDLA systems. It must be integral to the design. Feasibility of reusing EDLA systems is tightly coupled between system design and concept of operation. Initial reference designs are not practical for reuse, but changes to design and operation can enable reuse. Certain designs may be more “evolvable” for reusability than others. Operating life limits, including reuse for subsequent missions, will depend on total surface mission duration (including the pre-deployed cargo and post-crew departure robotic science mission phases), and whether subsequent human missions will return to the first mission landing site.

3.4.5.3 System Concepts

Table 3-30. Mars Entry, Descent, Landing, and Ascent Functions and Example Concepts

Function	Example Concept(s)		Heritage and Status
Delivers crew and surface cargo from Mars orbit to Mars surface Serves as a launch pad for Mars ascent operations	Mars Descent System		MDS conceptual design available for “flat bed” type lander. HIAD based on Low Earth Orbit Flight Test of an Inflatable Decelerator. Forward work to complete reference design of vertical lander.
Shirt-sleeve environment for transfer of crew and equipment between the deep space transport, habitation element, and MDS crew cabin (which may be a surface cargo element)	Pressurized Mating Adapter		Very high-level reference conceptual design available
Delivers crew and returns crew and cargo to Mars orbit	Mars Ascent Vehicle		Reference conceptual designs available
Shirt-sleeve environment transfer of crew and equipment between a pressurized surface asset and the MAV cabin	Surface Pressurized Tunnel		Very high-level reference conceptual design available

3.4.5.4 Concepts of Operations

Refer to HEOMD-415[14] for the initial surface concepts of operations for various mission and architecture implementations, including MAV fueling strategies; that document will be updated as the architecture evolves.

3.4.6 Earth-Mars Transportation Systems

Earth-Mars transportation systems serve to transport the crew, surface systems, and EDLA systems to Mars and return crew to Earth. All Earth-Mars transportation architectures will consist of a propulsion and power backbone paired with one or more payload elements. For the purpose of this document, this integrated transportation system stack is referred to as the “deep space transport” (DST). A single DST design could be used for both crew and cargo deliveries, but to optimize for cost, development schedule, or other metrics of interest, variants may be mixed within a single campaign: for example, a slower, less-expensive, non-nuclear transport for pre-deployed cargo with a faster, higher-powered nuclear system for crew transport. In the crew-variant DST, the payload is a crew habitation system and all the utilization payloads, logistics, supplies, and spares for the in-space portion of the mission, including contingency operations. For the purpose of current analyses, a common habitation system is assumed for all transportation architectures. In the cargo-variant DST, payloads include surface systems, surface utilization payloads, EDLA elements, or other support system payloads.

Selection of a human Mars transportation system will be a complex decision shaped by numerous factors, such as mission objectives (the “Why?” question), exploration partner contributions and commitments, programmatic factors, schedules, and integrated risk assessments. The four transportation propulsion systems presented here represent the range of options currently being analyzed.

Specific implementation of the different transportation systems will depend on the reference mission of interest and a balance between the optimization of the system and the robustness to other mission parameters. For each reference mission, transportation systems can be optimized, from both a configuration perspective and a performance perspective, for the specific requirements of that reference mission. But an optimized transportation implementation might come at the cost of compromising the extensibility and flexibility to other mission design parameters that may be of interest.

3.4.6.1 Functions

Regardless of propulsion type, all Earth-Mars transportation systems must provide a minimum set of functional capabilities.

3.4.6.1.1 Provide Sufficient Energy to Transport Crew and Cargo from Earth Vicinity to Mars Vicinity and Back Again

The planetary alignment between Earth and Mars constantly changes over a roughly 15- to 20-year synodic cycle, so the amount of energy needed to make the transit will vary depending on the mission opportunity. If the transport is designed for only the “easiest” opportunity, Mars missions may be possible only once per synodic cycle; if designed for the “hardest” opportunity, the transportation system will be robust for all mission opportunities, but will be over-powered for most opportunities and will likely require more upfront technology investment. If the transport carries all required propulsive energy from Earth, its design must ensure that energy remains

[14] *Reference Surface Activities for Crewed Mars Mission Systems and Utilization,* National Aeronautics and Space Administration (2022). HEOMD-415.

available throughout a long round-trip mission duration; if it plans to acquire return energy at Mars or an interim destination, the transport design must accommodate refueling or resupply operations with additional systems. To bound energy requirements, current analyses assume all propellant required for the round trip is launched from Earth and carried roundtrip, without the need to resupply. For the purpose of sizing the transportation concepts, a complement of four Mars crew is currently under evaluation. This is likely a minimum practical limit for the purposes of addressing risk and redundancy; however, larger crew complements would require larger habitats and more consumables, which in turn will increase transportation energy requirements.

3.4.6.1.2 Protect Crew and Cargo from the Deep Space Environment for Transit Duration

In addition to the temperature extremes and near-vacuum pressure common in LEO, Mars transit will have additional complications of increased radiation exposure and prolonged microgravity risks. To protect crew and cargo during the long transit duration, the transport and integrated habitation systems must be sized and configured to mitigate these risks. Leveraging the extensive complement of logistics and consumables (needed due to limited resupply options to address routine and contingency operations) and habitation system arrangement may mitigate long-term radiation exposure while crew exercise and countermeasure systems will address long-term crew health impacts from microgravity. Note that as more mass is added to protect crew and cargo, more energy will be required to transport crew and cargo to Mars and back.

3.4.6.2 Key Decisions and Drivers

3.4.6.2.1 Total Mission Duration

The in-space transportation architecture is dictated by the celestial mechanics of Earth, Mars, and the Sun. The total roundtrip mission duration for a Mars mission is the primary driver for any in-space transportation decisions. Longer mission durations (approximately three years) typically require lower energy, as they can rely on the more favorable alignments between Earth and Mars to perform two optimal transfers between the planets. Shorter missions would require more energy to complete, as the in-space transportation system will need to complete the roundtrip mission while fighting against the natural orbital energy of the two planets. The energy required, and therefore the propulsion technology and total propellant mass, scales exponentially with mission duration, so the shorter missions are exponentially harder than the longer missions. The total mission duration decision also cannot be made solely on the basis of the in-space transportation system; factors such as crew health and performance as a function of total mission duration must also be considered. This decision has broad implications for crew systems, crew health, Mars orbit time, and Mars surface time, which in turn will influence the scope of utilization activities.

3.4.6.2.2 Mars Vicinity Stay Time

The decision on Mars vicinity stay time is driven by three factors: the Mars surface mission duration, the Mars orbital operation requirements, and the total roundtrip mission duration. The minimum surface stay duration will be the minimum duration that the in-space transportation system needs to remain in Mars orbit. However, additional time is required to prepare and transfer crew to the MDS prior to the surface mission, as well as time for the MAV to rendezvous, dock, and transfer crew and cargo back to the transport after ascent from the surface. The current assumption for these activities is 10 Martian sols prior to descent and 10 sols following ascent, totaling 20 sols, but assessment of operational needs and constraints is required to guide the final Mars orbit stay time decision. Finally, the total roundtrip mission duration will also have significant impact on the orbit stay time. The shorter mission durations will have a lower bound for the orbit stay time, as the interplanetary trajectory is more energy efficient with more total duration in deep space, rather than in Mars orbit. For longer-duration missions, the need to await optimal planetary alignment for the return journey will likely mean there will be a significant Mars orbit stay time available.

3.4.6.2.3 Mission Operation Mode

Mission operation mode refers to how the end-to-end mission is conducted and has significant implications to all other Mars decisions. The current assumption for the mission mode is an “all-up” mode, where the crew transportation stack departs Earth with all the propellant and logistics required to support the roundtrip mission. This is assumed for crew risk mitigation considerations, as the crew does not need to rendezvous with any propellant or logistics assets after Earth departure to return safely, potentially descoping the surface mission in the event of an anomaly. Shorter duration missions with higher energy may necessitate the pre-deployment of propellant at Mars to reduce the overall size of the transportation system.

To support the surface missions, the current assumption is that the surface assets are pre-deployed to the surface to wait for the crew. Potential options exist to integrate the surface elements with the crew stack so that no rendezvous is required in Mars orbit to support surface missions.

3.4.6.2.4 Mars Parking Orbit

The selection of the parking orbit at Mars for staging and aggregation of the mission will depend on the architecture and mission mode decisions and surface abort timing constraints. The current assumption for Mars parking orbit is a five-sol orbit, with the perigee of the parking orbit directly above the landing site to support a direct landing. This high-altitude parking orbit is beneficial to the transportation system because it does not require the whole transportation stack to insert deep into Mars’ gravity well, but it puts an additional burden on the MAV, as the energy and time required to reach five-sol orbit are higher than for a lower parking orbit.

3.4.6.2.5 Mars Landing Site

Related to the selection of the parking orbit, the final selection of the landing site will have significant impact on the transportation system. This decision will be interlinked with the Mars EDLA system. Assuming the EDL system does not have its own cross-range capability, the transportation system needs to deliver the EDL system to the appropriate parking orbit for descent to the surface. This could mean the transportation system needs to perform additional orbital maneuvers to change the orbital parameter of the parking orbit to align for the descent and potentially ascent portions of the mission. This impact is particularly profound for the crew transportation system, as the integrated end-to-end trajectory needs to both bridge between the Mars arrival and departure interplanetary directions and satisfy the potential parking orbit constraint due to the landing site selection.

3.4.6.2.6 Number of Crew Members

The total number of crew members required will have a significant impact on the design of the transit habitation systems. Systems such as ECLSS (and associated maintenance and spares logistics) need to be scaled up as the number of crew increases, as do habitable volume and logistics consumables such as oxygen, food, water, medicine, clothing, and hygiene supplies, which has flow-down effects on the transportation systems. Conversely, selection and design of the propulsion system will also impact the decision about the number of crew members because of maintenance, repair, operational variations, and launch vehicle limitations between the different transportation system options.

3.4.6.2.7 Transit Habitation System

The primary decision about the transit habitation system concerns the integration between the habitat and the in-space transportation system. The habitation system can be integrated as part of the in-space transportation system or can be designed as an independent system. The current assumption for the transit habitation system is an independent system that will first facilitate early long-duration Mars precursor missions and Artemis activity in conjunction with Gateway before serving as the habitation system for the Mars missions. Another aspect to be decided is whether the habitat should be a monolithic unit or modular in nature.

3.4.6.2.8 Propulsion Technology

There are multiple options for the transportation propulsion system. The decision will be informed by a plethora of other decisions, including total mission duration, transit habitation strategy, mission mode operation, and others. Nuclear versus non-nuclear propulsion systems and high-thrust ballistic systems versus low-thrust systems versus hybrid high-/low-thrust systems are just a few of the propulsion technology decisions that must be made. However, propulsion system performance alone may not be a sufficient discriminator. The target date for a first human Mars mission will establish the propulsion system delivery date, which in turn will constrain technology development timelines—and may eliminate technologies that cannot be developed within the timeframe or dictate a phased strategy wherein early missions rely on available propulsion technologies and more advanced technologies are phased in during later missions. These key decisions will also be informed by non-technical considerations, such as the broader strategy question of long-term exploration objectives or technology development partnering arrangements with other agencies, industry partners, or international partners.

3.4.6.2.9 Aggregation Location & Strategy

The Artemis and Gateway Program lends itself to aggregation in cislunar space, such as NRHO; however, alternate orbits from LEO, medium-Earth orbit, and high-Earth orbit could also be considered, which may increase the Earth ascent vehicle options. The decision about where to aggregate the in-space transportation system and the strategy associated with it will depend heavily on several factors, such as the selection and design of the propulsion system, the availability of different launch vehicles and their associated launch mass, volume and crew complement capability, the launch cadence of the aggregation campaign, and the parking orbit distance from the Mars surface. Each transportation system option has optimal aggregation locations and strategies based on launch vehicle cadence and capability; however, the integrated nature of the aggregation strategy means that other variables complicate the decision about aggregation location.

3.4.6.2.10 Element Reuse Strategy

The reusability of any of the transportation elements is a key driver in the design of the system. If additional follow-on missions to Mars are desired to establish routine access to Mars' surface, then the ability to reuse elements will be a key decision in enabling these missions. If reusability drives in-space transportation system mass, impacts may flow down to the Earth launch campaign. Reuse strategy will include deciding whether to optimize the transportation system for all mission opportunities (enabling missions about every 2 years) or to optimize for other constraints (potentially limiting mission availability). Note that a 15-year service life is currently assumed for the transit habitat, enabling it to support dual roles as a Mars crew transport and for analog and lunar support missions.

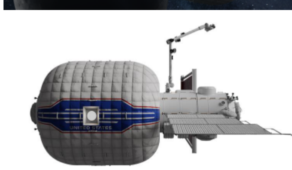
3.4.6.3 System Concepts

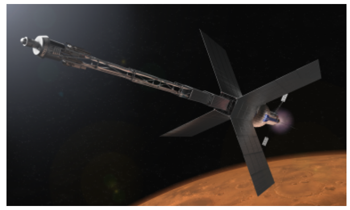
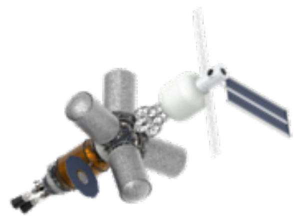
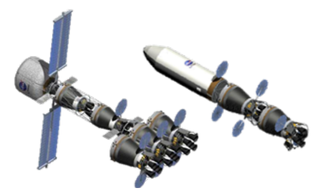
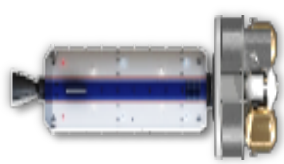
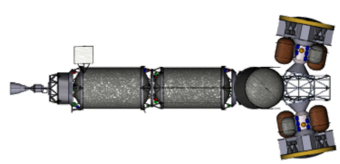
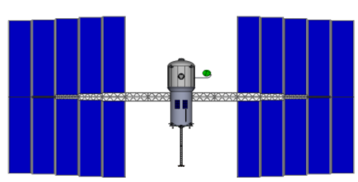
Table 3-31. SAC22 In-Space Transportation Analysis Trade Space

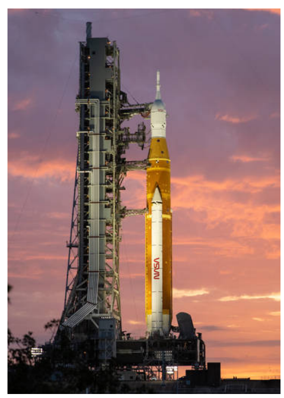
Transportation Options / Mission Options	Hybrid Nuclear Electric / Chemical 	Nuclear Thermal 	Hybrid Solar Electric / Chemical 	All-Chemical 
Reference Mission **0** Short Duration Light Footprint Short Surface Stay	**M0-NEP** 1.8 - 3.6 MW NEP 3x 25k lb$_f$ LCH4/LO2 NRHO Assembly NRHO Refueling SAC21	**M0-NTP** 5x 12.5k lb$_f$ NTP 10x 6mØ Drop Tanks LEO Assembly No Refueling	**M0-SEP** *TBD ConOp* *TBD Assembly* *TBD Refueling*	**M0-CP** *TBD ConOp* *TBD Assembly* *TBD Refueling*
Reference Mission **1** Moderate Duration Light Footprint Short Surface Stay	**M1-NEP** <1.8 MW NEP 3x 25k lb$_f$ LCH4/LO2 NRHO Assembly NRHO Refueling SAC22	**M1-NTP** 2x 12.5k lb$_f$ NTP 5x 6mØ Drop Tanks MEO Assembly No Refueling SAC22	**M1-SEP** 1MW Array / 400kW SEP 3x 25k lb$_f$ LCH4/LO2 NRHO Assembly NRHO Refueling SAC22	**M1-CP** Tanker + Depot Integrated Surface Payload LEO Assembly LEO Refueling SAC22
Reference Mission **2** Longer Duration Minimum Energy Light Footprint Short Surface Stay	**M2-NEP** *TBD ConOp* *TBD Assembly* *TBD Refueling*	**M2-NTP** *TBD ConOp* *TBD Assembly* *TBD Refueling*	**M2-SEP** 700kW Array / 400kW SEP 6x 1k lb$_f$ LCH4/LO2 NRHO Assembly NRHO Refueling SAC22	**M2-CP** Tanker + Depot Integrated Surface Payload LEO Assembly LEO Refueling SAC22

To better understand the performance of various propulsion system designs in the context of the analysis reference missions, four different propulsion and power options are currently under evaluation: a hybrid nuclear electric propulsion (NEP)/chemical propulsion system, nuclear thermal propulsion (NTP) system, hybrid solar electric propulsion (SEP)/chemical propulsion system, and all-chemical propulsion systems. The NEP/chem hybrid and NTP systems are nuclear options, and the SEP/chem and all-chem systems are non-nuclear. Table 3-31 summarizes the various potential implementations of each system being analyzed, with respect to each of the three reference missions. Campaign manifest designations represent implementations with enough conceptual design fidelity for preliminary campaign assessments; implementations without such designations remain forward work.

Table 3-32. Mars Transportation System Functions and Example Concepts

Functions	Example Concept(s)		Heritage and Status
Transport crew from Earth vicinity to Mars vicinity and return	Transit Habitat	 	Reference conceptual design of an independent transit habitat informed by previous Next Space Technologies for Exploration Partnerships (NextSTEP) Appendix A activities

Functions	Example Concept(s)		Heritage and Status
Transport crew system from Earth vicinity to Mars vicinity and return	Piloted Crewed Hybrid NEP/Chem Propulsion System		Power generation linked to terrestrial power systems; EP system potentially extensible from Gateway PPE
	Piloted Crewed Nuclear Thermal Propulsion System		Heritage to NERVA Program
	Piloted Crewed Hybrid SEP/Chem Propulsion System		Reference concepts derived from Gateway PPE, with extensibility to Mars NEP/chem hybrid
	Piloted Crewed Chemical Propulsion System		Concepts development ongoing, technology is relatively mature, but challenges remain
Transport cargo from Earth vicinity to Mars vicinity	Cargo Chemical Propulsion System		Potential utilization of chemical stage of the hybrid NEP/chem or SEP/chem system
	Cargo Nuclear Thermal Propulsion System		Similar to piloted variant, but potentially with fewer elements and/or lower thrust needs
	Cargo SEP/Chem Propulsion System		Similar to piloted variant, but potentially lower power needs

Functions	Example Concept(s)		Heritage and Status
Crew Earth launch; reposition to DST; and Earth entry, descent, landing	Orion Spacecraft		Flight design Orion available for all mission opportunities for use with all transportation architecture variants
Earth launch for cargo (> 5 m diameter; > 15,000 kg mass to translunar injection condition)	Commercial Heavy Lift Systems		Commercial heavy-lift conceptual designs available
Earth launch for cargo >7 m diameter TBD kg mass to various aggregation orbits	Super Heavy Lift Systems		Space Launch System flight design available; commercial super heavy lift conceptual designs in development
Aggregation and storage of propellant in space	Propellant Tanker Systems		Propellant tanker systems may not be needed for all architecture implementations; concepts development is ongoing
Provide systems and facilities to process, launch, and recover launch vehicles	Ground Systems		Government and commercial infrastructure available

As shown in Figure 3-22, Figure 3-23, Figure 3-24, and Figure 3-25, several conceptual designs of each transportation architecture are being developed to allow stakeholders to better assess option performance across the range of mission duration options. These figures demonstrate how vehicle size and complexity vary as just one parameter, total mission duration, is varied.

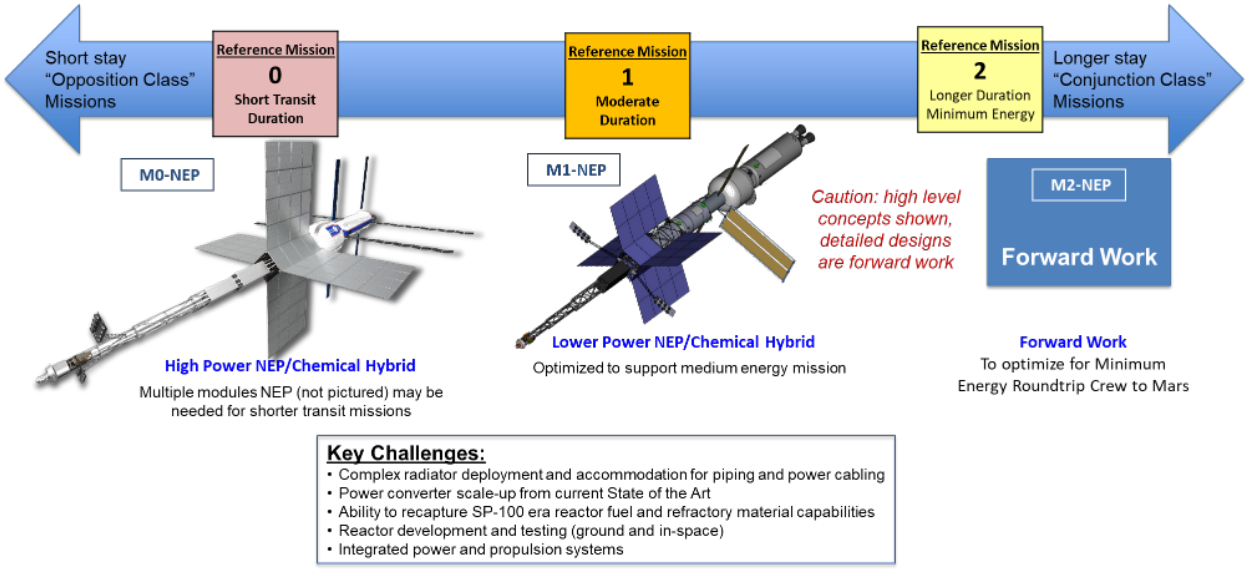


Figure 3-22. Hybrid NEP/Chem Concepts Across a Range of Total Mission Durations

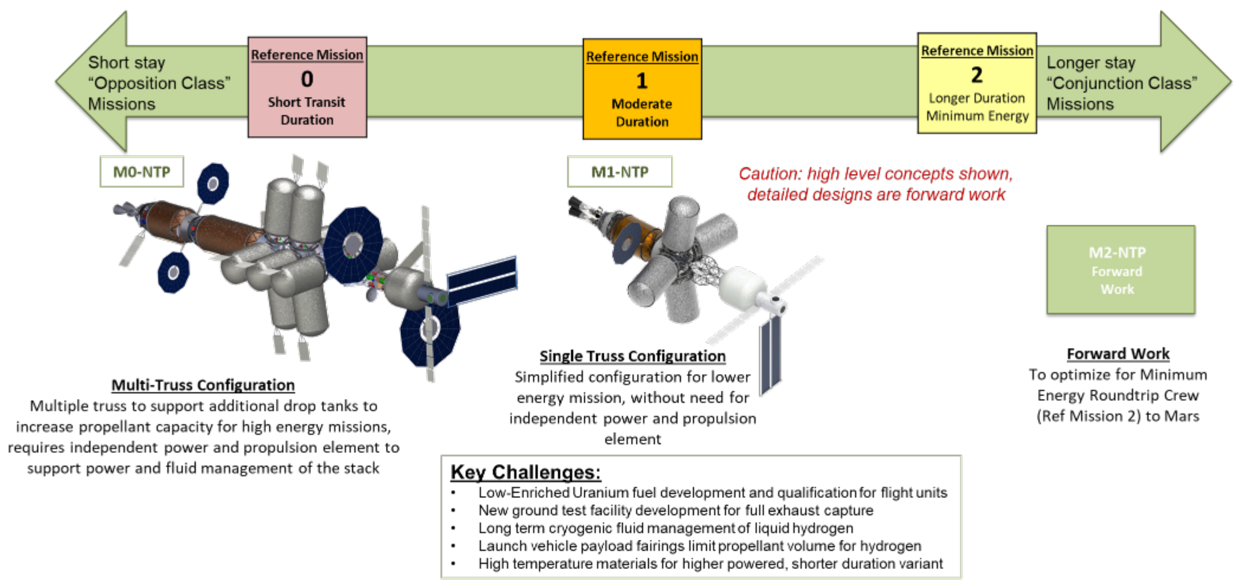


Figure 3-23. NTP Concepts Across a Range of Total Mission Durations

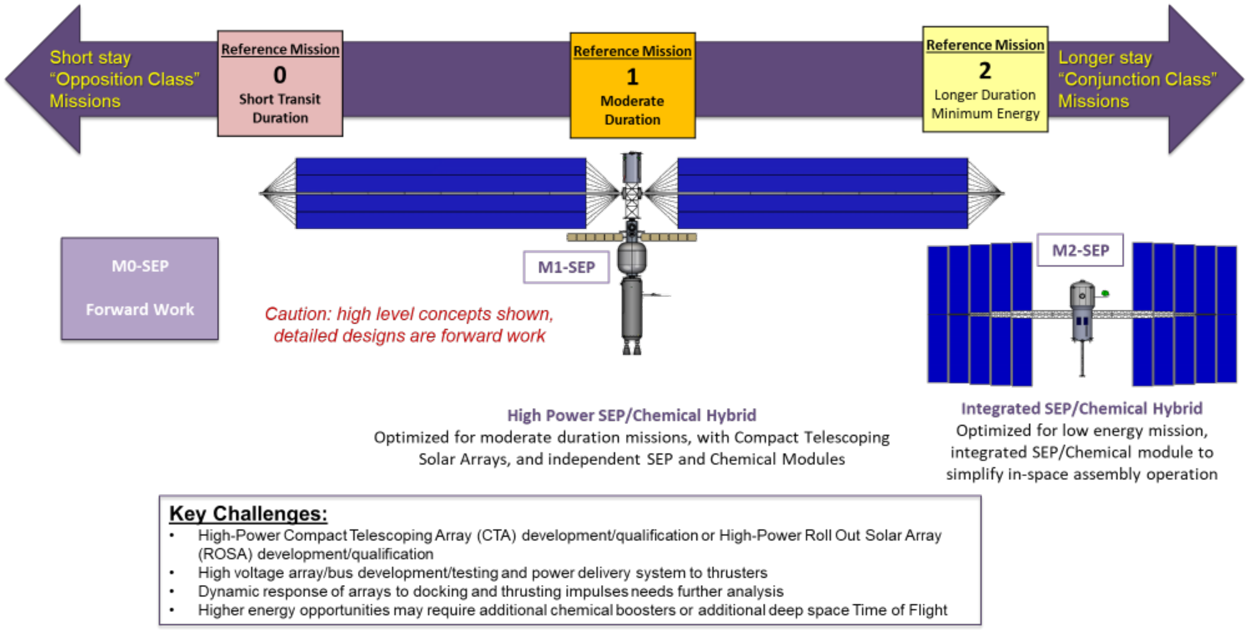


Figure 3-24. Hybrid SEP/Chem Concepts Across a Range of Total Mission Durations

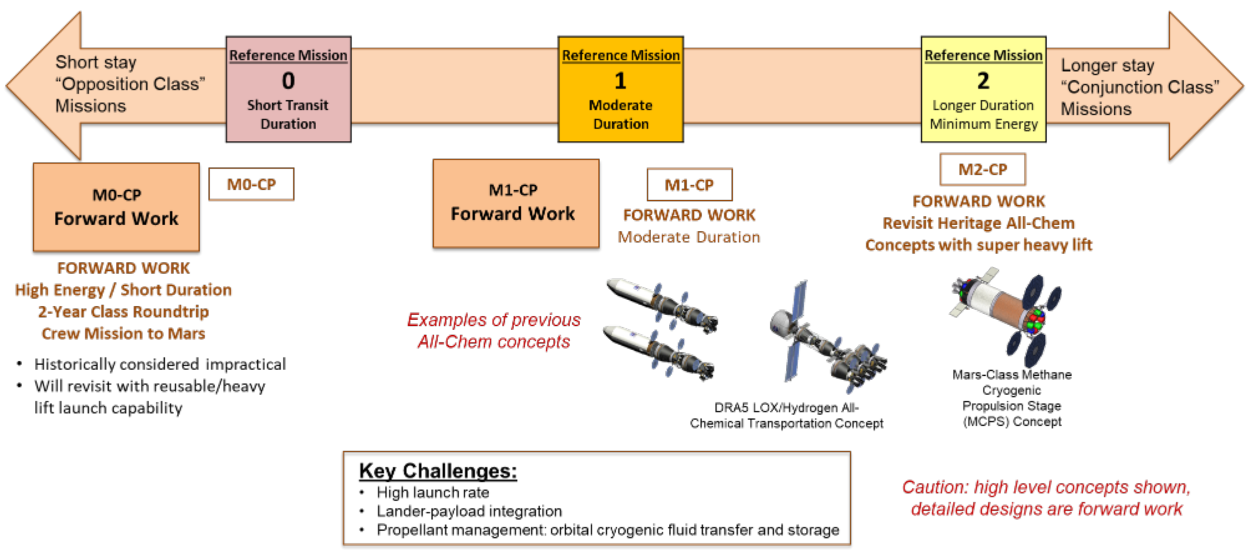


Figure 3-25. All-Chem Concepts Across a Range of Total Mission Durations

3.4.6.4 Concepts of Operations

All four major transportation propulsion system architectures will require multiple Earth launches to an aggregation point, as well as in-space assembly, outfitting, and fueling of the deep space transportation system prior to crew boarding. However, the details of where, how, and when these steps occur vary by architecture, optimization choices made, and potential policy direction.

3.4.7 Mars Crew Support Systems

The Mars crew support architecture category covers elements needed to ensure that crew can perform across multiple mission phases. For the purpose of this document, it is assumed that these systems are common across all transportation architectures and surface concepts.

3.4.7.1 Communications

The Mars surface and close vicinity communications architecture is assumed to closely mirror the Lunar Architecture until further study is completed. A unique challenge for a Mars mission will be addressing the approximately two-week period during which the Sun interrupts the line-of-sight path between the crew and Earth, making direct communication impossible. An uninterruptable relay could mitigate this blackout period, though it should be noted that this potentially increases the communications lag time, since the relay must be placed far enough from Mars to maintain line of sight to Earth when the Sun is between Earth and Mars. In addition to this disruption, the relatively long and variable time delay for communications poses a challenge. Both the disruption and delay will drive a need for more advanced Earth-independent operations.

3.4.7.1.1 Functions

The Mars communications system must transmit voice and data between Earth and the various Mars Architecture vehicles (crew and cargo DST, MDS, MAV, and Orion), between Mars Architecture vehicles, between Mars surface to Mars orbit, and between surface assets.

3.4.7.1.2 System Concepts

The Mars communications system elements will include communication components for EVA suits, mobility platforms, landers, transit vehicles, and uninterrupted Earth relay. Additional relay assets, if required, will be defined in future studies.

3.4.7.1.3 Concept of Operations

The Mars communications system concept of operations will be substantially different from lunar operations because of the delay caused by the increased distance from Earth-based ground support, up to 22 minutes each way, and the annual communications blackout of up to two weeks. The current architecture concepts posit the Mars transit vehicle acting as the primary relay between the surface systems network to Earth-based networks during the crewed surface phase of the mission. Another concept under consideration is having the surface crew rely on the orbital crew (that remain aboard the Mars transportation system) to provide low-latency verbal guidance and expertise to augment the longer latency-Earth support. It remains forward work to fully develop the Mars communications concept of operations that supports both near- and far-range operations with varying magnitudes of latency.

3.4.7.2 IVA and EVA Suits

3.4.7.2.1 Functions

The primary functions of the Mars IVA suit system are to provide life support and mobility to protect crew from the various environments encountered during Earth or Mars launch and landing. This includes potential contingencies such as cabin depressurization, fire, or toxic atmospheres. In addition, the IVA suit system must provide sufficient safety, mobility, communications, and comfort for crew to perform their duties inside a vehicle.

The primary function of the Mars EVA suit system is to protect crew from the various environments encountered during a Mars mission, independent of a pressurized cabin. This includes potential cabin depressurization or external vehicle contingency excursion events in the deep space transit environment, as well as nominal EVA operations on the Mars surface environment. In addition, the EVA suit system must provide sufficient safety, mobility, communications, and comfort for crew to perform their duties inside or outside a vehicle for time periods of up to a full workday. Functionality and design features of the suit must also support vehicle and element assembly, system check-out, maintenance and repair operations, and mission utilization objectives. The Mars EVA suit must also integrate with Mars surface systems to enable safe, rapid crew ingress/egress to and from Mars surface system habitable volumes.

3.4.7.2.2 System Concepts

Table 3-33 summarizes the major IVA and EVA suit system concepts and status. The current Mars Architecture assumes that IVA and EVA suit system elements used during Earth and Mars launch/entry and microgravity phases will be substantially like those used for similar operations at the Moon. However, the Mars surface suit, intended for Martian surface operations, will have some important differences from its lunar counterpart. The higher Martian gravity may make mass reduction a priority, and the thin Martian atmosphere will require changes in life support system operation. However, increasing mass can also improve joint design for mobility and suit ingress, so mass increases should not be discounted without accounting for the necessary operational, ergonomic, and injury prevention tradeoffs. As noted above, habitable volumes available to at least the first Mars crew are likely to be different than those available to Artemis lunar crews, so ingress/egress strategy for the Mars crew cabins will influence Mars EVA suit design. Finally, planetary protection requirements for Mars are expected to be more stringent than on the Moon, which may influence permissible leakage rates or venting operations, as well as dust control techniques.

Table 3-33. Mars IVA/EVA System Functions and Example Concepts

Functions	Example Concept(s)		Heritage & Status
Crew life support and protection from the environment primarily intended for use inside a decompressed vehicle cabin	Launch and Landing IVA Suit		Orion Crew Survival System planned for use by Artemis
Crew life support and protection from the environment for use inside a decompressed cabin, or for short excursions outside a vehicle in microgravity (not intended for planetary EVA)	Emergency EVA Suit		Reference concept available. May not be required if microgravity EVA suit and Mars surface suit can provide all necessary functionality.

Functions	Example Concept(s)		Heritage & Status
Crew life support and protection from the environment for longer excursions outside a vehicle during Earth-Mars transit	Microgravity EVA Suit		Reference conceptual design available. This concept may be substantially similar to EVA suits used on Gateway. May not be required if no nominal microgravity EVA is planned (default to emergency EVA suit in that case).
Crew life support and protection from the environment for excursions outside a vehicle on the Mars surface	Mars EVA Surface Suit		Reference conceptual design available. Can leverage Artemis lunar suit lessons learned, but the Mars suit will be unique due to gravity, environmental differences, and planetary protection strategies.
Primarily safety equipment, such as tethers	Crew-worn EVA Accessories		Forward work

3.4.7.2.3 Concept of Operation

The Mars IVA suit system concept of operation is expected to be substantially similar to crew Earth launch/landing, lunar transit, and Gateway operations. Mars descent and ascent operations are expected to be similar enough to crew Earth launch/landing that a common IVA suit can be used for both. The Mars EVA suit system will be designed to allow crew members to perform autonomous and robotically assisted EVA exploration, research, construction, servicing, and repair operations in environments that exceed human capability. Current concepts assume the suit can egress and ingress habitable vehicles and provide life support, thermal control, protection from the environment, waste management, hydration and in-suit nutrition, communications, and mobility/dexterity features designed to interact with spacecraft interfaces and supporting tools and equipment such that exploration, science, construction, and vehicle maintenance tasks can be done safely and effectively. Advanced concepts may also include designs that support rapid crew ingress/egress (to improve physical health outcomes associated with reduced pressure in suits and to reduce the risks of decompression sickness in crew) and enhance planetary protection protocols for the Mars environment or habitable vehicle and beyond (forward and backward contamination).

Current concepts assume that the pressure garment provides for resizing and modular component interchanges to enable proper fit across a wide range of anthropometries (1st–99th percentile). Interfaces in the Mars portable life support system and pressure garment enable incremental upgrades to new technologies as the mission and destination evolve. Contamination from Mars dust constitutes a challenge to the design of mobility joints and the like, along with solutions to the introduction of surface contamination to crew habitat. The EVA crew will utilize advanced informatics designed into the suit system. These informatics will grant the EVA crew more autonomy with both tasks and suit monitoring due to the signal latency between Mars and Earth. Developing concepts and operations to address compatibility with the chemically reactive soil, as well as forward (planetary protection) and backward (crew health) contamination during crew ingress/egress operations, remains as forward work. As one important link in breaking the chain of backward planetary protection, current operational concepts assume the Mars EVA surface suits are left behind on Mars and crew members return to Mars orbit in their IVA suits.

3.4.7.3 Logistics Management

Requirements for Mars exploration missions often overlap with those driving the Lunar Architecture. Where possible, Mars logistics management requirements should be met by leveraging these architectural similarities. In cases where options are also applicable to either the Moon or Mars, Moon to Mars considerations should drive the selection of a concept that can satisfy both. However, some requirements will be specific to Mars and require a different approach.

3.4.7.3.1 Functions

The primary purpose of Mars logistics management is to provide for the transportation, storage, tracking, and disposal of logistics, including crew consumables (e.g., food, clothing), life-support system commodities (e.g., breathing air, water), utilization, maintenance and spares, and other supplies and materials needed to implement crewed Mars missions. The logistics functions include coordination with in-space and surface transportation assets for performing support functions (either manually or with robotic assistants) needed to ensure that logistics arrive at the point of use as efficiently as possible. Functional capabilities assumed are detailed in the sections below.

3.4.7.3.2 Mars Transit Logistics Concepts of Operations

Logistics for the in-space phase of the crewed mission are delivered and aggregated within the transportation and habitation system prior to Earth departure. Because of the amount of logistics required for the crewed Mars mission, the majority of the required logistics are delivered to the transportation and habitation system prior to the actual Mars crew departure. Logistics modules (standalone flights, SLS co-manifested, or commercial co-manifested as needed) are used to both supply logistics for crew Gateway/transportation and habitation system operations in those years and to pre-emplace logistics for the crewed Mars mission.

A final logistics module is delivered to the transportation and habitation system in Earth orbit with the Mars crew immediately prior to the Mars mission. This final logistics module is used to deliver the logistics items that are most critical from a lifetime perspective, such as food, medicines, and crew-specific items. The logistics module is detached and disposed of, along with any trash, prior to trans-Mars injection. Lower–time priority items are delivered to the transportation and habitation system earlier.

The logistics stored on the transportation and habitation system prior to Earth departure include all of the logistics necessary to complete the mission. No pre-emplaced logistics are utilized to complete the in-space segment of the Mars mission. The total logistics include the logistics that are required for the crewed in-space duration of the mission, including time in Mars orbit, for the entire crew. While some or all of the crew will nominally spend a portion of that time on the surface, transportation and habitation logistics are still manifested for that period in case the crew are unable to complete the surface mission and must stay aboard the transportation and habitation system. Additional logistics are also manifested to cover the potential maximum crewed pre-departure duration. This period covers the potential Orion launch period, as well as an additional time to allow for logistics transfer and final mission preparations. This will allow Orion enough opportunities to get the crew to the spacecraft in the event of unexpected launch pad delays. Similarly, logistics are manifested to cover the end-of-mission Earth orbital duration, allowing for rendezvous and docking with Orion, as well as any time required for final transfers. If the entire

Orion launch duration is not needed in the transportation and habitation systems, any remaining consumables for that period are disposed of in the logistic module prior to trans-Mars injection.

In addition to the nominal durations listed above, additional logistics are also manifested to cover contingency situations. Contingency gas and water are manifested to cover periods where regenerative ECLSS may be unavailable during repair activities. It is assumed that waste products are stored during this period and then processed after the repair is completed to build the contingency store back up. Additional contingency logistics may be manifested in the safe haven to cover periods where the crew may be forced to shelter there.

Disposal of trash is a key issue for the in-space portion of the Mars mission. Because of the propulsive requirements, it is undesirable to accumulate trash in the transportation and habitation system. Methods to dispose of trash during the transits to and from Mars will be considered to reduce the total transportation and habitation system mass.

3.4.7.3.3 Mars Surface Logistics Concept of Operations

For surface operations, the logistics are pre-positioned in Mars orbit and then delivered to the Martian surface with the crew. Logistics delivery for surface operations is designed to reduce the burden on the crew and to preserve crew time for utilization activities. While logistics may be delivered either internally to the habitable surface elements or in external carriers, it is desirable to deliver the maximum possible amount of logistics in elements directly accessible to the crew, reducing the need to transfer logistics from carriers.

Surface logistics are provided to support the entire surface missions. These include all required consumables and utilization, as well as any maintenance items that are required to provide high availability for surface systems. Logistics are also provided to cover various surface contingency scenarios. This could include consumables to provide protection against system failures, spares for systems, and additional consumables to cover extend duration, if necessary.

Disposal of trash is also a key issue for surface operations. Because of planetary protection considerations, it will be necessary to dispose of trash on the surface in a manner that prevents contamination at the landing site.

3.4.7.4 Crew Systems

Crew systems for habitability include direct crew care systems, such as food and nutrition consumables and preparation equipment; personal hygiene systems, including body waste management, clothing, housekeeping equipment and consumables; physiological countermeasure systems (such as aerobic and resistance exercise equipment); crew privacy systems; and sleeping accommodations.

Crew systems for in-flight medical operations include medical diagnostic and treatment equipment and consumables typically found in medical kits, plus the appropriate volume and restraints to support and safely restrain an injured or incapacitated crew member. Vehicle systems also need to support accessing and updating crew medical health records, accommodating private medical conferences, and sharing medical data with ground-based flight surgeons. Each program typically includes a more detailed crew health concept of operations document.

Within the architecture, design for crew shall accommodate the physical characteristics, capabilities, and limitations of crew to ensure health, safety, and performance, as well as continued hardware and system functionality. Physical characteristics may include anthropometry as well as range of motion, strength, and visual and hearing acuity. Behavioral capabilities include cognition and perception. Limitations for continued health may include radiation, acceleration and dynamic loads, acoustics, and vibrations, as well as environmental hazards (e.g., thermal, atmospheric, water). Accommodations may drive design for size of physical volumes, configuration of systems within, placement of restraints and mobility aids, accessibility of translation paths through spaces and hatches, and lighting to support tasks, as well as emergencies and circadian alignment for sleep. For usability, durability, and maintenance and training minimization, systems design shall consider how and how often humans perform system tasking, typically planned for via early human system integration and demonstrated by task analysis and human-in-the-loop testing. Systems shall avoid injury to crew through design, such as smoothing of sharp edges, elimination of pinch points, and prevention of unexpected energy release, electrical hazards, or chemical release, etc. Finally, systems shall be designed to account for crew survival during various defined contingency scenarios.

As much as possible, these systems will be derived from Artemis and International Space Station systems, though the longer Mars mission duration, combined with limited resupply options, minimal spare parts, shelf-life limitations, and longer communications lag times will necessarily require modifications, particularly to medical capabilities and food systems. These systems also need to integrate Earth Independent Operations (EIO) strategies to support associated maintenance, repair, state monitoring and diagnostics, etc., during continuous long-duration operation with reduced/delayed ground support capability.

3.4.8 Open Questions, Ongoing Assessments, and Future Work

As noted, objective decomposition and use case and function definitions for the Mars segment have not been fully completed, and much of the trade space, particularly for sustained human presence, is still being assessed. Ongoing studies are evaluating return propellant strategies, surface infrastructure needs, and EDLA options to build integrated end-to-end campaign models, which in turn will support trade studies between the four candidate transportation technologies. Additional analysis remains to evaluate infrastructure and science objective implementation options, assess end-to-end architecture impacts, and develop integrated concepts of operation. Continuing human health and performance research is being assessed in the context of Mars mission durations and operational challenges, and risk mitigation options are being identified and evaluated. These examples are not intended to be a comprehensive list of open work; this document will be updated as additional analysis and research are identified and completed.

4.0 ASSESSMENT TO THE RECURRING TENETS

Within the Moon to Mars Strategy and Objectives Document, NASA established a high-level set of recurring tenets (RTs) to guide the exploration architecture. These tenets embody common themes that are broadly applicable across all the objectives. They provide guidance related to how objectives should be pursued to ensure successful execution of the Moon to Mars endeavor. Using these objectives as a guide, the Moon to Mars Architecture and the elements will be managed and coordinated through a framework of sub-architectures and campaign segments to organize the decomposition. The essential nature of this framework is to ensure the progression of development toward greater objective satisfaction through campaign segments to return and sustain human presence in deep space. This constant traceability and iteration through the architecture process between the current state of execution and future goals and desired outcome will ensure infusion of technology, innovation, and emerging partners.

To ensure this progression and iteration of approach, assessments of progress and adherence to the recurring tenets is incorporated as an ongoing process. The Moon to Mars Architecture will be assessed against each tenet, evaluating how these guiding principles are reflected in the current architecture. In addition, potential gaps in the current Moon to Mars Architecture will also be identified to help guide future iteration and refinement of the architecture. These assessments will be coordinated with the stakeholders of each tenet. The assessments are not exhaustive and future revisions of this document will continue to update, evaluate, and assess the progress of the architecture in adhering to the tenets.

4.1 RT-1 INTERNATIONAL COLLABORATION

RT-1: Partner with international community to achieve common goals and objectives.

Architecture Assessments:

An integral part of the Moon to Mars Architecture is the desire to usher in a new era of exploration with the recognition of the mutual interest between NASA and international partners in the exploration and use of outer space for peaceful purposes. Coordination and cooperation between and among established and emerging actors in space is a foundational principle of Artemis. This is best accomplished through partnership and collaboration with members of the global community and will be reflected in every segment of the Moon to Mars Architecture.

International partners can propose cooperation to address gaps in the Moon to Mars Architecture. NASA and potential partners would then conduct technical discussions to identify discrete cooperative activities. Once a proposed technical capability reaches a sufficient level of maturity and has passed internal NASA reviews, it formally enters the Moon to Mars Architecture and becomes a part of the subsequent ADD. Specific cooperative activities, such as those listed below (e.g., Gateway, PRISM) will be identified in the ADD once formal international agreements on project cooperation are concluded.

NASA has many such international partnerships already in place, as well as ongoing discussions with prospective partners about potential contributions to the Moon to Mars Architecture, such as the following:

- **European Service Module (ESM):** The European Space Agency (ESA) provided the ESM, which powered the Orion spacecraft around the Moon on Artemis I and will do so on future Artemis missions.

- **Gateway:** ESA, the Japan Aerospace Exploration Agency (JAXA), and the Canadian Space Agency (CSA) are NASA's partners on Gateway; all are providing key elements to develop and operate this cislunar outpost.
- **Artemis I:** Several international partners provided payloads to research key knowledge gaps for deep space exploration. These partners included ESA, the German Aerospace Center (DLR), and the Israel Space Agency (ISA), which provided radiation experiments, and JAXA and the Italian Space Agency (ASI), which provided CubeSats.
- **Lunar science:** NASA's SMD is leading the CLPS initiative, to deliver payloads to cislunar orbit and the lunar surface, as well as partnering on international partner-led missions to achieve science, exploration, and technology development goals and priorities for the Moon. International partners are participating by joining U.S.-led proposals to Payload and Research Investigation from the Surface of the Moon (PRISM) solicitations, being sponsored by NASA for delivery via CLPS, or contracting with a CLPS vendor directly for opportunities to reach the Moon. NASA has sponsored CLPS deliveries for payloads from ESA, the Korean Astronomy and Space Science Institute (KASI), CSA, and University of Bern, Switzerland. The French Centre National D'Études Spatiales (CNES) is participating in the U.S.-led far side seismic payload and an electromagnetics experiment. Additionally, university partners from Denmark, Switzerland, and the United Kingdom are participating in U.S.-led lunar surface payloads selected under PRISM. NASA is also contributing instruments to various international missions, including a laser retroreflector on JAXA's Smart Lander for Investigating Moon (SLIM) mission, an infrared imager on CSA's Lunar Exploration Accelerator Program (LEAP) rover, a laser retroreflector on the Indian Space Research Organisation's (ISRO) Chandrayaan-3 mission, a radiation experiment on ISA's Beresheet-2 mission, and a neutron spectrometer on JAXA and ISRO's Lunar Polar Exploration (LuPEX) mission. In addition, NASA contributed the ShadowCam, a camera that scans shadowed areas for ice deposits and landing zones, to the Korea Pathfinder Lunar Orbiter (KPLO), which was launched in 2022. International partners will have opportunities to submit proposals to Artemis science solicitations, such as the recent Artemis III Deployed Instruments call.
- **Space life sciences and human research**: NASA's Biological and Physical Sciences Division (BPS) is interested in investigating the properties of physical systems, including their functions and behavior, in the Moon's radiation environment and partial gravity. In addition to the objectives in the Artemis III Science Definition Team Report, research priorities will be based on the 2023 life and physical sciences decadal survey. Space and life sciences cooperative activities are discussed in the International Space Life Sciences Working Group (ISLSWG) and with international partners on human health and biological sciences utilization, including via working groups established through the Gateway Program. These teams have been developing collaborative science Gateway payloads, beginning on Artemis IV.
- **Mars science**: NASA and ESA are planning to bring the first samples of Mars material back to Earth. The Mars Perseverance rover, currently exploring the Jezero Crater, is the first leg of this international, interplanetary relay mission and includes several international participants. International partners have contributed in various ways to the NASA-led Mars orbiters, landers, and rovers in the past decades, with international dialogue occurring in the International Mars Exploration Working Group (IMWEG).
- **Space communications and navigation:** NASA is currently engaged in discussions with several space agencies regarding potential Artemis cooperation for ground stations, lunar relays, navigation assets, and lunar surface communications elements. These

international partners include ESA, ASI, and JAXA, as well as the United Kingdom Space Agency, the New Zealand Space Agency, and the Australian Space Agency (ASA), among others. In addition, NASA is coordinating its planned commercial lunar relay procurement with a similar ESA activity called Moonlight. Additionally, there is an effort to build a new ground station network of lunar antennas, including NASA-owned assets, commercial service providers, and international partner contributions; South Africa and Australia are potential hosts of these NASA-owned ground stations.

- **Additional capability discussions:** NASA is conducting technical studies and discussions with partners such as ESA, JAXA, ASI, CSA, the Luxembourg Space Agency, and the United Arab Emirates, developing concepts in multiple areas, including rovers, cargo delivery to the lunar surface, habitation, and lunar communications.
- **Technology:** International space technology partnerships generally focus on low technology readiness levels and fundamental research, the results of which are then shared publicly. An example of this type of cooperation would involve dissimilar but redundant capabilities to augment common technology development objectives, such as NASA's ongoing collaboration with the ASA regarding a mobile regolith collection capability on the lunar surface to support mutual ISRU demonstration objectives.
- **Public diplomacy/education:** NASA conducted public diplomacy and educational outreach events before and after the successful Artemis I mission to raise awareness and excitement about the Artemis Program. These included translating the children's book *You Are Going* into languages such as French, German, Italian, and Spanish. Additionally, the announcement of each new Artemis Accord signatory brings new awareness of the Artemis Program through social and traditional media. Prior to the launch, NASA and the Department of State organized a meeting with all the Artemis Accords signatories to brief them on the mission and our public engagement plans. Going forward, NASA is consolidating and sharing Artemis-related educational materials with a global audience.

RT Considerations:

NASA envisions that a wide range of international partnerships will be enabled by the Moon to Mars Architecture, which will identify potential gaps and opportunities for collaboration. Cooperation will occur across the full spectrum of opportunities—from infrastructure to science, technology, and education activities on and around the Moon, Mars, and beyond. New opportunities for cooperation will emerge as the architecture is further developed each year and NASA and its prospective international partners discuss collaboration. International cooperation will advance broad science, exploration, and space technology goals and objectives, as well any number of objectives related to education, inspiration, and public engagement.

NASA has engaged and will continue engaging with international counterparts, both bilaterally and multilaterally. Along with bilateral discussions, some of which are highlighted above, multilateral discussions have demonstrated utility in advancing mutual understanding and common exploration interests. NASA will continue to use multilateral forums to articulate its exploration and science objectives, with an eye toward identifying additional areas of potential cooperation, such as the following multilateral efforts:

- The International Space Exploration Coordination Group (ISECG) is a coordination forum for interested space agencies to share their objectives and plans for exploration.
- The Lunar Exploration Analysis Group (LEAG) was established to support NASA in providing analysis of scientific, technical, commercial, and operational issues in support of lunar exploration objectives and of their implications for Lunar Architecture planning and activity prioritization.

- The Mars Exploration Program Analysis Group (MEPAG) serves as a community-based, interdisciplinary forum for inquiry and analysis to support NASA Mars exploration objectives. MEPAG is responsible for providing the science input needed to plan and prioritize Mars exploration activities.
- The Solar System Exploration Research Virtual Institute (SSERVI) was formed to address fundamental questions about human and robotic exploration of the Moon, near-Earth asteroids, the Martian moons Phobos and Deimos, and the near space environments of these target bodies. As a virtual institute, SSERVI funds investigators from a broad range of domestic institutions, bringing them together along with international partners via virtual technology to enable new scientific efforts.
- The International Mars Exploration Working Group (IMEWG) is a coalition of space agencies and institutions around the world that seeks to advance our collective human and robotic future on Mars.
- The International Space Life Sciences Working Group (ISLSWG) is a multilateral forum aimed at providing a more complete coordination of international development and use of spaceflight and special ground research facilities to enhance Moon to Mars objectives pertaining to space life sciences.
- The Interagency Operations Advisory Group (IOAG) provides a forum for identifying common needs across multiple agencies related to mission operations, space communications, and navigation interoperability.
- NASA and the Department of State continue to engage with the community of Artemis Accords signatories to discuss the implementation of the principles of the Accords to ensure safe and sustainable space exploration.

4.2 RT-2 INDUSTRY COLLABORATION

RT-2: Partner with U.S. industry to achieve common goals and objectives.

Architecture Assessments:

NASA has long called upon the U.S. industrial base to provide the development and production of key exploration assets and provide foundational research to advance and enhance exploration capabilities. U.S. industry partners have contributed to the success of the Artemis I flight, which includes major hardware deliveries for three programs: Exploration Ground Systems (EGS), Orion, and the Space Launch System (SLS). U.S. industry contributions will be critical throughout the Moon to Mars campaign segments. The elements included in the HLR segment are already leveraging commercial partnerships. The EVA and Human Surface Mobility Program (EHP), Gateway, and Human Landing Systems (HLS) programs are working with multiple U.S. companies to design, deliver, and/or provide services for critical systems for Artemis III and IV.

Historically, NASA has partnered with industry to develop capabilities and technology that are needed for exploration, science, and technological development. STMD is supporting technology development in major areas that enable, safe landing on the lunar surface, enabling or increasing the ability to live in the lunar environment, and increasing our capability to explore the lunar surface. NASA expects to develop or increase capabilities that lower crew risk and increase crew survivability in harsh environments, provide evolvable powers systems, and develop in-situ manufacturing methods. The successful development of these capabilities will further enable the development of habitable structures and critical improvements in infrastructure, which will likely increase mission effectiveness, mission durations, and overall safety. To expand our ability to explore during later Artemis missions, NASA is focusing on technologies to increase the ability to map and locate lunar features, navigate in complex terrain, and travel between lunar surface assets.

Through the CLPS Program, NASA has also engaged U.S. industry in a new way, introducing members of academia that wish to perform standalone cislunar science missions and corporations that desire to test hardware in the lunar environment to suppliers of multiple launch vehicles and lunar landers. This provides a cost-effective means of transporting a wide variety of payloads with different goals and physical attributes to the cislunar environment or lunar surface.

Future segments will continue this partnership. NASA will continue collaboration with industry to develop technologies that continue to enable exploration, science and technology maturation, or demonstrations in preparation for Mars. The Moon to Mars Architecture will depend on partnership with U.S. industry to provide exploration services and critical technologies in a sustainable and affordable manner.

RT Considerations:

U.S. industry contribution in future segments to enable exploration activities has not been fully captured or leveraged. With significant commercial interest in developing LEO destinations in the near future, NASA needs to investigate opportunities to leverage and potentially supplement those investments to advance the state of knowledge of human spaceflight in support of the Moon to Mars Architecture. NASA will leverage U.S. industry plans for cislunar and lunar commercialization and look for key opportunities for partnering in support of long-term exploration of the lunar surface and Mars in a sustainable way. NASA will team with industry to develop and perfect systems that will contribute to future Artemis missions and are beneficial to the commercial partner. Some potential areas for collaboration of U.S. industry and the Moon to Mars Program are:

- Team with industry to develop, verify, and sufficiently validate new technology that future missions will need.
- Partner with industry to mature current technologies with risk and cost-cutting potential.
- Understand industry goals and how commercial activities could contribute to enabling permanent presence on the moon and future exploration of Mars.
- Involve industry in the development and refinement of future technology/system standards, which could include robotic interfaces; software information and management systems; rover systems; in-space servicing, assembly, and manufacturing (ISAM); power systems; and habitation systems.
- Collaborate with industry through appropriate mechanisms to address and resolve technical issues related to space exploration.
- Request industry develop concepts for the end-to-end management of pressurized logistics, beginning with loading on Earth and ending with the disposal or reuse of containers.
- Encourage industry collaboration in specific areas (power generation/distribution, logistics supply and handling, logistics handling, autonomous robotic operations, compatible/interchangeable components) through the use of technology demonstration and the communication of long-term strategic goals.

4.3 RT-3 Crew Return

RT-3: Crew Return: Return crew safely to Earth while mitigating adverse impact to crew health.

Architecture Assessments:

In recognition of the inherent risks associated with human spaceflight, NASA considers the wellbeing and safe return of crews to be of paramount importance. Considerations for safe crew return start well before the mission and are included in the system design, test and verification, and end-to-end mission testing and training using high-fidelity hardware, software, and mission support personnel. The following top-level standards to ensure safe crew return are assessed and appropriately applied across the architecture:

- NPR 8705.2 Human-Rating Requirements for Space Systems (for EGS, SLS, Orion)
- HEOMD-003 Crewed Deep Space Systems Human Rating Certification Requirements and Standards for NASA Missions (for other elements as part of the crewed deep space system)
- NASA-STD-3001 NASA Space Flight Human-System Standard

These requirements are tailored and applicable to every crewed vehicle across all campaign segments, including the integrated architecture or system of systems. For each design reference mission, the design will be assessed and certified as acceptably safe to carry NASA or NASA-sponsored crewmembers by meeting the human rating certification criteria, including human rating technical requirements, applicable technical authority design, construction, testing, human system and safety standards, and derived loss of crew/loss of mission requirements. The results can be broadly categorized as integrated vehicle capabilities and integrated mission operations, which include strategies, constraints, and vehicle uses to manage crew risk. A human-rated system accommodates human needs, effectively utilizes human capabilities, controls hazards with sufficient certainty to be considered safe for human operations, and provides, to the maximum extent practical, the capability to safely recover the crew from hazardous situations. While hazard controls (and required control redundancy) prevent hazardous events from occurring, crew survival methods are an independent layer of protection provided assuming those controls fail, and enable the crew to survive the immediate hazard, reach a safe state, and ultimately return to Earth. The Moon to Mars Program will derive contingency and abort use cases and functions by applying the Human Rating Standard. The results can be broadly categorized as architecture capabilities and integrated mission operations, which include strategies, constraints, and vehicle uses to manage crew risk. Architecture capabilities provide:

- Appropriate failure tolerance to catastrophic hazards, which can include similar/dissimilar redundancy, reliability, functional down-moding, etc.
- Medical systems, emergency systems, and crew survival capabilities
- Crew manual control (of vehicle dynamics and systems) or manual override (of software/automation) to prevent a catastrophic hazard
- Crew control of any uncrewed vehicle in the vicinity of the crewed vehicle
- Abort of a mission phase and safe return of the crew
- Crew/vehicle autonomy to return without Earth communication
- Vehicle operation and crew protection at vacuum
- Return of an incapacitated crew to Earth

Integrated mission operations provide:

- A strategy to minimize crew risk and/or the exposure duration during first-time operations or high-risk activities; this may include an initial uncrewed demo and an incremental approach to build up capability
- Clear mission authority, roles, and responsibilities across the entire Artemis team.
- Execution of launch commit criteria (LCC) and go/no-go flight rules prior to critical events
- Ability to monitor, command, and control vehicles and assist the crew from Earth or another remote location
- Operational constraints to ensure safe crew return in the event of a failure (e.g., EVA and rover range/time limits to return crew within suit consumables)
- Crew supporting critical activities, including rendezvous, proximity operations, docking, and undocking (RPODU); landing, ascent, and EVA; emergency response; rover operations; etc.
- Contingency capabilities (e.g., mission phase termination, catastrophic/critical system failure responses)
- Use of abort and crew survival methods (e.g., safe haven, pressure suits)
- Crew training and onboard products for crew to execute all nominal, contingency, and emergency operations with or without Earth communication
- In-flight assessments of crew health and readiness to support activities between crew and ground medical team

The following are mission-specific examples of the vehicle capabilities and mission operations to safely return the crew to Earth:

- Uncrewed initial lunar mission demonstrated the crewed launch and reentry systems prior to crewed flight.
- Crewed initial lunar mission will demonstrate life support and habitability in the lunar vicinity while minimizing return risk via a free-return trajectory.
- Crewed initial lunar surface mission will demonstrate complex operations with transferring crew across vehicles and conducting an initial lunar landing and EVA as a precursor to increasingly complex lunar surface missions.
- Crewed Gateway and lunar surface missions will demonstrate sustainable crewed and uncrewed mission capabilities in the lunar orbit and on the lunar surface.
- As infrastructure is added in the Artemis campaign, to extend human exploration further across the lunar surface, ensuring safe crew return will become increasingly complex across multiple elements. In later campaign segments, crew return will rely on EVA suits, rovers, surface habitats, landers, Gateway, and Orion, plus any supporting architecture, like communication and power systems. Furthermore, NASA's experience is to maintain a crew presence with the crew return vehicle; however, Artemis will demonstrate the concept of landing all crew on the lunar surface while Gateway/Orion is unoccupied.

RT Considerations:

The Moon to Mars Architecture treats the safety of the crew as an utmost concern. However, significant knowledge gaps exist relative to the adverse effects of long-term exposure to the deep space environment. The architecture will be developed to account for known health and medical concerns and for contingency scenarios involving failures in mission elements and systems. Significant knowledge has been gained from ongoing human health research aboard the International Space Station and will continue with lunar orbital and surface missions. Long-duration Mars precursor missions conducted in cislunar space and on the lunar surface will provide some knowledge and experience. Likewise, knowledge of the reliability gaps with mission hardware, software, and operations will be tested and refined based on knowledge of LEO missions. However, these missions may not be sufficient to provide the necessary data to fully understand the risk associated with roundtrip missions to Mars. Furthermore, while the assets around cislunar space provide crew with safe haven and Earth-return capabilities, such capabilities may not exist for the Mars exploration crew, regardless of the architecture, and that lack remains a significant challenge to crew safety.

If problems arise in LEO, the crew can return to Earth within hours; for lunar missions, crew return will take days. However, crew return during the Mars campaign may take months, since orbital dynamics make abort or contingency crew return extremely challenging and may not significantly shorten the return. Extending the capabilities outlined above will require a combination of system reliability, system redundancy, vehicle/crew autonomy, critical sparing, abort and crew survival options, crew health/performance/psychological support, and general robustness at a level higher than previous missions. The fault tolerance approach, covered in the previous section, is applicable for Artemis lunar missions but may need to be reassessed for Mars missions.

The following set of challenges are included in the "architecture gap" section for context. Some of these gaps may not be solved by the architecture alone; they are gaps in the knowledge, experience, and technology required to advance, test, and implement more complex lunar and Mars missions.

- Onboard autonomy capabilities for a Mars crew and their vehicle to account for time latency to Earth and time-to-effect events. Essentially, the crew will not have the real-time response capability of the mission control center (MCC).
- In the event of an unrecoverable loss of communication with Earth during lunar and Mars missions, onboard autonomy should provide a safe crew return, which includes vehicle capabilities and full resources for the crew to perform their own mission planning, skills training, return trajectory execution, psychological support, and more, potentially for an extended amount of time.
- Capabilities for a Mars crew to monitor, command, and control any uncrewed vehicle from other vehicles in the Mars vicinity to ensure their safe return. NASA's historical experience is to maintain a crew presence with the crew return vehicle. Artemis will demonstrate the capability to send the entire crew to the lunar surface with MCC oversight of nominal and off-nominal events aboard the uncrewed vehicles.
- Availability of robust crew survival methods, which may include safe havens, additional resources, rescue systems/vehicles, and more.
- Advanced health and performance monitoring and response, both onboard and on the ground.
- High-bandwidth telecom capabilities to upload video learning or instructional materials to guide medical procedures or critical equipment repairs that will be needed during multi-year crewed missions to Mars.

4.4 RT-4 Crew Time

RT-4: Maximize crew time available for science and engineering activities within planned mission duration.

Architecture Assessments:

One of the three pillars of the exploration strategy that is guiding the Moon to Mars Architecture is the pursuit of scientific knowledge. Maximizing crew time is a critical driver for the exploration architecture across all segments of the campaign. Specifically, this refers to crew time made available for utilization activities, separate from other crew time allocations, such as maintenance time. During the lunar campaign segments, the architecture and reference missions emphasize crew exploration on the lunar surface. This is enabled by allocating functions to the elements in this phase to minimize maintenance and construction overhead activities. Concurrently, utilization activities at Gateway are conducted in cislunar space to complement the surface exploration activities. The experiences gained in the exploration activities with the optimization of surface exploration missions on the Moon will guide the planning for the initial Mars surface mission to maximize the efficiency of crew time available for science and engineering activities.

Similar to RT-3, there are architecture capabilities and mission operations in development to optimize or maximize crew time allocated towards exploration and utilization.

Architecture capabilities:

- Lunar campaign elements have allocated limited time for vehicle maintenance on Gateway, HLS, EVA suits, and rover(s). This may be designed and implemented via system reliability, sparing strategy, crew accessibility, ease of use, operational use, and other methods.
- Engineering, operations, and crew evaluations of vehicle mockups and simulations influence capabilities in early design and development to enable reliable and efficient operations.
- Campaign elements incorporate automation/autonomy for routine housekeeping and system management to offload crew.

Integrated mission operations:

- Artemis crew training and integrated Artemis mission simulations (with full team) commence approximately two years and one year before the crew launch, respectively. These milestones drive the vehicle and personnel readiness and allow sufficient time to train critical skills and tasking across all Artemis vehicles and utilization tasks.
- Artemis training philosophy exercises the crew and ground teams in mission planning, decision making, and execution of critical and complex tasks. In addition to the skills, a time multiplier is applied in ground training for every hour of critical/complex mission execution to ensure efficient use of crew time.
- Distribution of system (monitor/control) functionality between crew and MCC to support crew in meeting the exploration and mission objectives.
- Use of tele-robotics, robotic assistance, and autonomous systems to increase crew time and effectiveness on science and utilization. For example, uncrewed operations like pre-positioning an asset can reduce the crew task burden before they arrive.
- Development of contingency plans and capabilities, including backup crew, to allow the mission to continue for non-critical events.

- Availability of task lists or alternate plans to efficiently pivot from the nominal plan and optimize the mission results. For example, if a lower-priority EVA or surface utilization task becomes time consuming, the crew may pursue other achievable tasks on the fly to optimize utilization. This may also include get-ahead tasks to support a downstream activity or a future Artemis mission.

RT Considerations:

There are knowledge gaps associated with the increasing exploration infrastructure and capabilities needed for the FE, SLE, and Humans to Mars segments. Although these increases are intended to result in a net benefit to available crew time, there is some uncertainty associated with the operational complexity, maintenance, and refurbishment demands they bring. Additional assessment is needed to bridge the knowledge gap and inform system design and operational planning.

4.5 RT-5 MAINTAINABILITY AND REUSE

RT-5: When practical, design systems for maintainability, reuse, and/or recycling to support the long-term sustainability of operations and increase Earth independence.

Architecture Assessments:

To enable a safe, effective, and affordable architecture that achieves NASA's long-term exploration goals, the Moon to Mars Architecture must be assessed to understand the implication of system maintainability, reuse, and/or recycling in support of long-term operation and increase Earth independence. Almost every element in the architecture is being designed to take advantage of some level of reuse, but understanding of risks associated with maintainability and reuse and their impact on safety, science, and long-term sustainability goals will be vital as the architecture is refined and matured.

According to NASA-STD-8729.1, maintainability is a measure of the ease with which a system or equipment can be restored to operational status, as a function of equipment design and installation, personnel availability, adequacy of maintenance procedures and support equipment, and the physical environment under which maintenance is performed. In other words, it is the probability that an item will be restored to a specified condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources. It is important to note that maintainability does not equate to maintenance. Maintainability is a design attribute and maintenance is a set or type of operational work.

Two principal areas drive maintainability and reuse within the Moon to Mars Program: mass delivery and available crew time. The delivery of mass to lunar orbit, the lunar surface, or Mars has limited opportunities and is a known cost and performance driver. Likewise, crew time is precious and drives three maintenance concepts: 1) reducing/limiting maintenance activities, 2) ensuring that maintenance activities are easy to perform, and 3) automating or having robotics perform maintenance tasks where possible. The last item is currently an architecture gap that needs additional development of concepts, potential operations, and understanding of potential tasks that can leverage the use of robotics and/or automation.

The Moon to Mars Program will promote the use of common orbital replaceable units (ORUs) when a common component can be incorporated into designs and must be periodically replaced (e.g., air filters). This philosophy will allow a set of ORUs to be shared across multiple elements of the Moon to Mars Architecture, thus reducing the amount of logistics and increasing contingency options.

Because many of the major systems in the Moon to Mars Architecture are designed to be in either lunar orbit or on the lunar surface for multiple years and missions, extended gaps between missions drive systems to react, providing a status notification, reconfiguring systems, and shutting down specific systems, and may drive self-maintenance operations. Increasing the number of critical maintenance activities that can be automatically or remotely performed will increase crew time for science and exploration.

As a preventative measure, it is important that designers consider reliability early in the design process to reduce future maintenance needs of a system and target a practical mean time to repair. Designing systems with human factors in mind to achieve easy accessibility, standardized replacement methods, and limited specialized tool requirements and considering the training required to perform maintenance operations should be key parts of the up-front design process. The combination of the complex lunar environment, with its changes in lighting conditions and terrain variation; the variety of systems being developed; and the need for crew time to perform science, exploration, and technology demonstrations, points to a stronger need to reduce mean time to repair.

The Moon to Mars architects and designers must also consider uses for decommissioned hardware. Can batteries or other consumables be recycled or reused? Could targeted system components be repurposed or reused beyond their original functions for another vehicle or element? Initially, the reuse of components or system may not be possible, but as we learn more about the lunar environment and ORU designs evolve, a good steward strategy will be developed.

RT Considerations:

The maintainability of the exploration assets remains a major concern especially with the desire to maximize crew time for science and engineering activities. Traditionally, a certain level of crew time was dedicated to the maintenance of systems to extend the lifetime of any asset. However, the advancement of robotics and autonomous systems provides a range of options for the maintenance of systems. Trades must be performed to determine which systems and maintenance tasks should be automated and which should be manually performed. Other areas of maintainability that should be studied include:

- Incorporation of robotic systems to perform maintenance on one or more lunar surface systems.
- An integrated system to track maintenance items/ORUs location and availability across the Moon to Mars Architecture.
- A process to dispose of or reuse systems or selected system components upon completion of their primary mission.
- Should a modular open systems approach be applied, and at what level, to enable a long-term autonomous repair capability supporting the SLE segment?

The maintenance approach should consider the long-term benefits and costs of design features that, if applied at the same level across the Artemis campaign, could enhance maintainability and reuse of systems. Each of these design features has an associated cost that must be considered along with the potential benefits. The Moon to Mars Architecture should consider incorporating such design features, including:

- Maintenance items/ORUs designed to provide notification of a degraded capability or failure to the broader system allowing timely corrective actions can be taken.
- Maintenance items/ORUs designed to be easily exchanged, both manually and by robotic means.

- Design systems/components to be robotically manipulated so that tasks can be performed without crew present (capability for after Artemis VII).
- Design major systems to be maintained using robotic capabilities—either automated or remotely operated under a variety of environmental conditions.
- Reduce the logistics train as much as possible by using common limited-life items (e.g., filters, lights).
- Standardize or require a set of common battery sizes, including enclosures and contact points.

Additional assessment is needed to bridge the knowledge gap and inform system designs and operational planning. The reuse of elements will also likely require the refurbishment of elements and these activities are not well defined within the current architecture. Finally, system lifetime limitations from both reuse and maintenance perspectives must be evaluated.

4.6 RT-6 Responsible Use

RT-6: Conduct all activities for the exploration and use of outer space for peaceful purposes consistent with international obligations and principles for responsible behavior in space.

Architecture Assessments:

Responsible use of space follows guidelines and principles of responsible behavior that are set forth in international agreements, international and national policies, and law. Given the uncertainties about how humanity will explore the broader solar system, questions about the nature of responsible activity will surely arise. The likelihood of creating a future where humanity collectively benefits from Moon to Mars activities will be increased by considering the responsible use of space from several legal, policy, ethical, and societal perspectives. The following context explores relevant history for how to consider the responsible use of space.

The legislation that founded NASA declared that “it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind.”[15] The U.S. also ratified the Outer Space Treaty of 1967, which identifies principles of behavior that represent the belief that the exploration and use of outer space should be for peaceful purposes, for the benefit of all peoples, and contribute to broad international cooperation in scientific and legal aspects of exploration. Article VI is of specific interest, as it expands the obligation of nations to ensure responsible behavior, even when activities are carried out by “non-governmental entities,” like commercial companies. This extends to private-sector operations not conducted on behalf of a nation.

The Artemis Accords reinforce and implement key obligations in the 1967 Outer Space Treaty. They also reinforce the commitment by the United States and signatory nations to the Registration Convention, the Rescue and Return Agreement, and best practices and guidelines for responsible behavior that NASA and its partners have supported, including the public release of scientific data. The Artemis Accords establish a practical set of principles to guide space exploration cooperation among nations, including those participating in NASA’s Artemis Program. Key tenets of the Artemis Accords include:

- Calls for partner nations to utilize open international standards, develop new standards when necessary, and strive to support interoperability to the greatest extent practical.

[15] National Aeronautics and Space Act of 1958, https://history.nasa.gov/spaceact.html

- Calls to provide public information regarding the general nature of operations, which will inform the sale and scope of safety zones to deconflict activities.
- Commitments to the protection of sites and artifacts with historic value.
- Reinforcing that space resource extraction and utilization can and will be conducted under the auspices of the Outer Space Treaty, with specific emphasis on Articles II, VI, and XI.

The 2020 U.S. National Space Policy provides additional clarity on the definition of responsible norms of behavior. It defines and advocates for development and promotion of responsible behaviors, including "improved practices for the collection and sharing of information on space objects; protection of critical space systems and supporting infrastructures, with special attention to cybersecurity and supply chains; and measures to mitigate orbital debris."

The 2021 United States Space Priorities Framework adds additional considerations about the responsible use in space. It leads with the concept that activities in space benefit the American people and that the U.S. should "lead the international community in preserving the benefits of space for future generations." The section on maintaining a robust and responsible U.S. space enterprise notes that "such efforts will be informed by economic data and research to better understand the space economy and will reflect the importance of the responsible and sustainable use of space." The section on preserving space for current and future generations acknowledges that as space activities evolve, norms, rules, and principles also must evolve. It goes on to clarify that "the United States will bolster space situational awareness sharing and space traffic coordination." It also identifies responsible behaviors; of interest here are "minimize the impact of space activities on the outer space environment" and "protect the Earth's biosphere by avoiding biological contamination by spacecraft returning to Earth."

In establishing the Artemis Accords, NASA is signaling intent for responsible behavior around Moon to Mars efforts and has identified a need for practices, rules, and standards in a number of areas that will be addressed by signatories moving forward.

From a technical perspective, there are payloads manifested on Commercial Lunar Payload Services (CLPS) flights to the moon that are collecting data needed to enable future responsible behavior. For example, the Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS) is an experiment to determine the effects of the lander's plume on the lunar surface during landings. The ability to predict landing effects is essential to responsible use in the future.

Recent calls from the 2022 planetary science and astrobiology decadal survey and the National Science and Technology Council's cislunar strategy highlight the need to include broader discussion and consideration of ethical and societal questions surrounding Moon to Mars efforts. NASA's 2023 Artemis and Ethics Workshop began a dialog on cultural and societal implications of future human exploration.

RT Considerations:

While NASA and its partners have made the commitment to pursue peaceful exploration and responsible use of space, significant policy questions and framework gaps exist with regards to the protection of future scientific and exploration needs. While there are treaties, law, policy, and guidelines on responsible use, the implementation is still in development. The Artemis Accords signatories are working on some of those issues now. Future success or failure will be driven by processes that embed responsible use in the exploration architecture as it is developed and implemented through programs, projects, procurements, and operations.

Given the global impact and influence of space exploration on the human condition, NASA must think about responsible use broadly, including the impact of Artemis on society. For conversations and considerations of this nature to be effective, NASA must to avoid making premature judgements about behaviors or outcomes. There must be discussion of costs in addition to benefits, with a goal of maximizing benefit to society, while minimizing potential harms. Reflection and discussion can be facilitated by deliberate analytical conversations as part of the architecture and systems engineering process. NASA has a mandate to explore and has now published objectives that outline what needs to be done to enable exploration of the inner solar system. Decisions about how those objectives are accomplished must also consider their meaning and impact.

For future ACRs, NASA will continue to reflect on how to best pursue responsible use of space.

4.7 RT-7 INTEROPERABILITY

RT-7: Enable interoperability and commonality (technical, operations, and process standards) among systems, elements, and crews throughout the campaign.

Architecture Assessments:

The Moon to Mars Architecture incorporates a diverse array of NASA programs, with contributions from industry and international partners. Safely and successfully orchestrating the resulting array of systems requires a commitment to interoperability. Existing Artemis programs have applied existing interoperability standards in many areas of the system design, including avionics, communication, PNT, docking, power rendezvous, and software. Critical system interfaces are designed to incorporate interoperability functions to perform necessary and contingency operations for the Human Return segment. The interoperability requirements may be tailored for each element to balance the performance of the individual element with the integrated mission architecture. NASA programs in pre-formulation or early development are defining initial requirement sets, establishing a baseline level of interoperability across the exploration ecosystem, including previously mentioned areas and additionally the areas: ECLSS, robotics, thermal control, logistics, and utilization. In many cases, the necessary categories of interoperability and the baseline interfaces have been identified, but specific implementations are still being developed.

The International Deep Space Interoperability Standards[16] will serve as the starting point for future interoperability assessments. Currently, nine International Deep Space Interoperability Standards exist. Three standards, the International Docking System Standard (IDSS), International Communication System Interoperability Standards (ICSIS), and International Space Power System Interoperability Standard (ISPSIS), have been updated since May 2021. Two additional standards have identified forward work to be addressed. To the greatest extent possible, interfaces are being developed to enable application of the same or very similar interface to be used during the Humans to Mars segment. Other actions taken to improve interoperability within the Moon to Mars Architecture include the following:

- Since 2020, architectural studies have mapped functional interoperability between systems assumed to be deployed for a given mission. These assessments have been and are being updated to reflect changes in the mission assumptions. The related results have already driven changes to the communication systems, identified potential gaps, and initiated specific tasks focused on closing assumptions and requirements.
- NASA developed a document that defines physical, data, power, etc. interfaces for utilization across the Moon to Mars Architecture. The interfaces are consistent with existing Gateway requirements, the International Space Power System Interoperability

[16] International Deep Space Interoperability Standard, https://www.internationaldeepspacestandards.com

Standards (ISPSIS), the International External Robotic Interface Interoperability Standards (IERIIS), and other applicable standards.

- A standard has been developed and approved for the design and functionality of Moon to Mars crew interfaces for all critical systems. This standard is intended to drive consistency in how astronauts will see information displayed and users' interface with systems. This will support a consistent look and feel across vehicles, which will promote ease of learning, ease of use, reduction of operator workload, increased situational awareness, and improved mission safety.
- The Icon and Symbol Library drives commonality in the use of icons and symbols across Artemis flight and lunar surface systems. The document includes icons and symbols approved for Orion consistently used by Gateway and HLS systems. As new symbols and icons are developed for new functions, the document will be updated and shared throughout NASA and with partners in international space agencies, industry, and academia. This should further promote consistency across multiple lunar and Mars systems while also increasing the overall ease of use.
- Ongoing lunar power concepts and emerging issues result in impacts to program/project analysis cycles that may drive trade studies or specific analysis. One of the results of these discussions is the assignment of a task to determine which systems should be able to share power, and what power quality should be shared for each defined mission.
- A related item is the need for a standardized power connector for use on the lunar surface. Discussions have focused on being dust tolerant, what voltages needs to be transmitted, the need to be "bi-directional," and other requirements to allow functionality with and without suited crews.
- The Moon to Mars Program has participated in and coordinated with the Lunar Surface Innovation Consortium (LSIC), LEAG, MEPAG, and other interested parties on interoperability topics. These forums enable sharing of concepts, hearing commercial and academic concerns, and reaching community consensus. NASA is encouraged by the level of participation and considers the LSIC and Lunar Surface Science Workshop (LSSW) as paths to interact with a wide range of partners to facilitate interoperability.
- NASA has developed and is tracing RPOD requirements to the system-to-system level to ensure that all requirements for planned and contingency docking operations for Artemis III and IV are addressed and have appropriate verification planning.
- The LunaNet Interoperability Specification for lunar communication and navigation standards has been developed by a team from NASA and ESA, with input from the IOAG and other government and commercial entities. The specification has been applied as a requirement in the NASA and ESA service procurements and is gaining widespread acceptance.
- Another aspect of interoperability is the mission operations and crew interactions across all the Artemis elements. To address this, the Artemis Flight Operations Standards were baselined and contain details of NASA expectations for operational products, processes, and facilities. NASA-operated vehicles (e.g., Orion, Gateway) use this consistent approach and NASA coordinates these standards and integrates mission operations with all providers across the Artemis Program.

RT Considerations:

Interface standardization for all elements is being guided by the recurring tenets, but specific designs and requirements for interoperability are still being studied and refined. In many cases, these studies focus on a subset of relevant elements and may fall short of enterprise-wide coordination. Three examples of lunar surface gaps related to the Moon to Mars Architecture are:

- Lunar Surface Docking system that is capable of mating two pressurized systems to provide the transfer of crew and supplies in a shirt-sleeve environment and without the need of pressurization cycles.
- The IERIIS currently only addresses robotic attachments in a microgravity environment. It needs additional work to define requirements for operation on the lunar and Martian surfaces.
- The Moon to Mars concept of operations for later missions must be updated to define the expected functions and additional systems to derive any interoperability capabilities that will be necessary.
- Creating an interoperable network that enables data connectivity, command, and control among a distributed set of local and remote users is an area of open work.

Formal, coordinated functional analysis and standardization policies need to be developed to govern cross-program and cross-partner element development. A top-level policy, aligned with the Humans to Mars segment needs, will guide the development of interoperability policies which, when communicated through NASA, to international partners, and to commercial partners for feedback will drive system configuration functions and requirements.

4.8 RT-8 Leverage Low Earth Orbit

RT-8: Leverage infrastructure in low Earth orbit to support Moon to Mars activities.

Architecture Assessments:

The Moon to Mars Architecture builds upon and leverages past and current human and robotic spaceflight experience to inform future system design and operational needs.

Enabled by a robust international partnership of five space agencies from 15 countries, the International Space Station has served as a space laboratory of unprecedented scale and sophistication and hosted a continuous human presence in LEO for more than two decades. During this time, over 3,700 scientific experiments have been conducted and more than 270 astronauts from 21 countries have lived and worked there. The International Space Station has facilitated the development of mature technological and operational concepts that will be leveraged as we embark upon more complex missions much further from home.

Further research, development, and testing will be critical to the successful execution of future deep space and planetary exploration missions. NASA will continue to operate and utilize the ISS to support exploration goals through 2030 and is preparing for a successful transition of these capabilities to other destinations in LEO.

As part of its strategy to enable a vibrant LEO economy, NASA is offering flight opportunities for commercial providers to utilize the International Space Station as a destination for private astronaut missions (PAMs). PAMs serve as pathfinders to demonstrate and stimulate demand for future commercial destinations. Two such missions have already been successfully executed in 2022 and 2023.

In addition, NASA's Commercial Low Earth Orbit Development Program (CLDP) is supporting the development of commercially owned and operated LEO destinations from which NASA, along with other customers, can purchase services. As commercial LEO destinations (CLDs) become available, NASA intends to implement an orderly transition from current ISS operations to these new destinations. Transition of LEO operations to the private sector will yield efficiencies in the long term, enabling NASA to shift resources toward other objectives.

After International Space Station operations have transitioned to commercial LEO destination operations, ESDMD will coordinate with CLDP to leverage available commercial LEO destination utilization facilities and services that may accommodate Moon to Mars objectives. Research and development opportunities may include studies of human behavioral and physiological exposure to in-space environments, habitability, and operations; development of in-space growth of alternative nutritional sources for human consumption; space-related technology demonstrations, tests, and certifications, and others.

NASA has a contract for commercial modules to be attached to an International Space Station docking port and awarded space act agreements for design of three free-flying commercial space stations. U.S. industry is developing these commercial destinations to begin operations in the late 2020s for both government and private-sector customers, concurrent with space station operations, to ensure these new capabilities can meet the needs of the United States and its partners.

The International Space Station, in-development commercial space stations, and other CLDs yet to be envisioned should be leveraged to enable the successful execution of future exploration missions. These platforms should be used to conduct research, demonstrate new technologies, test and certify hardware, develop sound operational concepts, inform mission concept and design decisions, characterize and reduce risk, and train our space- and ground-based human operators.

Envisioned opportunities for research and development in LEO to support Moon to Mars activities include:

- Fundamental and applied scientific research
- Understanding and mitigating the impact of the space environment on human health will be critical for both lunar and Mars missions. Ongoing fundamental human health research in LEO will help the scientific and space medicine communities better understand the effects of and potential mitigations for:
    - Microgravity
    - Radiation exposure
    - Immune system adaptation
    - Vision changes
- Plant growth experiments that will inform crop growth on transport vehicles or other planetary bodies
- Technology demonstrations
    - Environmental and life support systems
    - Waste management systems
    - In-space manufacturing
    - Leveraging automation, robotics technology, and artificial intelligence (e.g., Astrobee)

  - Synthetic biology applications (e.g., food, nutrient, and pharmaceutical production, waste stream management)
  - Techniques are being developed and tested to make use of existing Earth-orbiting GPS and GNSS signals for navigation at the Moon
- Hardware test and certification
  - Test component hardware in microgravity, radiation, and thermal space environments
  - Opportunity to evaluate new hardware (e.g., upgraded microgravity or new planetary spacesuits) alongside heritage hardware
  - Validate efficacy of new exercise hardware and other exercise countermeasures
- Operational concepts
  - Understanding the impact of communication delays on safe mission execution. Space stations offer an opportunity to evaluate:
    - How astronaut and flight controller training will need to evolve for increasingly independent decision making and operations
    - Whether current procedural philosophy will be effective
    - Whether new tools will be needed
    - For example: testing of operations procedures and medical care could be enhanced by demonstrating crew handling a simulated medical emergence in microgravity, autonomously, and with significant communications delay
  - Novel robotics operations concepts (e.g., ground-based robotics operation support during spacewalks)
- Architecture design
  - Habitability:
    - Isolation and confinement effects of deep space transit could be studied on space stations to validate current habitable volume requirements for Mars transit and provide context for validating the results of the extensive ground-based simulations in analog environments
  - Surface operations after the physiological deconditioning of long-duration microgravity exposure could be conducted to validate crew ability to perform critical ground tasks after a six-month Mars transit and aid in operational concept development and conceptual design of Mars surface element architectures
- Crew spaceflight experience
  - Communication and decision making in dynamic phases of flight and complex operations (e.g., launch, rendezvous, re-entry, spacewalks)
  - Long-duration missions
  - Spacewalk and robotics operation skills
  - Problem solving in a resource constrained environment
  - Developing and demonstrating resilience, strong expeditionary skills, and crew cohesion

- Human health and performance
    - Exercise countermeasures
    - Behavioral health
    - Individual and team performance optimization
    - Crew cohesion
    - Nutrition and food systems
    - Sleep
    - Re-adaptation to gravity and rehabilitation

RT Considerations:

Potential opportunities to leverage LEO infrastructure have not been fully explored, and additional studies and refinement are needed to evaluate all available options. LEO will be leveraged to the extent practical to inform human system risks for Mars, despite inherent limitations in the fidelity of certain spaceflight hazards. NASA will continue planning to ensure we take full advantage of the International Space Station before its planned decommission after 2030, and to ensure we enable the development of and transition to other LEO assets. NASA should also create and demonstrate decision support system capabilities in the content of future architectural assumptions.

4.9 RT-9 Commerce and Space Development

RT-9: Foster the expansion of the economic sphere beyond Earth orbit to support U.S. industry and innovation.

Architecture Assessments:

Historically, the growth of the U.S. space industrial base has been both an enabler of space exploration activities and a significant benefit to the broader economic sphere. In the past, U.S. industry and innovation was sustained both by NASA developed technologies that were transferred to industry and directed hardware development for NASA owned systems and infrastructure. In order to grow activities in space beyond what can be sustained by federal funding alone, NASA and industry have developed partnerships and are testing new procurement methods for services in and beyond Earth orbit. This tenet represents the intent to continue and expand these efforts to include architecting to benefit commerce and space development. It points the way towards a future where commerce and development are the norm in space.

This tenet is well aligned with U.S. space policy that directs NASA to foster commercial industry and economic opportunities beyond Earth orbit. The policies provide insight and specifics around how the architecture can be assessed against RT-9. The 2010 National Space Policy endorsed space commerce and defined the term *commercial* as “space goods, services, or activities provided by private sector enterprises that bear a reasonable portion of the investment risk and responsibility for the activity, operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment, and have the legal capacity to offer these goods or services to existing or potential nongovernmental customers.” The more recent US Space Priorities Framework from December 2021 endorsed space development and identified the need for U.S. regulations to provide clarity and certainty around space development activities including space-based manufacturing and recovery and use of space resources among others. It further reinforced the 2015 Space Resource Exploration and Utilization Act, which directs facilitation of commercial exploration and utilization of space resources to meet national needs; discourages government barriers to the development of economically viable, safe, and stable industries for the exploration and utilization of space resources; and promotes the right of United States commercial entities to explore outer space and utilize space resources.

Commerce, when successful, involves large-scale purchases and sales of goods and services among two or more parties. Space development, when successful, extends human and robotic activities beyond the Earth into the solar system. It includes semi-permanent or permanent human scale infrastructure that enables growth in human and robotic space activities and commerce in an operationally diverse manner in multiple locations beyond LEO.

Partnerships are being considered for all elements and infrastructure developed to support the Moon to Mars Architecture. In alignment with this tenet, they can be formulated to facilitate the growth of a cislunar economic sphere in campaign segments beginning with Human Lunar Return that enables a robust lunar economy in the Sustaining Lunar Evolution segment through commerce and development activities. Early on, infrastructure objectives that drive development of lunar power, communications, and PNT may be implemented in a way that builds initial commerce capabilities and activities. Lunar and Martian exploration and demonstrations identified in the objectives represent opportunities to gain the knowledge needed and demonstrate capabilities that are core to enabling space development as identified in this Tenet.

RT Considerations:

Both architecture and procurement design can encourage commerce and space development beyond LEO. Plans for activities beyond the Human Lunar Return segment remain in the formulation stage.

There is currently no trade in commodities in cislunar space or on the surface of the Moon. NASA should consider how opportunities for trade of services and goods could be fostered in support of the Moon to Mars Architecture through program and procurement design. Plans for initial exploration and demonstration missions are in formulation as a foundation that can support potential future space commerce and development activities. The intent of the Sustaining Lunar Evolution campaign segment is to address these gaps with respect to RT-9. Architecture plans and activities in prior segments are needed to build toward that future. Through pathfinder efforts, demonstrations, and master planning, the legal and operational precedents can be set in a timely manner to enable industry to partner with NASA to achieve the intent of RT-9. Discussions need to begin in earnest during formulation of the initial campaign segments to determine the desired future state and steps necessary for expansion of the economic sphere beyond Earth orbit.

APPENDIX A: FULL DECOMPOSITION OF LUNAR OBJECTIVES

This appendix shows the comprehensive decomposition for the lunar objectives into characteristic and needs, use cases, and functions.

A.1 SCIENCE

A.1.1 Lunar/Planetary Science

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Crewed mission(s) to landing sites in the lunar south polar regions	UC-021-L	Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	CN-055-L	Uncover the record of solar system origin and early history, by determining how and when planetary bodies formed and differentiated, characterizing the impact chronology of the inner solar system as recorded on the Moon and Mars, and characterize how impact rates in the inner solar system have changed over time as recorded on the Moon and Mars.	LPS-01-LM
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	FN-044-L	Crewed mission(s) to distributed landing sites on the lunar surface	UC-022-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest	UC-023-L				
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	UC-048-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	CN-056-L		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide local unpressurized crew surface mobility	**FN-030-L**						
Provide pressurized crew surface mobility	**FN-031-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew extravehicular explorations and identification of surface samples	**UC-025-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from non-PSRs and sunlit regions	**UC-026-L**				
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-032-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						
Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-048-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from PSRs	**UC-030-L**				
Provide local unpressurized crew surface mobility	**FN-030-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-054-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-218-L**						
Stow collected surface samples from PSRs on the lunar surface	**FN-220-L**						
Utilize tools to collect surface samples from PSRs on the lunar surface	**FN-258-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Stow collected surface samples on the lunar surface from PSRs in conditioned state	**FN-274-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport collected surface samples on the lunar surface	FN-277-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Document sample details prior to collection on the lunar surface	UC-107-L				
Record sample position, orientation, context and time prior to collection on the lunar surface	FN-132-L						
Provide accurate location tracking and position data on the lunar surface	FN-227-L						
Capture imagery on the lunar surface	FN-269-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar sub-surface.	CN-057-L		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide local unpressurized crew surface mobility	FN-030-L						
Provide pressurized crew surface mobility	FN-031-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew extravehicular explorations and identification of surface samples	UC-025-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Conduct crew lunar surface extravehicular activity	FN-028-L	Collect sub-surface samples from non-PSRs and sunlit regions	UC-034-L				
Conduct crew survey of areas of interests and sample identification	FN-046-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state	**FN-055-L**						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-143-L**						
Utilize tools to collect sub-surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-259-L**						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-262-L**						
Transport collected sub-surface samples on the lunar surface in conditioned state	**FN-278-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**				
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect sub-surface samples from PSRs	**UC-111-L**				
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**FN-219-L**						
Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state	**FN-221-L**						
Utilize tools to collect sub-surface samples from PSRs on the lunar surface	**FN-260-L**						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**FN-261-L**						
Transport collected sub-surface samples on the lunar surface in conditioned state	**FN-278-L**						
Transport cargo from the lunar surface to Earth	**FN-042-L**	Return collected surface samples (non-conditioned) to Earth in sealed sample containers	**UC-020-L**	Return a variety of samples from the lunar surface and subsurface, including regolith, pebbles, and rocks, back to curation facilities on Earth.	**CN-058-L**		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**						
Prepare unconditioned cargo or samples for Earth return	**FN-153-L**						
Transport cargo from the lunar surface to Earth	**FN-042-L**	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers	**UC-097-L**	Return a variety of samples, including drill cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum,	**CN-059-L**		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport cargo from the lunar surface to cislunar space	**FN-146-L**			from the lunar subsurface back to curation facilities on Earth.			
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to Earth	**FN-265-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	**FN-267-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation	**UC-014-L**	Deploy and operate utilization payload(s), related to understanding impact chronology, at distributed sites on the lunar surface.	**CN-060-L**		
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**						
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**	Accurate location identification, tracking, and imagery of collected samples.	**CN-061-LM**		
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Position, navigation, and timing for accurate sample tracking	**UC-127-L**				
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Provide reference time/frequency generation on the lunar surface	**FN-242-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Transport cargo to specific pre-defined location within exploration area on the lunar surface	**UC-072-L**	Deploy utilization payloads outside the blast zone of the propulsive vehicles.	**CN-062-LM**		
Provide precision landing for cargo transport to the lunar surface	**FN-088-L**						
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	**FN-257-L**						
Unload cargo on the lunar surface	**FN-019-L**	Deploy cargo to the lunar surface	**UC-100-L**				

Functions		Use Cases		Characteristics/Needs		Objectives	
Reposition cargo on the lunar surface	**FN-020-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide the ability for the Science Team to directly or indirectly communicate in real-time via either written or verbal means with the crew for EVA and IVA activities.	**CN-065-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	**FN-013-L**	Crewed mission(s) to landing sites in the lunar south polar regions	**UC-021-L**	Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	**CN-055-L**	Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.	**LPS-02-LM**
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	**FN-044-L**	Crewed mission(s) to distributed landing sites on the lunar surface	**UC-022-L**				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Robotically survey potential crewed landing and exploration sites to identify locations of interest	**UC-023-L**				
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**FN-040-L**						
Survey potential exploration sites on the lunar surface from lunar orbit	**FN-196-L**						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	**FN-248-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	**UC-048-L**				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**FN-045-L**						
Survey potential exploration sites on the lunar surface from lunar orbit	**FN-196-L**						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	**FN-248-L**						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**FN-040-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	**UC-019-L**	Identify, collect, and document samples from multiple globally distributed locations,	**CN-056-L**		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**FN-045-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L			including frozen samples from PSRs, from the lunar surface.			
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide local unpressurized crew surface mobility	FN-030-L						
Provide pressurized crew surface mobility	FN-031-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew extravehicular explorations and identification of surface samples	UC-025-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Conduct crew lunar surface extravehicular activity	FN-028-L	Collect surface samples from non-PSRs and sunlit regions	UC-026-L				
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-032-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	FN-048-L						
Transport collected surface samples on the lunar surface	FN-277-L						
Conduct crew lunar surface extravehicular activity	FN-028-L	Collect surface samples from PSRs	UC-030-L				
Provide local unpressurized crew surface mobility	FN-030-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	FN-054-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	FN-218-L						
Stow collected surface samples from PSRs on the lunar surface	FN-220-L						
Utilize tools to collect surface samples from PSRs on the lunar surface	FN-258-L						
Provide power for conditioning to sample containers on the lunar surface	FN-266-L						
Stow collected surface samples on the lunar surface from PSRs in conditioned state	FN-274-L						
Transport collected surface samples on the lunar surface	FN-277-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Record sample position, orientation, context and time prior to collection on the lunar surface	FN-132-L	Document sample details prior to collection on the lunar surface	UC-107-L				
Provide accurate location tracking and position data on the lunar surface	FN-227-L						
Capture imagery on the lunar surface	FN-269-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L				
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L			Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar sub-surface.	CN-057-L		
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide local unpressurized crew surface mobility	FN-030-L	Crew excursions to locations distributed around landing site	UC-024-L				
Provide pressurized crew surface mobility	FN-031-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew extravehicular explorations and identification of surface samples	**UC-025-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect sub-surface samples from non-PSRs and sunlit regions	**UC-034-L**				
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state	**FN-055-L**						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-143-L**						
Utilize tools to collect sub-surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-259-L**						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-262-L**						
Transport collected sub-surface samples on the lunar surface in conditioned state	**FN-278-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**				
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect sub-surface samples from PSRs	**UC-111-L**				
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**FN-219-L**						
Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state	**FN-221-L**						
Utilize tools to collect sub-surface samples from PSRs on the lunar surface	**FN-260-L**						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**FN-261-L**						
Transport collected sub-surface samples on the lunar surface in conditioned state	**FN-278-L**						
Transport cargo from the lunar surface to Earth	**FN-042-L**	Return collected surface samples (non-conditioned) to Earth in sealed sample containers	**UC-020-L**	Return a variety of samples from the lunar surface and subsurface, including regolith,	**CN-058-L**		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport cargo from cislunar space to Earth	FN-145-L			pebbles, and rocks, back to curation facilities on Earth.			
Transport cargo from the lunar surface to cislunar space	FN-146-L						
Prepare unconditioned cargo or samples for Earth return	FN-153-L						
Transport cargo from the lunar surface to Earth	FN-042-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers	UC-097-L	Return a variety of samples, including drill cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum, from the lunar subsurface back to curation facilities on Earth.	CN-059-L		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Transport cargo from cislunar space to Earth	FN-145-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from the lunar surface to Earth	FN-265-L						
Provide power for conditioning to sample containers on the lunar surface	FN-266-L						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	FN-267-L						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	FN-268-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Document sample details prior to collection on the lunar surface	UC-107-L	Accurate location identification, tracking, and imagery of collected samples.	CN-061-LM		
Record sample position, orientation, context and time prior to collection on the lunar surface	FN-132-L						
Provide accurate location tracking and position data on the lunar surface	FN-227-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Position, navigation, and timing for accurate sample tracking	UC-127-L				
Provide accurate location tracking and position data on the lunar surface	FN-227-L						
Provide reference time/frequency generation on the lunar surface	FN-242-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface	UC-072-L	Deploy utilization payloads outside the blast zone of the propulsive vehicles.	CN-062-LM		
Provide precision landing for cargo transport to the lunar surface	FN-088-L						
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	FN-257-L						
Unload cargo on the lunar surface	FN-019-L	Deploy cargo to the lunar surface	UC-100-L				
Reposition cargo on the lunar surface	FN-020-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM		
Provide Earth based ground stations for exploration communications	FN-081-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	UC-067-L				
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L	Utilize common interface(s) for power transfers and distribution on the lunar surface	UC-084-L				
Provide common data interface on the lunar surface	FN-202-L	Utilize common interface(s) for data transfer and distribution	UC-085-L				
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						
Provide power for deployed surface asset(s)	FN-051-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	UC-123-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Distribute power on the lunar surface	FN-080-L	Deliver power to assets on the lunar surface	UC-187-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide the ability for the Science Team to directly or indirectly communicate in real-time via either written or verbal means with the crew for EVA and IVA activities.	CN-065-L		
Provide Earth based ground stations for exploration communications	FN-081-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation	UC-014-L	Deploy and operate utilization payload(s), related to geologic processes, at distributed sites on the lunar surface.	CN-217-L		
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Crewed mission(s) to landing sites in the lunar south polar regions	UC-021-L	Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	CN-055-L	Reveal inner solar system volatile origin and delivery processes by determining the age, origin, distribution, abundance, composition, transport, and sequestration of lunar and Martian volatiles.	LPS-03-LM
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	FN-044-L	Crewed mission(s) to distributed landing sites on the lunar surface	UC-022-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest	UC-023-L				
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	UC-048-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	CN-056-L		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide local unpressurized crew surface mobility	FN-030-L						
Provide pressurized crew surface mobility	FN-031-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew extravehicular explorations and identification of surface samples	UC-025-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Conduct crew lunar surface extravehicular activity	FN-028-L	Collect surface samples from non-PSRs and sunlit regions	UC-026-L				
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-032-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	FN-048-L						
Transport collected surface samples on the lunar surface	FN-277-L						
Conduct crew lunar surface extravehicular activity	FN-028-L	Collect surface samples from PSRs	UC-030-L				
Provide local unpressurized crew surface mobility	FN-030-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	FN-054-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	FN-218-L						
Stow collected surface samples from PSRs on the lunar surface	FN-220-L						
Utilize tools to collect surface samples from PSRs on the lunar surface	FN-258-L						
Provide power for conditioning to sample containers on the lunar surface	FN-266-L						
Stow collected surface samples on the lunar surface from PSRs in conditioned state	FN-274-L						
Transport collected surface samples on the lunar surface	FN-277-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Document sample details prior to collection on the lunar surface	UC-107-L				
Record sample position, orientation, context and time prior to collection on the lunar surface	FN-132-L						
Provide accurate location tracking and position data on the lunar surface	FN-227-L						
Capture imagery on the lunar surface	FN-269-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar sub-surface.	CN-057-L		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew excursions to locations distributed around landing site	**UC-024-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide local unpressurized crew surface mobility	**FN-030-L**						
Provide pressurized crew surface mobility	**FN-031-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew extravehicular explorations and identification of surface samples	**UC-025-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect sub-surface samples from non-PSRs and sunlit regions	**UC-034-L**				
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state	**FN-055-L**						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-143-L**						
Utilize tools to collect sub-surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-259-L**						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-262-L**						
Transport collected sub-surface samples on the lunar surface in conditioned state	**FN-278-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**				
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect sub-surface samples from PSRs	**UC-111-L**				
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**FN-219-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state	FN-221-L						
Utilize tools to collect sub-surface samples from PSRs on the lunar surface	FN-260-L						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	FN-261-L						
Transport collected sub-surface samples on the lunar surface in conditioned state	FN-278-L						
Transport cargo from the lunar surface to Earth	FN-042-L	Return collected surface samples (non-conditioned) to Earth in sealed sample containers	UC-020-L	Return a variety of samples from the lunar surface and subsurface, including regolith, pebbles, and rocks, back to curation facilities on Earth.	CN-058-L		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Transport cargo from cislunar space to Earth	FN-145-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L						
Prepare unconditioned cargo or samples for Earth return	FN-153-L						
Transport cargo from the lunar surface to Earth	FN-042-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers	UC-097-L	Return a variety of samples, including drill cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum, from the lunar subsurface back to curation facilities on Earth.	CN-059-L		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Transport cargo from cislunar space to Earth	FN-145-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from the lunar surface to Earth	FN-265-L						
Provide power for conditioning to sample containers on the lunar surface	FN-266-L						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	FN-267-L						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	FN-268-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Document sample details prior to collection on the lunar surface	UC-107-L	Accurate location identification, tracking, and imagery of collected samples.	CN-061-LM		
Record sample position, orientation, context and time prior to collection on the lunar surface	FN-132-L						
Provide accurate location tracking and position data on the lunar surface	FN-227-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Position, navigation, and timing for accurate sample tracking	UC-127-L				
Provide accurate location tracking and position data on the lunar surface	FN-227-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide reference time/frequency generation on the lunar surface	FN-242-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface	UC-072-L	Deploy utilization payloads outside the blast zone of the propulsive vehicles.	CN-062-LM		
Provide precision landing for cargo transport to the lunar surface	FN-088-L						
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	FN-257-L						
Unload cargo on the lunar surface	FN-019-L	Deploy cargo to the lunar surface	UC-100-L				
Reposition cargo on the lunar surface	FN-020-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM		
Provide Earth based ground stations for exploration communications	FN-081-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	UC-067-L				
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L	Utilize common interface(s) for power transfers and distribution on the lunar surface	UC-084-L				
Provide common data interface on the lunar surface	FN-202-L	Utilize common interface(s) for data transfer and distribution	UC-085-L				
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide the ability for the Science Team to directly or indirectly communicate in real-time via either written or verbal means with the crew for EVA and IVA activities.	**CN-065-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation	**UC-014-L**	Deploy and operate utilization payload(s), related to Solar System volatiles, at distributed sites on the lunar surface.	**CN-218-L**		
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**	Accurate location identification, tracking, and imagery of collected samples.	**CN-061-LM**	Advance understanding of the origin of life in the solar system by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have co-evolved over time, and whether there is evidence of past or present life in the solar system beyond Earth.	**LPS-04-L**
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Position, navigation, and timing for accurate sample tracking	**UC-127-L**				
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Provide reference time/frequency generation on the lunar surface	**FN-242-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Transport cargo to specific pre-defined location within exploration area on the lunar surface	**UC-072-L**	Deploy utilization payloads outside the blast zone of the propulsive vehicles.	**CN-062-LM**		
Provide precision landing for cargo transport to the lunar surface	**FN-088-L**						
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	**FN-257-L**						
Unload cargo on the lunar surface	**FN-019-L**	Deploy cargo to the lunar surface	**UC-100-L**				
Reposition cargo on the lunar surface	**FN-020-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						

A.1.2 Heliophysics Science

Functions		Use Cases		Characteristics/Needs		Objectives	
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation	UC-031-L	Deploy and operate utilization payload(s) in a variety of lunar orbits relevant to addressing the associated science objectives.	CN-080-L	Improve understanding of space weather phenomena to enable enhanced observation and prediction of the dynamic environment from space to the surface at the Moon and Mars.	HS-01-LM
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L						
Distribute power to utilization payloads in cislunar space	FN-134-L						
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Deliver free flying asset(s) to cislunar space	FN-058-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term	UC-032-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation	UC-057-L				
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L						
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Deliver free flying asset(s) to cislunar space	FN-058-L	Deploy and operate free-flying assets in a variety of lunar and heliocentric orbits long-term	UC-058-L	Deploy and operate utilization payload(s) for Solar monitoring off the Earth-Sun line.	CN-081-LM		
Deliver free-flying asset(s) to heliocentric and deep space	FN-225-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation	UC-033-L	Deploy and Operate utilization payload(s), related to in-space weather, at distributed sites on the lunar surface.	CN-082-L		
Conduct crew lunar surface extravehicular activity	FN-028-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Utilize common interface(s) for power transfers and distribution in cislunar space	**UC-106-L**				
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**		**UC-175-L**				

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide Earth based ground stations for exploration communications	**FN-081-L**	Communications and data exchange between assets in cislunar space and Earth					
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**FN-040-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	**UC-019-L**	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	**CN-056-L**	Determine the history of the Sun and solar system as recorded in the lunar and Martian regolith.	**HS-02-LM**
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**FN-045-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**						
Robotic identification of potential samples and resources on the lunar surface	**FN-249-L**						
Robotic collection of lunar surface samples	**FN-250-L**						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	**FN-251-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew excursions to locations distributed around landing site	**UC-024-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide local unpressurized crew surface mobility	**FN-030-L**						
Provide pressurized crew surface mobility	**FN-031-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew extravehicular explorations and identification of surface samples	**UC-025-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from non-PSRs and sunlit regions	**UC-026-L**				
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-032-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						
Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-048-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from PSRs	**UC-030-L**				
Provide local unpressurized crew surface mobility	**FN-030-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-054-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-218-L**						
Stow collected surface samples from PSRs on the lunar surface	**FN-220-L**						
Utilize tools to collect surface samples from PSRs on the lunar surface	**FN-258-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Stow collected surface samples on the lunar surface from PSRs in conditioned state	**FN-274-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**				
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Transport cargo from the lunar surface to Earth	**FN-042-L**		**UC-097-L**	Return a variety of samples, including drill	**CN-**		

Functions		Use Cases		Characteristics/Needs		Objectives	
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers		cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum, from the lunar subsurface back to curation facilities on Earth.			
Transport cargo from cislunar space to Earth	**FN-145-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to Earth	**FN-265-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	**FN-267-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						
Provide power for deployed surface asset(s)	FN-051-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	UC-123-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Distribute power on the lunar surface	FN-080-L	Deliver power to assets on the lunar surface	UC-187-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation	UC-033-L	Deploy and operate utilization payload(s), related to the history of the Sun and solar system, at distributed sites on the lunar surface.	CN-085-L		
Conduct crew lunar surface extravehicular activity	FN-028-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	CN-056-L	Investigate and characterize fundamental plasma processes, including dust-plasma interactions, using the cislunar, near-Mars, and surface environments as laboratories.	HS-03-LM
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Robotic identification of potential samples and resources on the lunar surface	**FN-249-L**						
Robotic collection of lunar surface samples	**FN-250-L**						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	**FN-251-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew excursions to locations distributed around landing site	**UC-024-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide local unpressurized crew surface mobility	**FN-030-L**						
Provide pressurized crew surface mobility	**FN-031-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew extravehicular explorations and identification of surface samples	**UC-025-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from non-PSRs and sunlit regions	**UC-026-L**				
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-032-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						
Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-048-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from PSRs	**UC-030-L**				
Provide local unpressurized crew surface mobility	**FN-030-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-054-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-218-L**						
Stow collected surface samples from PSRs on the lunar surface	**FN-220-L**						
Utilize tools to collect surface samples from PSRs on the lunar surface	**FN-258-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Stow collected surface samples on the lunar surface from PSRs in conditioned state	**FN-274-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**				
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Deliver utilization payload(s) to cislunar space	**FN-056-L**	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation	**UC-031-L**	Deploy and operate utilization payload(s) in a variety of lunar orbits relevant to addressing the associated science objectives.	**CN-080-L**		
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	**FN-057-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Monitor operating asset(s)	**FN-140-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	**FN-276-L**						
Deliver free flying asset(s) to cislunar space	**FN-058-L**	Deploy and operate free-flying assets in a variety of lunar orbits long-term	**UC-032-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	**FN-276-L**						
Deliver utilization payload(s) to cislunar space	**FN-056-L**	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation	**UC-057-L**				
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	**FN-057-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						
Monitor operating asset(s)	**FN-140-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	**FN-276-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**				
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**						
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Provide common data interface on the lunar surface	**FN-202-L**						
Provide common data interface in cislunar space	**FN-203-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Utilize common interface(s) for power transfers and distribution in cislunar space	**UC-106-L**				
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**		**UC-175-L**				

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide Earth based ground stations for exploration communications	FN-081-L	Communications and data exchange between assets in cislunar space and Earth					
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Distribute power on the lunar surface	FN-080-L	Deliver power to assets on the lunar surface	UC-187-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation	UC-124-L	Deploy and operate utilization payload(s) related to fundamental plasma processes around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	CN-220-L		
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation	UC-031-L	Deploy and operate science package(s), related to the magnetotail and solar wind, in cislunar space.	CN-090-L	Improve understanding of magnetotail and pristine solar wind dynamics in the vicinity of the Moon and around Mars.	HS-04-LM
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L						
Distribute power to utilization payloads in cislunar space	FN-134-L						
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Deliver free flying asset(s) to cislunar space	FN-058-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term	UC-032-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport cargo from Earth to the lunar surface	**FN-018-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation	**UC-014-L**	Deploy and operate science package(s), related to the magnetotail and solar wind, at distributed sites on the lunar surface.	**CN-091-L**		
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**						
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Utilize common interface(s) for power transfers and distribution in cislunar space	**UC-106-L**				
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						

A.1.3 Human and Biological Science

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants.	HBS-01-LM
Provide Earth based ground stations for exploration communications	FN-081-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	UC-067-L				
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L	Utilize common interface(s) for power transfers and distribution on the lunar surface	UC-084-L				
Provide common data interface on the lunar surface	FN-202-L	Utilize common interface(s) for data transfer and distribution	UC-085-L				
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						
Provide power for deployed surface asset(s)	FN-051-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	UC-123-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Distribute power on the lunar surface	FN-080-L	Deliver power to assets on the lunar surface	UC-187-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	UC-018-L	Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	CN-093-L		
Provide crew health care on the lunar surface	FN-149-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Reuse habitation system(s) on the lunar surface	UC-092-L				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface	UC-128-L				
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	FN-271-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	UC-191-L				
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Docking/berthing between pressurized assets on the lunar surface	FN-124-L						
Transfer gases and water to habitable assets on the lunar surface	FN-177-L						
Transport cargo on the lunar surface between landing location and surface assets	FN-178-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space	UC-015-L	Conduct mid-duration (month+) to extended-duration (year+) crew exploration mission(s) in cislunar space prior to lunar surface mission.	CN-094-L		
Transport cargo from Earth to assets in cislunar space	FN-033-L						
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Manage waste from habitable asset(s) in cislunar space	FN-036-L						
Provide remote crew medical systems in cislunar space	FN-039-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.	UC-035-L				
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Transport crew from cislunar space to the lunar surface after extended duration (year+) in space	FN-136-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Reuse habitation system(s) on the lunar surface	UC-092-L				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.	UC-035-L	Transition crew from micro-gravity environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.	CN-095-LM		
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Transport crew from cislunar space to the lunar surface after extended duration (year+) in space	FN-136-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Transport cargo from cislunar space to Earth	FN-145-L	Transport conditioned cargo from cislunar space to Earth	UC-178-L	Return biological and human research sample(s), including frozen samples, from the lunar surface back to Earth.	CN-096-L		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	FN-268-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L	Transport conditioned cargo from the lunar surface to cislunar space	UC-180-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	FN-267-L						
Recover crew, crew system(s), and cargo after Earth landing	FN-017-L	Transport conditioned cargo to appropriate facilities on Earth	UC-181-L				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	FN-121-L						
Transport cargo from cislunar space to Earth	FN-145-L	Transport conditioned cargo from cislunar space to Earth	UC-178-L	Return biological and human research sample(s), including frozen samples, from the cislunar space back to Earth.	CN-097-L		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	FN-268-L						
Recover crew, crew system(s), and cargo after Earth landing	FN-017-L	Transport conditioned cargo to appropriate facilities on Earth	UC-181-L				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	FN-121-L						
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	FN-060-L	Crew conduct biological science and human research activities on the lunar surface	UC-036-L	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the lunar surface to enable biological science analysis and human research.	CN-098-L		
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	FN-060-L	Conduct intravehicular science and utilization activities on the lunar surface	UC-043-L				
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) in cislunar space	FN-062-L	Crew conduct biological science and human research activities while in habitable volume in cislunar space	UC-037-L	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) in cislunar space to enable biological science analysis and human research.	CN-099-L		
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces), in transit assets	FN-133-L	Crew conduct biological science and human research activities in habitable volume while in transit	UC-112-L	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) during transits in cislunar and/or deep space to enable biological	CN-100-LM		

Functions		Use Cases		Characteristics/Needs		Objectives	
				science analysis and human research.			
Transport crew and associated cargo from the lunar surface to cislunar space	**FN-014-L**	Prepare crew for transition and transport from the lunar surface to cislunar space	**UC-129-L**	Transition crew from partial gravity environment to micro-gravity environment.	**CN-105-LM**		
Ready and transition crew to transportation asset for return to orbit	**FN-179-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide capabilities to collect, document, and transmit data from human research and space biology experiment for investigating physiological responses to transitions between partial and micro-gravity environment.	**CN-212-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**FN-224-L**	Communications and data exchange between assets in cislunar space and the lunar surface	**UC-173-L**				
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Format, transmit, and receive data from cislunar space to the lunar surface	**FN-238-L**						
Format, transmit, and receive data from the lunar surface to cislunar space	**FN-239-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Receive and format data on Earth	**FN-232-L**	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received	**UC-174-L**				
Format and transit data to Earth from cislunar space	**FN-236-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Protect and/or secure data for storage and transmission	FN-244-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Format and transmit data to Earth from the lunar surface	FN-231-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received	UC-176-L				
Receive and format data on Earth	FN-232-L						
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up assets to monitor natural environments on the lunar surface	UC-169-L	Deploy and operate utilization payload(s) related to understanding the environment around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	CN-219-L		
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up assets to monitor induced environment on the lunar surface	UC-171-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Evaluate and validate progressively Earth-independent crew health & performance systems and operations with mission durations representative of Mars-class missions.	HBS-02-LM
Provide Earth based ground stations for exploration communications	FN-081-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	UC-067-L				
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L	Utilize common interface(s) for power transfers and distribution on the lunar surface	UC-084-L				
Provide common data interface on the lunar surface	FN-202-L	Utilize common interface(s) for data transfer and distribution	UC-085-L				
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						
Provide power for deployed surface asset(s)	FN-051-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	UC-123-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Provide remote crew medical systems on the lunar surface	**FN-026-L**	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	**UC-018-L**	Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	**CN-093-L**		
Provide crew health care on the lunar surface	**FN-149-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	**FN-107-L**	Reuse habitation system(s) on the lunar surface	**UC-092-L**				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	**FN-113-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface	**UC-128-L**				
Transfer pressurized cargo into habitable assets on the lunar surface	**FN-027-L**						
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	**FN-271-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	**UC-191-L**				
Transfer pressurized cargo into habitable assets on the lunar surface	**FN-027-L**						
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**						
Docking/berthing between pressurized assets on the lunar surface	**FN-124-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Transfer gases and water to habitable assets on the lunar surface	**FN-177-L**						
Transport cargo on the lunar surface between landing location and surface assets	**FN-178-L**						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	**FN-013-L**	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.	**UC-035-L**	Transition crew from micro-gravity environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.	**CN-095-LM**		
Transfer cargo into habitable asset(s) in cislunar space	**FN-035-L**						
Transport crew from cislunar space to the lunar surface after extended duration (year+) in space	**FN-136-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	**FN-273-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**	Transport conditioned cargo from cislunar space to Earth	**UC-178-L**	Return biological and human research sample(s), including frozen samples, from the lunar surface back to Earth.	**CN-096-L**		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**	Transport conditioned cargo from the lunar surface to cislunar space	**UC-180-L**				
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	**FN-267-L**						
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**	Transport conditioned cargo to appropriate facilities on Earth	**UC-181-L**				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**FN-121-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**	Transport conditioned cargo from cislunar space to Earth	**UC-178-L**	Return biological and human research sample(s), including frozen samples, from the cislunar space back to Earth.	**CN-097-L**		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**	Transport conditioned cargo to appropriate facilities on Earth	**UC-181-L**				

Functions		Use Cases		Characteristics/Needs		Objectives	
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**FN-121-L**						
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	**FN-060-L**	Crew conduct biological science and human research activities on the lunar surface	**UC-036-L**	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the lunar surface to enable biological science analysis and human research.	**CN-098-L**		
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	**FN-060-L**	Conduct intravehicular science and utilization activities on the lunar surface	**UC-043-L**				
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) in cislunar space	**FN-062-L**	Crew conduct biological science and human research activities while in habitable volume in cislunar space	**UC-037-L**	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) in cislunar space to enable biological science analysis and human research.	**CN-099-L**		
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces), in transit assets	**FN-133-L**	Crew conduct biological science and human research activities in habitable volume while in transit	**UC-112-L**	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) during transits in cislunar and/or deep space to enable biological science analysis and human research.	**CN-100-LM**		
Transport crew and associated cargo from the lunar surface to cislunar space	**FN-014-L**	Prepare crew for transition and transport from the lunar surface to cislunar space	**UC-129-L**	Transition crew from partial gravity environment to micro-gravity environment.	**CN-105-LM**		
Ready and transition crew to transportation asset for return to orbit	**FN-179-L**						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	**FN-010-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space	**UC-015-L**	Conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	**CN-106-LM**		
Transport cargo from Earth to assets in cislunar space	**FN-033-L**						
Transfer cargo into habitable asset(s) in cislunar space	**FN-035-L**						
Manage waste from habitable asset(s) in cislunar space	**FN-036-L**						
Provide remote crew medical systems in cislunar space	**FN-039-L**						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	**FN-273-L**						
Operate habitation system(s) in dormancy/remote mode between crewed missions in cislunar space	**FN-155-L**	Reuse habitation systems(s) in cislunar space	**UC-149-L**				

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide capabilities to collect, document, and transmit data from human research and space biology experiment for investigating physiological responses to transitions between partial and micro-gravity environment.	**CN-212-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**FN-224-L**	Communications and data exchange between assets in cislunar space and the lunar surface	**UC-173-L**				
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Format, transmit, and receive data from cislunar space to the lunar surface	**FN-238-L**						
Format, transmit, and receive data from the lunar surface to cislunar space	**FN-239-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Receive and format data on Earth	**FN-232-L**	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received	**UC-174-L**				
Format and transit data to Earth from cislunar space	**FN-236-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received	**UC-176-L**				
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up assets to monitor natural environments on the lunar surface	**UC-169-L**				
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**			Deploy and operate utilization payload(s) related to understanding the environment around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	**CN-219-L**		
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Deploy and set up assets to monitor induced environment on the lunar surface	**UC-171-L**				
Provide power for deployed surface asset(s)	**FN-051-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**	Characterize and evaluate how the interaction of exploration systems and the deep space environment affect human health, performance, and space human factors to inform future exploration-class missions.	**HBS-03-LM**
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Provide remote crew medical systems on the lunar surface	**FN-026-L**	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	**UC-018-L**	Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	**CN-093-L**		
Provide crew health care on the lunar surface	**FN-149-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	**FN-107-L**	Reuse habitation system(s) on the lunar surface	**UC-092-L**				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	**FN-113-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface	**UC-128-L**				
Transfer pressurized cargo into habitable assets on the lunar surface	**FN-027-L**						
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	**FN-271-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	**UC-191-L**				
Transfer pressurized cargo into habitable assets on the lunar surface	**FN-027-L**						
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**						
Docking/berthing between pressurized assets on the lunar surface	**FN-124-L**						
Transfer gases and water to habitable assets on the lunar surface	**FN-177-L**						
Transport cargo on the lunar surface between landing location and surface assets	**FN-178-L**						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	**FN-013-L**	Conduct missions with extended-duration (year+) in microgravity,	**UC-035-L**	Transition crew from micro-gravity	**CN-**		

Functions		Use Cases		Characteristics/Needs		Objectives	
Transfer cargo into habitable asset(s) in cislunar space	**FN-035-L**	followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.		environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.			
Transport crew from cislunar space to the lunar surface after extended duration (year+) in space	**FN-136-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	**FN-273-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**	Transport conditioned cargo from cislunar space to Earth	**UC-178-L**	Return biological and human research sample(s), including frozen samples, from the lunar surface back to Earth.	**CN-096-L**		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**	Transport conditioned cargo from the lunar surface to cislunar space	**UC-180-L**				
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	**FN-267-L**						
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**	Transport conditioned cargo to appropriate facilities on Earth	**UC-181-L**				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**FN-121-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**	Transport conditioned cargo from cislunar space to Earth	**UC-178-L**	Return biological and human research sample(s), including frozen samples, from the cislunar space back to Earth.	**CN-097-L**		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**	Transport conditioned cargo to appropriate facilities on Earth	**UC-181-L**				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**FN-121-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	FN-060-L	Crew conduct biological science and human research activities on the lunar surface	UC-036-L	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the lunar surface to enable biological science analysis and human research.	CN-098-L		
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	FN-060-L	Conduct intravehicular science and utilization activities on the lunar surface	UC-043-L				
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) in cislunar space	FN-062-L	Crew conduct biological science and human research activities while in habitable volume in cislunar space	UC-037-L	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) in cislunar space to enable biological science analysis and human research.	CN-099-L		
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces), in transit assets	FN-133-L	Crew conduct biological science and human research activities in habitable volume while in transit	UC-112-L	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) during transits in cislunar and/or deep space to enable biological science analysis and human research.	CN-100-LM		
Transport crew and associated cargo from the lunar surface to cislunar space	FN-014-L	Prepare crew for transition and transport from the lunar surface to cislunar space	UC-129-L	Transition crew from partial gravity environment to micro-gravity environment.	CN-105-LM		
Ready and transition crew to transportation asset for return to orbit	FN-179-L						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space	UC-015-L	Conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	CN-106-LM		
Transport cargo from Earth to assets in cislunar space	FN-033-L						
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Manage waste from habitable asset(s) in cislunar space	FN-036-L						
Provide remote crew medical systems in cislunar space	FN-039-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Operate habitation system(s) in dormancy/remote mode between crewed missions in cislunar space	FN-155-L	Reuse habitation systems(s) in cislunar space	UC-149-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide capabilities to collect, document, and transmit data from human research and	CN-212-L		
Provide Earth based ground stations for exploration communications	FN-081-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Format and transmit data to Earth from the lunar surface	**FN-231-L**			space biology experiment for investigating physiological responses to transitions between partial and micro-gravity environment.			
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**FN-224-L**	Communications and data exchange between assets in cislunar space and the lunar surface	**UC-173-L**				
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Format, transmit, and receive data from cislunar space to the lunar surface	**FN-238-L**						
Format, transmit, and receive data from the lunar surface to cislunar space	**FN-239-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Receive and format data on Earth	**FN-232-L**	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received	**UC-174-L**				
Format and transit data to Earth from cislunar space	**FN-236-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received	**UC-176-L**				
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up assets to monitor natural environments on the lunar surface	**UC-169-L**				
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**			Deploy and operate utilization payload(s) related to understanding the environment around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	**CN-219-L**		
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up assets to monitor induced environment on the lunar surface	**UC-171-L**				
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**						
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						

A.1.4 Physics and Physical Science

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Conduct astrophysics and fundamental physics investigations of space and time from the radio quiet environment of the lunar far side.	PPS-01-L
Provide Earth based ground stations for exploration communications	FN-081-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	UC-067-L				
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L	Utilize common interface(s) for power transfers and distribution on the lunar surface	UC-084-L				
Provide common data interface on the lunar surface	FN-202-L	Utilize common interface(s) for data transfer and distribution	UC-085-L				
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						
Provide power for deployed surface asset(s)	FN-051-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	UC-123-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Transport cargo from Earth to the far side of the lunar surface	**FN-066-L**	Deploy and set up astrophysics utilization payload(s) on the far side of the lunar surface with long-term remote operation	**UC-039-L**	Deploy and operate astrophysics utilization payload(s) on the far side of the lunar surface.	**CN-107-L**		
Conduct crew surface extravehicular activities at the lunar far side region	**FN-067-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Implement communication methods to coordinate and preserve the radio environment on the lunar far side	**FN-174-L**	Preserve lunar far side environment to ensure scientific data integrity	**UC-055-L**				
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface	**FN-060-L**	Crew conduct fundamental physics experiments while in habitable volume on the lunar surface	**UC-040-L**	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) on the lunar surface to enable fundamental physics experiments.	**CN-108-L**		
Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) in cislunar space	**FN-062-L**	Crew conduct fundamental physics experiments while in habitable volume in cislunar space	**UC-044-L**	Provide intravehicular activity facilities (e.g., instruments, racks, stowage, power) in cislunar space to enable fundamental physics experiments.	**CN-109-L**		
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Utilize common interface(s) for power transfers and distribution in cislunar space	**UC-106-L**				
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Transport cargo from the lunar surface to Earth	**FN-042-L**						
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**						
Prepare unconditioned cargo or samples for Earth return	**FN-153-L**	Return physical artifacts from experiments to Earth	**UC-116-L**	Return science experiment result(s), including test sample(s), back to Earth.	**CN-113-LM**		
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to Earth	**FN-265-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**				
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**			Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**	Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.	**PPS-02-LM**
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**						
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide common data interface on the lunar surface	FN-202-L	Utilize common interface(s) for data transfer and distribution	UC-085-L				
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						
Provide power for deployed surface asset(s)	FN-051-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	UC-123-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Distribute power on the lunar surface	FN-080-L	Deliver power to assets on the lunar surface	UC-187-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Deliver free flying asset(s) to cislunar space	FN-058-L	Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation	UC-042-L	Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, in cislunar space.	CN-110-L		
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation	UC-053-L				
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation	UC-062-L				
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation	UC-041-L	Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, at distributed and south polar region sites on the lunar surface.	CN-111-L		
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation	UC-063-L				
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Transport cargo from the lunar surface to Earth	FN-042-L	Return physical artifacts from experiments to Earth	UC-116-L	Return science experiment result(s), including test sample(s), back to Earth.	CN-113-LM		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Transport cargo from cislunar space to Earth	FN-145-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L						
Prepare unconditioned cargo or samples for Earth return	FN-153-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from the lunar surface to Earth	FN-265-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						

A.1.5 Science Enabling

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide crew training prior to mission	**FN-068-L**	Provide advanced geology training, integrated geology and EVA ops training, as well as detailed objective-specific training to astronauts for science activities	**UC-045-L**	Train astronauts to be field scientists and to perform additional science tasks during crewed missions, through integrated geology, field and EVA ops and classroom training.	**CN-116-LM**	Provide in-depth, mission-specific science training for astronauts to enable crew to perform high-priority or transformational science on the surface of the Moon, and Mars, and in deep space.	**SE-01-LM**
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Provide in-situ training to astronauts for science tasks during mission(s)	**UC-046-L**				
Provide in-mission crew training in cislunar space	**FN-069-L**						
Provide in-mission crew training on the lunar surface	**FN-070-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide scalable communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, surface crew, and assets on the surface.	**CN-117-LM**	Enable Earth-based scientists to remotely support astronaut surface and deep space activities using advanced techniques and tools.	**SE-02-LM**
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received	**UC-176-L**				
Receive and format data on Earth	**FN-232-L**						
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Receive and format data on Earth	FN-232-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received	UC-174-L	Provide scalable communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, in-space crew, and in-space assets.	CN-118-LM		
Format and transit data to Earth from cislunar space	FN-236-L						
Store and distribute data between assets in cislunar space	FN-237-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities	UC-047-L	Train Earth-based scientists to support crew activities in real time.	CN-119-L		
Provide in-mission crew training in cislunar space	FN-069-L						
Provide in-mission crew training on the lunar surface	FN-070-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L						
Transport cargo from cislunar space to Earth	FN-145-L	Transport conditioned cargo from cislunar space to Earth	UC-178-L	Provide capabilities to return samples, including frozen samples in their pristine state, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface, with supporting equipment, back to curation facilities on Earth.	CN-050-L	Develop the capability to retrieve core samples of frozen volatiles from permanently shadowed regions on the Moon and volatile-bearing sites on Mars and to deliver them in pristine states to modern curation facilities on Earth.	SE-03-LM
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	FN-268-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L	Transport conditioned cargo from the lunar surface to cislunar space	UC-180-L				
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	FN-267-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**	Transport conditioned cargo to appropriate facilities on Earth	**UC-181-L**				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**FN-121-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**	Transport cargo from the lunar surface to cislunar space	**UC-179-L**	Provide capabilities to return samples, collected from the lunar surface, including regolith, pebbles, and rocks, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	**CN-051-L**		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare unconditioned cargo or samples for Earth return	**FN-153-L**						
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**	Transport collected samples to appropriate curation facilities on Earth	**UC-182-L**				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**	Transport conditioned cargo from cislunar space to Earth	**UC-178-L**	Provide capabilities to return samples, including drill cores, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	**CN-121-L**		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**	Transport conditioned cargo from the lunar surface to cislunar space	**UC-180-L**				
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	**FN-267-L**						
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**	Transport conditioned cargo to appropriate facilities on Earth	**UC-181-L**				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**FN-121-L**						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-143-L**	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples	**UC-117-L**	Provide tools, including temperature sensors, to support acquisition of frozen samples, manufactured in accordance with science requirements to minimize sample contamination.	**CN-122-LM**		
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**FN-219-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide containers to package sub-surface samples	FN-263-L	Package sub-surface samples for return	UC-118-L	Provide sample containers appropriate for the specimens collected and science needs (e.g. contamination considerations), including sealed containers and drill core tubes.	CN-123-LM		
Recover crew, crew system(s), and cargo after Earth landing	FN-017-L	Transport collected samples to appropriate curation facilities on Earth	UC-182-L	Provide curation facilities on Earth equipped for preserving acquired samples in their pristine state.	CN-124-LM		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L	Transport cargo from the lunar surface to cislunar space	UC-179-L	Provide capabilities to return samples, collected from the lunar surface, including regolith, pebbles, and rocks, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	CN-051-L	Return representative samples from multiple locations across the surface of the Moon and Mars, with sample mass commensurate with mission-specific science priorities.	SE-04-LM
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare unconditioned cargo or samples for Earth return	FN-153-L						
Recover crew, crew system(s), and cargo after Earth landing	FN-017-L	Transport collected samples to appropriate curation facilities on Earth	UC-182-L				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Transport cargo from cislunar space to Earth	FN-145-L	Transport conditioned cargo from cislunar space to Earth	UC-178-L	Provide capabilities to return samples, including drill cores, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	CN-121-L		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	FN-268-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L	Transport conditioned cargo from the lunar surface to cislunar space	UC-180-L				
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	FN-267-L						
Recover crew, crew system(s), and cargo after Earth landing	FN-017-L	Transport conditioned cargo to appropriate facilities on Earth	UC-181-L				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	FN-121-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide containers to package sub-surface samples	FN-263-L	Package sub-surface samples for return	UC-118-L	Provide sample containers appropriate for the specimens collected and science needs (e.g. contamination considerations), including sealed containers and drill core tubes.	CN-123-LM		
Recover crew, crew system(s), and cargo after Earth landing	FN-017-L	Transport collected samples to appropriate curation facilities on Earth	UC-182-L	Provide curation facilities on Earth equipped for preserving acquired samples in their pristine state.	CN-124-LM		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Crewed mission(s) to landing sites in the lunar south polar regions	UC-021-L	Provide capabilities to visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	CN-126-L		
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	FN-044-L	Crewed mission(s) to distributed landing sites on the lunar surface	UC-022-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest	UC-023-L				
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	UC-048-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L	Provide capabilities to identify, collect, and document samples from globally distributed and south polar region locations on the lunar surface.	CN-127-L		
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide local unpressurized crew surface mobility	FN-030-L						
Provide pressurized crew surface mobility	FN-031-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew extravehicular explorations and identification of surface samples	**UC-025-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from non-PSRs and sunlit regions	**UC-026-L**				
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-032-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						
Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-048-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from PSRs	**UC-030-L**				
Provide local unpressurized crew surface mobility	**FN-030-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-054-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-218-L**						
Stow collected surface samples from PSRs on the lunar surface	**FN-220-L**						
Utilize tools to collect surface samples from PSRs on the lunar surface	**FN-258-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Stow collected surface samples on the lunar surface from PSRs in conditioned state	**FN-274-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from non-PSRs and sunlit regions	**UC-026-L**	Provide tools to support acquisition of samples, including dust, soil, pebbles, hand-sized rock samples, and drill cores, manufactured in accordance with	**CN-128-L**		
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-032-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L			science requirements to minimize sample contamination.			
Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	FN-048-L						
Transport collected surface samples on the lunar surface	FN-277-L						
Conduct crew lunar surface extravehicular activity	FN-028-L	Collect surface samples from PSRs	UC-030-L				
Provide local unpressurized crew surface mobility	FN-030-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	FN-054-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	FN-218-L						
Stow collected surface samples from PSRs on the lunar surface	FN-220-L						
Utilize tools to collect surface samples from PSRs on the lunar surface	FN-258-L						
Provide power for conditioning to sample containers on the lunar surface	FN-266-L						
Stow collected surface samples on the lunar surface from PSRs in conditioned state	FN-274-L						
Transport collected surface samples on the lunar surface	FN-277-L						
Provide containers to package sub-surface samples	FN-263-L	Package sub-surface samples for return	UC-118-L	Provide sample containers appropriate for the specimens collected and science needs (e.g. contamination considerations), including sealed containers and drill core tubes.	CN-123-LM	Use robotic techniques to survey sites, conduct in-situ measurements, and identify/stockpile samples in advance of and concurrent with astronaut arrival, to optimize astronaut time on the lunar and Martian surface and maximize science return.	SE-05-LM
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest	UC-023-L	Conduct robotic surveys of potential landing sites, including video and in situ measurements.	CN-132-LM		
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey PSRs near potential crewed landing and	UC-048-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**FN-045-L**	exploration sites to identify locations of interest					
Survey potential exploration sites on the lunar surface from lunar orbit	**FN-196-L**						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	**FN-248-L**						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**FN-040-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	**UC-019-L**	Provide appropriate robotic tools to support acquisition of samples, including dust, soil, pebbles, hand-sized rock samples, and drill cores, manufactured in accordance with science requirements to minimize sample contamination.	**CN-133-L**		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**FN-045-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**						
Robotic identification of potential samples and resources on the lunar surface	**FN-249-L**						
Robotic collection of lunar surface samples	**FN-250-L**						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	**FN-251-L**						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**FN-040-L**	Remotely manage robotic system(s) during surface operation as required	**UC-094-L**				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**FN-045-L**						
Monitor robotic system(s) performance and health	**FN-252-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**	Enable long-term, planet-wide research by delivering science instruments to multiple science-relevant orbits and surface locations at the Moon and Mars.	**SE-06-LM**
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Deliver utilization payload(s) to cislunar space	**FN-056-L**	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation	**UC-031-L**	Deploy and operate utilization payload(s) in a variety of lunar orbits relevant to addressing the associated science objectives.	**CN-080-L**		
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	**FN-057-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Monitor operating asset(s)	**FN-140-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Deliver free flying asset(s) to cislunar space	FN-058-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term	UC-032-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation	UC-057-L				
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L						
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation	UC-014-L	Deploy and operate utilization payload(s) around globally distributed locations on the lunar surface relevant to addressing associated science objectives.	CN-088-L		
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	CN-112-L		
Provide Earth based ground stations for exploration communications	FN-081-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Utilize common interface(s) for power transfers and distribution in cislunar space	**UC-106-L**				
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Implement communication methods to coordinate and preserve the radio environment on the lunar far side	**FN-174-L**	Preserve lunar far side environment to ensure scientific data integrity	**UC-055-L**	Preserve radio free environment on the far side of the Moon.	**CN-**	Preserve and protect representative features of special interest, including lunar permanently shadowed regions and the radio quiet far side as well as Martian recurring slope lineae, to enable future high-priority science investigations.	**SE-07-LM**
Reduce blast ejecta	**FN-126-L**	Reduce blast ejecta to limit the migration of ejecta across the lunar surface	**UC-114-L**	Limit contamination of PSRs.	**CN-138-L**		
Inhibit dust migration and impacts	**FN-127-L**	Reduce path erosion, dust lofting, and sample contamination	**UC-115-L**				
Inhibit dust migration and impacts	**FN-127-L**	Limit spread of dust raised by lunar surface operations	**UC-125-L**				
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**	Manage disposal of hardware and waste products	**UC-136-L**				
Manage undesired samples and investigation items	**FN-156-L**						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	**FN-013-L**	Land exploration missions at sites removed from sites of historic significance	**UC-056-L**	Protect sites of historic significance.	**CN-139-LM**		
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	**FN-044-L**						
Reduce blast ejecta	**FN-126-L**						

A.1.6 Applied Science

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Characterize and monitor the contemporary environments of the lunar and Martian surfaces and orbits, including investigations of micrometeorite flux, atmospheric weather, space weather, space weathering, and dust, to plan, support, and monitor safety of crewed operations in these locations.	AS-01-LM
Provide Earth based ground stations for exploration communications	FN-081-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	UC-067-L				
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L	Utilize common interface(s) for power transfers and distribution on the lunar surface	UC-084-L				
Provide common data interface on the lunar surface	FN-202-L	Utilize common interface(s) for data transfer and distribution	UC-085-L				
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						
Provide power for deployed surface asset(s)	FN-051-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	UC-123-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Utilize common interface(s) for power transfers and distribution in cislunar space	UC-106-L				
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						
Provide power for deployed surface asset(s)	FN-051-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	UC-123-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Distribute power on the lunar surface	FN-080-L	Deliver power to assets on the lunar surface	UC-187-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy assets to monitor natural environments in cislunar space	UC-165-L	Provide system(s) to monitor cislunar space and lunar surface natural environments, including space weather, meteoroids, cosmic weather, thermal conditions, and plasma environments, and provide early warnings to in-space and surface assets and crew.	CN-143-L		
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges	UC-166-L				
Monitor operating asset(s)	FN-140-L						
Monitor electrostatic charging in space	FN-208-L						
Monitor natural radiation levels in space	FN-209-L						
Monitor plasma environment in space	FN-212-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Monitor meteoroid activities in cislunar space	FN-213-L						
Provide advanced warning of threats from natural environmental hazards in cislunar space	FN-216-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up assets to monitor natural environments on the lunar surface	UC-169-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Provide advanced warning of threats from natural environmental hazards on the lunar surface	FN-200-L	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges	UC-170-L				
Monitor radiation on the lunar surface	FN-210-L						
Monitor electrostatic charging on the lunar surface	FN-211-L						
Monitor plasma environment on the lunar surface	FN-214-L						
Monitor meteoroid activities on the lunar surface	FN-215-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up assets to monitor natural environments on the lunar surface	UC-169-L	Deploy and operate utilization payload(s) related to understanding the environment around globally distributed locations on the lunar surface relevel ant to addressing associated science objectives.	CN-219-L		
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up assets to monitor induced environment on the lunar surface	UC-171-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	UC-066-L	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	CN-063-LM	Coordinate on-going and future science measurements from orbital and surface platforms to optimize human-led science campaigns on the Moon and Mars.	AS-02-LM
Provide Earth based ground stations for exploration communications	FN-081-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	UC-067-L				
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L	Utilize common interface(s) for power transfers and distribution on the lunar surface	UC-084-L				
Provide common data interface on the lunar surface	FN-202-L	Utilize common interface(s) for data transfer and distribution	UC-085-L				
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Deliver utilization payload(s) to cislunar space	**FN-056-L**	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation	**UC-031-L**	Deploy and operate utilization payload(s) in a variety of lunar orbits relevant to addressing the associated science objectives.	**CN-080-L**		
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	**FN-057-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Monitor operating asset(s)	**FN-140-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	**FN-276-L**						
Deliver free flying asset(s) to cislunar space	**FN-058-L**	Deploy and operate free-flying assets in a variety of lunar orbits long-term	**UC-032-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	**FN-276-L**						
Deliver utilization payload(s) to cislunar space	**FN-056-L**	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation	**UC-057-L**				
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	**FN-057-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Monitor operating asset(s)	**FN-140-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	**FN-276-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation	**UC-014-L**	Deploy and operate utilization payload(s) around globally distributed locations on the lunar surface relevant to addressing associated science objectives.	**CN-088-L**		
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**						
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Utilize common interface(s) for power transfers and distribution in cislunar space	UC-106-L				
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	FN-125-L	Deliver power to asset(s) in cislunar space	UC-110-L				
Distribute power to utilization payloads in cislunar space	FN-134-L						
Provide power for deployed surface asset(s)	FN-051-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	UC-123-L				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Distribute power on the lunar surface	FN-080-L	Deliver power to assets on the lunar surface	UC-187-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
				Coordinate delivery and deployment of utilization payloads in cislunar space and on the lunar surface to address associated science objectives.	CN-136-L		
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Crewed mission(s) to landing sites in the lunar south polar regions	UC-021-L	Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	CN-055-L	Characterize accessible lunar and Martian resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable In-Situ Resource Utilization	AS-03-LM
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	FN-044-L	Crewed mission(s) to distributed landing sites on the lunar surface	UC-022-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest	UC-023-L				
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L					(ISRU) on successive missions.	
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	UC-048-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	CN-056-L		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide local unpressurized crew surface mobility	FN-030-L						
Provide pressurized crew surface mobility	FN-031-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew extravehicular explorations and identification of surface samples	UC-025-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from non-PSRs and sunlit regions	**UC-026-L**				
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-032-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						
Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-048-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from PSRs	**UC-030-L**				
Provide local unpressurized crew surface mobility	**FN-030-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-054-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-218-L**						
Stow collected surface samples from PSRs on the lunar surface	**FN-220-L**						
Utilize tools to collect surface samples from PSRs on the lunar surface	**FN-258-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Stow collected surface samples on the lunar surface from PSRs in conditioned state	**FN-274-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**				
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**FN-040-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	**UC-019-L**	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs,	**CN-057-L**		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**FN-045-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**			from the lunar sub-surface.			
Robotic identification of potential samples and resources on the lunar surface	**FN-249-L**						
Robotic collection of lunar surface samples	**FN-250-L**						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	**FN-251-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew excursions to locations distributed around landing site	**UC-024-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide local unpressurized crew surface mobility	**FN-030-L**						
Provide pressurized crew surface mobility	**FN-031-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew extravehicular explorations and identification of surface samples	**UC-025-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect sub-surface samples from non-PSRs and sunlit regions	**UC-034-L**				
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state	**FN-055-L**						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-143-L**						
Utilize tools to collect sub-surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-259-L**						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-262-L**						
Transport collected sub-surface samples on the lunar surface in conditioned state	**FN-278-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**				
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**FN-219-L**						
Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state	**FN-221-L**	Collect sub-surface samples from PSRs	**UC-111-L**				
Utilize tools to collect sub-surface samples from PSRs on the lunar surface	**FN-260-L**						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	**FN-261-L**						
Transport collected sub-surface samples on the lunar surface in conditioned state	**FN-278-L**						
Transport cargo from the lunar surface to Earth	**FN-042-L**						
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**	Return collected surface samples (non-conditioned) to Earth in sealed sample containers	**UC-020-L**	Return a variety of samples from the lunar surface and subsurface, including regolith, pebbles, and rocks, back to curation facilities on Earth.	**CN-058-L**		
Transport cargo from the lunar surface to cislunar space	**FN-146-L**						
Prepare unconditioned cargo or samples for Earth return	**FN-153-L**						
Transport cargo from the lunar surface to Earth	**FN-042-L**						
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers	**UC-097-L**	Return a variety of samples, including drill cores and frozen samples from a variety of depths, in containers sealed in lunar vacuum, from the lunar subsurface back to curation facilities on Earth.	**CN-059-L**		
Provide power for conditioning to sample containers during transit from the lunar surface to Earth	**FN-265-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	**FN-267-L**						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	**FN-268-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**	Accurate location identification, tracking, and imagery of collected samples.	**CN-061-LM**		
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Position, navigation, and timing for accurate sample tracking	**UC-127-L**				
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Provide reference time/frequency generation on the lunar surface	**FN-242-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Transport cargo to specific pre-defined location within exploration area on the lunar surface	**UC-072-L**	Deploy utilization payloads outside the blast zone of the propulsive vehicles.	**CN-062-LM**		
Provide precision landing for cargo transport to the lunar surface	**FN-088-L**						
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	**FN-257-L**						
Unload cargo on the lunar surface	**FN-019-L**	Deploy cargo to the lunar surface	**UC-100-L**				
Reposition cargo on the lunar surface	**FN-020-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						
Transport cargo from the lunar surface to Earth	**FN-042-L**	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers	**UC-097-L**	Return samples, including frozen samples in their pristine state, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface, with supporting equipment, back to curation facilities on Earth.	**CN-148-L**		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Transport cargo from cislunar space to Earth	**FN-145-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**						
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to Earth	**FN-265-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide power for conditioning to sample containers on the lunar surface	FN-266-L						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	FN-267-L						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	FN-268-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L	Provide mobility capabilities to conduct prospecting traverses with appropriate scientific instrumentation and drill capabilities over sites of interest.	CN-149-LM		
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide local unpressurized crew surface mobility	FN-030-L						
Provide pressurized crew surface mobility	FN-031-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation	UC-159-L	Deploy and operate utilization payload(s), related to available resources, at distributed and south polar region sites on the lunar surface.	CN-150-L		
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Operate utilization payloads related to bio-regenerative ECLSS (demonstration) in space	FN-076-L	Demonstrate utilization payload(s) related to bio-regenerative oxygen and water recovery in cislunar space	UC-060-L	Demonstrate operation of bioregenerative ECLSS sub-systems in LEO and/or deep space.	CN-152-LM	Conduct applied scientific investigations essential for the development of bioregenerative-based, ecological life support systems.	AS-04-LM
Operate utilization payloads related to bioregenerative ECLSS in space (demonstration)	FN-223-L	Conduct reduced gravity materials and processes science experiments, other extreme environments-related research, and associated modeling to support in-space technologies related to support bioregenerative ECLSS	UC-155-L				
Operate utilization payloads related to advanced ECLSS in space (demonstration)	FN-222-L	Conduct experiments that can be used to gather data to inform the advanced ECLSS analysis/trade study in cislunar space	UC-156-L				
Operate utilization payloads related to plant growth (demonstration) in space	FN-077-L	Demonstrate plant growth in cislunar asset(s)	UC-061-L	Demonstrate operation of plant based ECLSS sub-systems in LEO and/or deep space.	CN-153-LM	Define crop plant species, including methods for their productive growth, capable of providing	AS-05-LM

Functions		Use Cases		Characteristics/Needs		Objectives	
						sustainable and nutritious food sources for lunar, Deep Space transit, and Mars habitation.	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation on the lunar surface for mid-durations (month+) to extended-durations (year+).	**CN-063-LM**	Advance understanding of how physical systems and fundamental physical phenomena are affected by partial gravity, microgravity, and general environment of the Moon, Mars, and deep space transit.	**AS-06-LM**
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**		**UC-175-L**				

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide Earth based ground stations for exploration communications	FN-081-L	Communications and data exchange between assets in cislunar space and Earth					
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Distribute power on the lunar surface	FN-080-L	Deliver power to assets on the lunar surface	UC-187-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Deliver free flying asset(s) to cislunar space	FN-058-L	Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation	UC-042-L	Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, in cislunar space.	CN-110-L		
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation	UC-053-L				
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation	UC-062-L				
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Monitor operating asset(s)	FN-140-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation	UC-041-L	Deploy and operate utilization payload(s), related to the physical systems and fundamental physics, at distributed and south polar region sites on the lunar surface.	CN-111-L		
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**						
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation	**UC-063-L**				
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**						
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide power, communications, and data transfer to deployed utilization payloads to enable sustained operation in cis-lunar space for mid-durations (month+) to extended-durations (year+).	**CN-112-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**	Utilize common interface(s) for power transfers and distribution on the lunar surface	**UC-084-L**				
Provide common data interface on the lunar surface	**FN-202-L**	Utilize common interface(s) for data transfer and distribution	**UC-085-L**				
Provide common data interface in cislunar space	**FN-203-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide common data interface on Earth	**FN-204-L**						
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Utilize common interface(s) for power transfers and distribution in cislunar space	**UC-106-L**				
Provide power to utilization payloads through common power distribution interface(s) in cislunar space	**FN-125-L**	Deliver power to asset(s) in cislunar space	**UC-110-L**				
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Provide power for deployed surface asset(s)	**FN-051-L**	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs	**UC-123-L**				
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Distribute power on the lunar surface	**FN-080-L**	Deliver power to assets on the lunar surface	**UC-187-L**				
Provide power through common power distribution interface(s) on the lunar surface	**FN-102-L**						

A.2 LUNAR INFRASTRUCTURE

Functions		Use Cases		Characteristics/Needs		Objectives	
Generate power on the lunar surface	FN-021-L	Deploy power generation and energy storage system(s) on the lunar surface	UC-064-L	Provide scalable power generation, energy storage, and power distribution system(s) on the lunar surface to support large exploration assets.	CN-154-L	Develop an incremental lunar power generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels.	LI-01-L
Store energy on the lunar surface	FN-022-L						
Distribute power on the lunar surface	FN-080-L	Deploy power distribution capabilities around power generation and energy storage system(s) on the lunar surface	UC-065-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Provide capability for bi-directional power exchange	FN-264-L						
Generate power on the lunar surface	FN-021-L	Deploy power generation and energy storage system(s) on the lunar surface	UC-064-L	Provide scalable power generation, energy storage, and power distribution system(s) on the lunar surface to allow power utilization to support assets at multiple distributed locations around exploration sites.	CN-155-L		
Store energy on the lunar surface	FN-022-L						
Distribute power on the lunar surface	FN-080-L	Deploy power distribution capabilities around power generation and energy storage system(s) on the lunar surface	UC-065-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Provide capability for bi-directional power exchange	FN-264-L						
Distribute power on the lunar surface	FN-080-L	Deliver power to assets on the lunar surface	UC-187-L				
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L						
Provide power through common power distribution interface(s) on the lunar surface	FN-102-L	Utilize common interface(s) for power transfers and distribution on the lunar surface	UC-084-L	Provide power generation, energy storage, and power distribution system(s) on the lunar surface that are able to supply continuous power availability during crew safety critical mission operation and are able to support contingency operations.	CN-156-L		
Store energy on the lunar surface	FN-022-L	Provide continuous power availability during mission critical activities	UC-188-L				
Distribute power on the lunar surface	FN-080-L						
Provide capability for bi-directional power exchange	FN-264-L						
Store energy on the lunar surface	FN-022-L	Provide continuous power availability in off-nominal conditions	UC-189-L				
Distribute power on the lunar surface	FN-080-L						
Provide power during crew critical mission events	FN-168-L						
Provide capability for bi-directional power exchange	FN-264-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide scalable communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, surface crew, and assets on the surface.	**CN-117-LM**	Develop a lunar surface, orbital, and Moon-to-Earth communications architecture capable of scaling to support long term science, exploration, and industrial needs.	**LI-02-L**
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received	**UC-176-L**				
Receive and format data on Earth	**FN-232-L**						
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Receive and format data on Earth	**FN-232-L**	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received	**UC-174-L**	Provide scalable communication system(s) to enable high bandwidth, high availability communications between Earth-based personnel, in-space crew, and in-space assets.	**CN-118-LM**		
Format and transit data to Earth from cislunar space	**FN-236-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**FN-224-L**	Communications and data exchange between assets in cislunar space and the lunar surface	**UC-173-L**	Provide scalable communication system(s) to enable high bandwidth, high availability communications between In-space personnel, surface crew, and assets on the surface.	**CN-157-LM**		
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Format, transmit, and receive data from cislunar space to the lunar surface	**FN-238-L**						
Format, transmit, and receive data from the lunar surface to cislunar space	**FN-239-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Receive and format data on Earth	**FN-232-L**	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received	**UC-174-L**				
Format and transit data to Earth from cislunar space	**FN-236-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received	**UC-176-L**				
Receive and format data on Earth	**FN-232-L**						
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide communication capabilities to allow NASA to inspire and inform the general public, students, and teachers by enabling them to interact, learn about, and experience	**CN-158-L**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Store and distribute data to user(s) on Earth	FN-233-L			missions in a direct and tangible way.			
Protect and/or secure data for storage and transmission	FN-244-L						
Capture imagery on the lunar surface	FN-269-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Communications and data exchange between assets in cislunar space and Earth	UC-175-L				
Provide Earth based ground stations for exploration communications	FN-081-L						
Capture imagery in cislunar space	FN-199-L						
Receive and format data on Earth	FN-232-L						
Store and distribute data to user(s) on Earth	FN-233-L						
Format and transit data to Earth from cislunar space	FN-236-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide high availability position, navigation, and timing capability in cislunar space	FN-009-L	Position, navigation, and timing for crew and robotic assets in cislunar space	UC-068-L	Provide scalable navigation, positioning, and timing system(s) to enable high availability navigation and tracking in cislunar space.	CN-159-L	Develop a lunar position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.	LI-03-L
Provide accurate location tracking and position data in cislunar space	FN-226-L						
Provide reference time/frequency generation in cislunar space	FN-229-L						
Provide reference time/frequency distribution in cislunar space	FN-230-L						
Format and transmit data to Earth from the lunar surface	FN-231-L						
Provide tracking and analysis of orbital/trajectory parameters for assets in cislunar space	FN-240-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface	UC-126-L	Provide scalable navigation, positioning, and timing system(s) to enable high availability navigation and tracking on the lunar surface.	CN-160-L		
Provide accurate location tracking and position data on the lunar surface	FN-227-L						
Provide planning, tracking, and analysis of traverse paths for assets on the lunar surface	FN-241-L						
Provide reference time/frequency generation on the lunar surface	FN-242-L						
Provide reference time/frequency distribution on the lunar surface	FN-243-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Position, navigation, and timing for accurate sample tracking	UC-127-L	Provide system(s) to enable accurate location identification, tracking, and	CN-161-L		
Provide accurate location tracking and position data on the lunar surface	FN-227-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide reference time/frequency generation on the lunar surface	**FN-242-L**			documentation of collected surface samples.			
Transport cargo from Earth to the lunar surface	**FN-018-L**	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation	**UC-142-L**	Deploy and operate autonomous construction demonstration utilization payload(s) to the lunar surface, including partial-scale demonstrations of regolith management and construction of structures, to demonstrate scalable capabilities and applications.	**CN-162-L**	Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.	**LI-04-L**
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	**FN-184-L**	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction	**UC-143-L**				
Collect regolith at scale and subscale (demonstration)	**FN-185-L**						
Provide storage for collected regolith (demonstration)	**FN-186-L**						
Compact scalable quantities of lunar regolith (demonstration)	**FN-188-L**						
Form scalable quantities of structures from lunar regolith (demonstration)	**FN-189-L**						
Test product(s) from regolith processing (demonstration)	**FN-205-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation	**UC-144-L**	Deploy and operate advanced manufacturing demonstration utilization payload(s) to the lunar surface, including scaled demonstration of additive/subtractive manufacturing techniques and inspection/certification processes, to demonstrate scalable capabilities and applications.	**CN-163-L**		
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	**FN-184-L**	Demonstrate regolith based additive/subtractive manufacturing techniques	**UC-145-L**				
Collect regolith at scale and subscale (demonstration)	**FN-185-L**						
Provide storage for collected regolith (demonstration)	**FN-186-L**						
Manufacture (additive or subtractive) scalable quantities of item(s) from lunar regolith (demonstration)	**FN-190-L**						
Test product(s) from additive/subtractive manufacturing (demonstration)	**FN-206-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide precision landing for crew transport to the lunar surface	FN-087-L	Land crew lander(s) at specific pre-defined locations	UC-071-L	Demonstrate the capability for lunar landers to reliably and safely land within a defined radius around an intended location.	CN-164-L	Demonstrate precision landing capabilities in support of continuous human lunar presence and a robust lunar economy.	LI-05-L
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	FN-257-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface	UC-072-L				
Provide precision landing for cargo transport to the lunar surface	FN-088-L						
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	FN-257-L						
Provide precision landing for cargo transport to the lunar surface	FN-088-L	Transport large exploration asset(s) to the lunar surface	UC-098-L				
Transport large exploration asset(s) from Earth to the lunar surface	FN-144-L						
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	FN-257-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Support crew extravehicular operations on the lunar surface	UC-011-L	Demonstrate the capability to allow crew to move locally around landing sites to visit multiple locations of interest.	CN-165-L	Demonstrate local, regional, and global surface transportation and mobility capabilities in support of continuous human lunar presence and a robust lunar economy.	LI-06-L
Conduct crew lunar surface extravehicular activity	FN-028-L						
Crew ingress/egress from habitable asset(s) to lunar surface vacuum	FN-029-L						
Access from habitable volume to lunar surface exterior vacuum	FN-158-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide local unpressurized crew surface mobility	FN-030-L						
Provide pressurized crew surface mobility	FN-031-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region	UC-075-L	Demonstrate the capability to relocate large exploration assets to locations around the lunar south polar region during uncrewed phases of missions.	CN-166-L		
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Operate mobility systems semi-autonomously on the lunar surface (demonstration)	FN-089-L						
Operate mobility system(s) in dormancy/remote mode between crew surface missions (demonstration)	FN-111-L						
Provide accurate location tracking and position data on the lunar surface	FN-227-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide planning, tracking, and analysis of traverse paths for assets on the lunar surface	FN-241-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Crewed mission(s) to landing sites in the lunar south polar regions	UC-021-L	Demonstrate the capability for crew to access surface assets at different potential locations distributed across the lunar globe.	CN-167-L		
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	FN-044-L	Crewed mission(s) to distributed landing sites on the lunar surface	UC-022-L				
Provide precision landing for crew transport to the lunar surface	FN-087-L	Land crew lander(s) at specific pre-defined locations	UC-071-L				
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	FN-257-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Land crew on the lunar surface in proximity to previously positioned surface assets	UC-137-L				
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation	UC-134-L	Deploy and operate scalable demonstration ISRU utilization payload(s) to the lunar surface.	CN-168-L	Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy.	LI-07-L
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Produce scalable quantities of oxygen from lunar regolith (demonstration)	FN-090-L	Demonstrate operational techniques to recover oxygen from lunar regolith	UC-076-L	Deploy and operate demonstration utilization payload(s) on the lunar surface to collect, produce, store, and transfer commodities, including water, oxygen, and/or construction feedstock, for potential use by system and/or crew.	CN-169-L		
Store oxygen on the lunar surface (demonstration)	FN-116-L						
Transport scalable quantities of oxygen produced to exploration elements (demonstration)	FN-117-L						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	FN-184-L						
Collect regolith at scale and subscale (demonstration)	FN-185-L						
Provide storage for collected regolith (demonstration)	FN-186-L						
Produce scalable quantities of water from in-situ materials (demonstration)	FN-093-L	Demonstrate operational techniques to recover water from the lunar regolith in the polar regions	UC-077-L				
Collect water/ice from the polar region of the lunar surface (demonstration)	FN-118-L						
Store collected water/ice on the lunar surface (demonstration)	FN-119-L						
Transport scalable quantities of water produced to exploration elements (demonstration)	FN-120-L						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	FN-184-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	FN-184-L	Demonstrate operational techniques to recover and refine metals from the lunar regolith	UC-150-L				
Collect regolith at scale and subscale (demonstration)	FN-185-L						
Provide storage for collected regolith (demonstration)	FN-186-L						
Test product(s) from metal production/refinement (demonstration)	FN-207-L						
Produce scalable quantities of metal from lunar regolith (demonstration)	FN-246-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest	UC-023-L	Demonstrate the capability to identify and locate potential site(s) for resource utilization.	CN-170-L		
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	UC-048-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	FN-008-L	Aggregate and physically assemble spacecraft components in cislunar space	UC-003-L	Demonstrate the capability to transfer propellant from one spacecraft to another in space (including interfaces for non-cryogenic propellants, cryogenic propellants, power, data, commands, and buffer gases).	CN-171-L	Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.	LI-08-L
Docking/berthing of spacecraft components	FN-012-L						
Transfer propellant/fluids between assets in space (demonstration)	FN-094-L	Demonstrate operational techniques to transfer fluid and/or propellant in space	UC-078-L				
Provide propellant/fluid transfer through common interface(s) between assets in space (demonstration)	FN-103-L						
Rendezvous, proximity operations, docking, and undocking of the assets on the lunar surface (demonstration)	FN-142-L	Demonstrate aggregation and physical assembly of assets on the lunar surface	UC-113-L				
Provide propellant/fluid transfer through common interface(s) between assets on the lunar surface (demonstration)	FN-123-L	Demonstrate operational techniques to transfer fluid and/or propellant on the lunar surface	UC-151-L	Demonstrate the capability to transfer propellant from one asset to another on the lunar surface (including interfaces for non-cryogenic propellants, cryogenic propellants, power, data, commands, and buffer gases).	CN-172-L		
Transfer propellant/fluids between assets on the lunar surface (demonstration)	FN-129-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide storage of cryogenic propellant in space (demonstration)	**FN-095-L**	Demonstrate propellant storage for extended-duration (year+) in space	**UC-079-L**	Demonstrate the capability to store propellant for extended-durations (year+) in space (including cryogenic propellant, leak management, and mass gauging).	**CN-173-L**		
Provide storage of non-cryogenic propellant in space (demonstration)	**FN-128-L**						
Provide remote propellant management system(s) in microgravity environment (demonstration)	**FN-192-L**						
Provide storage of cryogenic propellant on the lunar surface (demonstration)	**FN-096-L**	Demonstrate propellant storage for extended-duration (year+) on the lunar surface	**UC-080-L**	Demonstrate the capability to store propellant for extended-durations (year+) on the lunar surface (including cryogenic propellant, leak management, and mass gauging).	**CN-174-L**		
Provide storage of non-cryogenic propellant on the lunar surface (demonstration)	**FN-109-L**						
Provide remote propellant management system(s) in partial gravity environment (demonstration)	**FN-193-L**						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	**FN-184-L**	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction	**UC-143-L**	Deploy and operate autonomous demonstration construction utilization payload(s) that are reliant on surface-borne feedstock to demonstrate scalable capabilities and applications, such as additive/subtractive manufacturing and construction of structures.	**CN-175-L**		
Collect regolith at scale and subscale (demonstration)	**FN-185-L**						
Provide storage for collected regolith (demonstration)	**FN-186-L**						
Compact scalable quantities of lunar regolith (demonstration)	**FN-188-L**						
Form scalable quantities of structures from lunar regolith (demonstration)	**FN-189-L**						
Test product(s) from regolith processing (demonstration)	**FN-205-L**						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	**FN-184-L**	Demonstrate regolith based additive/subtractive manufacturing techniques	**UC-145-L**				
Collect regolith at scale and subscale (demonstration)	**FN-185-L**						
Provide storage for collected regolith (demonstration)	**FN-186-L**						
Manufacture (additive or subtractive) scalable quantities of item(s) from lunar regolith (demonstration)	**FN-190-L**						
Test product(s) from additive/subtractive manufacturing (demonstration)	**FN-206-L**						
Deliver utilization payload(s) to cislunar space	**FN-056-L**	Deploy assets to monitor natural environments in cislunar space	**UC-165-L**	Provide system(s) to monitor cislunar space and lunar surface natural environments, including space weather, meteoroids, cosmic weather, thermal conditions, and plasma environments,	**CN-143-L**	Develop environmental monitoring, situational awareness, and early warning capabilities to support a resilient, continuous human/robotic lunar presence.	**LI-09-L**
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	**FN-057-L**						
Monitor operating asset(s)	**FN-140-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	**FN-276-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges	UC-166-L	and provide early warnings to in-space and surface assets and crew.			
Monitor operating asset(s)	FN-140-L						
Monitor electrostatic charging in space	FN-208-L						
Monitor natural radiation levels in space	FN-209-L						
Monitor plasma environment in space	FN-212-L						
Monitor meteoroid activities in cislunar space	FN-213-L						
Provide advanced warning of threats from natural environmental hazards in cislunar space	FN-216-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and set up assets to monitor natural environments on the lunar surface	UC-169-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Provide advanced warning of threats from natural environmental hazards on the lunar surface	FN-200-L	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges	UC-170-L				
Monitor radiation on the lunar surface	FN-210-L						
Monitor electrostatic charging on the lunar surface	FN-211-L						
Monitor plasma environment on the lunar surface	FN-214-L						
Monitor meteoroid activities on the lunar surface	FN-215-L						
Deliver utilization payload(s) to cislunar space	FN-056-L	Deploy asset(s) to monitor induced environment in cislunar space	UC-167-L	Provide system(s) to monitor cislunar space and lunar surface induced environments, including radiation, thermal conditions, high-energy debris, contamination, electrostatics, and	CN-176-L		
Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)	FN-057-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space	FN-276-L						
Monitor environmental conditions within habitable volume in space	FN-194-L	Monitor, characterize, and provide advance warning for induced	UC-168-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Detect and monitor high energy debris in cislunar space	**FN-195-L**	environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics		acoustics, and provide early warnings to in-space and surface assets and crew.			
Monitor electrostatic charging in space	**FN-208-L**						
Provide advanced warning of threats from induced environmental hazards in cislunar space	**FN-217-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Deploy and set up assets to monitor induced environment on the lunar surface	**UC-171-L**				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide power for deployed surface asset(s)	**FN-051-L**						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	**FN-139-L**						
Deliver cargo(s) to distributed sites on the lunar surface	**FN-141-L**						
Deliver cargo(s) to south polar region sites on the lunar surface	**FN-164-L**						
Monitor environmental conditions within habitable volume on the lunar surface	**FN-197-L**	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics	**UC-172-L**				
Detect and monitor high energy debris on the lunar surface	**FN-198-L**						
Provide advanced warning of threats from induced environmental hazards on the lunar surface	**FN-201-L**						
Monitor electrostatic charging on the lunar surface	**FN-211-L**						

A.3 Transportation & Habitation

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide ground services on Earth	**FN-001-L**	Transport crew and supporting system(s) from Earth to cislunar space	**UC-001-L**	Provide capabilities to transport crew and crew system(s) from Earth to cislunar space.	**CN-001-L**	Develop cislunar systems that crew can routinely operate to and from lunar orbit and the lunar surface for extended durations.	**TH-01-L**
Stack and integrate system(s) on Earth	**FN-002-L**						
Manage consumables and propellant	**FN-003-L**						
Enable vehicle launch(es)	**FN-004-L**						
Allow multiple launch attempts	**FN-005-L**						
Enable abort(s) to safety	**FN-006-L**						
Transport crew and associated cargo from Earth to cislunar space to support short-duration (days to weeks) missions	**FN-007-L**						
Distribute power to utilization payloads in cislunar space	**FN-134-L**						
Transport crew and associated cargo from Earth to cislunar space to support mid-duration (month+) to extended (year+) durations	**FN-272-L**						
Provide high availability position, navigation, and timing capability in cislunar space	**FN-009-L**	Stage crewed lunar surface missions from cislunar space	**UC-002-L**	Provide capabilities to enable staging and/or assembly operations of crew and cargo system(s) in cislunar space with accessibility to both Earth and the lunar surface, including the lunar South Polar region.	**CN-002-L**		
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	**FN-010-L**						
Provide pressurized, habitable environment in cislunar space	**FN-034-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**FN-224-L**						
Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	**FN-008-L**	Aggregate and physically assemble spacecraft components in cislunar space	**UC-003-L**				
Docking/berthing of spacecraft components	**FN-012-L**						
Provide high availability position, navigation, and timing capability in cislunar space	**FN-009-L**	Stage crewed lunar surface missions from cislunar space	**UC-002-L**	Provide capabilities to transport crew between stable lunar orbit, including NRHO, and the lunar surface.	**CN-003-L**		
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	**FN-010-L**						
Provide pressurized, habitable environment in cislunar space	**FN-034-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**FN-224-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	**FN-013-L**	Transport crew and supporting system(s) between cislunar space and the lunar surface	**UC-004-L**				
Transport crew and associated cargo from the lunar surface to cislunar space	**FN-014-L**						
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	**FN-044-L**						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	**FN-013-L**	Crewed mission(s) to landing sites in the lunar south polar regions	**UC-021-L**				
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	**FN-044-L**	Crewed mission(s) to distributed landing sites on the lunar surface	**UC-022-L**				
Orbital observations and sensing of the lunar surface	**FN-050-L**	Orbital survey(s) before, during, and after crew mission	**UC-027-L**				
Provide precision landing for crew transport to the lunar surface	**FN-087-L**	Land crew lander(s) at specific pre-defined locations	**UC-071-L**				
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	**FN-257-L**						
Operate crew system(s) from Earth on the lunar surface during crewed missions	**FN-015-L**	Operate transportation assets(s) from Earth during crew surface missions	**UC-005-L**	Provide capabilities to operate crew transportation system(s) in uncrewed mode for mid-durations (month+) to extended-durations (year+) in cislunar space and on the lunar surface.	**CN-004-L**		
Operate assets on the lunar surface in uncrewed mode for extended (year+) durations	**FN-270-L**						
Provide high availability position, navigation, and timing capability in cislunar space	**FN-009-L**	Stage crewed lunar surface missions from cislunar space	**UC-002-L**	Provide capabilities to safely return crew and system(s) to Earth from lunar surface and cislunar space.	**CN-005-L**		
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	**FN-010-L**						
Provide pressurized, habitable environment in cislunar space	**FN-034-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**FN-224-L**						
Transport crew and associated cargo from cislunar space to Earth	**FN-016-L**	Return crew and systems from cislunar space to Earth	**UC-006-L**				
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**						
Transport crew and associated cargo from the lunar surface to cislunar space	**FN-014-L**	Return crew and associated cargo from the lunar surface to cislunar space	**UC-099-L**				
Provide precision landing for cargo transport to the lunar surface	**FN-088-L**	Transport large exploration asset(s) to the lunar surface	**UC-098-L**	Implement stable transportation capabilities, which minimize required	**CN-006-L**		
Transport large exploration asset(s) from Earth to the lunar surface	**FN-144-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	FN-257-L			upgrades over time, to support lunar missions.			
Transport crew and associated cargo from Earth to cislunar space to support short-duration (days to weeks) missions	FN-007-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface	UC-119-L				
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L						
Transport crew and associated cargo from the lunar surface to cislunar space	FN-014-L						
Transport crew and associated cargo from cislunar space to Earth	FN-016-L						
Transport cargo from Earth to the lunar surface	FN-018-L						
Transport cargo from the lunar surface to Earth	FN-042-L						
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	FN-044-L						
Operate assets on the lunar surface in uncrewed mode for extended (year+) durations	FN-270-L						
Transport crew and associated cargo from cislunar space to Earth	FN-016-L	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space	UC-120-L				
Operate assets in cislunar space in uncrewed mode for extended (year+) durations	FN-157-L						
Transport crew and associated cargo from Earth to cislunar space to support mid-duration (month+) to extended (year+) durations	FN-272-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to the lunar south polar region	UC-131-L	Implement robust transportation capabilities, where systems can perform a variety of design reference missions, to support lunar missions.	CN-007-L		
Transport crew and associated cargo from the lunar surface to cislunar space	FN-014-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Cislunar space to lunar surface transportation supporting mid-duration (month+) missions to the lunar south polar region	UC-132-L				
Transport crew and associated cargo from the lunar surface to cislunar space	FN-014-L						
Transport crew and associated cargo from the lunar surface to cislunar space	FN-014-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to distributed landing sited on the lunar surface	UC-133-L				
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	FN-044-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface	UC-072-L	Provide capabilities to deliver system(s) from Earth to the lunar surface.	CN-008-L	Develop system(s) that can routinely deliver a range of elements to the lunar surface.	TH-02-L
Provide precision landing for cargo transport to the lunar surface	FN-088-L						
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	FN-257-L						
Provide precision landing for cargo transport to the lunar surface	FN-088-L	Transport large exploration asset(s) to the lunar surface	UC-098-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport large exploration asset(s) from Earth to the lunar surface	FN-144-L						
Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris	FN-257-L						
Unload large utilization assets on the lunar surface	FN-159-L	Unload large exploration assets on the lunar surface	UC-007-L	Provide capabilities to unload cargo from delivery system(s).	CN-009-L		
Unload cargo on the lunar surface	FN-019-L	Deploy utilization payloads and equipment on the lunar surface	UC-008-L				
Reposition cargo on the lunar surface	FN-020-L						
Decommission surface delivery system(s) and/or surface asset(s)	FN-122-L	Conduct end-of-life operations	UC-101-L	Implement end-of-life strategies for transportation systems to ensure future viable usage of exploration sites on the lunar surface.	CN-010-L		
Repurpose and/or recycle equipment that is no longer useful in its primary function	FN-173-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface	UC-010-L	Provide capabilities to conduct short-duration (days to weeks) crew exploration mission(s) on the lunar surface.	CN-011-L	Develop system(s) to allow crew to explore, operate, and live on the lunar surface and in lunar orbit with scalability to continuous presence; conducting scientific and industrial utilization as well as Mars analog activities.	TH-03-L
Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)	FN-025-L						
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Support crew extravehicular operations on the lunar surface	UC-011-L				
Conduct crew lunar surface extravehicular activity	FN-028-L						
Crew ingress/egress from habitable asset(s) to lunar surface vacuum	FN-029-L						
Access from habitable volume to lunar surface exterior vacuum	FN-158-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Reuse habitation system(s) on the lunar surface	UC-092-L				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Land crew on the lunar surface in proximity to previously positioned surface assets	UC-137-L				
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface	UC-152-L				
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Resupply cargo and manage wastes to/from habitable assets on surface to	UC-191-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Transfer pressurized cargo into habitable assets on the lunar surface	**FN-027-L**	support repeated crew missions on the lunar surface					
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**						
Docking/berthing between pressurized assets on the lunar surface	**FN-124-L**						
Transfer gases and water to habitable assets on the lunar surface	**FN-177-L**						
Transport cargo on the lunar surface between landing location and surface assets	**FN-178-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Support crew extravehicular operations on the lunar surface	**UC-011-L**	Provide capabilities to conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	**CN-012-L**		
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Crew ingress/egress from habitable asset(s) to lunar surface vacuum	**FN-029-L**						
Access from habitable volume to lunar surface exterior vacuum	**FN-158-L**						
Provide remote crew medical systems on the lunar surface	**FN-026-L**	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	**UC-018-L**				
Provide crew health care on the lunar surface	**FN-149-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	**FN-107-L**	Reuse habitation system(s) on the lunar surface	**UC-092-L**				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	**FN-113-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface	**UC-128-L**				
Transfer pressurized cargo into habitable assets on the lunar surface	**FN-027-L**						
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	**FN-271-L**						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	**FN-107-L**	Land crew on the lunar surface in proximity to previously positioned surface assets	**UC-137-L**				
Transport cargo from Earth to the lunar surface	**FN-018-L**	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	**UC-191-L**				
Transfer pressurized cargo into habitable assets on the lunar surface	**FN-027-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**						
Docking/berthing between pressurized assets on the lunar surface	**FN-124-L**						
Transfer gases and water to habitable assets on the lunar surface	**FN-177-L**						
Transport cargo on the lunar surface between landing location and surface assets	**FN-178-L**						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	**FN-010-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space	**UC-015-L**	Provide capabilities to conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	**CN-013-L**		
Transport cargo from Earth to assets in cislunar space	**FN-033-L**						
Transfer cargo into habitable asset(s) in cislunar space	**FN-035-L**						
Manage waste from habitable asset(s) in cislunar space	**FN-036-L**						
Provide remote crew medical systems in cislunar space	**FN-039-L**						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	**FN-273-L**						
Provide remote crew medical systems in cislunar space	**FN-039-L**	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space	**UC-017-L**				
Provide crew health care in cislunar space	**FN-160-L**						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	**FN-273-L**						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	**FN-010-L**	Support crew extravehicular operations in cislunar space	**UC-190-L**				
Conduct crew cislunar extravehicular activity	**FN-175-L**						
Crew ingress/egress from habitable asset(s) to cis lunar vacuum	**FN-187-L**						
Access from habitable volume to cislunar exterior vacuum	**FN-191-L**						
Transport cargo from Earth to assets in cislunar space	**FN-033-L**	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions	**UC-192-L**				
Transfer cargo into habitable asset(s) in cislunar space	**FN-035-L**						
Manage waste from habitable asset(s) in cislunar space	**FN-036-L**						
Docking/berthing between pressurized assets in cislunar space	**FN-138-L**						
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Support crew extravehicular operations on the lunar surface	**UC-011-L**	Provide capabilities to enable crew transition in/out of habitable	**CN-014-L**		
Conduct crew lunar surface extravehicular activity	**FN-028-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Crew ingress/egress from habitable asset(s) to lunar surface vacuum	FN-029-L			space to conduct EVA activities.			
Access from habitable volume to lunar surface exterior vacuum	FN-158-L						
Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)	FN-025-L	Habitation capabilities for short-duration (days to weeks) missions on the lunar surface	UC-146-L	Implement stable habitation capabilities, which minimize required upgrades over time, to support lunar missions.	CN-015-L		
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface	UC-147-L				
Operate assets in cislunar space in uncrewed mode for extended (year+) durations	FN-157-L						
Operate assets on the lunar surface in uncrewed mode for extended (year+) durations	FN-270-L						
Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	FN-271-L						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Habitation capabilities for extended-duration (year+) missions in cislunar space	UC-148-L				
Operate assets in cislunar space in uncrewed mode for extended (year+) durations	FN-157-L						
Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)	FN-025-L	Habitation capabilities for short-duration (days to weeks) missions on the lunar surface	UC-146-L	Implement robust habitation capabilities, where systems can support all design reference missions, to support lunar missions.	CN-016-L		
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface	UC-147-L				
Operate assets in cislunar space in uncrewed mode for extended (year+) durations	FN-157-L						
Operate assets on the lunar surface in uncrewed mode for extended (year+) durations	FN-270-L						
Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	FN-271-L						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Habitation capabilities for extended-duration (year+) missions in cislunar space	UC-148-L				
Operate assets in cislunar space in uncrewed mode for extended (year+) durations	FN-157-L						
Provide high availability position, navigation, and timing capability in cislunar space	FN-009-L	Stage crewed lunar surface missions from cislunar space	UC-002-L	Provide capabilities to enable staging and/or assembly operations of crew and cargo system(s) in cislunar space with accessibility to both Earth and the lunar surface, including the lunar South Polar region.	CN-002-L	Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.	TH-04-LM
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L						
Provide pressurized, habitable environment in cislunar space	FN-034-L						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	FN-071-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	FN-224-L						
Rendezvous, proximity operations, docking, and undocking of assets in cislunar space	FN-008-L		UC-003-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Docking/berthing of spacecraft components	FN-012-L	Aggregate and physically assemble spacecraft components in cislunar space					
Transport cargo from Earth to the lunar surface	FN-018-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface	UC-010-L	Provide capabilities to conduct short-duration (days to weeks) crew exploration mission(s) on the lunar surface.	CN-011-L		
Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)	FN-025-L						
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Support crew extravehicular operations on the lunar surface	UC-011-L				
Conduct crew lunar surface extravehicular activity	FN-028-L						
Crew ingress/egress from habitable asset(s) to lunar surface vacuum	FN-029-L						
Access from habitable volume to lunar surface exterior vacuum	FN-158-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Reuse habitation system(s) on the lunar surface	UC-092-L				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Land crew on the lunar surface in proximity to previously positioned surface assets	UC-137-L				
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface	UC-152-L				
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	UC-191-L				
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Docking/berthing between pressurized assets on the lunar surface	FN-124-L						
Transfer gases and water to habitable assets on the lunar surface	FN-177-L						
Transport cargo on the lunar surface between landing location and surface assets	FN-178-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Support crew extravehicular operations on the lunar surface	UC-011-L	Provide capabilities to conduct mid-duration (month+) crew	CN-012-L		
Conduct crew lunar surface extravehicular activity	FN-028-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Crew ingress/egress from habitable asset(s) to lunar surface vacuum	**FN-029-L**			exploration mission(s) on the lunar surface.			
Access from habitable volume to lunar surface exterior vacuum	**FN-158-L**						
Provide remote crew medical systems on the lunar surface	**FN-026-L**	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	**UC-018-L**				
Provide crew health care on the lunar surface	**FN-149-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	**FN-107-L**	Reuse habitation system(s) on the lunar surface	**UC-092-L**				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	**FN-113-L**						
Transport cargo from Earth to the lunar surface	**FN-018-L**	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface	**UC-128-L**				
Transfer pressurized cargo into habitable assets on the lunar surface	**FN-027-L**						
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						
Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	**FN-271-L**						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	**FN-107-L**	Land crew on the lunar surface in proximity to previously positioned surface assets	**UC-137-L**				
Transport cargo from Earth to the lunar surface	**FN-018-L**	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	**UC-191-L**				
Transfer pressurized cargo into habitable assets on the lunar surface	**FN-027-L**						
Manage waste from habitable asset(s) on the lunar surface	**FN-037-L**						
Docking/berthing between pressurized assets on the lunar surface	**FN-124-L**						
Transfer gases and water to habitable assets on the lunar surface	**FN-177-L**						
Transport cargo on the lunar surface between landing location and surface assets	**FN-178-L**						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	**FN-010-L**	Crew habitation for extended-duration (year+) mission(s) in cislunar space	**UC-015-L**	Provide capabilities to conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	**CN-013-L**		
Transport cargo from Earth to assets in cislunar space	**FN-033-L**						
Transfer cargo into habitable asset(s) in cislunar space	**FN-035-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Manage waste from habitable asset(s) in cislunar space	**FN-036-L**						
Provide remote crew medical systems in cislunar space	**FN-039-L**						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	**FN-273-L**						
Provide remote crew medical systems in cislunar space	**FN-039-L**	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space	**UC-017-L**				
Provide crew health care in cislunar space	**FN-160-L**						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	**FN-273-L**						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	**FN-010-L**	Support crew extravehicular operations in cislunar space	**UC-190-L**				
Conduct crew cislunar extravehicular activity	**FN-175-L**						
Crew ingress/egress from habitable asset(s) to cis lunar vacuum	**FN-187-L**						
Access from habitable volume to cislunar exterior vacuum	**FN-191-L**						
Transport cargo from Earth to assets in cislunar space	**FN-033-L**	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions	**UC-192-L**				
Transfer cargo into habitable asset(s) in cislunar space	**FN-035-L**						
Manage waste from habitable asset(s) in cislunar space	**FN-036-L**						
Docking/berthing between pressurized assets in cislunar space	**FN-138-L**						
Provide crew health care during transit	**FN-150-L**	Crew health care, diagnosis, and treatment in space	**UC-016-L**	Provide crew health and performance capabilities in cislunar space and in deep space, including demonstration of remote and autonomous healthcare and advanced diagnostics, to prepare for future Mars missions.	**CN-031-L**	Develop systems that monitor and maintain crew health and performance throughout all mission phases, including during communication delays to Earth, and in an environment that does not allow emergency evacuation or terrestrial medical assistance.	**TH-08-LM**
Provide crew health care in cislunar space	**FN-160-L**						
Provide remote crew medical systems in cislunar space	**FN-039-L**	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space	**UC-017-L**				
Provide crew health care in cislunar space	**FN-160-L**						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	**FN-273-L**						
Provide remote crew medical systems in cislunar space	**FN-039-L**	In-situ diagnosis and treatment of crew in cislunar space	**UC-103-L**				
Provide remote crew medical systems on the lunar surface	**FN-026-L**	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	**UC-018-L**	Provide crew health and performance capabilities on the lunar surface, including demonstration of remote and autonomous healthcare	**CN-032-L**		
Provide crew health care on the lunar surface	**FN-149-L**						
Provide crew health maintenance capabilities in partial gravity environment	**FN-228-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide remote crew medical systems on the lunar surface	FN-026-L	In-situ diagnosis and treatment of crew on the lunar surface	UC-104-L	and advanced diagnostics, to prepare for future Mars missions.			
Monitor crew health on the lunar surface	FN-275-L	In-situ diagnosis and treatment of crew on the lunar surface	UC-104-L				
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface	UC-152-L				
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface	UC-152-L				
Provide crew health care on the lunar surface	FN-149-L	Crew emergency health care, diagnosis, and treatment on the lunar surface	UC-154-L				
Collect and store medical data and health information	FN-151-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth	UC-158-L	Provide robust Integrated Data Architecture (IDA) to support Crew Health and Performance System(s).	CN-033-LM		
Format and transmit data to Earth from the lunar surface	FN-231-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth	UC-158-L	Provide robust Integrated Data Architecture (IDA) to support Crew Health and Performance System(s).	CN-033-LM		
Format and transit data to Earth from cislunar space	FN-236-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth	UC-158-L	Provide robust Integrated Data Architecture (IDA) to support Crew Health and Performance System(s).	CN-033-LM		
Protect and/or secure data for storage and transmission	FN-244-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth	UC-158-L	Provide robust Integrated Data Architecture (IDA) to support Crew Health and Performance System(s).	CN-033-LM		
Provide food system(s) on the lunar surface	FN-180-L	Nutrition monitoring for crew during mission	UC-161-L	Provide countermeasures capabilities (e.g., exercise, nutrition, sensorimotor, cardiovascular, immune) that are commensurate in scope with the human system needs for the mission.	CN-034-LM		
Provide food system(s) in cislunar space	FN-181-L	Nutrition monitoring for crew during mission	UC-161-L	Provide countermeasures capabilities (e.g., exercise, nutrition, sensorimotor, cardiovascular, immune) that are commensurate in scope with the human system needs for the mission.	CN-034-LM		
Provide crew health maintenance capabilities in microgravity environment	FN-038-L	Crew health maintenance with countermeasure activities in microgravity environment	UC-162-L	Provide countermeasures capabilities (e.g., exercise, nutrition, sensorimotor, cardiovascular, immune) that are commensurate in scope with the human system needs for the mission.	CN-034-LM		
Provide crew exercise system(s) in cislunar space	FN-182-L	Crew health maintenance with countermeasure activities in microgravity environment	UC-162-L	Provide countermeasures capabilities (e.g., exercise, nutrition, sensorimotor, cardiovascular, immune) that are commensurate in scope with the human system needs for the mission.	CN-034-LM		
Provide crew exercise system(s) on the lunar surface	FN-183-L	Crew health maintenance with countermeasure activities in partial gravity environment	UC-163-L	Provide countermeasures capabilities (e.g., exercise, nutrition, sensorimotor, cardiovascular, immune) that are commensurate in scope with the human system needs for the mission.	CN-034-LM		
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L	Crew health maintenance with countermeasure activities in partial gravity environment	UC-163-L	Provide countermeasures capabilities (e.g., exercise, nutrition, sensorimotor, cardiovascular, immune) that are commensurate in scope with the human system needs for the mission.	CN-034-LM		
Provide remote crew medical systems in cislunar space	FN-039-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space	UC-017-L	Provide appropriate medical monitoring capabilities (including behavioral health) that enables inflight crew health diagnosis and decision making.	CN-035-LM		
Provide crew health care in cislunar space	FN-160-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space	UC-017-L	Provide appropriate medical monitoring capabilities (including behavioral health) that enables inflight crew health diagnosis and decision making.	CN-035-LM		
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space	UC-017-L	Provide appropriate medical monitoring capabilities (including behavioral health) that enables inflight crew health diagnosis and decision making.	CN-035-LM		
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	UC-018-L	Provide appropriate medical monitoring capabilities (including behavioral health) that enables inflight crew health diagnosis and decision making.	CN-035-LM		
Provide crew health care on the lunar surface	FN-149-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	UC-018-L	Provide appropriate medical monitoring capabilities (including behavioral health) that enables inflight crew health diagnosis and decision making.	CN-035-LM		
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	UC-018-L	Provide appropriate medical monitoring capabilities (including behavioral health) that enables inflight crew health diagnosis and decision making.	CN-035-LM		
Provide remote crew medical systems in cislunar space	FN-039-L	In-situ diagnosis and treatment of crew in cislunar space	UC-103-L	Provide appropriate medical monitoring capabilities (including behavioral health) that enables inflight crew health diagnosis and decision making.	CN-035-LM		

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide remote crew medical systems on the lunar surface	FN-026-L	In-situ diagnosis and treatment of crew on the lunar surface	UC-104-L				
Monitor crew health on the lunar surface	FN-275-L						
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface	UC-152-L				
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Monitor electrostatic charging in space	FN-208-L	Monitor environmental factors in habitation systems in space	UC-140-L	Provide appropriate environmental monitoring capabilities (including acoustics, microbial, chemical, and radiation) that enables inflight crew health decision making and mitigation of relevant system/vehicle hazards.	CN-036-LM		
Monitor natural radiation levels in space	FN-209-L						
Monitor radiation on the lunar surface	FN-210-L	Monitor environmental factors in habitation systems on the lunar surface	UC-141-L				
Monitor electrostatic charging on the lunar surface	FN-211-L						
Provide remote crew medical systems in cislunar space	FN-039-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space	UC-017-L	Provide comprehensive Earth-independent medical care capabilities that is scoped to support the mission and address relevant inflight medical conditions and long-term crew health considerations.	CN-037-LM		
Provide crew health care in cislunar space	FN-160-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Provide remote crew medical systems in cislunar space	FN-039-L	In-situ diagnosis and treatment of crew in cislunar space	UC-103-L				
Implement supportability to correct system failures	FN-130-L	Crew survival during off-nominal situations	UC-160-L	Demonstrate crew survival capabilities in cislunar space and on the lunar surface, including safe havens, system supportability, and/or aborts, for nominal and off-nominal scenarios to prepare for future Mars missions.	CN-038-L		
Provide safe haven capability for crew to shelter during off-nominal scenario	FN-165-L						
Provide hazard remediation capabilities	FN-166-L						
Provide capability to restore and stabilize the habitable environment after off-nominal scenario	FN-167-L						
Transport crew and crew system(s) from cislunar space to Earth in off-nominal situation	FN-131-L	Crew abort to Earth in off-nominal situations	UC-164-L				
Provide capability for crew loiter until return window	FN-169-L						
Transport crew from the lunar surface to cislunar space in off-nominal scenario	FN-170-L						
Perform repairs and/or replacement of subsystems	FN-171-L	Crew repair and/or replacement of failed or off-nominal systems	UC-183-L				
Provide storage for necessary spares and repair equipment	FN-172-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource	UC-019-L	Provide appropriate robotic system(s) that	CN-	Develop integrated human and robotic	TH-

Functions		Use Cases		Characteristics/Needs		Objectives	
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L	locating, documentation, and sample retrieval		can conduct or assist in tasks that would otherwise be performed by the crew alone on the lunar surface.		systems with inter-relationships that enable maximum science and exploration during lunar missions.	
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest	UC-023-L				
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	UC-048-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Remotely manage robotic system(s) during surface operation as required	UC-094-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Monitor robotic system(s) performance and health	FN-252-L						
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L	Perform lunar surface activities with surface robotic system(s) assistance	UC-105-L				
Perform robotic manipulation of payloads, logistics, and/or equipment at multiple scales	FN-148-L						
Control robotic system(s) in cislunar space from Earth and/or cislunar space	FN-041-L	Remotely manage robotic system(s) during in space operation as required	UC-184-L	Provide appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone in cislunar or deep space.	CN-043-L		
Monitor robotic system(s) performance and health	FN-252-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L	Perform activities in space with robotic system(s) assistance	UC-185-L				
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Demonstrate in-situ crew command and control of robotic system(s)	UC-093-L	Demonstrate the capability for safe and	CN-		

Functions		Use Cases		Characteristics/Needs		Objectives	
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L			effective interactions between crew and automated/autonomous system(s).			
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	FN-224-L						
Monitor robotic system(s) performance and health	FN-252-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L						
Provide safety features on robotic and/or autonomous system(s)	FN-254-L						
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L	Perform lunar surface activities with surface robotic system(s) assistance	UC-105-L				
Perform robotic manipulation of payloads, logistics, and/or equipment at multiple scales	FN-148-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L	Perform activities in space with robotic system(s) assistance	UC-185-L				
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Demonstrate in-situ crew command and control of robotic system(s)	UC-093-L	Demonstrate capabilities to allow in-space and surface crew to control and command robotic system(s).	CN-045-L		
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	FN-224-L						
Monitor robotic system(s) performance and health	FN-252-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L						
Provide safety features on robotic and/or autonomous system(s)	FN-254-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L	Minimize crew time required for inspection, commissioning, maintenance, and logistics operations to maximize crew time available for science and exploration activities.	CN-046-L		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L	Robotic system(s) support of logistic operations on the lunar surface as required	UC-121-L				
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Interface robotic system(s) with logistics carriers on the lunar surface	FN-255-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L	Robotic system(s) support of maintenance and repair operations as appropriate	UC-122-L				
Provide safety features on robotic and/or autonomous system(s)	FN-254-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L	Transport cargo from the lunar surface to cislunar space	UC-179-L	Provide capabilities to return cargo from the lunar surface back to cislunar space.	CN-048-L	Develop systems capable of returning a range of cargo mass from the lunar surface to Earth, including the capabilities necessary to meet scientific and utilization objectives.	TH-11-L
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare unconditioned cargo or samples for Earth return	FN-153-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L	Transport conditioned cargo from the lunar surface to cislunar space	UC-180-L				
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	FN-267-L						
Recover crew, crew system(s), and cargo after Earth landing	FN-017-L	Transport conditioned cargo to appropriate facilities on Earth	UC-181-L	Provide capabilities to return cargo from cislunar space back to Earth-based facilities.	CN-049-L		
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	FN-121-L						
Recover crew, crew system(s), and cargo after Earth landing	FN-017-L	Transport collected samples to appropriate curation facilities on Earth	UC-182-L				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	FN-043-L						
Transport cargo from the lunar surface to Earth	FN-042-L	Transport cargo from the lunar surface or cislunar space back to Earth	UC-186-L				
Transport cargo from cislunar space to Earth	FN-145-L						
Transport cargo from cislunar space to Earth	FN-145-L	Transport conditioned cargo from cislunar space to Earth	UC-178-L	Provide capabilities to return samples, including frozen samples in their pristine state, from a variety of depths, in containers sealed in lunar vacuum, from the lunar surface, with supporting equipment, back to curation facilities on Earth.	CN-050-L		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						
Prepare conditioned cargo or samples for return to Earth	FN-154-L						
Provide power for conditioning to sample containers during transit from cislunar space to Earth	FN-268-L						
Transport cargo from the lunar surface to cislunar space	FN-146-L	Transport conditioned cargo from the lunar surface to cislunar space	UC-180-L				
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	FN-147-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Prepare conditioned cargo or samples for return to Earth	**FN-154-L**						
Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space	**FN-267-L**						
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**	Transport conditioned cargo to appropriate facilities on Earth	**UC-181-L**				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						
Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing	**FN-121-L**						
Transport cargo from the lunar surface to cislunar space	**FN-146-L**	Transport cargo from the lunar surface to cislunar space	**UC-179-L**	Provide capabilities to return samples, collected from the lunar surface, including regolith, pebbles, and rocks, in containers sealed in lunar vacuum, from the lunar surface back to curation facilities on Earth.	**CN-051-L**		
Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth	**FN-147-L**						
Prepare unconditioned cargo or samples for Earth return	**FN-153-L**						
Recover crew, crew system(s), and cargo after Earth landing	**FN-017-L**	Transport collected samples to appropriate curation facilities on Earth	**UC-182-L**				
Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing	**FN-043-L**						

A.4 Operations

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	UC-018-L	Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	CN-093-L	Conduct human research and technology demonstrations on the surface of Earth, low-Earth orbit platforms, cislunar platforms, and on the surface of the moon, to evaluate the effects of extended mission durations on the performance of crew and systems, reduce risk, and shorten the timeframe for system testing and readiness prior to the initial human Mars exploration campaign.	OP-01-L
Provide crew health care on the lunar surface	FN-149-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Reuse habitation system(s) on the lunar surface	UC-092-L				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface	UC-128-L				
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	FN-271-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	UC-191-L				
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Docking/berthing between pressurized assets on the lunar surface	FN-124-L						
Transfer gases and water to habitable assets on the lunar surface	FN-177-L						
Transport cargo on the lunar surface between landing location and surface assets	FN-178-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.	UC-035-L	Transition crew from micro-gravity environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.	CN-095-LM		
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Transport crew from cislunar space to the lunar surface after extended duration (year+) in space	FN-136-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport crew and associated cargo from the lunar surface to cislunar space	FN-014-L	Prepare crew for transition and transport from the lunar surface to cislunar space	UC-129-L	Transition crew from partial gravity environment to micro-gravity environment.	CN-105-LM		
Ready and transition crew to transportation asset for return to orbit	FN-179-L						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space	UC-015-L	Conduct extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	CN-106-LM		
Transport cargo from Earth to assets in cislunar space	FN-033-L						
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Manage waste from habitable asset(s) in cislunar space	FN-036-L						
Provide remote crew medical systems in cislunar space	FN-039-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Operate habitation system(s) in dormancy/remote mode between crewed missions in cislunar space	FN-155-L	Reuse habitation systems(s) in cislunar space	UC-149-L				
Transport cargo from Earth to the lunar surface	FN-018-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface	UC-010-L	Conduct short-duration (days to weeks) crew exploration mission(s) on the lunar surface.	CN-188-L		
Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)	FN-025-L						
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Reuse habitation system(s) on the lunar surface	UC-092-L				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L						
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface	UC-152-L				
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	UC-191-L				
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Docking/berthing between pressurized assets on the lunar surface	FN-124-L						
Transfer gases and water to habitable assets on the lunar surface	FN-177-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport cargo on the lunar surface between landing location and surface assets	FN-178-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface	UC-010-L	Conduct crewed and uncrewed testing of surface habitable system(s).	CN-189-L		
Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)	FN-025-L						
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L	Operate habitation system(s) on the lunar surface while uncrewed	UC-102-L				
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space	UC-015-L	Conduct crewed and uncrewed testing of in-space habitable system(s).	CN-190-L		
Transport cargo from Earth to assets in cislunar space	FN-033-L						
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Manage waste from habitable asset(s) in cislunar space	FN-036-L						
Provide remote crew medical systems in cislunar space	FN-039-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Operate habitation system(s) in dormancy/remote mode between crewed missions in cislunar space	FN-155-L	Reuse habitation systems(s) in cislunar space	UC-149-L				
Command and control uncrewed asset(s) in cislunar space from Earth	FN-100-L	Conduct autonomous/semi-autonomous mission operations in cislunar space	UC-082-L	Operate and gain experience with onboard autonomous system(s) and crew autonomy to train, plan, and execute safe mission(s) with reduced reliance on Earth based systems.	CN-191-LM	Optimize operations, training and interaction between the team on Earth, crew members on orbit, and a Martian surface team considering communication delays, autonomy level, and time required for an early return to the Earth.	OP-02-LM
Command and control uncrewed asset(s) on the lunar surface from Earth	FN-101-L	Conduct autonomous/semi-autonomous mission operations on the lunar surface	UC-083-L				
Command and control autonomous asset(s) on the lunar surface from cislunar space	FN-135-L						
Conduct crew training in simulation of increasingly Earth-independent operations	FN-163-L	Conduct in-situ crew training in cislunar space	UC-157-L				
Perform regular training and drills to simulate off-nominal scenarios	FN-245-L	Conduct testing, contingency planning, and run edge-case analyses of flight systems	UC-177-L	Operate and gain experience with flight control and mission integration to ensure safety and mission success in nominal and off-nominal conditions.	CN-192-LM		
Provide safety features on robotic and/or autonomous system(s)	FN-254-L	Ensure safe and effective interaction between crew and autonomous asset(s)	UC-138-L	Operate and gain experience with remote & autonomous system(s) to reduce crew workload.	CN-193-LM		
Provide physical and electronic safeguards for automated asset(s) operating near crew	FN-256-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Simulate up to Mars distance communication latency or disruptions during operations in cislunar space	FN-161-L	Test, analyze, and evaluate responses to range of communication latency expected of Mars-class missions	UC-130-L	Operate and gain experience with in-situ training and planning capabilities to ensure safety and mission success.	CN-194-LM		
Simulate up to Mars distance communication latency or disruptions during operations on the lunar surface	FN-162-L						
Conduct crew training in simulation of increasingly Earth-independent operations	FN-163-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Crewed mission(s) to landing sites in the lunar south polar regions	UC-021-L	Visit geographically diverse sites on the lunar surface, including the south polar region, and non-polar destinations.	CN-055-L	Characterize accessible resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable use of resources on successive missions.	OP-03-LM
Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface	FN-044-L	Crewed mission(s) to distributed landing sites on the lunar surface	UC-022-L				
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest	UC-023-L				
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	UC-048-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar surface.	CN-056-L		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L				
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L						
Conduct crew lunar surface extravehicular activity	FN-028-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide local unpressurized crew surface mobility	**FN-030-L**						
Provide pressurized crew surface mobility	**FN-031-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew extravehicular explorations and identification of surface samples	**UC-025-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from non-PSRs and sunlit regions	**UC-026-L**				
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-032-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						
Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface	**FN-048-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect surface samples from PSRs	**UC-030-L**				
Provide local unpressurized crew surface mobility	**FN-030-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-054-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs	**FN-218-L**						
Stow collected surface samples from PSRs on the lunar surface	**FN-220-L**						
Utilize tools to collect surface samples from PSRs on the lunar surface	**FN-258-L**						
Provide power for conditioning to sample containers on the lunar surface	**FN-266-L**						
Stow collected surface samples on the lunar surface from PSRs in conditioned state	**FN-274-L**						
Transport collected surface samples on the lunar surface	**FN-277-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**	Document sample details prior to collection on the lunar surface	**UC-107-L**				
Record sample position, orientation, context and time prior to collection on the lunar surface	**FN-132-L**						
Provide accurate location tracking and position data on the lunar surface	**FN-227-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**FN-040-L**	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	**UC-019-L**	Identify, collect, and document samples from multiple globally distributed locations, including frozen samples from PSRs, from the lunar sub-surface.	**CN-057-L**		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**FN-045-L**						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	**FN-047-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**						
Robotic identification of potential samples and resources on the lunar surface	**FN-249-L**						
Robotic collection of lunar surface samples	**FN-250-L**						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	**FN-251-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew excursions to locations distributed around landing site	**UC-024-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Provide local unpressurized crew surface mobility	**FN-030-L**						
Provide pressurized crew surface mobility	**FN-031-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Crew extravehicular explorations and identification of surface samples	**UC-025-L**				
Provide high availability position, navigation, and timing capability on the lunar surface	**FN-024-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**						
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						
Conduct crew lunar surface extravehicular activity	**FN-028-L**	Collect sub-surface samples from non-PSRs and sunlit regions	**UC-034-L**				
Conduct crew survey of areas of interests and sample identification	**FN-046-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state	FN-055-L						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-143-L						
Utilize tools to collect sub-surface samples from non-PSRs and sunlit regions on the lunar surface	FN-259-L						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-262-L						
Transport collected sub-surface samples on the lunar surface in conditioned state	FN-278-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Document sample details prior to collection on the lunar surface	UC-107-L				
Record sample position, orientation, context and time prior to collection on the lunar surface	FN-132-L						
Provide accurate location tracking and position data on the lunar surface	FN-227-L						
Capture imagery on the lunar surface	FN-269-L						
Conduct crew lunar surface extravehicular activity	FN-028-L	Collect sub-surface samples from PSRs	UC-111-L				
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	FN-219-L						
Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state	FN-221-L						
Utilize tools to collect sub-surface samples from PSRs on the lunar surface	FN-260-L						
Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from PSRs	FN-261-L						
Transport collected sub-surface samples on the lunar surface in conditioned state	FN-278-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation	UC-159-L	Deploy and operate utilization payload(s), related to available resources, at distributed and south polar region sites on the lunar surface.	CN-150-L		
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide power for deployed surface asset(s)	FN-051-L						
Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface	FN-139-L						
Deliver cargo(s) to distributed sites on the lunar surface	FN-141-L						
Deliver cargo(s) to south polar region sites on the lunar surface	FN-164-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L		UC-023-L	Demonstrate the capability to identify	CN-		

Functions		Use Cases		Characteristics/Needs		Objectives	
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	**FN-040-L**	Robotically survey potential crewed landing and exploration sites to identify locations of interest		and locate potential site(s) for resource utilization.			
Survey potential exploration sites on the lunar surface from lunar orbit	**FN-196-L**						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	**FN-248-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	**UC-048-L**				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	**FN-045-L**						
Survey potential exploration sites on the lunar surface from lunar orbit	**FN-196-L**						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	**FN-248-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide capabilities to integrate networks and mission systems to exchange data between Earth-based systems, in-space exploration assets, and surface exploration assets.	**CN-195-LM**	Establish command and control processes, common interfaces, and ground systems that will support expanding human missions at the Moon and Mars.	**OP-04-LM**
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Capture imagery on the lunar surface	**FN-269-L**						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	**FN-082-L**	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	**UC-067-L**				
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	**FN-224-L**	Communications and data exchange between assets in cislunar space and the lunar surface	**UC-173-L**				
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Format, transmit, and receive data from cislunar space to the lunar surface	**FN-238-L**						
Format, transmit, and receive data from the lunar surface to cislunar space	**FN-239-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Protect and/or secure data for storage and transmission	**FN-244-L**						
Receive and format data on Earth	**FN-232-L**	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received	**UC-174-L**				
Format and transit data to Earth from cislunar space	**FN-236-L**						
Store and distribute data between assets in cislunar space	**FN-237-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space	**FN-071-L**	Communications and data exchange between assets in cislunar space and Earth	**UC-175-L**				
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Capture imagery in cislunar space	**FN-199-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Format and transit data to Earth from cislunar space	**FN-236-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received	**UC-176-L**				
Receive and format data on Earth	**FN-232-L**						
Format, transmit, and receive data between assets on the lunar surface	**FN-234-L**						
Store and distribute data between assets on the lunar surface	**FN-235-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	**FN-023-L**	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth	**UC-066-L**	Provide capabilities to utilize common data interface(s) for exchanges between Earth-based systems, in-space exploration assets, and surface exploration assets.	**CN-196-LM**		
Provide Earth based ground stations for exploration communications	**FN-081-L**						
Format and transmit data to Earth from the lunar surface	**FN-231-L**						
Receive and format data on Earth	**FN-232-L**						
Store and distribute data to user(s) on Earth	**FN-233-L**						
Protect and/or secure data for storage and transmission	**FN-244-L**						

Functions		Use Cases		Characteristics/Needs		Objectives	
Capture imagery on the lunar surface	FN-269-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface	UC-067-L				
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide common data interface on the lunar surface	FN-202-L	Utilize common interface(s) for data transfer and distribution	UC-085-L				
Provide common data interface in cislunar space	FN-203-L						
Provide common data interface on Earth	FN-204-L						
Format and transmit data to Earth from the lunar surface	FN-231-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received	UC-176-L				
Receive and format data on Earth	FN-232-L						
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Receive and format data on Earth	FN-232-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received	UC-174-L	Provide capabilities to store and protect data on exploration assets.	CN-197-LM		
Format and transit data to Earth from cislunar space	FN-236-L						
Store and distribute data between assets in cislunar space	FN-237-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Format and transmit data to Earth from the lunar surface	FN-231-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received	UC-176-L				
Receive and format data on Earth	FN-232-L						
Format, transmit, and receive data between assets on the lunar surface	FN-234-L						
Store and distribute data between assets on the lunar surface	FN-235-L						
Protect and/or secure data for storage and transmission	FN-244-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Crew excursions to locations distributed around landing site	UC-024-L	Operate and gain experience with	CN-	Operate surface mobility systems, e.g., extra-	OP-

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L			capabilities to transport crew and cargo between landing or base site and exploration sites at varying distances from fixed assets.		vehicular activity (EVA) suits, tools and vehicles.	
Conduct crew lunar surface extravehicular activity	FN-028-L						
Provide local unpressurized crew surface mobility	FN-030-L						
Provide pressurized crew surface mobility	FN-031-L						
Conduct crew survey of areas of interests and sample identification	FN-046-L						
Provide high availability position, navigation, and timing capability on the lunar surface	FN-024-L	Support crew extravehicular operations on the lunar surface	UC-011-L	Operate and gain experience with capabilities to conduct extravehicular activities utilizing mobility assets and tools.	CN-199-LM		
Conduct crew lunar surface extravehicular activity	FN-028-L						
Crew ingress/egress from habitable asset(s) to lunar surface vacuum	FN-029-L						
Access from habitable volume to lunar surface exterior vacuum	FN-158-L						
Utilize tools to collect surface samples from non-PSRs and sunlit regions on the lunar surface	FN-105-L	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning	UC-089-L				
Utilize tools for equipment cleaning and maintenance	FN-106-L						
Utilize tools to assist in contingency scenarios	FN-137-L						
Utilize tools to collect surface samples from PSRs on the lunar surface	FN-258-L						
Utilize tools to collect sub-surface samples from non-PSRs and sunlit regions on the lunar surface	FN-259-L						
Utilize tools to collect sub-surface samples from PSRs on the lunar surface	FN-260-L						
Command and control uncrewed asset(s) in cislunar space from Earth	FN-100-L	Conduct autonomous/semi-autonomous mission operations in cislunar space	UC-082-L	Operate and gain experience with capabilities to remotely operate surface mobility system(s) from Earth, in-space assets, and/or other surface assets.	CN-200-LM		
Command and control uncrewed asset(s) on the lunar surface from Earth	FN-101-L	Conduct autonomous/semi-autonomous mission operations on the lunar surface	UC-083-L				
Command and control autonomous asset(s) on the lunar surface from cislunar space	FN-135-L						
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	UC-018-L	Conduct mid-duration (month+) crew exploration mission(s) on the lunar surface.	CN-093-L	Evaluate, understand, and mitigate the impacts on crew health and performance of a long deep space orbital mission, followed by partial gravity surface operations on the Moon.	OP-06-L
Provide crew health care on the lunar surface	FN-149-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Reuse habitation system(s) on the lunar surface	UC-092-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface	UC-128-L				
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use	FN-271-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	UC-191-L				
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Docking/berthing between pressurized assets on the lunar surface	FN-124-L						
Transfer gases and water to habitable assets on the lunar surface	FN-177-L						
Transport cargo on the lunar surface between landing location and surface assets	FN-178-L						
Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region	FN-013-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.	UC-035-L	Transition crew from micro-gravity environment to partial gravity environment, following mid-duration (month+) to extended-duration (year+) in space.	CN-095-LM		
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Transport crew from cislunar space to the lunar surface after extended duration (year+) in space	FN-136-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Transport crew and associated cargo from the lunar surface to cislunar space	FN-014-L	Prepare crew for transition and transport from the lunar surface to cislunar space	UC-129-L	Transition crew from partial gravity environment to micro-gravity environment.	CN-105-LM		
Ready and transition crew to transportation asset for return to orbit	FN-179-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface	UC-010-L	Conduct short-duration (days to weeks) crew exploration mission(s) on the lunar surface.	CN-188-L		
Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)	FN-025-L						
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Reuse habitation system(s) on the lunar surface	UC-092-L				
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L						
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface	UC-152-L				
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface	UC-191-L				
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Docking/berthing between pressurized assets on the lunar surface	FN-124-L						
Transfer gases and water to habitable assets on the lunar surface	FN-177-L						
Transport cargo on the lunar surface between landing location and surface assets	FN-178-L						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space	UC-015-L	Conduct numerous extended-duration (year+) crew exploration mission(s) in cislunar and deep space.	CN-202-L		
Transport cargo from Earth to assets in cislunar space	FN-033-L						
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Manage waste from habitable asset(s) in cislunar space	FN-036-L						
Provide remote crew medical systems in cislunar space	FN-039-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Habitation capabilities for extended-duration (year+) missions in cislunar space	UC-148-L				
Operate assets in cislunar space in uncrewed mode for extended (year+) durations	FN-157-L						
Operate habitation system(s) in dormancy/remote mode between crewed missions in cislunar space	FN-155-L	Reuse habitation systems(s) in cislunar space	UC-149-L				
Provide crew health care during transit	FN-150-L	Crew health care, diagnosis, and treatment in space	UC-016-L	Provide crew health and performance capabilities in cislunar space and in deep space, including demonstration of remote and autonomous healthcare and advanced	CN-031-L	Validate readiness of systems and operations to support crew health and performance for the initial human Mars exploration campaign.	OP-07-LM
Provide crew health care in cislunar space	FN-160-L						
Provide remote crew medical systems in cislunar space	FN-039-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space	UC-017-L				
Provide crew health care in cislunar space	FN-160-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L			diagnostics, to prepare for future Mars missions.			
Provide remote crew medical systems in cislunar space	FN-039-L	In-situ diagnosis and treatment of crew in cislunar space	UC-103-L				
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface	UC-018-L	Provide crew health and performance capabilities on the lunar surface, including demonstration of remote and autonomous healthcare and advanced diagnostics, to prepare for future Mars missions.	CN-032-L		
Provide crew health care on the lunar surface	FN-149-L						
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Provide remote crew medical systems on the lunar surface	FN-026-L	In-situ diagnosis and treatment of crew on the lunar surface	UC-104-L				
Monitor crew health on the lunar surface	FN-275-L						
Provide remote crew medical systems on the lunar surface	FN-026-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface	UC-152-L				
Provide crew health maintenance capabilities in partial gravity environment	FN-228-L						
Provide crew health care on the lunar surface	FN-149-L	Crew emergency health care, diagnosis, and treatment on the lunar surface	UC-154-L				
Implement supportability to correct system failures	FN-130-L	Crew survival during off-nominal situations	UC-160-L	Demonstrate crew survival capabilities in cislunar space and on the lunar surface, including safe havens, system supportability, and/or aborts, for nominal and off-nominal scenarios to prepare for future Mars missions.	CN-038-L		
Provide safe haven capability for crew to shelter during off-nominal scenario	FN-165-L						
Provide hazard remediation capabilities	FN-166-L						
Provide capability to restore and stabilize the habitable environment after off-nominal scenario	FN-167-L						
Transport crew and crew system(s) from cislunar space to Earth in off-nominal situation	FN-131-L	Crew abort to Earth in off-nominal situations	UC-164-L				
Provide capability for crew loiter until return window	FN-169-L						
Transport crew from the lunar surface to cislunar space in off-nominal scenario	FN-170-L						
Perform repairs and/or replacement of subsystems	FN-171-L	Crew repair and/or replacement of failed or off-nominal systems	UC-183-L				
Provide storage for necessary spares and repair equipment	FN-172-L						
Transport cargo from Earth to the lunar surface	FN-018-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface	UC-010-L	Conduct crewed and uncrewed testing of surface habitable system(s).	CN-189-L		
Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)	FN-025-L						
Transfer pressurized cargo into habitable assets on the lunar surface	FN-027-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Manage waste from habitable asset(s) on the lunar surface	FN-037-L						
Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface	FN-113-L	Operate habitation system(s) on the lunar surface while uncrewed	UC-102-L				
Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations	FN-010-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space	UC-015-L	Conduct crewed and uncrewed testing of in-space habitable system(s).	CN-190-L		
Transport cargo from Earth to assets in cislunar space	FN-033-L						
Transfer cargo into habitable asset(s) in cislunar space	FN-035-L						
Manage waste from habitable asset(s) in cislunar space	FN-036-L						
Provide remote crew medical systems in cislunar space	FN-039-L						
Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations	FN-273-L						
Operate habitation system(s) in dormancy/remote mode between crewed missions in cislunar space	FN-155-L	Reuse habitation systems(s) in cislunar space	UC-149-L				
Access residual propellant from surface assets (demonstration)	FN-108-L	Demonstrate recovery of excess propellant from surface asset(s)	UC-090-L	Demonstrate the capabilities to locate, access, and reuse surface assets from previous crewed and uncrewed missions.	CN-203-LM	Demonstrate the capability to find, service, upgrade, or utilize instruments and equipment from robotic landers or previous human missions on the surface of the Moon and Mars.	OP-08-LM
Provide propellant/fluid transfer through common interface(s) between assets on the lunar surface (demonstration)	FN-123-L						
Transfer propellant/fluids between assets on the lunar surface (demonstration)	FN-129-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Demonstrate equipment recovery from surface asset(s)	UC-153-L				
Access equipment from other assets (demonstration)	FN-247-L						
Transfer equipment from extravehicular to intravehicular environment (demonstration)	FN-152-L	Demonstrate maintenance, modification, and/or upgrades of asset(s)	UC-139-L	Demonstrate the capabilities to service and/or upgrade assets.	CN-204-LM		
Provide intravehicular maintenance, upgrade, and/or repair accommodations (demonstration)	FN-176-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval	UC-019-L	Provide appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone on the lunar surface.	CN-042-L	Demonstrate the capability of integrated robotic systems to support and maximize the useful work performed by crewmembers on the surface, and in orbit.	OP-09-LM
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions	FN-047-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L						
Robotic identification of potential samples and resources on the lunar surface	FN-249-L						
Robotic collection of lunar surface samples	FN-250-L						
Robotic collection, containment, and documentation of lunar surface samples from PSRs	FN-251-L						

Functions		Use Cases		Characteristics/Needs		Objectives	
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest	UC-023-L				
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth	FN-023-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest	UC-048-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Survey potential exploration sites on the lunar surface from lunar orbit	FN-196-L						
Robotic surveys of potential exploration sites on the lunar surface with assets on surface	FN-248-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Remotely manage robotic system(s) during surface operation as required	UC-094-L				
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Monitor robotic system(s) performance and health	FN-252-L						
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L	Perform lunar surface activities with surface robotic system(s) assistance	UC-105-L				
Perform robotic manipulation of payloads, logistics, and/or equipment at multiple scales	FN-148-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Demonstrate in-situ crew command and control of robotic system(s)	UC-093-L	Demonstrate the capability for safe and effective interactions between crew and automated/autonomous system(s).	CN-044-L		
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	FN-224-L						
Monitor robotic system(s) performance and health	FN-252-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L						
Provide safety features on robotic and/or autonomous system(s)	FN-254-L						
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L	Perform lunar surface activities with surface robotic system(s) assistance	UC-105-L				
Perform robotic manipulation of payloads, logistics, and/or equipment at multiple scales	FN-148-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L	Perform activities in space with robotic system(s) assistance	UC-185-L				
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Demonstrate in-situ crew command and control of robotic system(s)	UC-093-L	Demonstrate capabilities to allow in-	CN-		

Functions		Use Cases		Characteristics/Needs		Objectives	
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L			space and surface crew to control and command robotic system(s).			
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	FN-224-L						
Monitor robotic system(s) performance and health	FN-252-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L						
Provide safety features on robotic and/or autonomous system(s)	FN-254-L						
Control robotic system(s) on the lunar surface from Earth and/or cislunar space	FN-040-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface	UC-108-L	Demonstrate the capabilities to operate appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone on the lunar surface.	CN-213-L		
Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space	FN-045-L						
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L						
Control robotic system(s) in cislunar space from Earth and/or cislunar space	FN-041-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations in cislunar space	UC-109-L	Demonstrate the capabilities to operate appropriate robotic system(s) that can conduct or assist in tasks that would otherwise be performed by the crew alone in cislunar space.	CN-214-L		
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L						
Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface	FN-082-L	Demonstrate in-situ crew command and control of robotic system(s)	UC-093-L	Demonstrate the capability for safe and effective interactions between crew and automated/autonomous system(s).	CN-044-L	Demonstrate the capability to operate robotic systems that are used to support crew members on the lunar or Martian surface, autonomously or remotely from the Earth or from orbiting platforms.	OP-10-LM
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L						
Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space	FN-224-L						
Monitor robotic system(s) performance and health	FN-252-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L						
Provide safety features on robotic and/or autonomous system(s)	FN-254-L						
Control robotic system(s) on the lunar surface by crew on the lunar surface	FN-114-L	Perform lunar surface activities with surface robotic system(s) assistance	UC-105-L				
Perform robotic manipulation of payloads, logistics, and/or equipment at multiple scales	FN-148-L						
Control robotic system(s) in cislunar space by in-situ crew	FN-253-L	Perform activities in space with robotic system(s) assistance	UC-185-L				
Command and control uncrewed asset(s) on the lunar surface from Earth	FN-101-L		UC-083-L	Demonstrate autonomous and	CN-		

Functions		Use Cases		Characteristics/Needs		Objectives	
Command and control autonomous asset(s) on the lunar surface from cislunar space	**FN-135-L**	Conduct autonomous/semi-autonomous mission operations on the lunar surface		remote operations of surface systems from external systems, including Earth, orbital, and/or other surface locations.			
Command and control uncrewed asset(s) in cislunar space from Earth	**FN-100-L**	Conduct autonomous/semi-autonomous mission operations in cislunar space	**UC-082-L**	Demonstrate autonomous and remote operations of in-space systems from external systems, including Earth, orbital, and/or surface locations.	**CN-206-LM**		
Produce scalable quantities of oxygen from lunar regolith (demonstration)	**FN-090-L**	Demonstrate operational techniques to recover oxygen from lunar regolith	**UC-076-L**	Deploy and operate demonstration utilization payload(s) on the lunar surface to collect, produce, store, and transfer commodities, including water, oxygen, and/or construction feedstock, for potential use by system and/or crew.	**CN-169-L**	Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.	**OP-11-LM**
Store oxygen on the lunar surface (demonstration)	**FN-116-L**						
Transport scalable quantities of oxygen produced to exploration elements (demonstration)	**FN-117-L**						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	**FN-184-L**						
Collect regolith at scale and subscale (demonstration)	**FN-185-L**						
Provide storage for collected regolith (demonstration)	**FN-186-L**						
Produce scalable quantities of water from in-situ materials (demonstration)	**FN-093-L**	Demonstrate operational techniques to recover water from the lunar regolith in the polar regions	**UC-077-L**				
Collect water/ice from the polar region of the lunar surface (demonstration)	**FN-118-L**						
Store collected water/ice on the lunar surface (demonstration)	**FN-119-L**						
Transport scalable quantities of water produced to exploration elements (demonstration)	**FN-120-L**						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	**FN-184-L**						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	**FN-184-L**	Demonstrate operational techniques to recover and refine metals from the lunar regolith	**UC-150-L**				
Collect regolith at scale and subscale (demonstration)	**FN-185-L**						
Provide storage for collected regolith (demonstration)	**FN-186-L**						
Test product(s) from metal production/refinement (demonstration)	**FN-207-L**						
Produce scalable quantities of metal from lunar regolith (demonstration)	**FN-246-L**						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	**FN-184-L**	Demonstrate autonomous construction techniques, e.g.,	**UC-143-L**	Demonstrate the capability to use	**CN-**		

Functions		Use Cases		Characteristics/Needs		Objectives	
Collect regolith at scale and subscale (demonstration)	FN-185-L	collection of regolith, processing regolith into feedstock, and regolith construction		surface-borne resources for potential construction and/or manufacturing on the lunar surface.			
Provide storage for collected regolith (demonstration)	FN-186-L						
Compact scalable quantities of lunar regolith (demonstration)	FN-188-L						
Form scalable quantities of structures from lunar regolith (demonstration)	FN-189-L						
Test product(s) from regolith processing (demonstration)	FN-205-L						
Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)	FN-184-L	Demonstrate regolith based additive/subtractive manufacturing techniques	UC-145-L				
Collect regolith at scale and subscale (demonstration)	FN-185-L						
Provide storage for collected regolith (demonstration)	FN-186-L						
Manufacture (additive or subtractive) scalable quantities of item(s) from lunar regolith (demonstration)	FN-190-L						
Test product(s) from additive/subtractive manufacturing (demonstration)	FN-206-L						
Implement communication methods to coordinate and preserve the radio environment on the lunar far side	FN-174-L	Preserve lunar far side environment to ensure scientific data integrity	UC-055-L	Preserve radio free environment on the far side of the Moon.	CN-	Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration.	OP-12-LM
Reduce blast ejecta	FN-126-L	Reduce blast ejecta to limit the migration of ejecta across the lunar surface	UC-114-L	Limit contamination of PSRs.	CN-138-L		
Inhibit dust migration and impacts	FN-127-L	Reduce path erosion, dust lofting, and sample contamination	UC-115-L				
Inhibit dust migration and impacts	FN-127-L	Limit spread of dust raised by lunar surface operations	UC-125-L				
Manage waste from habitable asset(s) on the lunar surface	FN-037-L	Manage disposal of hardware and waste products	UC-136-L				
Manage undesired samples and investigation items	FN-156-L						
Access residual propellant from surface assets (demonstration)	FN-108-L	Demonstrate recovery of excess propellant from surface asset(s)	UC-090-L	Demonstrate the capabilities to recover useful equipment from surface assets, where valuable.	CN-209-L		
Provide propellant/fluid transfer through common interface(s) between assets on the lunar surface (demonstration)	FN-123-L						
Transfer propellant/fluids between assets on the lunar surface (demonstration)	FN-129-L						
Manage undesired samples and investigation items	FN-156-L	Repurpose hardware and materials brought to the surface for subsequent missions	UC-135-L				
Repurpose and/or recycle equipment that is no longer useful in its primary function	FN-173-L						
Transport crew to the lunar surface in proximity of deployed exploration asset(s)	FN-107-L	Demonstrate equipment recovery from surface asset(s)	UC-153-L				

Functions		Use Cases		Characteristics/Needs		Objectives	
Access equipment from other assets (demonstration)	**FN-247-L**						
Access residual propellant from surface assets (demonstration)	**FN-108-L**	Demonstrate recovery of excess propellant from surface asset(s)	**UC-090-L**	Demonstrate the capabilities to recovery of excess fluids and gases, including propellant residuals, from lunar landers and separation of products.	**CN-210-L**		
Provide propellant/fluid transfer through common interface(s) between assets on the lunar surface (demonstration)	**FN-123-L**						
Transfer propellant/fluids between assets on the lunar surface (demonstration)	**FN-129-L**						
Decommission surface delivery system(s) and/or surface asset(s)	**FN-122-L**	Conduct end-of-life operations	**UC-101-L**				
Repurpose and/or recycle equipment that is no longer useful in its primary function	**FN-173-L**						

A.5 List of Use Cases

ID	Use Cases
UC-001-L	Transport crew and supporting system(s) from Earth to cislunar space
UC-002-L	Stage crewed lunar surface missions from cislunar space
UC-003-L	Aggregate and physically assemble spacecraft components in cislunar space
UC-004-L	Transport crew and supporting system(s) between cislunar space and the lunar surface
UC-005-L	Operate transportation assets(s) from Earth during crew surface missions
UC-006-L	Return crew and systems from cislunar space to Earth
UC-007-L	Unload large exploration assets on the lunar surface
UC-008-L	Deploy utilization payloads and equipment on the lunar surface
UC-009-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-010-L	Crew inhabit assets on the surface for short-durations (days to weeks) on the lunar surface
UC-011-L	Support crew extravehicular operations on the lunar surface
UC-012-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-013-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-014-L	Deploy and setup utilization payload(s) on the lunar surface with long-term remote operation
UC-015-L	Crew habitation for extended-duration (year+) mission(s) in cislunar space
UC-016-L	Crew health care, diagnosis, and treatment in space
UC-017-L	Remotely monitor, diagnose, and treat crew health during extended-duration (year+) missions in cislunar space
UC-018-L	Remotely monitor, diagnose, and treat crew health during mid-duration (month+) missions on the lunar surface
UC-019-L	Robotically assist crew exploration, site surveying, sample and resource locating, documentation, and sample retrieval
UC-020-L	Return collected surface samples (non-conditioned) to Earth in sealed sample containers
UC-021-L	Crewed mission(s) to landing sites in the lunar south polar regions
UC-022-L	Crewed mission(s) to distributed landing sites on the lunar surface
UC-023-L	Robotically survey potential crewed landing and exploration sites to identify locations of interest
UC-024-L	Crew excursions to locations distributed around landing site
UC-025-L	Crew extravehicular explorations and identification of surface samples
UC-026-L	Collect surface samples from non-PSRs and sunlit regions
UC-027-L	Orbital survey(s) before, during, and after crew mission
UC-028-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-029-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases

ID	Use Cases
UC-030-L	Collect surface samples from PSRs
UC-031-L	Deploy and set up Heliophysics utilization payload(s) at cislunar asset(s) with long term remote operation
UC-032-L	Deploy and operate free-flying assets in a variety of lunar orbits long-term
UC-033-L	Deploy and set up Heliophysics utilization payload(s) on the lunar surface with long-term remote operation
UC-034-L	Collect sub-surface samples from non-PSRs and sunlit regions
UC-035-L	Conduct missions with extended-duration (year+) in microgravity, followed by short-duration (days to weeks) in partial gravity, and then ending with extended-duration (year+) in microgravity prior to return to Earth.
UC-036-L	Crew conduct biological science and human research activities on the lunar surface
UC-037-L	Crew conduct biological science and human research activities while in habitable volume in cislunar space
UC-038-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-039-L	Deploy and set up astrophysics utilization payload(s) on the far side of the lunar surface with long-term remote operation
UC-040-L	Crew conduct fundamental physics experiments while in habitable volume on the lunar surface
UC-041-L	Deploy and set up fundamental physics utilization payload(s) on the lunar surface with long term remote operation
UC-042-L	Deploy and set up fundamental physics utilization payload(s) in cislunar space with long term remote operation
UC-043-L	Conduct intravehicular science and utilization activities on the lunar surface
UC-044-L	Crew conduct fundamental physics experiments while in habitable volume in cislunar space
UC-045-L	Provide advanced geology training, integrated geology and EVA ops training, as well as detailed objective-specific training to astronauts for science activities
UC-046-L	Provide in-situ training to astronauts for science tasks during mission(s)
UC-047-L	Allow ground personnel and science team to directly engage with crew on the surface and in cislunar space, augmenting the crew's effectiveness at conducting science and utilization activities
UC-048-L	Robotically survey PSRs near potential crewed landing and exploration sites to identify locations of interest
UC-049-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-050-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-051-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-052-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-053-L	Deploy and set up fundamental physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
UC-054-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-055-L	Preserve lunar far side environment to ensure scientific data integrity
UC-056-L	Land exploration missions at sites removed from sites of historic significance
UC-057-L	Deploy and set up utilization payload(s) at cislunar asset(s) with long term remote operation

ID	Use Cases
UC-058-L	Deploy and operate free-flying assets in a variety of lunar and heliocentric orbits long-term
UC-059-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-060-L	Demonstrate utilization payload(s) related to bio-regenerative oxygen and water recovery in cislunar space
UC-061-L	Demonstrate plant growth in cislunar asset(s)
UC-062-L	Deploy and set up physics utilization payload(s) at asset(s) in cislunar space with long term remote operation
UC-063-L	Deploy and set up physics utilization payload(s) on the lunar surface with long term remote operation
UC-064-L	Deploy power generation and energy storage system(s) on the lunar surface
UC-065-L	Deploy power distribution capabilities around power generation and energy storage system(s) on the lunar surface
UC-066-L	Communications and data exchange from assets at a variety of exploration locations on the lunar surface to Earth
UC-067-L	Communications and data exchange between assets at a variety of exploration locations on the lunar surface
UC-068-L	Position, navigation, and timing for crew and robotic assets in cislunar space
UC-069-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-070-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-071-L	Land crew lander(s) at specific pre-defined locations
UC-072-L	Transport cargo to specific pre-defined location within exploration area on the lunar surface
UC-073-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-074-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-075-L	Demonstrate uncrewed relocation of large exploration assets to sites around the lunar south polar region
UC-076-L	Demonstrate operational techniques to recover oxygen from lunar regolith
UC-077-L	Demonstrate operational techniques to recover water from the lunar regolith in the polar regions
UC-078-L	Demonstrate operational techniques to transfer fluid and/or propellant in space
UC-079-L	Demonstrate propellant storage for extended-duration (year+) in space
UC-080-L	Demonstrate propellant storage for extended-duration (year+) on the lunar surface
UC-081-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-082-L	Conduct autonomous/semi-autonomous mission operations in cislunar space
UC-083-L	Conduct autonomous/semi-autonomous mission operations on the lunar surface
UC-084-L	Utilize common interface(s) for power transfers and distribution on the lunar surface
UC-085-L	Utilize common interface(s) for data transfer and distribution
UC-086-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-087-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases

ID	Use Cases
UC-088-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-089-L	Crew use of tools to assist in performing extravehicular activities, e.g., sample collection and suit cleaning
UC-090-L	Demonstrate recovery of excess propellant from surface asset(s)
UC-091-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-092-L	Reuse habitation system(s) on the lunar surface
UC-093-L	Demonstrate in-situ crew command and control of robotic system(s)
UC-094-L	Remotely manage robotic system(s) during surface operation as required
UC-095-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-096-L	REMOVED from ESDMD-001 Baseline Mapping: Replaced by new or updated Use Cases
UC-097-L	Return collected surface and sub-surface samples to Earth in sealed conditioned sample containers
UC-098-L	Transport large exploration asset(s) to the lunar surface
UC-099-L	Return crew and associated cargo from the lunar surface to cislunar space
UC-100-L	Deploy cargo to the lunar surface
UC-101-L	Conduct end-of-life operations
UC-102-L	Operate habitation system(s) on the lunar surface while uncrewed
UC-103-L	In-situ diagnosis and treatment of crew in cislunar space
UC-104-L	In-situ diagnosis and treatment of crew on the lunar surface
UC-105-L	Perform lunar surface activities with surface robotic system(s) assistance
UC-106-L	Utilize common interface(s) for power transfers and distribution in cislunar space
UC-107-L	Document sample details prior to collection on the lunar surface
UC-108-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations on the lunar surface
UC-109-L	Demonstrate operational techniques for utilizing robotic system(s) to assist crew operations in cislunar space
UC-110-L	Deliver power to asset(s) in cislunar space
UC-111-L	Collect sub-surface samples from PSRs
UC-112-L	Crew conduct biological science and human research activities in habitable volume while in transit
UC-113-L	Demonstrate aggregation and physical assembly of assets on the lunar surface
UC-114-L	Reduce blast ejecta to limit the migration of ejecta across the lunar surface
UC-115-L	Reduce path erosion, dust lofting, and sample contamination
UC-116-L	Return physical artifacts from experiments to Earth
UC-117-L	Provide tools, including EVA tools, to collect, recover, and package sub-surface samples
UC-118-L	Package sub-surface samples for return

ID	Use Cases
UC-119-L	Transport crew from Earth to cislunar space to support short-duration (days to weeks) to mid-duration (month+) crewed missions in cislunar space and the lunar surface
UC-120-L	Transport crew from Earth to cislunar space to support mid-duration (month+) to extended-duration(year+) crewed missions in cislunar space
UC-121-L	Robotic system(s) support of logistic operations on the lunar surface as required
UC-122-L	Robotic system(s) support of maintenance and repair operations as appropriate
UC-123-L	Deploy and set up power utilization payload(s) in areas with long darkness periods on the lunar surface, e.g., PSRs
UC-124-L	Deploy and set up plasma utilization payload(s) on the lunar surface with long term remote operation
UC-125-L	Limit spread of dust raised by lunar surface operations
UC-126-L	Position, navigation, and timing for crew and robotic assets at distributed and south polar region locations on the lunar surface
UC-127-L	Position, navigation, and timing for accurate sample tracking
UC-128-L	Crew inhabit assets on the surface for mid-durations (month+) on the lunar surface
UC-129-L	Prepare crew for transition and transport from the lunar surface to cislunar space
UC-130-L	Test, analyze, and evaluate responses to range of communication latency expected of Mars-class missions
UC-131-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to the lunar south polar region
UC-132-L	Cislunar space to lunar surface transportation supporting mid-duration (month+) missions to the lunar south polar region
UC-133-L	Cislunar space to lunar surface transportation supporting short-duration (days to weeks) missions to distributed landing sited on the lunar surface
UC-134-L	Deploy and set up demonstration ISRU utilization payload(s) on the lunar surface with long-term remote operation
UC-135-L	Repurpose hardware and materials brought to the surface for subsequent missions
UC-136-L	Manage disposal of hardware and waste products
UC-137-L	Land crew on the lunar surface in proximity to previously positioned surface assets
UC-138-L	Ensure safe and effective interaction between crew and autonomous asset(s)
UC-139-L	Demonstrate maintenance, modification, and/or upgrades of asset(s)
UC-140-L	Monitor environmental factors in habitation systems in space
UC-141-L	Monitor environmental factors in habitation systems on the lunar surface
UC-142-L	Deploy and set up autonomous construction demonstration utilization payload(s) on the lunar surface with long-term remote operation
UC-143-L	Demonstrate autonomous construction techniques, e.g., collection of regolith, processing regolith into feedstock, and regolith construction
UC-144-L	Deploy and set up advanced manufacturing demonstration utilization payload(s) on the lunar surface with long-term remote operation
UC-145-L	Demonstrate regolith based additive/subtractive manufacturing techniques
UC-146-L	Habitation capabilities for short-duration (days to weeks) missions on the lunar surface

ID	Use Cases
UC-147-L	Habitation capabilities for mid-duration (month+) missions in cislunar space and on the lunar surface
UC-148-L	Habitation capabilities for extended-duration (year+) missions in cislunar space
UC-149-L	Reuse habitation systems(s) in cislunar space
UC-150-L	Demonstrate operational techniques to recover and refine metals from the lunar regolith
UC-151-L	Demonstrate operational techniques to transfer fluid and/or propellant on the lunar surface
UC-152-L	Remotely monitor, diagnose, and treat crew health during short-duration (days to weeks) missions on the lunar surface
UC-153-L	Demonstrate equipment recovery from surface asset(s)
UC-154-L	Crew emergency health care, diagnosis, and treatment on the lunar surface
UC-155-L	Conduct reduced gravity materials and processes science experiments, other extreme environments-related research, and associated modeling to support in-space technologies related to support bioregenerative ECLSS
UC-156-L	Conduct experiments that can be used to gather data to inform the advanced ECLSS analysis/trade study in cislunar space
UC-157-L	Conduct in-situ crew training in cislunar space
UC-158-L	Transmit data from in-space and surface asset(s) to medical personnel on Earth
UC-159-L	Deploy and setup of utilization payload(s) related to available resources on the lunar surface with long term remote operation
UC-160-L	Crew survival during off-nominal situations
UC-161-L	Nutrition monitoring for crew during mission
UC-162-L	Crew health maintenance with countermeasure activities in microgravity environment
UC-163-L	Crew health maintenance with countermeasure activities in partial gravity environment
UC-164-L	Crew abort to Earth in off-nominal situations
UC-165-L	Deploy assets to monitor natural environments in cislunar space
UC-166-L	Monitor, characterize, and provide advance warning for natural environmental threats in cislunar space, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
UC-167-L	Deploy asset(s) to monitor induced environment in cislunar space
UC-168-L	Monitor, characterize, and provide advance warning for induced environmental threats in cislunar space, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
UC-169-L	Deploy and set up assets to monitor natural environments on the lunar surface
UC-170-L	Monitor, characterize, and provide advance warning for natural environmental threats on the lunar surface, e.g., high energy debris, natural radiation level, thermal conditions, plasma environments, and electrostatic charges
UC-171-L	Deploy and set up assets to monitor induced environment on the lunar surface
UC-172-L	Monitor, characterize, and provide advance warning for induced environmental threats on the lunar surface, e.g., induced radiation level, thermal conditions, high-energy debris, contamination, electrostatic, and acoustics
UC-173-L	Communications and data exchange between assets in cislunar space and the lunar surface

ID	Use Cases
UC-174-L	Aggregate and store data in cislunar space until it is able to be transmitted and confirmed received
UC-175-L	Communications and data exchange between assets in cislunar space and Earth
UC-176-L	Aggregate and store data on the lunar surface until it is able to be transmitted and confirmed received
UC-177-L	Conduct testing, contingency planning, and run edge-case analyses of flight systems
UC-178-L	Transport conditioned cargo from cislunar space to Earth
UC-179-L	Transport cargo from the lunar surface to cislunar space
UC-180-L	Transport conditioned cargo from the lunar surface to cislunar space
UC-181-L	Transport conditioned cargo to appropriate facilities on Earth
UC-182-L	Transport collected samples to appropriate curation facilities on Earth
UC-183-L	Crew repair and/or replacement of failed or off-nominal systems
UC-184-L	Remotely manage robotic system(s) during in space operation as required
UC-185-L	Perform activities in space with robotic system(s) assistance
UC-186-L	Transport cargo from the lunar surface or cislunar space back to Earth
UC-187-L	Deliver power to assets on the lunar surface
UC-188-L	Provide continuous power availability during mission critical activities
UC-189-L	Provide continuous power availability in off-nominal conditions
UC-190-L	Support crew extravehicular operations in cislunar space
UC-191-L	Resupply cargo and manage wastes to/from habitable assets on surface to support repeated crew missions on the lunar surface
UC-192-L	Resupply cargo and manage wastes to/from habitable assets in cislunar space to support repeated crew missions

A.5 List of Functions

ID	Functions
FN-001-L	Provide ground services on Earth
FN-002-L	Stack and integrate system(s) on Earth
FN-003-L	Manage consumables and propellant
FN-004-L	Enable vehicle launch(es)
FN-005-L	Allow multiple launch attempts
FN-006-L	Enable abort(s) to safety
FN-007-L	Transport crew and associated cargo from Earth to cislunar space to support short-duration (days to weeks) missions
FN-008-L	Rendezvous, proximity operations, docking, and undocking of assets in cislunar space
FN-009-L	Provide high availability position, navigation, and timing capability in cislunar space
FN-010-L	Provide pressurized, habitable environment in cislunar space for moderate (months+) to extended (year+) durations
FN-011-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-012-L	Docking/berthing of spacecraft components
FN-013-L	Transport crew and associated cargo from cislunar space to lunar surface sites in the south polar region
FN-014-L	Transport crew and associated cargo from the lunar surface to cislunar space
FN-015-L	Operate crew system(s) from Earth on the lunar surface during crewed missions
FN-016-L	Transport crew and associated cargo from cislunar space to Earth
FN-017-L	Recover crew, crew system(s), and cargo after Earth landing
FN-018-L	Transport cargo from Earth to the lunar surface
FN-019-L	Unload cargo on the lunar surface
FN-020-L	Reposition cargo on the lunar surface
FN-021-L	Generate power on the lunar surface
FN-022-L	Store energy on the lunar surface
FN-023-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and Earth
FN-024-L	Provide high availability position, navigation, and timing capability on the lunar surface
FN-025-L	Provide pressurized, habitable environment on the lunar surface for short durations (days to weeks)
FN-026-L	Provide remote crew medical systems on the lunar surface
FN-027-L	Transfer pressurized cargo into habitable assets on the lunar surface
FN-028-L	Conduct crew lunar surface extravehicular activity
FN-029-L	Crew ingress/egress from habitable asset(s) to lunar surface vacuum

ID	Functions
FN-030-L	Provide local unpressurized crew surface mobility
FN-031-L	Provide pressurized crew surface mobility
FN-032-L	Collect, recover, and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions
FN-033-L	Transport cargo from Earth to assets in cislunar space
FN-034-L	Provide pressurized, habitable environment in cislunar space
FN-035-L	Transfer cargo into habitable asset(s) in cislunar space
FN-036-L	Manage waste from habitable asset(s) in cislunar space
FN-037-L	Manage waste from habitable asset(s) on the lunar surface
FN-038-L	Provide crew health maintenance capabilities in microgravity environment
FN-039-L	Provide remote crew medical systems in cislunar space
FN-040-L	Control robotic system(s) on the lunar surface from Earth and/or cislunar space
FN-041-L	Control robotic system(s) in cislunar space from Earth and/or cislunar space
FN-042-L	Transport cargo from the lunar surface to Earth
FN-043-L	Recover samples and transport in a clean environment, minimizing contamination to/from the container, to curation facilities after Earth landing
FN-044-L	Transport crew and associated cargo from cislunar space to distributed sites on the lunar surface
FN-045-L	Control robotic system(s) in PSRs on the lunar surface from Earth and/or cislunar space
FN-046-L	Conduct crew survey of areas of interests and sample identification
FN-047-L	Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions
FN-048-L	Stow collected surface samples from non-PSRs and sunlit regions on the lunar surface
FN-049-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-050-L	Orbital observations and sensing of the lunar surface
FN-051-L	Provide power for deployed surface asset(s)
FN-052-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-053-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-054-L	Collect, recover, and package surface samples, avoiding cross-contamination of samples, from PSRs
FN-055-L	Stow collected sub-surface samples from non-PSRs and sunlit regions on the lunar surface in conditioned state
FN-056-L	Deliver utilization payload(s) to cislunar space
FN-057-L	Deploy (setup, activate, and operate) external utilization payload(s) at cislunar asset(s)
FN-058-L	Deliver free flying asset(s) to cislunar space
FN-059-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions

ID	Functions
FN-060-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) on the lunar surface
FN-061-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-062-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces) in cislunar space
FN-063-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-064-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-065-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-066-L	Transport cargo from Earth to the far side of the lunar surface
FN-067-L	Conduct crew surface extravehicular activities at the lunar far side region
FN-068-L	Provide crew training prior to mission
FN-069-L	Provide in-mission crew training in cislunar space
FN-070-L	Provide in-mission crew training on the lunar surface
FN-071-L	Provide high bandwidth, high availability communications and data exchange between Earth and cislunar space
FN-072-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-073-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-074-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-075-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-076-L	Operate utilization payloads related to bio-regenerative ECLSS (demonstration) in space
FN-077-L	Operate utilization payloads related to plant growth (demonstration) in space
FN-078-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-079-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-080-L	Distribute power on the lunar surface
FN-081-L	Provide Earth based ground stations for exploration communications
FN-082-L	Provide high bandwidth, high availability communication and data exchange between assets on the lunar surface
FN-083-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-084-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-085-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-086-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-087-L	Provide precision landing for crew transport to the lunar surface
FN-088-L	Provide precision landing for cargo transport to the lunar surface
FN-089-L	Operate mobility systems semi-autonomously on the lunar surface (demonstration)
FN-090-L	Produce scalable quantities of oxygen from lunar regolith (demonstration)

ID	Functions
FN-091-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-092-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-093-L	Produce scalable quantities of water from in-situ materials (demonstration)
FN-094-L	Transfer propellant/fluids between assets in space (demonstration)
FN-095-L	Provide storage of cryogenic propellant in space (demonstration)
FN-096-L	Provide storage of cryogenic propellant on the lunar surface (demonstration)
FN-097-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-098-M	Provide remote crew medical systems in deep space
FN-099-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-100-L	Command and control uncrewed asset(s) in cislunar space from Earth
FN-101-L	Command and control uncrewed asset(s) on the lunar surface from Earth
FN-102-L	Provide power through common power distribution interface(s) on the lunar surface
FN-103-L	Provide propellant/fluid transfer through common interface(s) between assets in space (demonstration)
FN-104-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-105-L	Utilize tools to collect surface samples from non-PSRs and sunlit regions on the lunar surface
FN-106-L	Utilize tools for equipment cleaning and maintenance
FN-107-L	Transport crew to the lunar surface in proximity of deployed exploration asset(s)
FN-108-L	Access residual propellant from surface assets (demonstration)
FN-109-L	Provide storage of non-cryogenic propellant on the lunar surface (demonstration)
FN-110-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-111-L	Operate mobility system(s) in dormancy/remote mode between crew surface missions (demonstration)
FN-112-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-113-L	Operate habitation system(s) in dormancy/remote mode between crewed missions on the lunar surface
FN-114-L	Control robotic system(s) on the lunar surface by crew on the lunar surface
FN-115-L	REMOVED from ESDMD-001 Baseline mapping, Replaced by new or updated Functions
FN-116-L	Store oxygen on the lunar surface (demonstration)
FN-117-L	Transport scalable quantities of oxygen produced to exploration elements (demonstration)
FN-118-L	Collect water/ice from the polar region of the lunar surface (demonstration)
FN-119-L	Store collected water/ice on the lunar surface (demonstration)
FN-120-L	Transport scalable quantities of water produced to exploration elements (demonstration)
FN-121-L	Provide power for conditioning to sample containers during transit to Earth curation facilities after Earth landing

ID	Functions
FN-122-L	Decommission surface delivery system(s) and/or surface asset(s)
FN-123-L	Provide propellant/fluid transfer through common interface(s) between assets on the lunar surface (demonstration)
FN-124-L	Docking/berthing between pressurized assets on the lunar surface
FN-125-L	Provide power to utilization payloads through common power distribution interface(s) in cislunar space
FN-126-L	Reduce blast ejecta
FN-127-L	Inhibit dust migration and impacts
FN-128-L	Provide storage of non-cryogenic propellant in space (demonstration)
FN-129-L	Transfer propellant/fluids between assets on the lunar surface (demonstration)
FN-130-L	Implement supportability to correct system failures
FN-131-L	Transport crew and crew system(s) from cislunar space to Earth in off-nominal situation
FN-132-L	Record sample position, orientation, context and time prior to collection on the lunar surface
FN-133-L	Provide intravehicular activity facilities, utilization accommodation, and resources (e.g. power, data, and physical interfaces), in transit assets
FN-134-L	Distribute power to utilization payloads in cislunar space
FN-135-L	Command and control autonomous asset(s) on the lunar surface from cislunar space
FN-136-L	Transport crew from cislunar space to the lunar surface after extended duration (year+) in space
FN-137-L	Utilize tools to assist in contingency scenarios
FN-138-L	Docking/berthing between pressurized assets in cislunar space
FN-139-L	Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) on the lunar surface
FN-140-L	Monitor operating asset(s)
FN-141-L	Deliver cargo(s) to distributed sites on the lunar surface
FN-142-L	Rendezvous, proximity operations, docking, and undocking of the assets on the lunar surface (demonstration)
FN-143-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions
FN-144-L	Transport large exploration asset(s) from Earth to the lunar surface
FN-145-L	Transport cargo from cislunar space to Earth
FN-146-L	Transport cargo from the lunar surface to cislunar space
FN-147-L	Transfer cargo from asset(s) in cislunar space to vehicles for return to Earth
FN-148-L	Perform robotic manipulation of payloads, logistics, and/or equipment at multiple scales
FN-149-L	Provide crew health care on the lunar surface
FN-150-L	Provide crew health care during transit
FN-151-L	Collect and store medical data and health information

ID	Functions
FN-152-L	Transfer equipment from extravehicular to intravehicular environment (demonstration)
FN-153-L	Prepare unconditioned cargo or samples for Earth return
FN-154-L	Prepare conditioned cargo or samples for return to Earth
FN-155-L	Operate habitation system(s) in dormancy/remote mode between crewed missions in cislunar space
FN-156-L	Manage undesired samples and investigation items
FN-157-L	Operate assets in cislunar space in uncrewed mode for extended (year+) durations
FN-158-L	Access from habitable volume to lunar surface exterior vacuum
FN-159-L	Unload large utilization assets on the lunar surface
FN-160-L	Provide crew health care in cislunar space
FN-161-L	Simulate up to Mars distance communication latency or disruptions during operations in cislunar space
FN-162-L	Simulate up to Mars distance communication latency or disruptions during operations on the lunar surface
FN-163-L	Conduct crew training in simulation of increasingly Earth-independent operations
FN-164-L	Deliver cargo(s) to south polar region sites on the lunar surface
FN-165-L	Provide safe haven capability for crew to shelter during off-nominal scenario
FN-166-L	Provide hazard remediation capabilities
FN-167-L	Provide capability to restore and stabilize the habitable environment after off-nominal scenario
FN-168-L	Provide power during crew critical mission events
FN-169-L	Provide capability for crew loiter until return window
FN-170-L	Transport crew from the lunar surface to cislunar space in off-nominal scenario
FN-171-L	Perform repairs and/or replacement of subsystems
FN-172-L	Provide storage for necessary spares and repair equipment
FN-173-L	Repurpose and/or recycle equipment that is no longer useful in its primary function
FN-174-L	Implement communication methods to coordinate and preserve the radio environment on the lunar far side
FN-175-L	Conduct crew cislunar extravehicular activity
FN-176-L	Provide intravehicular maintenance, upgrade, and/or repair accommodations (demonstration)
FN-177-L	Transfer gases and water to habitable assets on the lunar surface
FN-178-L	Transport cargo on the lunar surface between landing location and surface assets
FN-179-L	Ready and transition crew to transportation asset for return to orbit
FN-180-L	Provide food system(s) on the lunar surface
FN-181-L	Provide food system(s) in cislunar space
FN-182-L	Provide crew exercise system(s) in cislunar space

ID	Functions
FN-183-L	Provide crew exercise system(s) on the lunar surface
FN-184-L	Process and refine scalable quantities of in-situ resources on the lunar surface (demonstration)
FN-185-L	Collect regolith at scale and subscale (demonstration)
FN-186-L	Provide storage for collected regolith (demonstration)
FN-187-L	Crew ingress/egress from habitable asset(s) to cis lunar vacuum
FN-188-L	Compact scalable quantities of lunar regolith (demonstration)
FN-189-L	Form scalable quantities of structures from lunar regolith (demonstration)
FN-190-L	Manufacture (additive or subtractive) scalable quantities of item(s) from lunar regolith (demonstration)
FN-191-L	Access from habitable volume to cislunar exterior vacuum
FN-192-L	Provide remote propellant management system(s) in microgravity environment (demonstration)
FN-193-L	Provide remote propellant management system(s) in partial gravity environment (demonstration)
FN-194-L	Monitor environmental conditions within habitable volume in space
FN-195-L	Detect and monitor high energy debris in cislunar space
FN-196-L	Survey potential exploration sites on the lunar surface from lunar orbit
FN-197-L	Monitor environmental conditions within habitable volume on the lunar surface
FN-198-L	Detect and monitor high energy debris on the lunar surface
FN-199-L	Capture imagery in cislunar space
FN-200-L	Provide advanced warning of threats from natural environmental hazards on the lunar surface
FN-201-L	Provide advanced warning of threats from induced environmental hazards on the lunar surface
FN-202-L	Provide common data interface on the lunar surface
FN-203-L	Provide common data interface in cislunar space
FN-204-L	Provide common data interface on Earth
FN-205-L	Test product(s) from regolith processing (demonstration)
FN-206-L	Test product(s) from additive/subtractive manufacturing (demonstration)
FN-207-L	Test product(s) from metal production/refinement (demonstration)
FN-208-L	Monitor electrostatic charging in space
FN-209-L	Monitor natural radiation levels in space
FN-210-L	Monitor radiation on the lunar surface
FN-211-L	Monitor electrostatic charging on the lunar surface
FN-212-L	Monitor plasma environment in space
FN-213-L	Monitor meteoroid activities in cislunar space

ID	Functions
FN-214-L	Monitor plasma environment on the lunar surface
FN-215-L	Monitor meteoroid activities on the lunar surface
FN-216-L	Provide advanced warning of threats from natural environmental hazards in cislunar space
FN-217-L	Provide advanced warning of threats from induced environmental hazards in cislunar space
FN-218-L	Provide tools and containers to recover and package surface samples, avoiding cross-contamination of samples, from PSRs
FN-219-L	Provide tools and containers to recover and package sub-surface samples, avoiding cross-contamination of samples, from PSRs
FN-220-L	Stow collected surface samples from PSRs on the lunar surface
FN-221-L	Stow collected sub-surface samples from PSRs on the lunar surface in conditioned state
FN-222-L	Operate utilization payloads related to advanced ECLSS in space (demonstration)
FN-223-L	Operate utilization payloads related to bioregenerative ECLSS in space (demonstration)
FN-224-L	Provide high bandwidth, high availability communication and data exchange between the lunar surface and cislunar space
FN-225-L	Deliver free-flying asset(s) to heliocentric and deep space
FN-226-L	Provide accurate location tracking and position data in cislunar space
FN-227-L	Provide accurate location tracking and position data on the lunar surface
FN-228-L	Provide crew health maintenance capabilities in partial gravity environment
FN-229-L	Provide reference time/frequency generation in cislunar space
FN-230-L	Provide reference time/frequency distribution in cislunar space
FN-231-L	Format and transmit data to Earth from the lunar surface
FN-232-L	Receive and format data on Earth
FN-233-L	Store and distribute data to user(s) on Earth
FN-234-L	Format, transmit, and receive data between assets on the lunar surface
FN-235-L	Store and distribute data between assets on the lunar surface
FN-236-L	Format and transit data to Earth from cislunar space
FN-237-L	Store and distribute data between assets in cislunar space
FN-238-L	Format, transmit, and receive data from cislunar space to the lunar surface
FN-239-L	Format, transmit, and receive data from the lunar surface to cislunar space
FN-240-L	Provide tracking and analysis of orbital/trajectory parameters for assets in cislunar space
FN-241-L	Provide planning, tracking, and analysis of traverse paths for assets on the lunar surface
FN-242-L	Provide reference time/frequency generation on the lunar surface
FN-243-L	Provide reference time/frequency distribution on the lunar surface
FN-244-L	Protect and/or secure data for storage and transmission

ID	Functions
FN-245-L	Perform regular training and drills to simulate off-nominal scenarios
FN-246-L	Produce scalable quantities of metal from lunar regolith (demonstration)
FN-247-L	Access equipment from other assets (demonstration)
FN-248-L	Robotic surveys of potential exploration sites on the lunar surface with assets on surface
FN-249-L	Robotic identification of potential samples and resources on the lunar surface
FN-250-L	Robotic collection of lunar surface samples
FN-251-L	Robotic collection, containment, and documentation of lunar surface samples from PSRs
FN-252-L	Monitor robotic system(s) performance and health
FN-253-L	Control robotic system(s) in cislunar space by in-situ crew
FN-254-L	Provide safety features on robotic and/or autonomous system(s)
FN-255-L	Interface robotic system(s) with logistics carriers on the lunar surface
FN-256-L	Provide physical and electronic safeguards for automated asset(s) operating near crew
FN-257-L	Detect and avoid hazards during landing in darkness, high contrast, and long-shadowed lighting conditions in the presence of lunar dust and debris
FN-258-L	Utilize tools to collect surface samples from PSRs on the lunar surface
FN-259-L	Utilize tools to collect sub-surface samples from non-PSRs and sunlit regions on the lunar surface
FN-260-L	Utilize tools to collect sub-surface samples from PSRs on the lunar surface
FN-261-L	Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from PSRs
FN-262-L	Collect, recover, and package sub-surface samples, avoiding cross-contamination of samples, from non-PSRs and sunlit regions
FN-263-L	Provide containers to package sub-surface samples
FN-264-L	Provide capability for bi-directional power exchange
FN-265-L	Provide power for conditioning to sample containers during transit from the lunar surface to Earth
FN-266-L	Provide power for conditioning to sample containers on the lunar surface
FN-267-L	Provide power for conditioning to sample containers during transit from the lunar surface to cislunar space
FN-268-L	Provide power for conditioning to sample containers during transit from cislunar space to Earth
FN-269-L	Capture imagery on the lunar surface
FN-270-L	Operate assets on the lunar surface in uncrewed mode for extended (year+) durations
FN-271-L	Provide pressurized, habitable environment on the lunar surface for moderate duration (month+) use
FN-272-L	Transport crew and associated cargo from Earth to cislunar space to support mid-duration (month+) to extended (year+) durations
FN-273-L	Provide crew health maintenance capabilities in microgravity environment for extended (year+) durations
FN-274-L	Stow collected surface samples on the lunar surface from PSRs in conditioned state

ID	Functions
FN-275-L	Monitor crew health on the lunar surface
FN-276-L	Deploy (setup, activate, and operate) science and/or monitoring utilization payload(s) in cislunar space
FN-277-L	Transport collected surface samples on the lunar surface
FN-278-L	Transport collected sub-surface samples on the lunar surface in conditioned state

APPENDIX B: ACRONYMS, ABBREVIATIONS, AND GLOSSARY OF TERMS

B.1 ACRONYMS AND ABBREVIATIONS

ACR	Architecture Concept Review
ADD	Architecture Definition Document
AFS	Augmented Forward Signal
AS	Applied Sciences
ASA	Australian Space Agency
ASI	Italian Space Agency (Agenzia Spaziale Italiana)
AU	Astronomical Unit
BEO	Beyond Earth Orbit
CAPSTONE	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment
CLDP	Commercial Low Earth Orbit Development Program
CLPS	Commercial Lunar Payload Services
CM	Crew Module
CNES	Centre National D'Etudes Spatiales
CPNT	Communication, Positioning, Navigation, and Timing
CMP	Co-Manifested Payload
CSA	Canadian Space Agency
DLR	German Aerospace Center
DSN	Deep Space Network
DST	Deep Space Transport
DTE	Direct-to-Earth
ECLS	Environmental Control and Life Support
EDL	Entry, Descent, and Landing
EDLA	Entry, Descent, Landing, and Ascent
EGS	Exploration Ground Systems
EP	Electric Propulsion
ERM	ESPRIT Refueling Module
ESA	European Space Agency
ESM	European Service Module
ESPRIT	European System Providing Refueling, Infrastructure and Telecommunications
EUS	Exploration Upper Stage
EVA	Extravehicular Activity
FE	Foundational Exploration
FSP	Fission Surface Power
GERS	Gateway External Robotic System

GLE	Gateway Logistics Element
GNSS	Global Navigation Satellite System
HALO	Habitation and Logistics Outpost
HBS	Human and Biological Science
HDL	Human-class Delivery Lander
HIAD	Hypersonic Inflatable Aerodynamic Decelerator
HLCS	HALO Lunar Communications Systems
HLR	Human Lunar Return
HLS	Human Landing System
HS	Heliophysics Science
iCPS	Interim Cryogenic Propulsion Stage
ICSIS	International Communication System Interoperability Standards
I-Hab	International Habitation Module
IMEWG	International Mars Exploration Working Group
IOAG	Interagency Operations Advisory Group
IoT	Internet of Things
ISA	Israel Space Agency
ISECG	International Space Exploration Coordination Group
ISLSWG	International Space Life Sciences Working Group
ISRO	Indian Space Research Organization
ISRU	In-Situ Resource Utilization
ISS	International Space Station
IVA	Intra-Vehicular Activities
JAXA	Japan Aerospace Exploration Agency
KASI	Korea Astronomy and Space Science Institute
KPLO	Korea Pathfinder Lunar Orbiter
LAS	Launch Abort System
LCRNS	Lunar Communication Relay and Navigation System
LEAG	Lunar Exploration Analysis Group
LEGS	Lunar Exploration Ground System
LEO	Low Earth Orbit
LI	Lunar Infrastructure
LIFT	Lunar Infrastructure Foundational Technology
LNIS	LunaNet Interoperability Specification
LOC	Loss of Crew
LOFTID	Low-Earth Orbit Flight Test of an Inflatable Decelerator
LOM	Loss of Mission
LPS	Lunar/Planetary Science
LTV	Lunar Terrain Vehicle
MAV	Mars Ascent Vehicle

MCC	Mission Control Center
MDS	Mars Descent System
MEPAG	Mars Exploration Program Analysis Group
ML	Mobile Launcher
ML2	Mobile Launcher 2
MSolo	Mass Spectrometer observing lunar operations
NASA	National Aeronautics and Space Administration
NEP	Nuclear Electric Propulsion
NextSTEP	Next Space Technologies for Exploration Partnerships
NPR	NASA Procedural Requirements
NRHO	Near Rectilinear Halo Orbit
NTP	Nuclear Thermal Propulsion
OP	Operations
PPE	Power Propulsion Element
PPS	Physics and Physical Sciences
PR	Pressurized Rover
PRIME-1	Polar Resources Ice Mining Experiment-1
PRISM	Payload and Research Investigations from the Surface of the Moon
PSR	Permanently Shadowed Regions
RT	Recurring Tenet
RPODU	Rendezvous, Proximity Operations, Docking, and Undocking
SAC	Strategic Analysis Cycles
SE	Science-Enabling
SEP	Solar Electric Propulsion
SLE	Sustained Lunar Evolution
SLS	Space Launch System
SM	Service Module
SMD	Science Mission Directorate
SRTs	Safety Reporting Thresholds
SSERVI	Solar System Exploration Research Virtual Institute
TH	Transportation and Habitation
TRIDENT	The Regolith and Ice Drill for Exploring New Terrain
UHF	Ultra-High Frequency
VAB	Vehicle Assembly Building
VIPER	Volatiles Investigating Polar Exploration Rover
xEVA	Exploration Extra-Vehicular Activity
xEVAS	Exploration Extra-Vehicular Activity Services

B.2 GLOSSARY OF TERMS

Term	Description
Architecture	The high-level unifying structure that defines a system. It provides a set of rules, guidelines, and constraints that defines a cohesive and coherent structure consisting of constituent parts, relationships and connections that establish how those parts fit and work together. (Definition from NASA's System Engineering Handbook)
Architecture Characteristic Decision	Decisions that define an architecture feature or characteristic, where the selection of an alternative option would be considered a different architecture.
Architecture Constraint Decision	Decisions that apply across all possible architecture variants, but do not directly define an architecture characteristic. Options for these types of decisions do not narrow or expand the feasible architecture trade space,
Artemis Mission	The crewed portion of an Artemis Mission Campaign, beginning at crew liftoff from Earth and ending at crew return to Earth.
Artemis Mission Campaign	A collective grouping of uncrewed missions and their associated crewed mission.
Asset	All items that are in place and being used as part of the exploration architecture.
Automation	Automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labor (e.g., computer control of a docking operation or vehicle surface traverse). Human intervention can be available, as determined by hazard controls (e.g., breakout or transition to safe mode), but not required to complete an automated operation.
Autonomy	The ability of a system to achieve goals while operating independently of external communications. Autonomy does not preclude external reprioritization or generation of new goals. It only requires execution of existing goals without external control.
Baseline	An agreed-to set of requirements, designs, or documents that will have changes controlled through a formal approval and monitoring process.
Campaign	A series of interrelated missions that together achieve Agency goals and objectives. (Definition from Moon to Mars Strategy and Objectives)
Cargo	Items less than 6t that are transported from one location to another.
Carrier	A transport structure or container used to secure and protect logistics items that require transport to the point of use.
Characteristics	Features or activities of exploration mission implementation that are necessary to satisfy the goals and objectives.
Cislunar	The region of space from the Earth to the Moon. Specifically for the Moon to Mars Architecture, elements under the influence of lunar gravity.
Co-Manifested Payload	Cargo on a transportation element utilizing excess volume and mass (e.g., cargo located inside the payload attach fitting adapter ring).

Term	Description
Concept of Operations	Developed early in Pre-Phase A, describes the overall high-level concept of how the system will be used to meet stakeholder expectations, usually in a time-sequenced manner. It describes the system from an operational perspective and helps facilitate an understanding of the system goals. It stimulates the development of the requirements and architecture related to the user elements of the system. It serves as the basis for subsequent definition documents and provides the foundation for the long-range operational planning activities (for nominal and contingency operations). It provides the criteria for the validation of the system. In cases where an operations concept is developed, the concept of operations feeds into the operations concept and they evolve together. The concept of operations becomes part of the concept documentation.
Consumables	Supplies (not including propellant) that are needed to support mission activities.
Continuous Presence	Steady cadence of human/robotic missions in subject orbit/surface with the desired endpoint of 24/7/365 operations. (Definition from Moon to Mars Strategy and Objectives)
Control Mass	Used to define the capability and baseline architecture of the system. It represents the controlled, not-to-exceed allocation of mass to an element.
Decision Authority	The highest-ranking official or body (such as a control board or executive council) that will sign a formal decision outcome, thus indicating responsibility for—and commitment to implementing—that decision outcome.
Decision Definition	The set of inputs required to reach a decision outcome, which includes a question, options, context, dependencies, and a recommendation that will be deliberated on by a decision authority.
Decision Outcome	A formal judgement of the options as a result of deliberation, culminating in agreement on which option(s) to implement.
Deep Space Environments	Deep space is the vast region of space that extends to interplanetary space, to Mars and beyond. It is the region of space beyond Earth's Moon, including Lagrange 2, or L2, (274,000 miles from Earth). This environment has many defining factors, including harsh radiation (both solar particle events and galactic cosmic rays), space weather, and microgravity.
Deep Space Transport (DST)	DST is used to describe the assembled Mars transit vehicle stack, which will consist of a propulsion and power transportation system backbone and attached cargo. There are two DST variants: in the crew variant, the cargo will consist of a transit habitat that may or may not be a separate free-flyer that docks with transport; in the cargo variant, the cargo will consist of orbital assets to be delivered to Mars orbit, or surface assets mounted to Mars descent systems that will be delivered to the Mars surface.
Demonstrate	Deploy an initial capability to enable system maturation and future industry growth in alignment with architecture objectives. (Definition from Moon to Mars Strategy and Objectives)
Deploy	To move into place or bring into effective action.
Develop	Design, build, and deploy a system, ready to be operated by the user, to fully meet architectural objectives. (Definition from Moon to Mars Strategy and Objectives)
Earth Vicinity	The region of space around the Earth-Moon system, including cislunar space, low Earth orbit, and orbits around the Earth-Moon barycenter.

Term	Description
Effectivity	The conditions or mission for which a requirement is initially applicable.
Element	Any exploration system that enables a high-level functional allocation (e.g., crew transport, habitation, logistics delivery) that are primarily self-sufficient.
Equipment	Other non-utilization assets less than 6t in mass.
Explore	Excursion-based expeditions focused on science and technology tasks. (Definition from Moon to Mars Strategy and Objectives)
Exploration Strategy	Establish the scenarios, conceptual missions, and systems needed to extend humanity's reach beyond low Earth orbit, return to the Moon, and proceed on toward Mars and beyond.
Function	Actions that an architecture would perform that are necessary to complete the desired use case.
Global	Infrastructure and capabilities that support human and robotic operations and utilization across the subject planetary surface. (Definition from Moon to Mars Strategy and Objectives)
Gravity	"Gravity" refers to acceleration on Earth (~9.81 ms−2), and is expressed in the international system of units (SI) as g. A gravity level lower than 1 g is called "partial gravity" or "reduced gravity".
Habitable Environment	The environment that is necessary to sustain the life of the crew and to allow the crew to perform their functions in an efficient manner.
Human Landing System - Initial Configuration	Any crewed mission to the lunar surface executed with the initial HLS configurations as defined in the HLS Broad Agency Announcement Option A. (Effectivity for requirements unique to this configuration are noted as "HLS Initial Configuration.")
Human-Rating	A human-rated system accommodates human needs, effectively utilizes human capabilities, controls hazard with sufficient certainty to be considered safe for human operations, and provides, to the maximum extent practical, the capability to safely recover the crew from hazardous situations. Human-rating consists of three fundamental tenets: 1) Human-rating is the process of designing, evaluating, and assuring that the total system can safely conduct the required human missions. 2) Human-rating includes the incorporation of design features and capabilities that accommodate human interaction with the system to enhance overall safety and mission success. 3) Human-rating includes the incorporation of design features and capabilities to enable safe recovery of the crew from hazardous situations.
Hybrid Propulsion System	A vehicle consisting of two or more unique propulsion systems, each optimized for different types of maneuvers. For the purpose of this document, two hybrid systems are considered: SEP/chem, which combines a solar electric propulsion system with a chemical stage, and NEP/chem, which combines a nuclear electric propulsion system with a chemical stage.
Increment	The period of time between the end of one crew mission (i.e., crew splashdown) and the end of a second crew mission, including the uncrewed activities and operations that commence during this defined timeframe.

Term	Description
Incremental	Building compounding operational capabilities within the constraints of schedule, cost, risk, and access. (Definition from Moon to Mars Strategy and Objectives)
Interoperability	The ability of two or more systems to physically interact; exchange data, information, or consumables; or share common equipment while successfully performing intended functions.
Key Architecture Decision	A decision that influences the end-to-end architecture and warrants elevated scrutiny.
Large Exploration Asset	An asset that is heavier than 6t in mass.
Limited Capability Mission	A mission to a polar landing site where the utilization capability of the mission is limited to the threshold capabilities of HLS and Orion, with no additional delivery or return mass available from goal capabilities or other elements. Additionally, certain missions may prioritize crew time and transportation mass to the delivery and outfitting of new elements in NRHO (e.g., Gateway elements) or the lunar surface (e.g., PR and SH). For the purposes of analysis, a two-crew, 6.5-day sortie was assumed as a representative case. In such a mission, it is expected that a significant amount of crew time will be needed to ingress, setup, outfit, and checkout new elements being delivered to or operated for the first time in NRHO or on the lunar surface, leaving less time available for utilization activities. In addition to crew time, it is expected that the delivery and outfitting of these new elements will require a greater fraction of the overall logistics mass delivery capability, further reducing the utilization potential of the mission. Thus, this mission category represents a case in which only a threshold of utilization activities is expected to be performed.
Live	The ability to conduct activities beyond tasks on a schedule. Engage in hobbies, maintain contact with friends and family, and maintain healthy work-life balance. (Definition from Moon to Mars Strategy and Objectives)
Logistics	Capabilities associated with packaging, handling, storage, transportation, and tracking of logistics items and goods not initially delivered as part of an exploration element, including equipment, tools, consumables, maintenance items, spares, and subsystem components needed to support mission activities such as operations, outfitting, science, research, and utilization. Logistics also includes capabilities associated with reuse, recycling, and disposal of trash and waste.
Logistic Items	Supplies (not including propellant) that are needed to support mission activities.
Loss of Crew	Death of or permanently debilitating injury to one or more crew members.
Loss of Mission	Loss of or inability to complete significant/primary mission objectives, which includes Loss of Crew. Each mission is defined with different assumptions and mission objectives. Therefore, specific mission LOM assessments are accomplished evaluating the attainment of specific mission objectives, using methods tailored to the specific mission risk drivers and each specific program but consistent with defined NASA Probabilistic Risk Assessment standards.

Term	Description
Maintenance	The function of keeping items or equipment in, or restoring them to, a specified operational condition. It includes servicing, test, inspection, adjustment/alignment, removal, replacement, access, assembly/disassembly, lubrication, operation, decontamination, installation, fault location, calibration, condition determination, repair, modification, overhaul, rebuilding, and reclamation. Preventative maintenance is performed before a failure occurs, whereas corrective maintenance occurs in response to a failure.
Mechanical Assistance	Device intended to allow the crew to transport more mass than they can hand carry while walking.
Mission	A major activity required to accomplish an Agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an Agency goal. Mission needs are independent of any particular system or technological solution. (Definition from Moon to Mars Strategy and Objectives)
Mobility	Powered surface travel that extends the exploration range beyond what is possible for astronauts to cover on foot. Spans robotic and crewed systems and can be accomplished on and above the surface. (Definition from Moon to Mars Strategy and Objectives)
Needs	A statement that drives architecture capability, is necessary to satisfy the Moon to Mars objectives, and identifies a problem to be solved, but is not the solution.
Planetary Protection	Approaches used to avoid harmful contamination of solar system bodies during exploration activities, as well as avoiding possible harmful extraterrestrial contamination from material that may be returned from other solar system bodies, in compliance with Outer Space Treaty constraints.
Powered Mobility Asset	Asset that allows the crew to travel further distances than they can walk (e.g., Lunar Terrain Vehicle or Pressurized Rover).
Reconfiguration	If a system is required to provide a function, any time required by the crew associated with making that function available for use, including changing spaces and moving logistics to allow for use of the space for a different purpose (e.g., exercise, eating, sleeping, medical, training, working).
Reference Mission	A defined set of elements with assumed functional allocations working together in a focused mission context that serves as a common point of comparison for strategic analysis and early program formulation activities (prior to Authority to Proceed) and will be updated when necessary to remain in alignment with the overall exploration goals and objectives.
Routine	Recurring subject operations performed as part of a regular procedure rather than for a unique reason. (Definition from Moon to Mars Strategy and Objectives)
Routine Preventative Maintenance	Planned maintenance done on a regular (daily, weekly, monthly) basis that is part of the design, such as filter changes, lubrication, cleaning, etc.
Secondary Payloads	Additional cargo carried on a transportation element, currently on an adapter ring, after the primary and CPLs are accommodated, limited by the remaining transportation element resources (e.g., mass, volume, power).

Term	Description
Scalability	Initial systems designed such that minimal recurring DDT&E is needed to increase the scale of a design to meet end state requirements. (Definition from Moon to Mars Strategy and Objectives)
Segments	A portion of the architecture, identified by one or more notional missions or integrated use cases, illustrating the interaction, relationships, and connections of the sub-architectures through progressively increasing operational complexity and objective satisfaction.
Small Asset	Other, non-utilization assets less than 6t in mass.
Sol	Martian day, approximately 24 hours and 39 minutes long. For the purpose of this document, operational timekeeping on the surface of Mars uses Martian sols to align with the Martian day/night cycle.
Sortie Missions	A single crewed mission to a lunar surface location for a period of days supported solely by the lunar crewed lander. The main characteristics of the sortie mission are that crew habitation is provided by the crewed lander and the crew can perform all lunar surface activities using self-contained resources—although pre-deployment of resources is not necessarily precluded during a sortie mission.
Stakeholder	An organization with an interest in a particular architecture decision because it can either affect or be affected by the decision. Different architecture decisions may have different stakeholders who are responsible for contributing supporting data and analyses to an architecture decision package. In some cases, stakeholders are decision authorities for prerequisite decisions that feed into a particular architecture decision.
Sub-Architecture	A group of tightly coupled elements, functions, and capabilities that perform together to accomplish architecture objectives.
System	The combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose. (Refer to NPR 7120.5.)
Trade Space	An exploratory part of the systems engineering process that identifies and analyzes potential solutions for an architectural concept, function, or component. The trade space includes assessments of state-of-the-art and anticipated future capabilities applied as part of a range of solutions, and assessments of impacts that each solution could have across a system's development lifecycle or the architecture as a whole.
Transit	The carrying of people, goods, or materials from one place to another in space.
Traverse	To travel across or over the surface.
To Be Determined (TBD)	Used when the value to be placed in a requirement is not known and there is open work to determine what it should be.
To Be Resolved (TBR)	Used when a value for a requirement is presented but it is to be resolved or refined as to whether it is the right number.
Use Case	Operations that would be executed to produce the desired needs and/or characteristics.
Utilization	Use of the platform, campaign, and/or mission to conduct science, research, test and evaluation, public outreach, education, and industrialization. (Definition from Moon to Mars Strategy and Objectives)

Term	Description
Utilization Mass	The mass of utilization payloads.
Utilization Payload	Any item transported and/or supported by the Moon to Mars Architecture that is primarily in support of and attributed to utilization objectives. Utilization payload includes scientific experiments, software, technology demonstrators, instruments, instrument suites, tools, supplies, containers, and samples transported by or integrated into another element, system within an element, or used during execution of activities during any phase of an Artemis mission. This definition also includes internal and external utilization equipment that supports utilization payloads.
Validate	Confirming that a system satisfies its intended use in the intended environment (i.e., did we build the right system?). (Definition from Moon to Mars Strategy and Objectives)
Verification (of a product)	Proof of compliance with a requirement. Verification may be determined by testing, analysis, demonstration or inspection.
Work Time	Non-personal time. Time during which the crew is in a duty status (e.g., typically 8–8.5 hours, but could be 11.5 hours for an EVA day or other mission-specific extension).