Space Commodities in Service of National Security*

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Abstract

This paper describes the role that standardized space commodities and space commodities markets will play in national security. As commercialization of low earth orbit, lunar, asteroid and outer space geographies expand, the space economy's needs for protection and its capacity to be protected expand. The history of military success and failure has depended on assured logistical arrangements that are robustly available and adapt to situational priorities. Assuming that a formalized space commodities exchange exists, how might the national space interests and force protection needs become easier to identify and service through terrestrial and in-space supply chains and arrangements? This paper will also consider how growth of the space economy and protecting it might depend upon the arrangements for space commodities, how those commodities are owned and financed, and where the national security would be without adequate space commodities access.

I. Introduction

"*National security*" is an evolving multidimensional construct, encompassing agricultural, cultural, cyber, economic, energy, governance, human rights, natural resources, political, regional boundaries, social, strategic industrial, technological and other interests. (1) (2) (3) (4) The international legal and commercial framework for national security services that leverage outer space is likewise evolving. (5)

National security as empowered by outer space hinges, in part, on the procurement of commodities that form supply chains for manufacturing, operating, transporting and housing military and civilian operations. (6) Commodities are more than physical goods like minerals or products and services built from them. Commodities exchanges transfer, transform and hedge financial and virtual commodities, including interest rates, currency rates, political risks, credit defaults, CO2 pollution credits and other items. All companies participating in the space economy use or rely on their suppliers, lenders and customers to use the commodities exchanges for such purposes. By analogy to credit default swaps (**CDS**) for terrestrial businesses, the technology and operational risks of space business models could be turned into a space commodity, allowing space investors to assume a portion of the risks now borne by space companies' shareholders, lenders and insurers. Commodification of space services and more efficient transfer and transformation of military contractors' risks in this way might serve to (1) reduce the final cost paid by the U.S. Government, (2) improve the industry-based capacity to rapidly scale up production and reuse of assets generating commodity services, and (3) add private sector innovation and partnership to national security.

Terrestrially, the United States Department of Defense (**DoD**) and the 16 members of the U.S. intelligence community (**IC**) rely – some contend overly rely – on government's capacity to define its target deliverables and outsource and manage its contractors and their raw materials and processed commodities, products and services supply chains

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across large national boundaries, shipping routes, political transitions, currency revaluations, skilled federal and civilian labor shortages and furloughs, credit rating downgrades, insurance shortages and the cyclicality of affection from stock and bond markets. (7) (8) (9) (10) (11)

Minerals and other commodities transformed into new commodities are a key enabler or barrier to the national security interests of the United States. For terrestrial and space purposes, nation state direct and indirect ownership of, and regulation of the markets for, mineral supplies is a critical commercial, economic, financial and national security concern. (12) (13) (14) (15) At least as early as 1979 – 40 years ago - the Peoples Republic of China (**PRC**) began forecasting the new materials, where they would be sourced and how they would be fabricated to launch and sustain spacecraft. (16) Chinese control of major mineral and other commodities reserves, production and trading helps strengthen the yuan currency. (17) New players, products, technologies and forecasted uses for minerals are rearranging global markets for minerals and other commodities. (18) (19)

Assured access to global minerals and other commodities is essential for safety, competitiveness, success and innovation at traditional aerospace companies, and emerging U.S. launch services companies, such as Orbital ATK (now absorbed in Northrop Grumman), Blue Origin, SpaceX and United Launch Alliance (**ULA**) (a partnership of Boeing and Lockheed). Given commercial and government demand for launch services, aerospace companies must buy commodities futures contracts or enter into similar arrangement to keep their bids and services competitive.

II. Where Space Guardianship fits in National Security

According to the U.S. National Security Space Strategy:

> "Space is vital to U.S. national security and our ability to understand emerging threats, project power globally, conduct operations, support diplomatic efforts, and enable global economic viability. As more nations and non-state actors recognize these benefits and seek their own space or counterspace capabilities, we are faced with new opportunities and new challenges in the space domain. The current and future strategic environment is driven by three trends – space is becoming increasingly *congested, contested* and *competitive*." (20)

Recent strategic threat assessments require assured space capabilities as a cornerstone of U.S. national security:

> "Space capabilities enable the American way of warfare by making it possible for U.S. military commanders and forces to see the battlespace more clearly, communicate with certainty, navigate with accuracy, and strike with precision. Acknowledging this importance and consistent with prior administrations of both political parties, the current National Security Strategy recognizes that unimpeded access to and use of space is a vital national interest.
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> "Our adversaries and potential adversaries have noted these significant advantages and have moved aggressively to field forces that can challenge our space capabilities from the ground, in space, and through cyberspace. From simple (and widely available and affordable) jammers to highly sophisticated antisatellite (ASAT) weapons, today the U.S. is facing serious threats in a domain that is increasingly an arena for conflict. Denying U.S. space capabilities is a central tenet of adversary strategies designed to diminish our prestige and raise the risks and costs of intervention in regional affairs." (21)

Responsibility for planning and carrying out DoD space operations is authorized, delineated and coordinated through the *Space Operations* Doctrine of the Joint Chiefs of Staff (the **Joint Chiefs' Doctrine**). (22)

Under the Cold War era United Nations Outer Space Treaties, space may not be used for nuclear, biological chemical or other weapons of mass destruction. With the use of space for civilian commerce, communications, finance and insurance, and for government peacekeeping and military situational planning and coordination, access to and safety in space today poses a widening and sliding scale of national security interests. (23)

III. A Short History of the Critical Role of Commodities and Logistics in Terrestrial Peacekeeping and Warfare

Throughout military history, innovations in supply chain logistics have been a determining factor in which physical, financial, cyber and space territory can be acquired and retained for strategic and tactical advantage. Logistics remain a key vulnerability and advantage in warfighting and peacekeeping. (24)

In 1775, British dependence on resupply by sea sealed the success of the Continental Army in the Thirteen Colonies' War for Independence. (25) During the U.S. Civil War, General Ulysses S. Grant established a vast supply depot in City Point Virginia (now part of the city of Hopewell) at the confluence of the James and Appomattox Rivers from which to coordinate men and supplies arriving and departing by ship, train and horse drawn carriage from throughout the Union in order to overwhelm the logistics and supplies of the Confederate Army (26) (27) (28) (29) In 1812, Napoléon was repelled by Russians freshly resupplied in Moscow. (30)

Scientists and engineers involved in mobilizing industrial production for World War I soon thereafter pressed President Woodrow Wilson to consider the national security implications of holding sufficient quantities of minerals during peacetime to respond to future conflicts, and advocated the National Minerals Plan and the National Stockpile for Strategic and Critical Minerals. Their foresight went unheeded until 1938, spurred by the collapse and recovery of industrial production and supply linkages following the Great Depression and in preparation for World War II, when the Navy was authorized to create a small stockpile of chromite, ferromanganese, manila fibers, optical glass, tin and tungsten. (31) (32)

In 1940, President through expedient intergovernmental protocols with Prime Minister Winston Churchill, Franklin Delano Roosevelt via U.S. Steel Corporation, provided England with artillery and ammunition to rearm British soldiers fighting Nazi Aggression across Europe. (33 p. 33) In January 1942, Adolph Hitler's defeat in the Battle for Moscow resulted in large part from Soviet knowledge and control of local water, roadways, food and recruits, as a means to ensnare Nazi troops in fighting the harsh Soviet winter and its ice and snow, on unpaved muddy roads with Panzer tanks not designed for such conditions. (34) (35) In 1943, through hastily crafted intergovernmental protocols with USSR Premier Joseph Stalin, President Roosevelt, provided tons of steel, planes, tanks and other war materiel that the Soviet troops used to push the Nazis across Germany's Eastern Front. (33 p. 102) Israel's 2006 Second War with Lebanon failed to rout Hizbollah due to pre-positioned supplies in Southern Lebanon, and tactical, organizational and logistical shortcomings that the Israeli Defense Forces have since investigated and corrected. (36) (37) (38)

United Nations peacekeeping missions and hundreds of nongovernmental organization (**NGO**) projects require logistical support and assurance to safeguard personnel, build local housing, healthcare and infrastructure and respond to migration, pandemic, systemic or disaster conditions. (39) (40)

> "In March 2017 the UN deployed 82,712 troops, 1,821 military observers, 11,944 police officers, 5,062 international civilian staff, and 1,577 volunteers to sixteen peacekeeping operations covering 7 million square kilometers of terrain. These 103,119 individuals from over 120 countries required transport to, from, and within the mission areas; accommodation and work space; food, water, and electricity; and medical, office, and myriad other supplies. Their equipment required transportation, storage, and maintenance, as well as gasoline, oil, and other lubricants. In short, contemporary UN peacekeeping operations generate a staggering demand for logistics support.
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> "Adequate logistics support is crucial both to the safety, health, and comfort of deployed peacekeepers and to the effectiveness and success of contemporary peace operations. Peace operations increasingly deploy to high-risk environments; in December 2015, 43 percent of the area of operations covered by UN peacekeeping missions was assessed as presenting a "substantial, high or extreme danger," compared with 25 percent in December 2011, and two-thirds of UN Peacekeepers were deployed in conflict environments. Under these circumstances, adequate logistics support to peacekeepers is both extremely challenging and vitally important to mitigating the risks of deployment." (41)

For the U.S. DoD, logistics is a massively complex enterprise, exceeding $210BN annually, using assets worth more than $595BN, across 100,000 suppliers servicing more than 49,000 customer sites worldwide. (42)

Hundreds more examples from antiquity through today's regional conflicts demonstrate the role of logistics for acquiring, using and distributing commodities as simple as clean water, as rare as titanium, and as complex as aircraft, spacecraft, terrestrial vehicles and ships.

IV. Cold War Lessons of Space-Based Surveillance Successes, Failures and Vulnerabilities

Beginning with Cold War activities of the U.S. National Reconnaissance Office (**NRO**), the advantages of surveillance via space-based photography and satellite platforms emerged as essential for intelligence acquisition and logistical planning. (43) (44) (45) The interception of U.S. Air Force pilot Gary Powers' U2 spy plane on May 1, 1960 using Soviet C-75 (SA-2) surface to air missile highlighted the limitations and vulnerability of using airpower alone to maintain battlespace situational awareness for strategic purposes.

Since the 1960s, the power and other requirements for operating orbital assets have confounded national security personnel. For example, the early history of the NRO's AFTRACK Program, reports of testing low-power orbiting surveillance: "In Vehicle 1107 flown 16 June 1961 the TAKI was operational through 38 orbits. Failure after the 38^{th}

orbit was due to loss of power…" (46) (47)

During this same period, concerns about the capacity of aggressors (then the Soviet Union) to physically interfere with, capture or sabotage space satellites on reconnaissance missions were first aired, and countermeasures sought to be put in place. (48) Relying on photographic films, modified military cameras, capsules carried aloft on expensive rockets and parachutes, the Corona and later surveillance missions proved the value of space surveillance, and its optical limitations, such as cloud cover, forest cover and other visual obstructions and image distortions. (49)

In the intervening 50 years, with massive miniaturization of satellites, optical, sensor and computational capacities and the development of the CubeSat miniaturization of satellite size and weight, space imagining and the bandwidth to communicate in LEO and terrestrially via ground station or networked satellites have removed much of the launch, electronics, energy and physics barriers. (50) (51) (52) (53)

With the rapid emergence and scaling of the commercial space industry and its ability to attract new forms of capital, such as from venture investors and strategic corporate investors, commercial sources of traditionally military space-based surveillance, navigation and other capabilities will multiply, and with them the benefit and burden of their availability for promoting national security, and threatening or compromising it. (54)

V. Military Procurement 101 – How Space Guardians Design, Buy and Supply for Future Needs

U.S. National Security Strategy requires access to supply chains, skilled workers, manufacturing capacity and high-technology innovations that would provide and assure space guardianship. (55) Whether organized as a "Space Force," "Space Guard," a capability inside the U.S. Air Force or co-equal branch alongside current Department of Defense military services, the nation's capacity for space guardianship will require mastering – and in many cases, anticipating and overcoming – the procurement bottlenecks of operations in air, on land and at sea terrestrially. (56) (57) (58)

Supplies of minerals and other commodities sufficient to meet the needs of National Security Strategy rely on consistent global sources to find, mine, refine, warehouse and sell them when needed of a quality, quantity and price that DoD and DoD contractors can readily obtain. (See discussion in Sections IX and X).

Historically, procurement of space launch or other commodities can take years, using iterative, bespoke specifications, technical feasibility requests for proposals, technical readiness milestones, progress payments and eventually, a commitment of government procurement. (59)

DoD outsourcing is "Big Business." In 2003, when DoD total procurement spending was $209BN, non-warfighting expenditures amounted to $118BN, as summarized in Fig. 1. (60)

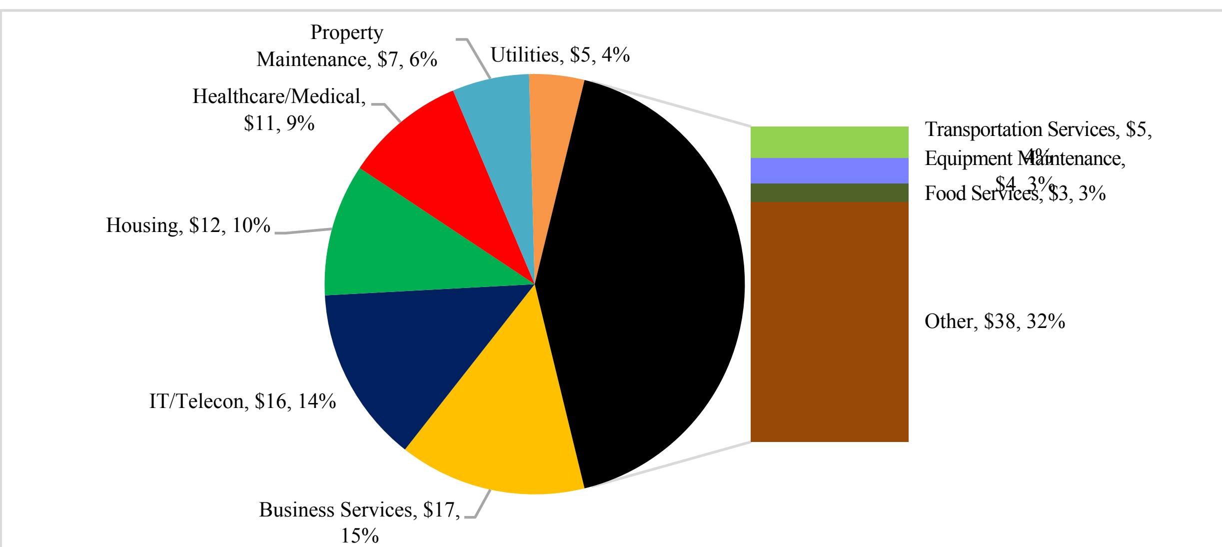

Fig. 1 Selected 2003 DoD Commercial Non-Combat Procurement Activities ($118BN)

Outsourcing complex systems, services, and innovation, can result in programmatic and technical failure in part because of misaligned stakeholder incentives. Over-the-counter contracts that intend to place total system performance responsibility on outsourced stakeholders creates attenuated chains of responsibility and accountability. The further outsourced or subcontracted work causes cascades of trusted relationships. Inevitably, the initial inspiration for the innovation or new services model degrades as split incentives and organizational affiliations splinter mindshare. Numerous government technology modernization projects that were partially or wholly unsuccessful demonstrate this procurement challenge for government. (61) (62)

Healthy policy and pragmatism guide when and where to set the fulcrum to balance between "inherently governmental" functions that should be performed by government employees, versus antecedents or enablers thereof that for cost-savings, technical sophistication or national competitiveness can readily be outsourced in order to spur private sector investment, risk-taking and market development. (63) (64) (65)

> "The result of DoD organization autonomy and independence in the outsourcing of support services was reflective of service autonomy and independence at the highest level of leadership in each military service. Each military service procured systems and services to support its own primary service-centric missions, while deemphasizing the integrated joint mission. Inter-service competition for resources reduced civilian control in budget matters, limiting the ability to establish joint capabilities and reduce similar weapon systems unique to each service. Procurement activity centered around the objectives of each military service and its organizations, as compared to focusing procurement activity around the national interest and joint combatant war fighting missions. For example, there are still four tactical air forces and each service has their own versions of the Unmanned Aerial Vehicle (UAV). It reinforces the unique identity and survival interests of each service. As Samuel Huntington pointed out nearly 50 years ago, 'the castles of the services will remain in existence, battered but untaken, long after the decisive battles, both political and military, have shifted to other fields.' " (66)

Striking the right balance between outsourcing and insourcing space commodities needs, and innovating novel procurement strategies that are transparent and accountable, will be key to assuring national security interests terrestrially and in space. That balance cannot functionally and reliably serve long-term capacity building on Earth or in space if policymakers reposition the balance beam and its justifying logic every election cycle. (67) For example, if OMB Circular A-76 cost-savings studies are to be required and traditionally take years to complete due to inadequate program and procurement data or the efforts required to manually find and analyze such data, then outsourcing strategies that add data and performance transparency and interoperability contribute to setting the balance appropriately for insourcing and outsourcing. (68) Rethinking logistics for the military services drives rethinking and reimagining how the national security role of each branch can be best organized to serve and leverage a very different declared and undeclared battlefield on land, in the air, on the seas, in cyberspace and in outer space. (69)

With the success of commercially available launch, telecommunications, imagery and other services, NASA, DoD and the IC rely increasingly on commercial-off-the-shelf types of procurement mechanisms. (70) As the DoD focuses on *readiness*, governmental and contractor *defense personnel quality of life* and *modernization* of the DoD armed forces and their methods of operation, outsourcing is a key strategic tool. (71) (72) The Air Force and its finely-tuned space guardianship mission require even more forward-thinking leadership in using, and anticipating the vulnerabilities, outsourcing's complexity, robustness and economic potential. (73)

Beyond Earth's LEO, national security will require innovations in procurement that mitigate inherent challenges of getting commodities and supplies to the right place terrestrially and in space at the right time in adequate quantity and quality. (74 pp. 397-435) For example, debris removal and space traffic management of high-velocity objects in LEO will de-risk civilian and military uses of space, but the DoD budget would likely be insufficient to continually assure space debris removal on behalf of others' space objects and operations. How the DoD and its civilian agency counterparts participate in growing vibrant markets for a broad range of commodities like space debris removal will determine the risks and costs to ongoing use of space for national security, commercial and other purposes.

VI. Materials that Build Spacecraft

Spacecraft, whether rockets, satellites, solar panels, fuel or otherwise, are fabricated from, and consume, a vast array of chemical elements, and their physical properties. Weight, conductivity, malleability and other properties play roles in choosing which elements to send into the space environment including vacuum, debris, radiation, micrometeorites, thermal environment, microgravity in-orbit, shock and vibe environment during launch, and many other considerations like how they behave there, and upon reentry through earth's atmosphere. NASA began publishing its outgassing test results for spacecraft materials in 1984. (75) (76) NASA's current inventory of materials for spacecraft tested for outgassing resilience numbers 11,684 (77)

As a starting point for the types of raw materials that would be required to fabricate and repair spacecraft, Table 1 lists materials and how they are used currently. (78) (79)

Table 1 Major Spacecraft Materials

Material (# alloys & variants)	**Sample Uses for Spacecraft**
Adhesive tapes and films (8)	Used extensively in developmental and acceptance testing during manufacturing and fabrication when mechanical access to space systems are required. Tapes and Films are used on flight assemblies to secure thermal blankets and maintain electrical isolation between conductive elements of the spacecraft.
Adhesives, Coatings, Varnishes (17)	High load-bearing adhesives are used in primary and secondary structures when securing materials of different types to each other. This is common in telescopes and in connecting payload assemblies onto spacecraft busses. Non-structural adhesives are useful when seeking unique specific characteristics such as high thermal conductivity and low electrical conductivity when electrical isolation is desired but thermal and mechanical control is required. Solar panel assemblies utilize adhesives that need to tolerate high temperature extremes.
Aluminum (70)	Structures, Thermal management, non-recurring aluminum-based tooling
Copper (35)	Electrical and thermal conductivity application for power and small-signal transport
Electric Propellants	Argon, Bismuth, Cesium, Iodine, Hydrogen, Krypton, Lithium, Water and Xenon, are all propellants that have been tested in various electric propulsion engines (with mixed success).
Filler materials: welding, brazing, soldering (12)	Welding is a common fabrication method in plumbing and structures that are fixed joints on spacecraft. N.B.: Space applications typically avoid the use of tin in electronics because of the growth of "whiskers" that short electric circuits.
Lubricants (11)	All moving parts and mechanisms on spacecraft require lubricants to reduce friction, mechanical failure, material seizure and to manage heat in applications from Articulating Communications Systems to Attitude Determination and Control System's reaction wheels and Solar Panel deployments and sun-tracking actuators.
Miscellaneous Alloys (20)	Noble metals are used as catalysts in chemical monopropellant thrusters. High temperature alloys are used to instrument sensors and systems near combustion chambers and other high-temperature applications. Magnetic materials are used in some applications for attitude control using the earth's magnetic field as well as a component that helps dampen or balance energy stored in reaction wheels. Memory Metals are useful in instruments and deployable structures. Gold Alloy materials are useful in applications ranging from low-friction surfaces to electric conductivity and thermal control. The "blackest" known material is a gold alloy and is useful in calibration and thermal control.
Miscellaneous non-metallic materials (13)	Ceramics are useful in high-temperature applications like re-entry surfaces and hypersonic structures. Ceramics are also used in propulsion systems as catalysts and thermal standoffs. They are also used in electronics during manufacture and sensing and measuring transducers.
Nickel (20)	Batteries, telescope structure (i.e. Inconel), 3D printed components and rocket engine components,
Optical Materials (8)	Often overlooked use of optical materials is as "cover glass" on solar panels. This application of optical material is pervasive on all current spacecraft missions, as it is needed to extend the effective lifetime of photovoltaic materials in space. Cover glass protects fragile solar panels from breaking during manufacturing and assembly, launch, and serves as structural support during deployment. The cover glass further protects the panels from hypervelocity impacts of micrometeoroids, neutral particles, and protects from corrosion caused by charged particles. Large aperture infrared and electro-optical telescopes used for remote sensing enabling space-based terrestrial environmental monitoring, Space Situational Awareness, Launch Detection and Missile Warning, Intelligence Surveillance and Reconnaissance, and Scientific missions push the state of the art for manufacturing uniform crystals to maintain low wave front error and minimize optical signal noise floor. Active Remote Sensing techniques like Hyperspectral Sensing and direct detect LIDAR requires optical materials with very high transparency and optical power density.

Material (# alloys & variants)	Sample Uses for Spacecraft
Paints & inks (12)	Paint is primarily used to manage thermal loads on spacecraft by changing the system's reflectivity, absorptivity and reflectivity of radiation. Paints are also used to enhance observation signatures for Space Traffic Management. Inks are primarily used to identify and track components during assembly, manufacturing, and test of space system components.
Potting compounds, sealants, foams (25)	Used pervasively in all space sub-systems to secure components and dampen mechanical resonance from shock and vibration during launch and deployment. Solar cell cover glass, solar panels, and wiring attachments to bus structures are common applications.
Reinforced plastics (17)	Electronic Circuit Boards are common in space systems, especially communications, telemetry, computation, mission data processing and handling. Many structures for secondary payload systems use plastics instead of metal for mechanical structure.
Rubbers & elastomers (4)	Space Systems use Rubbers and Elastomers for mechanical vibration dampening, electrical isolation, pressure seals and gaskets and bladders for fluids. Rubbers and Elastomers for space applications often require more tolerance of extreme temperature and pressure environments than terrestrial systems.
Stainless Steels (51)	Same as Steels but with corrosion resistance. Suitable for applications like plumbing of oxidizers and fasteners like bolts.
Steels (19)	Common in rocket motors and castings, as suitable for low-cost, disposable applications. Steel is a non-toxic material so human factor considerations makes manufacturing lower-cost than beryllium or other toxic materials. Steels are useful in applications as bearings and springs in mechanical actuators
Thermoplastics (non-adhesive tapes and foils [MLI]) (17)	Multi-Layer Insulations (MLI) are used as thermal blankets to manage thermal load from radiation from the sun as well as protection from micrometeoroid impact and corrosion from plasma and gasses in orbit. Thermoplastics are common in electronics as electrical insulators and thermal isolators. Various tubes for plumbing propellants and thermal fluids use reinforced thermoplastics. These uses are especially common in terrestrial-based testing and evaluation during development and manufacturing of space systems.
Thermoset plastics (1)	Carbon fiber components form tanks and structures. Deployment structures use Thermoset Plastics.
Titanium (12)	Titanium has particularly valuable mechanical properties including high tensile strength to weight ratio, low sensitivity to temperature fluctuations, relatively high corrosion resistance. Ti6Al4V is a commonly used titanium alloy that is used on spacecraft for its suitability to launch and space environments. Titanium as a current collector extends the lifetime of batteries. Commonly used in plumbing for thruster systems, known compatible with AF-M315E and other monopropellants as well as traditional hydrazine applications. Low coefficient of thermal expansion makes titanium useful in payload applications sensitive to pointing accuracy. Titanium is especially common in secondary structures like telescopes.
Wires and cables (24)	Electrical conductors for power distribution of direct current power is required as support for most space subassemblies and must survive extreme temperature and pressure environments. Small signal transport for Radio Frequency and Intermediate Frequency communication is required to support most space missions for communications of mission data and spacecraft telemetry. Coaxial cables capable of transporting millimeter wave signals are required on space missions with high information transport requirements like communications, radar, and other remote sensing missions.

VII. Examples of Real-Life Space Commodity Supply Challenges

Space assets are built up from raw materials, electrical and mechanical parts, to subassemblies, to subcomponents, to components, to major systems, to completed self-contained rockets, satellites or other space assets that render services, such as launch, bandwidth, imagery, robotic exploration and many others. Each step uses or might efficiently seek to use appropriate space standards for interoperability to connect the parts as commodities simpler and more reliably. Rockets need fuel to launch, including oxygen, RP-1 kerosene, and soon, methane. (80) Solar cells intended to withstand the radiation, cold and micro-meteorite impacts of space need special coatings and electronic circuits. Secure communications and the bandwidth in and for remote regions of earth and space differ, correcting for radiation and location disruptions. Space cameras and telescopes for imaging regions of earth are different than for imaging fast moving, faint objects (such as asteroids and comets) against the blackness of space, and each requires different optical glass, coatings, digital image capture, correction, enhancement, archiving and analysis in orbit and back on earth. Self-guidance and self-repair including repositioning, refocusing and refueling differs between legacy and newly-built space assets, relying on different legacy and new software code, including machine learning and artificially-intelligent reasoning.

Refueling and repurposing the nation's legacy satellite fleet represents a real-life commodity and space logistics support opportunity. The International Telecommunications Union (**ITU**) is responsible for allocating radio frequency bands terrestrially and "and, for space services, of any associated orbital position in the geostationary satellite orbit or of any associated characteristics of satellites in other orbits, in order to avoid harmful interference between radio stations of different countries." Article 1 (2) (a) (81) (82) Biweekly the ITU updates and distributes data on the radio frequency and orbital location registered by international satellite operators. (83) Geostationary orbits over densely-populated terrestrial regions are highly valuable and heavily contested. (84) (85) (86) (87) International law protects the locational claim of a satellite in such ITU-registered orbit as long as it occupies and maintains the utility of that orbital position. Eventually a satellite's orbit can degrade, fuel is depleted to maintain orbit, broadcast, navigation and other operations, or the satellite otherwise meets with end of life. In order to avoid creating space debris or taking up valuable real estate or radio spectrum in earth orbit, defunct satellites are moved to disposal orbits or descend to and disintegrate in earth's atmosphere at the end of their useful life. If legacy satellites could be refueled or their components (such as solar panels) reclaimed and repurposed, their useful life and salvage value could be improved, and the risks and costs of launching replacement satellites – albeit more energy and bandwidth efficient – mitigated.

Turning removal of space debris into a tradeable commodity is another real-life opportunity. Space is a very large place. Even constricting "space" to include only the potential orbital locations around Earth, it still is orders of magnitude larger than the surface of the earth. Certain orbits and altitudes over urban locations are more desirable, are becoming congested with satellites seeking the efficiency of minimal station keeping, which in turn, increases their collision risk. Earth has evolved to accommodate many billions of organisms including stationary and mobile organisms. Physical location on Earth's "two-dimensional" surface and in space's "three-dimensional" orbits are entirely different paradigms. At 500km altitude, space objects cross orbital planes at a velocity of 7.6km/s or 15,000 miles per hour, which makes it imperative for the space object to maintain a location that avoids accidental collisions. It is very hard to detect and track space objects to high enough precision to predict future collisions and maneuver to avoid the collision while maintaining operational capability. If two of the estimated 500,000 space objects of 1cm or larger collide, the resulting hypervelocity impact will completely destroy both objects. Today, removal of space objects is very expensive and very hard to do. The incentives are not aligned for stakeholders to be rewarded for removing debris – a classic economics problem known as the "tragedy of the commons," similar to pollution abatement or development of public lands on earth. Once space debris removal becomes a tradeable space commodity, the risk reduction its services supply, especially to protect geostationary orbits, can be monetized, and the technology for finding and removing the debris developed and deployed.

VIII. How Military Contractors Use, Create & Price Space Commodities Today

The Joint Chiefs' Doctrine recognizes that space is a high-demand use, low-density paradigm. (22) Surveillance, detection and targeting of threats to locations on earth or in space or cyberspace, launched from earth or space, require rapid use of limited space assets pre-positioned for that purpose. By their nature, space assets suitable for DoD use may be scarce, controlled by an adversary or not functioning at the time or with the capacity needed in the moment of greatest threat or chance of finding options for effective and measured response. Planning, procurement and logistics must source space capabilities and the commodities to build them to meet high demand volumes of sufficient density (abundant) numbers by relying on dual-purpose (military-commercial) components whose supply chains are persistent and accessible.

Traditionally, U.S. military contractors navigate a procurement process that is ill suited for rapid response in peacetime or wartime. Historically, DoD contractors gestate and await request for proposal (**RFP**) announcements, navigate the intricacies of the Federal Acquisition Regulations (**FAR**) and the DoD Supplement to the FAR (**DFAR**), and respond with pricing that reflects the market, technology and fabrication facilities available or justifiable of the moment. (88) (89) For space, NASA Systems Engineering adds additional requirements. (90)

"New Space" DoD contractors such as SpaceX pursue an alternative business model, using NASA's flexibility to enter into Space Act Agreements (**SAA**), to create space activities as a service (**SaaS**). (91) The SaaS business model

– as contrasted with the bespoke RFP model – transfers to non-federal sector providers more of the economic risks and costs of innovation through commercial investment – supplemented by government milestone payments – in the long horizon research and development (**R&D**), manufacturing and operations facilities needed to assure rendering the SaaS at the price bid in response to the SAA.

With New Space and commercial space business models, contractors have increased economic incentive to hedge the prices and availability of supply for commodities needed to produce their SaaS. On the flipside, SaaS launch, bandwidth, imagery, in orbit information and materials processing, debris removal and other services could be standardized and offered as commodities.

IX. Competition for Minerals on Earth

The U.S. depends on rare earth elements and other resource imports to support its economic vitality and rates of consumption. (92) Pursuant to Presidential Executive Order 13817, the U.S. Geological Survey recently identified 35 critical minerals, essential for national security, used throughout the U.S. economy, as shown in Table 2 (12) (13) (14)

Table 2 USGS' Critical 35 Minerals List

Mineral	Primary Uses in the U.S. Economy
Aluminum	Almost all sectors of the economy
Antimony	Batteries and flame retardants
Arsenic	Lumber preservatives, pesticides, and semi-conductors
Barite	Cement and petroleum industries
Beryllium	Alloying agent for aerospace and defense industries
Bismuth	Medical and atomic research
Cesium	Research and development
Chromium	Stainless steel and other alloys
Cobalt	Rechargeable batteries and superalloys
Fluorspar	Manufacture of aluminum, gasoline, and uranium fuel
Gallium	Integrated circuits and optical devices such as LEDs
Germanium	Fiber optics and night vision applications
Graphite (natural)	Lubricants, batteries, and fuel cells
Hafnium	Nuclear control rods, alloys, and high-temperature ceramics
Helium	MRIs, lifting agent, and research
Indium	LCD screens
Lithium	Batteries
Magnesium	Furnace linings for manufacturing steel and ceramics
Manganese	Steelmaking
Niobium	Steel alloys
Platinum	Catalytic agents
Potash	Fertilizer
Rare Earths	Batteries and electronics
Rhenium	Lead-free gasoline and superalloys
Rubidium	Research and development in electronics
Scandium	Alloys and fuel cells
Strontium	Pyrotechnics and ceramic magnets
Tantalum	Electronic components, mostly capacitors
Tellurium	Steelmaking and solar cells
Tin	Protective coatings and alloys for steel
Titanium	White pigment or metal alloys
Tungsten	Wear-resistant metals
Uranium	Nuclear fuel
Vanadium	Titanium alloys
Zirconium	High-temperature ceramics industries

China and the U.S. depend on commodity imports for traditional technologies, such as vehicle production, and advanced technologies, such as for producing semiconductors and solar panels. (93) While both countries hold reserve deposits of critical minerals, China produces more than 90% of rare earth elements (**REE**), and more than 80% of Antimony, Germanium, Magnesium and Natural Graphite. (94)

Using the analysis and data of Gulley et al, Table 3 shows the relative and aggregate net import reliance (**NIR**) in metric tons of minerals used in 2014 by the Chinese and U.S. economies. (93)

Table 3 Net Import Reliance (NIR in 2014 metric tons)

Commodity (metric tons)	China NIR	US NIR	Total NIR
Alumina	0.10	0.00	0.10
Aluminum	-	0.49	0.49
Antimony	0.19	1.00	1.19
Beryllium - mine	0.69	0.01	0.71
Bismuth - refinery	-	1.00	1.00
Boron	0.74	0.00	0.74
Cadmium	0.58	0.00	0.58
Chromite	0.98	1.00	1.98
Cobalt - mine	0.89	0.00	0.89
Cobalt - refinery	-	1.00	1.00
Copper - mine	0.60	0.00	0.60
Copper - refinery	0.12	0.32	0.44
Gallium – low purity	-	1.00	1.00
Gallium – high purity	0.65	0.00	0.65
Germanium	-	0.84	0.84
Indium	-	1.00	1.00
Iron Ore	0.60	0.00	0.60
Lead - mine	0.15	0.00	0.15
Lead - refinery	0.04	0.35	0.39
Lithium	0.83	0.50	1.33
Magnesium - metal	-	0.40	0.40
Manganese - mine	0.65	1.00	1.65
Molybdenum	-	0.00	-
Niobium	1.00	1.00	2.00
Palladium	0.84	0.62	1.46
Platinum	0.78	0.66	1.44
Potash	-	0.85	0.85
Rare Earths	-	0.68	0.68
Rhenium	0.53	0.75	1.28
Rhodium	0.95	0.74	1.70
Selenium	0.80	0.00	0.80
Silver	0.45	0.63	1.08
Steel	-	0.18	0.18
Sulfur	0.35	0.12	0.47
Tantalum	0.91	1.00	1.91
Tellurium	-	0.90	0.90
Tin - smelter	-	0.74	0.74
Titanium	0.56	0.92	1.48
Yttrium	-	0.97	0.97
Zinc - mine	0.16	0.00	0.16
Zinc - smelter	0.07	0.81	0.88
Zirconium – concentrates	0.84	0.50	1.34

Using the analysis and data of Gulley et al, Fig. 2 quantifies the relative competitive pressure on the U.S. that Chinese demand for and control of traded minerals represents, expressed as its Herfindahl – Hirschman Index (**HHI**). (93)

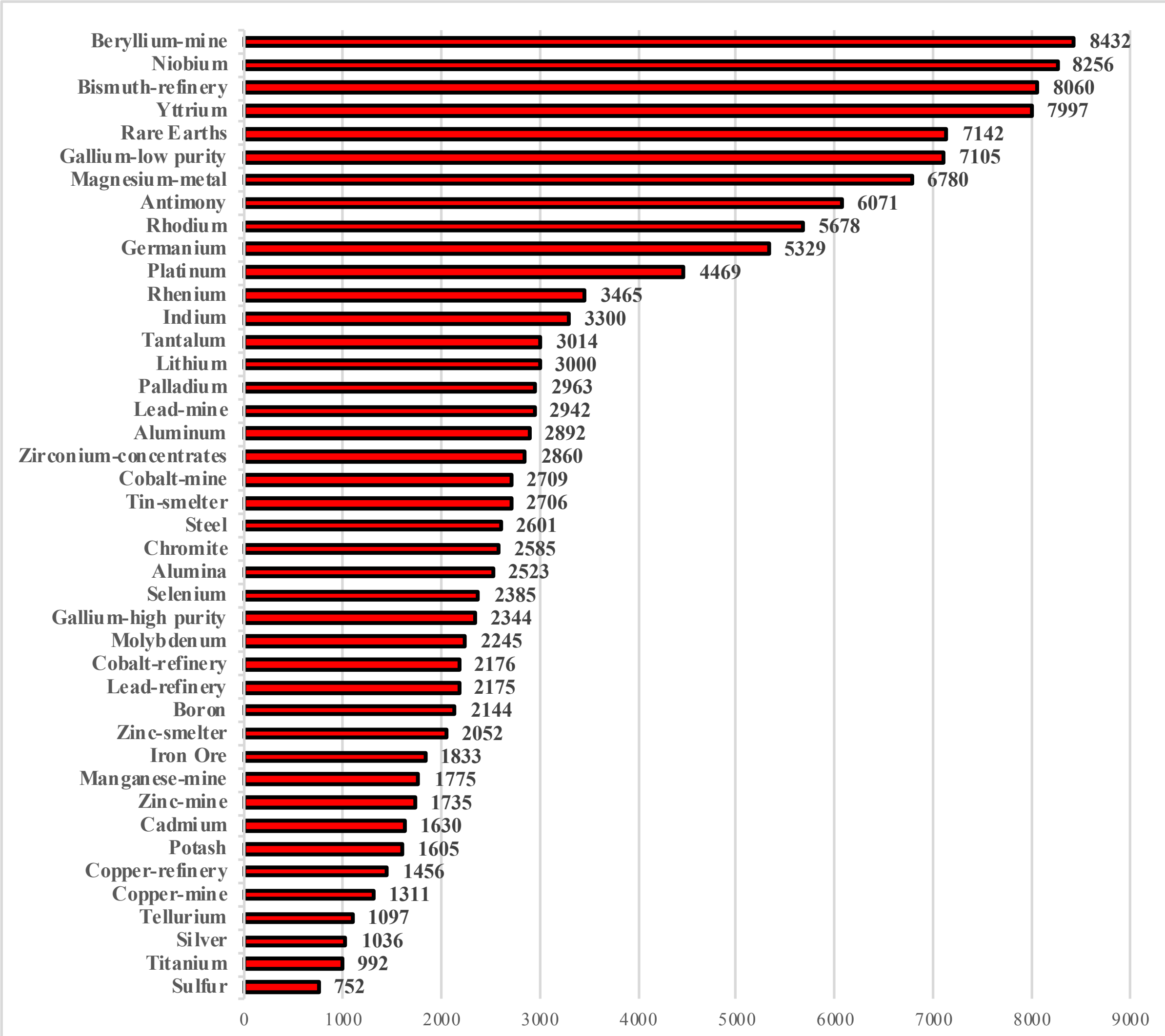

Fig. 2 China's Relative Competitive Advantage over U.S. in Obtaining Strategic Minerals (HHI score)

Certain elements are critical for the space economy and its new space corporate visionaries. Their dependence on minerals, noble gases and other rare commodities will evolve as technologies for launch, in-orbit propulsion, fabrication, energy and other services emerge using more plentiful commodities, such as Blue Origin's development of its methane-fed BE-4 engine. (95) (96) (97)

To illustrate the geography of strategic mineral abundance and scarcity on earth, consider three elements used in satellites, rockets and other industrial applications. Helium is used in aerospace rocket design, to maintain pressure for fuel tank structural soundness as oxygen, hydrogen, kerosene and other fuels are consumed in flight. (98) (99) Lithium is used in satellite batteries, and batteries provide the energy by which noble gases can generate micro-propulsion in orbit. Niobium is key to making special alloy used to withstand the high heat of jet and rocket engines. Global 2017 reserves and production of helium, lithium and niobium are shown in Fig. 3 - Fig. 8. (100)

A. Global Helium Market Overview

2017 constraints in the supply of helium illustrate how fragile and interdependent the space economy's access to commodity markets are, and the effect of U.S. Government policy. (101) (102) From a national security vantage point, the U.S. Government is on multiple sides of the helium market: As buyer, seller, investor and market regulator, Bureau of Land Management (**BLM**) operates the Federal Helium Program supplying 40% of domestic demand for helium. (103) (104) As buyer directly, and through helium-dependent contractors indirectly, NASA, the U.S. Air Force Space Command, DoD Defense Logistics Agency and other federal Agencies and Departments are buying helium and helium-based products and services. As BLM sells off and depletes domestic reserves of helium, and Qatari helium production - when not trade blockaded by neighboring countries - supports 28% or more of the global demand, U.S. Government pricing for helium-based services will need to be hedged through commodities futures, supplemental commercial storage or other means that allow for transfer of rights to acquire helium in sufficient quantities for future needs without relying solely on domestic reserves or production. If and how BLM coordinates the sale and replenishment of the federal helium stockpile with DoD, NASA, the USAF Space Command, DoD Defense Logistics Agency and other federal helium customers raises issues of national security access to space. Fig. 3 – Fig. 4.

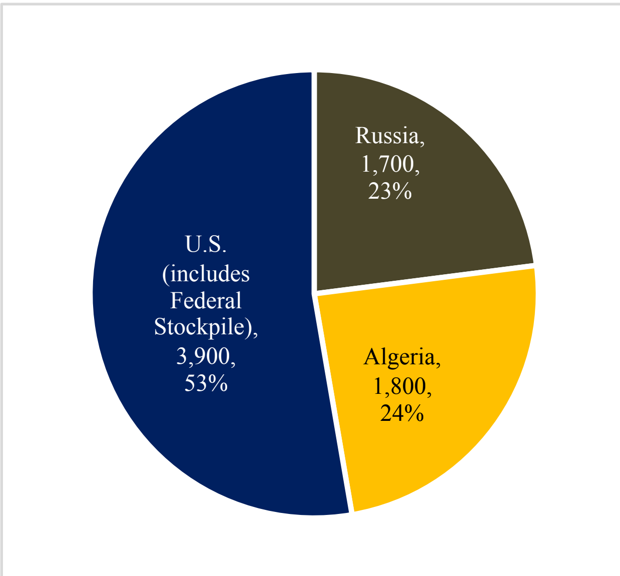

Fig. 3 2017 Global Helium Reserves (million m^3)

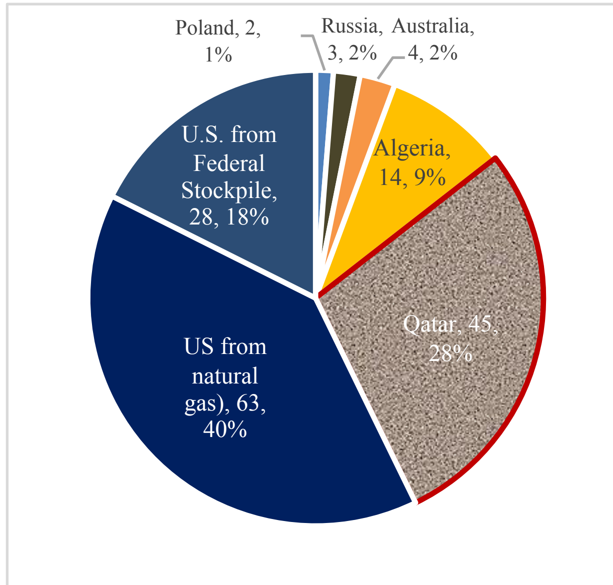

Fig. 4 2017 Global Helium Production (million m^3)

B. Global Lithium Market Overview

Batteries in cellphones, personal computers, home solar and grid energy systems and satellites have increased global demand for lithium. China, Chile, Argentina and Australia are key foreign player in holding the reserves and production capacity to meet global lithium demand. While investment in new sources of supply for lithium are emerging, prices for lithium have increased markedly over the past two years as electric vehicles (**EV**) and renewable energy storage have spiked demand. Fig. 5 – Fig. 6. (105) (106) (107)

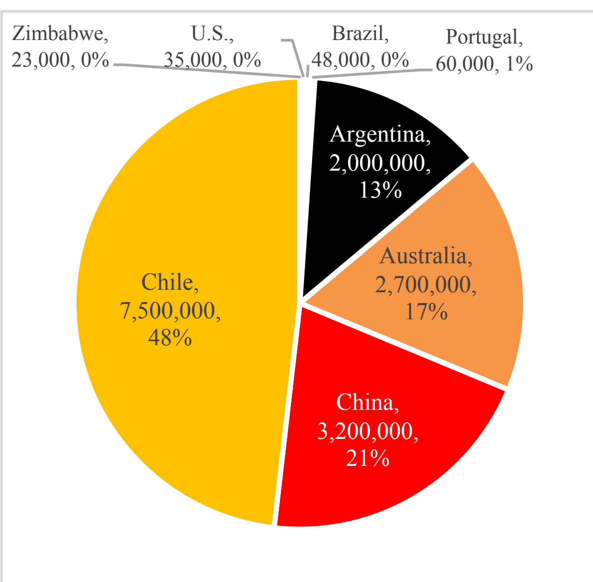

Fig. 5 2017 Global Lithium Reserves (metric tons)

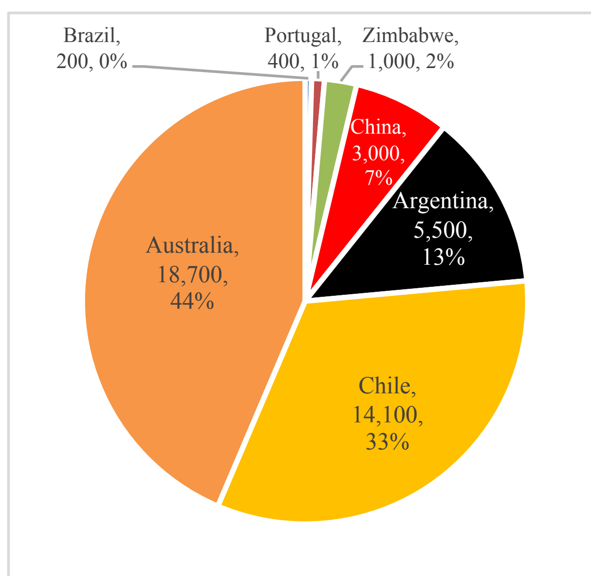

Fig. 6 2017 Global Lithium Production (metric tons)

C. Global Niobium Market Overview
Niobium strengthens steel used in aircraft and rocket engines, and played a role in finding the Higgs boson, the so-called "God particle." (108) Terrestrially 80% of global supply is produced in quantity by only one company, Cia. Brasileira de Metalurgia & Mineracao (**CBMM**) a privately-held family business in Brazil, started in 1965 and since 2011, 30% owned by investors from China, Japan and South Korea. (109) (110) (111) If an adverse party were to threaten or sabotage the CBMM niobium mines in Brazil, niobium supply and prices would be imperiled, raising the question as to if and how the CBMM mines and similar domestic and foreign terrestrial deposits of essential space commodities are protected to assure national security thorough the continuity of critical supply chains. Fig. 7 - Fig. 8.

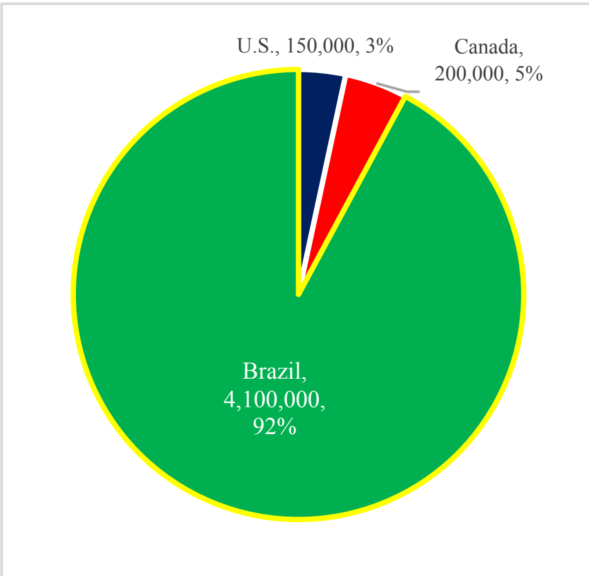

Fig. 7 2017 Global Niobium Reserves (metric tons)

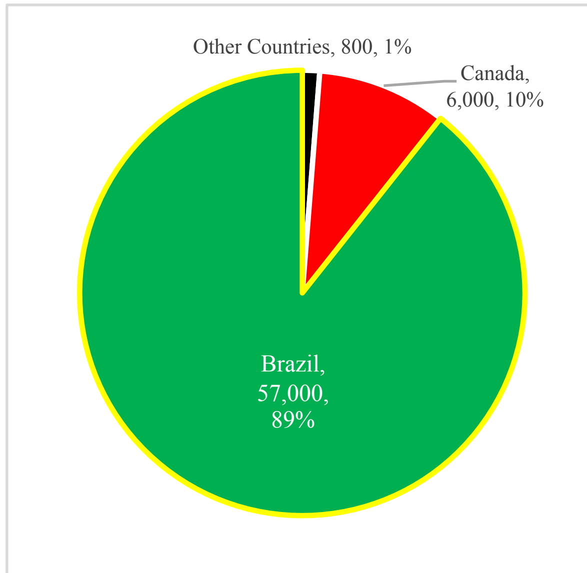

Fig. 8 2017 Global Niobium Production (metric tons)

Fig. 3 - Fig. 8 suggest that U.S. national security competes for minerals, noble gases and other raw materials, processed commodities, manufacturing facilities and talent through global channels, controlled in whole or part by countries where foreign national security frames of reference, currency fluctuations, regional political and economic risks might delay or obstruct U.S. government and contractor supply chains for such commodities. When the U.S. invests in stockpiling a particular commodity, such as helium, the free market supply and demand for the commodity is altered, and access to the commodity in sufficient future quantity at predictable prices is not necessarily assured, given that producer nations have differing economic and international relations priorities. Alternative market strategies terrestrially and in space are required to anticipate, hedge and buffer future national security needs for space commodities.

X. National Security Scenarios for 'Mining the Sky'

For decades, the potential of *Mining the Sky* has been discussed as a means to find, mine, refine and synthesize known and new minerals and compounds on asteroids and other celestial bodies in sufficient quantity and at reasonable cost and risk to complement Earth's supply. (112) (113)

At least five future national security scenarios emerge from a paradigm where Earth uses off-planet resources:

1. ***Good Earth Scenario*** - Terrestrial Resources are newly identified, synthesized and developed, or the means to mine, recycle, substitute for and better utilize them emerge, which eases pressures for military conflict (94)
2. ***Warfare on Earth Scenario*** – Warfare - cyber, economic, kinetic, regional, technological or other - reallocates economic or political control of Terrestrial Resources and their availability (114)
3. ***Good Space Scenario*** - Space Resources are readily harvestable via reliable and legally protected business models to supplement Terrestrial Resources, which increases global competition for the means to mine, transport and use them (112)
4. ***Space Too Far Scenario*** - Space Resources are too costly or the missions too risky and deferred to reliably supplement Terrestrial Resources, which increases tensions for using Terrestrial Resources

5. ***Warfare in Space Scenario*** - Warfare – cyber, economic, kinetic, technological or other - reallocates claims of resources in situ for use there or for re-supply of Earth

As Table 4 illustrates, each scenario mixes common strategies to drive its post-scenario allocation of resources, albeit that the reallocation may be as intended or unintended.

Table 4 Comparing Future National Security Scenarios

Scenario uses	#1	#2	#3	#4	#5
Commercially Viable Technologies	Yes	Yes	Yes	Yes	Yes
Economic Competition	Yes	Yes	Yes	Yes	Yes
Warfighting		Yes			Yes
Commodities Exchanges for Finding Resources	Yes	Yes	Yes	Yes	Yes
Commodities Stockpiles		Yes		Yes	Yes
Space Law that assures Resource Claims			Yes		

Scenarios 1 and 3 depend on well-functioning commodities exchanges to make terrestrial and space minerals and other resources discoverable in standard quantity, quality, timeframes and contract terms. (See discussion in Sections XI - XVI). Scenarios 2, 4 and 5 – warfighting and preparing for warfighting – implicitly assume and use commodities exchanges, stockpiles or both, so that military contractors can obtain the raw materials required. All five scenarios favor the advancement of dual-use technologies, able to support commercial and military applications. For Scenario 3 – *Good Space* – to be viable, space law would need to assure individual claims to mine and resell industrial quantities of extraterrestrial resources. (115) Without legal certainty as to claimants' rights to space commodities, and how to trade them, Scenarios 2 and 5 – *Warfare on Earth and in Space*- become more likely. In reality and in modern times, all five scenarios are unfolding, by choice, inadvertence, limited authorizations for innovation and limits of foresight.

XI. How Commodities Exchanges Enable and Impact National Security

Commodities exchange transactions, rules, and settlement systems determine the price, availability, quality and terms for trading and delivery of commodities, and the predecessor and value-added derivative products that depend on commodities. (116) In effect, commodities exchanges serve as toll booths for global commodities.

The Futures Industry Association (**FIA**) inventories the volume of commodities futures contracts traded on recognized global exchanges. Fig. 9 shows FIA futures data for January – June 2018 in the 40 most traded metals. (117)

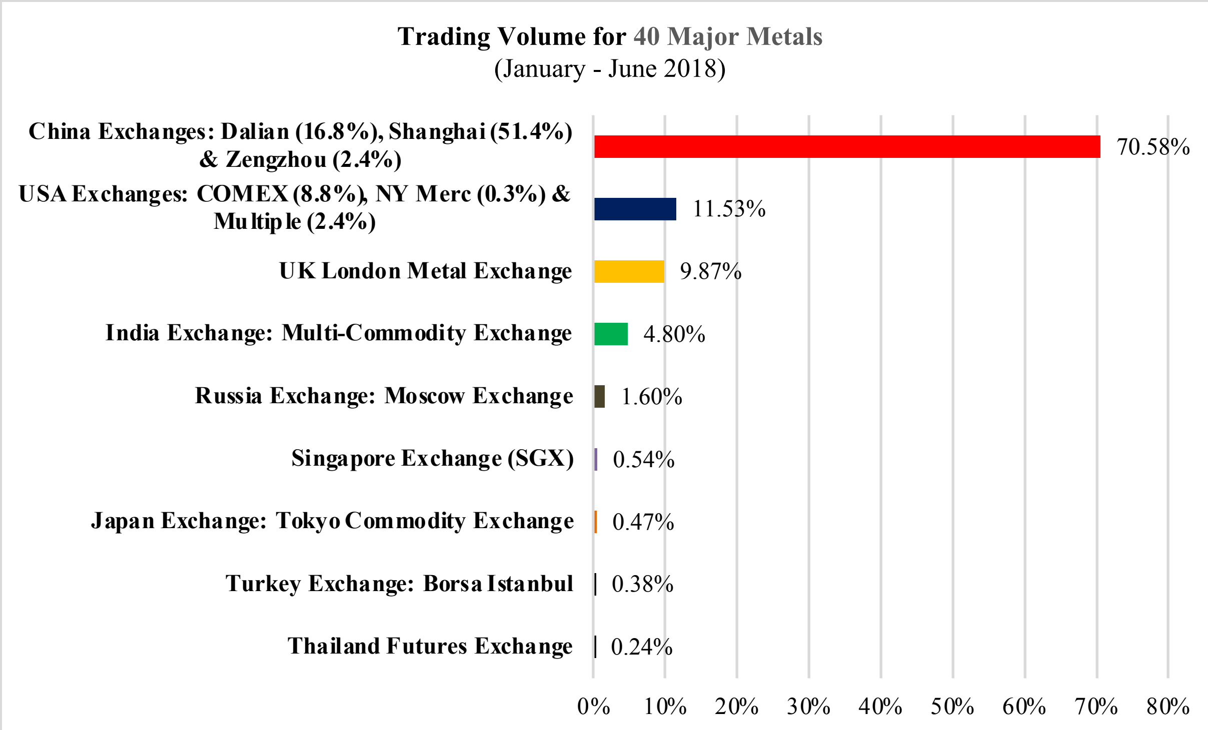

Fig. 9 Major Metals Trading Volumes on Global Exchanges

Terrestrially, China's Shanghai Futures Exchange (**SHFE**) plays an increasingly important role in owning, brokering, setting the demand and supply parameters for, and ultimately controlling ordinary and precious metals and other commodities used in electronics, manufacturing, medical equipment, space rocketry and other fields. (118) (119) SHFE, as a transactional hub for the foreign currency, foreign debt and commodity reserves held, refined, used and traded by China and Chinese state-owned or controlled enterprises, is positioned to challenge and outcompete other global commodities exchanges, such as the **CME Group** (consisting of the Chicago Mercantile Exchange, Chicago Board of Trade, New York Mercantile Exchange and the Commodity Exchange (COMEX)) and Intercontinental Commodities Exchange (**ICE**) by lowering commodity trade transaction fees, adjusting margin deposit requirements and adopting accommodative regulatory procedures, and through such means of denominating commodities trades in its official currency, renminbi (unitized as yuan), as a global currency. (120) (121) (122)

XII. A Brief Overview of a Space Commodities Exchange

As depicted in Fig. 10, a space commodities exchange (**Space Commodities Exchange**) has been proposed as a platform for trading **Five Buckets** of space commodities: (123)

1. ***Raw Materials*** such as minerals and gases mined on earth, lunar, asteroid or other locations to support space exploration.
2. ***Processed Goods***, such as water from lunar ice, manufactured from Raw Materials, or the refined and purified minerals and noble gases needed on earth to support space exploration.
3. ***Services in Space***, such as bandwidth, imagery, launch, robotic assembly and debris removal, offered to facilitate in-space operations.
4. ***Financial Derivatives***, such as futures contracts to supply, purchase or hedge risks relating to, Raw Materials, Processed Goods or Services, as well as interest rate, currency swaps and other derivatives of the space economy's activities, revenues and risks.
5. ***Financial Indexes*** reflecting the current and future pooled value and forecasts of space commodities that relate to the space economy.

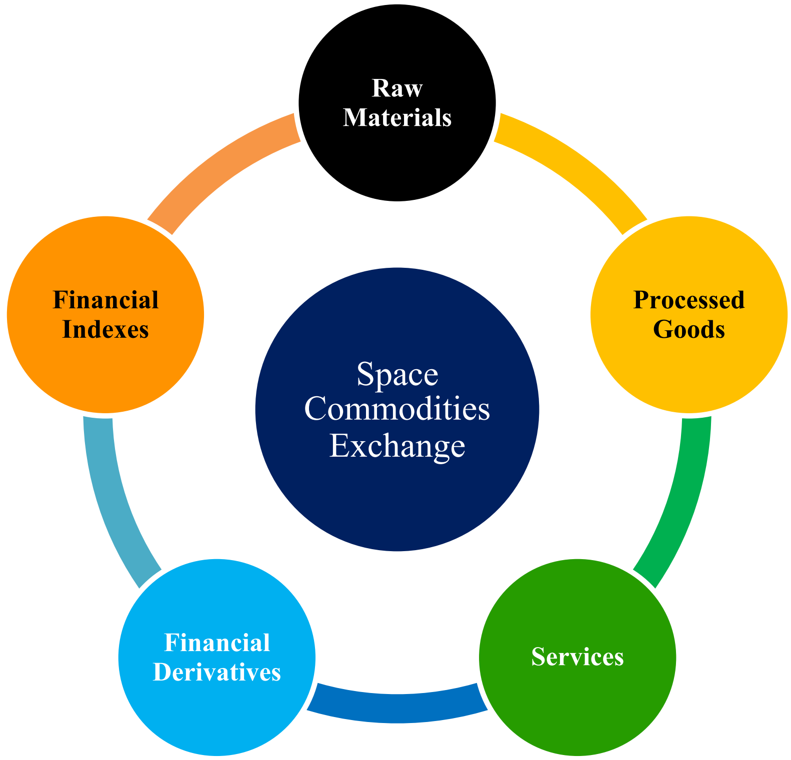

Fig. 10 Space Commodities Exchange's Five Buckets of Commodities

Following precedent from how the Chicago Mercantile Exchange and other exchanges formed historically, the Space Commodities Exchange would be formed by a board of trade comprised of the suppliers, customers, investors, regulators and government agencies who depend upon space commodities. (123) The Board of Trade members' familiarity with how different types and gradations of "space commodities" should be defined (for instance, launch services), and on what contractual terms they can and should be traded as "futures", the Space Commodities Exchange would bring interoperable standards and commercial accountability processes to grow the space economy, and assure a consistent quantity and quality of space commodities critical to the supply chains supporting commercial and national security interests in space. (123) Offering graded and tradeable risk transfer derivatives and other innovative financial instruments would likely reduce insurance costs and enhance creditworthiness for traditional and new space companies and their customers.

XIII. How a Space Commodities Exchange Shifts the Use, Creation & Pricing of Space Commodities

The Joint Chiefs' Doctrine defines key national security capabilities that hinge on space operations: (22)

- ***Passive, Observational and Communications Capabilities***: Space Situational Awareness, Space Control, Positioning, Navigation and Timing, Intelligence, Surveillance and Reconnaissance, Satellite Communications (**SATCOM**) and Satellite Operations, Environmental Monitoring, Missile Warning, Nuclear Detonation Detection and Space Lift
- ***Active Capabilities***: Warfighting Command and Control, Intelligence Gathering, Fires, Movement and Maneuver, Protection, Sustainment and Information Use and Analysis

The Joint Chiefs recognize that space assets need to be designed to serve (or be capable of being rapidly repurposed to serve) multiple capabilities. The space asset as finished product should rely on multiple supply chains and procurement options. Many of the DoD's *Passive, Observational and Communications Capabilities* are available commercially, or as a version thereof. With computer gaming, logistics movement for online and branch retailers (like Amazon, Apple and Walmart) and the ubiquity of artificial intelligence analytics for industries as diverse as banking, law and medicine, commercial versions of DoD's *Active Capabilities* will increasingly be available, with technology and user features outpacing traditional military bespoke versions.

National security activities in space (as on earth) use a mixture of bespoke and commercial-off-the-shelf (**COTS)** assets constructed from, and powered by, commodities produced terrestrially in the short term, and terrestrially and in orbit or in situ, over the longer term.

A key benefit of regulated commodities exchanges is their role in providing the transparency and standardization to better match supply and demand for listed commodities, and goods and services derived or priced based on them. Futures contracts for corn, soybeans and wheat inform farmers how much and what grade of seed to plant in order to meet demand for delivery at harvest time. (124) Futures contracts for copper, steel and other metals help inform mining and refining companies as to how much and what grades of metal will be needed to justify the expense of investing in mineral exploration and other industrial operations. Buffering the annual trends for supply and demand are investors in commodities whose capital supports mostly healthy speculation in order to relieve producers and consumers of raising equity or suffering extreme price swings or shortage in predicting future market movements.

XIV. How a Space Commodities Exchange Assures Commercial Rights in Space Commodities

Five major United Nations Space Treaties (**UN Space Treaties**) set part of the legal framework for national security and commercial activities in space, adopted and known as follows:

1967 – the **Outer Space Treaty**, (125)
1968 – the **Rescue Agreement**, (126)
1972 – the **Liability Convention**, (127)
1976 – the **Registration Convention**, (128) and
1984 – the **Moon Agreement**. (129)

United Nations and other international treaties do not become binding until a nation ratifies them as binding under its internal legislative process. The U.S. has ratified the Outer Space, Rescue, Liability and Registration Treaties, but not the Moon Agreement. (130)

Under the UN Space Treaties, private property rights derive from the launching state's sovereign and co-equal rights to space exploration. Under the Registration Convention, space objects, such as satellites, must be registered by the launching state with the United Nations Office of Outer Space Affairs (**UNOOSA**), and are accountable under the Space Treaties as ratified and implemented by, and supplemented by, the launching state's internal laws. (131) If damage results on earth or in outer space by or to a space object, the Liability Convention and principles of international law govern resolution of the dispute. (132) (133)

Nuclear nonproliferation in the 1960s, rather than commercial space activity in the 2010s, was the primary motivation for the original Cold War Era UN Space Treaties. The omission of commercial activities' nuances from the UN Space Treaties, and the United Nations inability to get international ratification to bring the Treaties up to date in recognizing the scope and pace of commercial and nation state space activities, creates significant ambiguities for space lawyers to debate, and risks for their clients to absorb. (134)

Nonetheless, commercial satellites do launch and private companies offer space imagery, bandwidth, habitat, and mining in reliance UN Space Treaties protections of "non-interference" and principles of international law to claim and use valuable geostationary orbits and other rights for private profit. Such rights, derived from sovereign co-equal exploratory precedents like the Law of the Sea, can be held, transferred and serve as collateral for loans and investments in space activities.

Thus far, calls for an "international space authority" have not been adopted, whereby the authority might act as and be delegated powers sufficient to serve as a port authority for coordinated development and finance of space exploration pursuant to the UN Space Treaties. (Unpublished, Urban Logic, Inc. Framing an Interstellar Development & Finance Authority, submitted December 1, 2016 as NASA Proposal Number 15-ESO-B1-0004)

Consider how a Space Commodities Exchange might add to the legal certainty of transactions and finance for space commodities.

Every exchange requires its members and users to respect the laws and rules governing conduct relating to the commodities traded on the exchange, and their ongoing rights and obligations within the exchange. Were an exchange registered trader to default on a futures contract, that trader's rights to buy or sell other futures contracts would be suspended until the default were cured and additional collateral posted to meet exchange margin, guaranty, bonding and other requirements. Rulebooks, such as adopted by U.S. commodities exchanges CME and ICE, China's Shanghai Futures Exchange (**SHFE**) and Singapore's SGX, delineate exchange member and participant roles, responsibility and remedies upon default. (135) (136) (137) (138) (139)

In similar fashion, the members of a Space Commodities Exchange could adopt a commercially pragmatic rules that promote the certainty of rights traded on it for the protection of all parties relying on such certainty. Members, traders or their customers who default in respecting such rules would be suspended from use of the Exchange until the default was cured. In cases of sovereign country disruption or interference in other nation's space objects or refusal to enforce other nation's private rights, the noncompliant nation's futures contracts might be stayed, terminated or held as collateral until the disruption or interference and its damages were settled.

If well structured, a Space Commodities Exchange would present pragmatic resource access, revenue and supply chain consequences that might deter rogue actor behavior that threatens others' commercial or national security interests in space. In adding commercial consequences, a Space Commodities Exchange would provide greater certainty for national security assets priced based on or relying on space commodities. Given the delays in updating the UN Space Treaties to facilitate commercialization of space, and the limited forums through which to achieve certainty as to legitimate legal claims relating to space activities, a Space Commodities Exchange brings a pragmatic portfolio of mutual protection to encourage and assure respect for legal claims, and transactions built thereon.

Hypothetically, a financial derivative – akin to a credit default swap (**CDS**) or other risk transfer instrument – could contain the economic loss of legal claims to specific space minerals, orbits and mining operations. Risk transfer derivatives also could buffer the risk of rogue or innocent disturbance of space commodity claims. Finally, a basic function of an organized commodities exchange is to assure performance of the contracts traded on the exchange, and thus serves informally to guarantee the smooth function of supply chains dependent on traded commodities.

XV. What Happens if Military Supply Chains Remain Bespoke While Commercial Space Uses a Commodities Exchange?

As Sections VI, VII and IX discussed, minerals and other commodities required for space operations compete with industry and government terrestrial uses of them. The earth's supply of such resources may be limited or stockpiled to buffer the uncertainty of demand. Technological hunger for a specific commodity – like helium, lithium or niobium – may spike, sending spot market prices for the commodity skyward.

Once a Space Commodities Exchange forms, it will serve as marketplace for matching supply and demand for the Five Buckets of space commodities. Through the Exchange, users will have supplemental market forecasts of, commercial access to, and rights to offer and reserve space commodities. The Exchange should alleviate shortages and by better forecasting demand and supply, discourage hoarding of commodities.

From Biblical Times to today, hoarding of essential commodities (such as food and fuel) is discouraged, risky, taxed and even outlawed, and as a result, hoarders face multiple obstacles in recouping return on investment. (140) (141) (142) Commodity investors do, however, bridge mismatches between current year output and current year use of the commodity, drawing on and filling up the investors' reserves and rights to acquire the commodity for lower price.

Due to the DoD's position as ultimate customer for goods and services manufactured from rare commodities, bespoke procurements can expose the U.S. Treasury and national security to hiccups in commodity access. If the DoD's bespoke procurement is used to incentivize exploration for and creation of the space commodity, the Space Commodities Exchange can assure a continuity of commercial space and non-space demand for the commodity, beyond the DoD's needs. If the DoD's bespoke procurement spikes demand for a rare commodity in one year, and removes that demand the next year, then the commodity price will rise quickly in response, but without assurance of future similar procurements, neither the DoD's long-term commodity sourcing nor commercial space and other industries' needs will be predictably and economically served.

XVI. How a Space Commodities Exchange Accelerates the Space Economy and its Needs for Protection

A Space Commodities Exchange built to serve the space economy will grow the space economy faster than relying on terrestrial exchanges to provide equivalent trading services.

"Space commodities" may be chemically identical or have physical properties identical to their terrestrial cousins. Energy in kilowatts or joules on earth and in space may describe a similar commodity. Transporting freight by airplane, ship, truck, railroad, drone and rocket all can be described mathematically and generically as "transport services."

Given their additional operational and reliance risk, their higher demand for quality assurance in space's remote settings and the human and mechanical interdependencies they serve in the space economy, sourcing, delivery, quality, quantity and other characteristics of space commodities will be vastly different than supply chains historically relied upon on earth. While terrestrial commodity exchanges could offer a subset of space commodities (and today, in part, do), the technical expertise needed to define and update definitions of "space commodities" and the contracts for trading in them would best be assembled and curated within a Space Commodities Exchange, where the mission of growing a sustainable space economy, beyond commodities markets profit-taking, is paramount in dictating how the Exchange operates.

History provides numerous examples of economic growth once bespoke manufacturing and services business models yield to standardized commodities manufacturing and services business models. Henry Ford's Model T automobile, Andy Grove's Intel microcircuit, DARPA's Internet, Marc Andreessen's Netscape web browser, Google Earth's Keyhole Markup Language (**KML**), and hundreds more industrial example showcase how commodities were built on interoperability standards that accelerated the economic activity of transportation, electronics, geospatial and location-aware digital commerce, and others. Reusable rockets, CubeSats, satellite imagery and other advances in space technologies are providing future examples of commodities that grew the space economy faster.

Two examples of how a Space Commodities Exchange could grow the space economy. Assume that robotic space object capture, component, assembly, repair, disassembly and re-assembly of parts in space becomes a viable business model. (143) The excess parts could be sorted and their rare earth and other minerals recycled to become raw materials and processed goods, and ultimately remanufactured into assets (like satellites) that provide services, all tradeable on the Exchange. Recycling that minimizes or repurposes space debris is likewise a tradeable commodity, of value to space insurers and those holding financial derivatives in space launch, operations and debris risk.

A second example results from the greater transparency and predictability of supply and demand that a Space Commodities Exchange offers. Once shortages and surpluses are readily known and priced transparently based on commodities futures contractual commitments, investors, lenders and businesses have the market assurance to mine, refine and store in space rare earth and other critical minerals that are in short supply on earth for use there or in space.

As the space economy's growth accelerates, the assets in outer space and their potential benefits reduce the cost, risk and capital barriers of space exploration and commercialization. Simultaneously, the more space assets that grow the value and functional use of space for terrestrial and extraterrestrial purposes, the greater the need to protect them robustly, sooner.

How fast the space economy grows presents a two-sided coin for national security: On one side, the space economy provides faster and cheaper advances for procurement as capital and operational assets that can meet, or be adapted to meet, DoD/IC requirements. That's the good news. On the other side, a fast-growing space economy presents options for non-DoD/IC actors - sovereign, corporate and independent – deliberately, inadvertently or opportunistically to acquire the means to disrupt, threaten or inadvertently compromise assets representing single or multiple points of failure in the national security infrastructure.

XVII. Would foreign sponsorship, ownership or control of Space Commodities and a Space Commodities Exchange affect National Security?

Financial markets seek clarity and certainty in regulatory process.

U.S. financial markets are viewed internationally as reliable and trusted in terms of consistency of regulatory oversight and supervision. After the 2008 Credit Crisis and enactment of the 2010 Dodd-Frank Wall Street Reform and Consumer Protection Act (**Dodd-Frank**), U.S. market structures were reevaluated and harmonized to improve transparency, reduce regulatory "forum-shopping" and restore consumer, counter-party and global investor trust in U.S. financial institutions and markets. (144) Similar harmonization and regulatory consistency measures have been adopted in the U.K., European Union and other major financial centers, catalyzed in part through the work of the Bank for International Settlements (**BIS**) that coordinates policies and procedures for global financial payments, settlements and related activities. (145) (146)

If a Space Commodities Exchange forms in the U.S., then U.S. law and consent to the application of U.S. law would apply to all space commodities traded on the Exchange. If a Space Commodities Exchange forms in other countries, U.S. law would not be the paramount driver in determining how the Exchange operates, what commodities are traded, how the trades are regulated, and what nations and parties can participate.

Terrestrially, cartels, like OPEC: The Organization of Petroleum Exporting Countries, that control the price, availability and grades of commodity, have the power to alter economic capacity, and through the profits of commodities traded, fund warfare, instability and other activities that threaten national security regionally. (147) As has been noted, importing U.S. domestic needs for oil from OPEC cartel member countries at pricing that does not reflect true free market supply and demand, annually, sends an amount in U.S. dollars that exceeds the U.S. DoD Budget, further funding certain OPEC countries' destabilizing activities internally, in the Middle East, North Africa and elsewhere. (148) (149) A Space Commodities Exchange would limit the justification for, and capacity of, cartels to form to control or claim or exercise control over space commodities by reducing the economic incentive and profits of oligopoly membership.

As a conduit for financing, investment and trading in space commodities, a Space Commodities Exchange might be a strategic peacekeeping asset for the country where it is registered and regulated, and for the countries and their agencies, contractors and corporations using the Exchange for purposes of anticipating and pacing their activities in the space economy.

XVIII. Would Financial Sponsorship, Ownership or Control of Space Commodities and Commodities Exchanges Affect the National Security Interests?

Increasingly, global economic power is displacing military power as the *de facto* arbitrator of national security maneuverability and readiness.

50 years ago, intellectual property, financial flows and information could be largely monitored and contained within national borders, and thus domestic and foreign use and misuse of them constrained in order to enhance national security. (150) Today, financial, intellectual and knowledge capital and the technological advantages of knowing how to build useful products and services flow relatively seamlessly, globally through legal and illegal channels, for mostly legal, and rarely, illegal purposes. (151) (152) (153) The post-World War II architecture through which economics would work to enhance and not threaten U.S. national security interests are being redefined and reshaped by fast-growing economies such as China and fast-paced changes in intellectual property and its emergent business models (like Facebook, Google, and Uber). (154)

XIX. Concluding Thoughts

The space economy is growing, and with its growth come new national security options, threats and logistical needs. A Space Commodities Exchange would add robust supply, demand, interoperability, transparency and risk transfer capacities to support the space economy. A Space Commodities Exchange also would enhance and become an asset for national security. Given the increasing role and dominance of commodities exchanges in China, a Space Commodities Exchange organized in the U.S. could serve as a means for minimizing resource constraints on U.S. national security interests terrestrially and in space. Commodity futures, risk transfer hedges, indexes and other financial derivatives traded on a Space Commodities Exchange would bring liquidity and diversify risk for the space economy, enhancing the viability of commercial space business models that support national security operations in space.

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