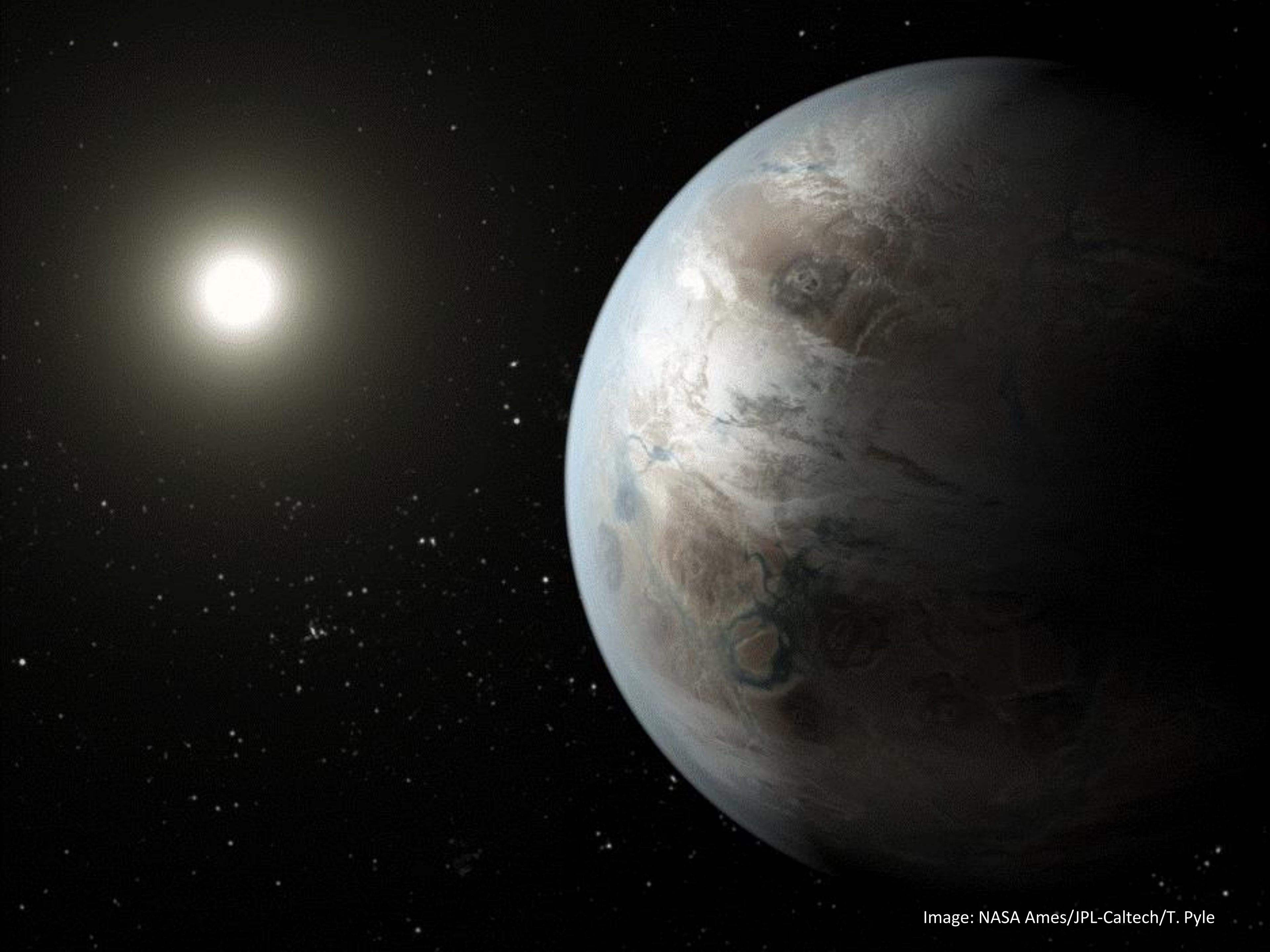
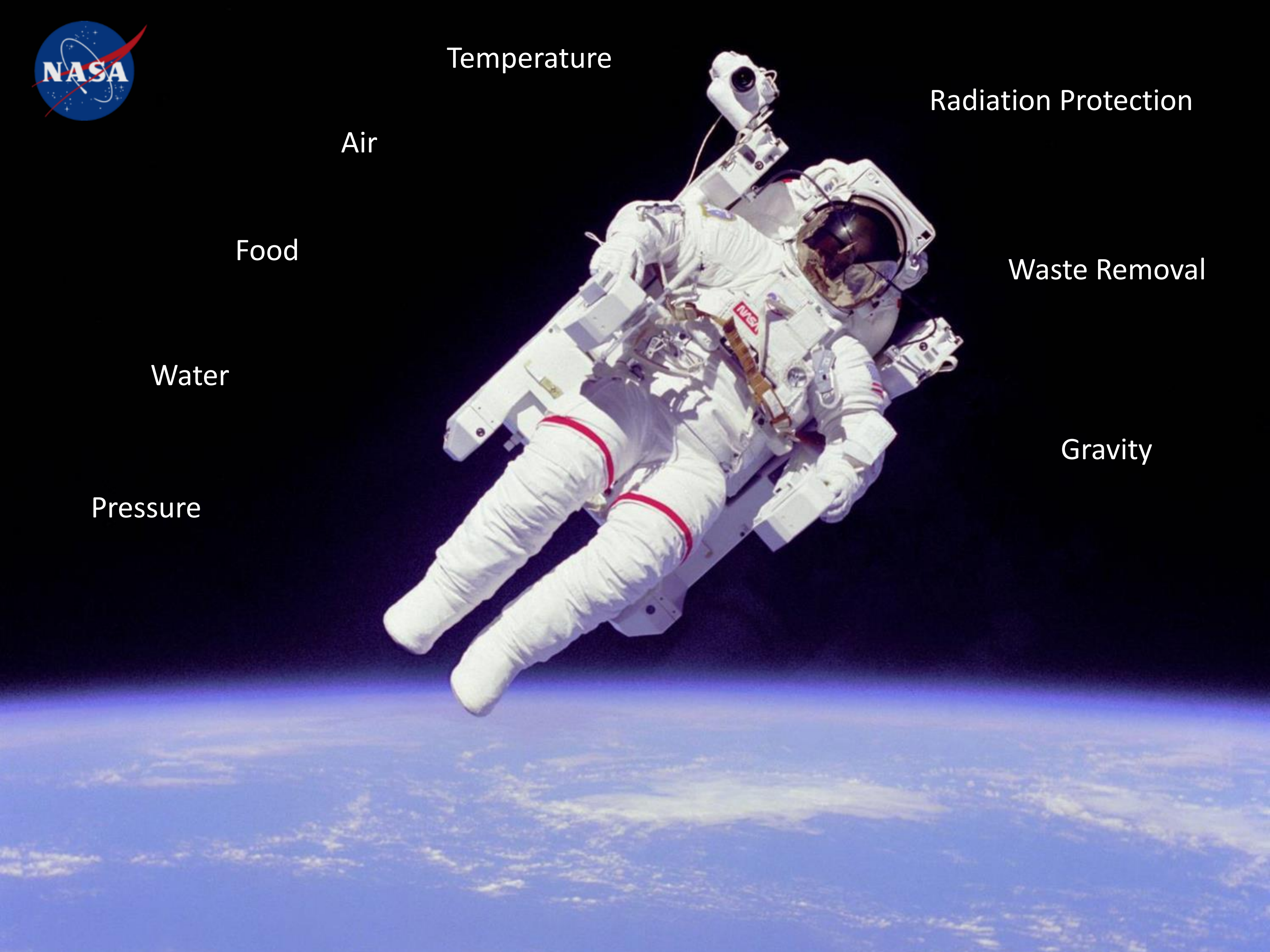


Image: NASA Ames/JPL-Caltech/T. Pyle

Life Support for Long Duration Missions

John A. Hogan, Ph.D.
Chief, Bioengineering Branch
PI – STMD GCD Synthetic Biology Project
NASA Ames Research Center

ARC Space Portal
April 21, 2021


Temperature
Radiation Protection
Air
Food
Waste Removal
Water
Gravity
Pressure

Earth’s Life Support Systems (ELSS)

<u>Physical/Chemical Properties & Processes</u>

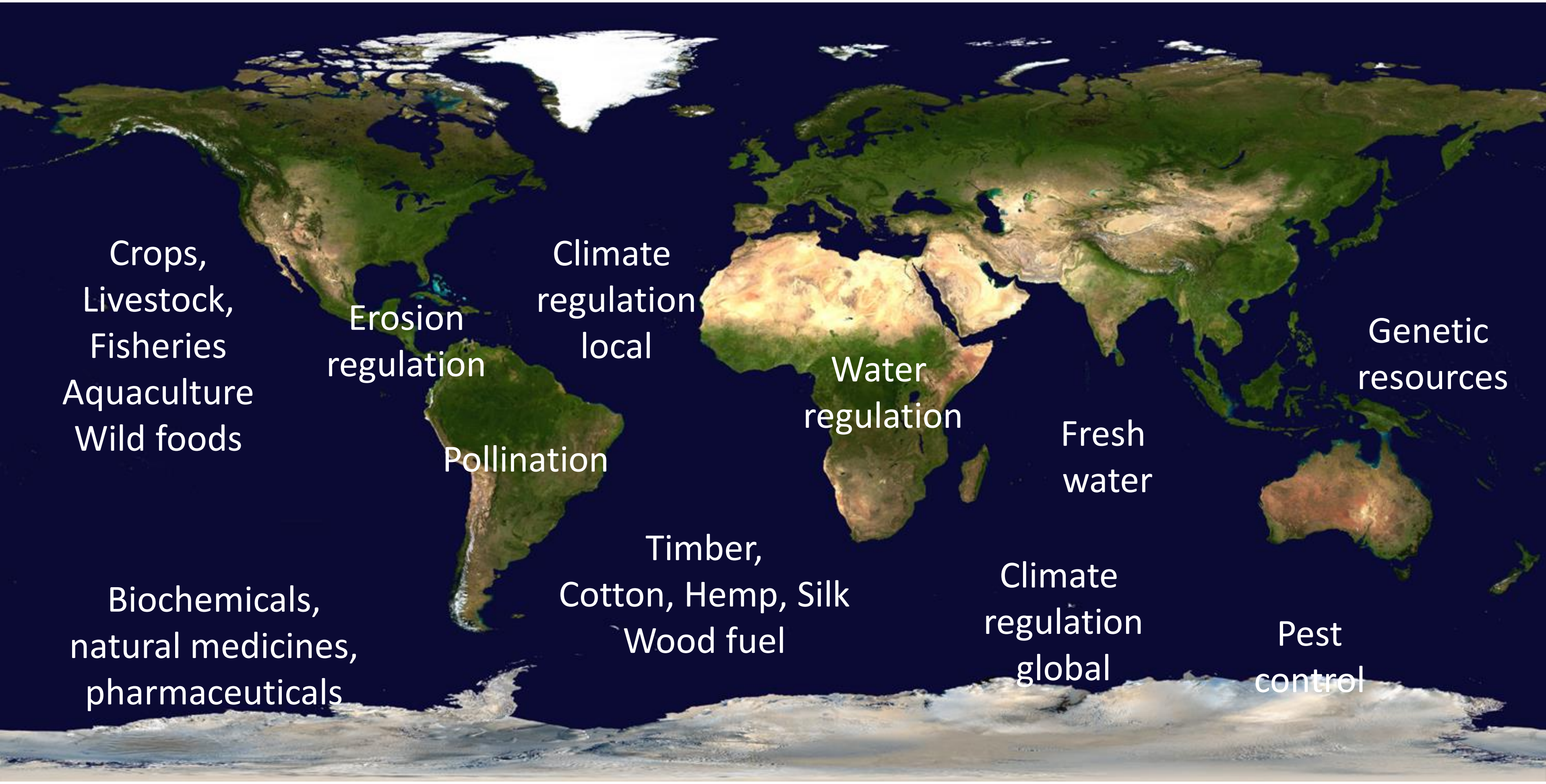
- Resource diversity/distribution/cycling
- Radiation protection – Earth’s core
- Proper gravitational field
- Stable rotation
- Proper solar radiation levels
- Proper atmospheric pressure

Earth's Ecosystem Services

Water/waste
purification

Air quality
regulation

Aesthetic/Spiritual values
Recreation/Ecotourism



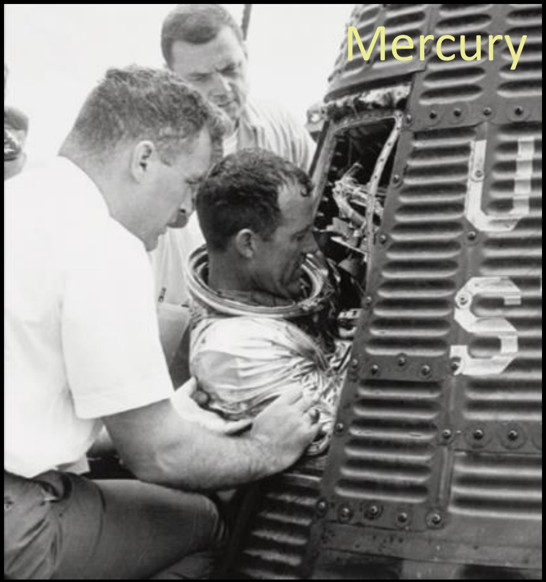
Disease
regulation

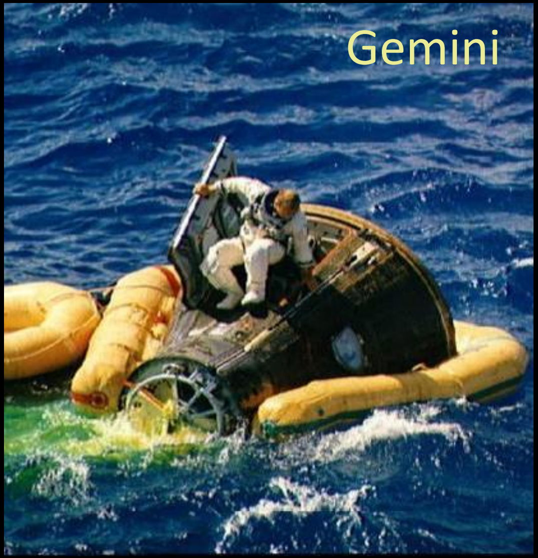
Natural hazard
regulation

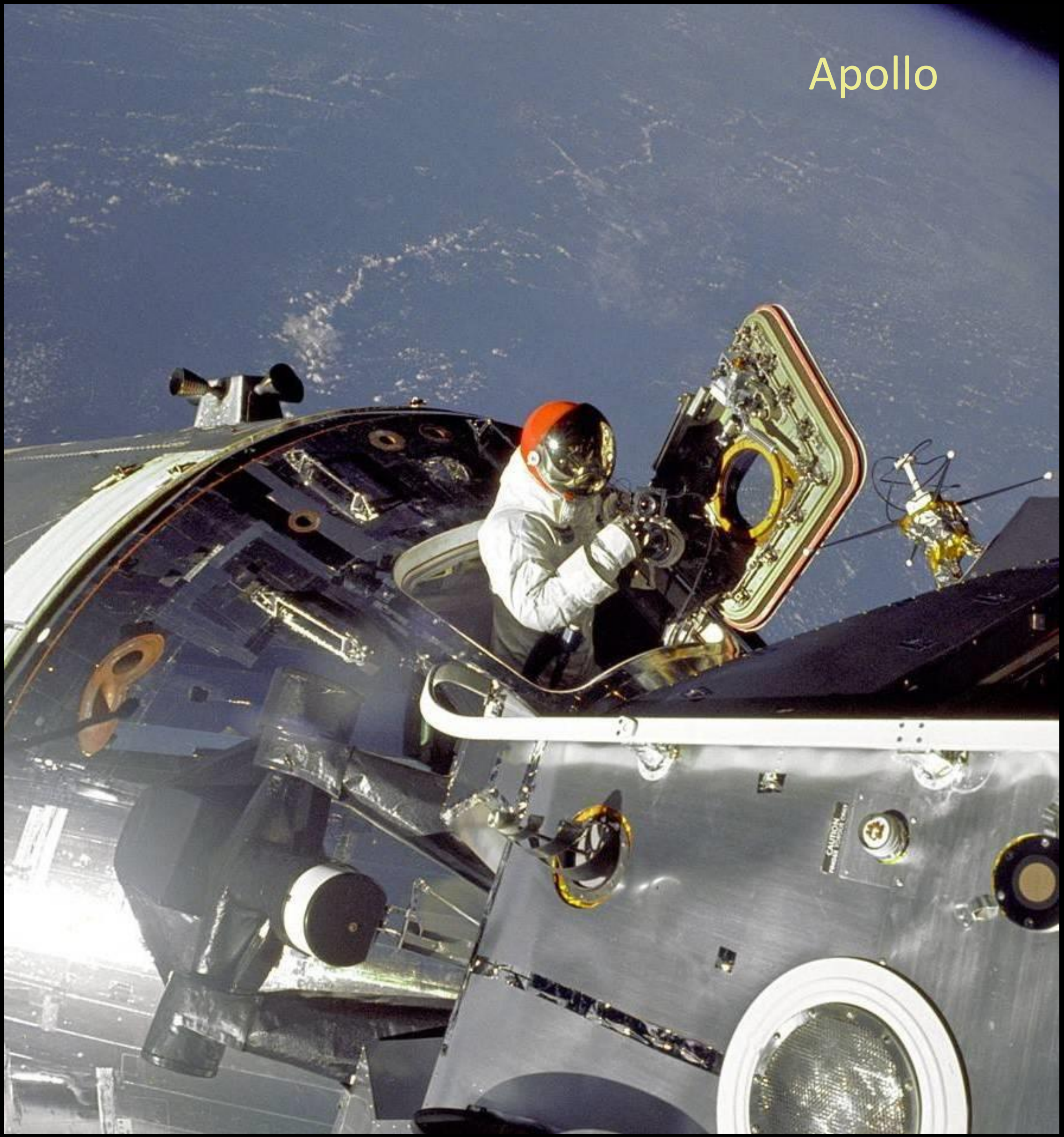
Ref.: Millennium Ecosystem Assessment
United Nations Environment Programme (2005)

Human Space Exploration

Early Missions

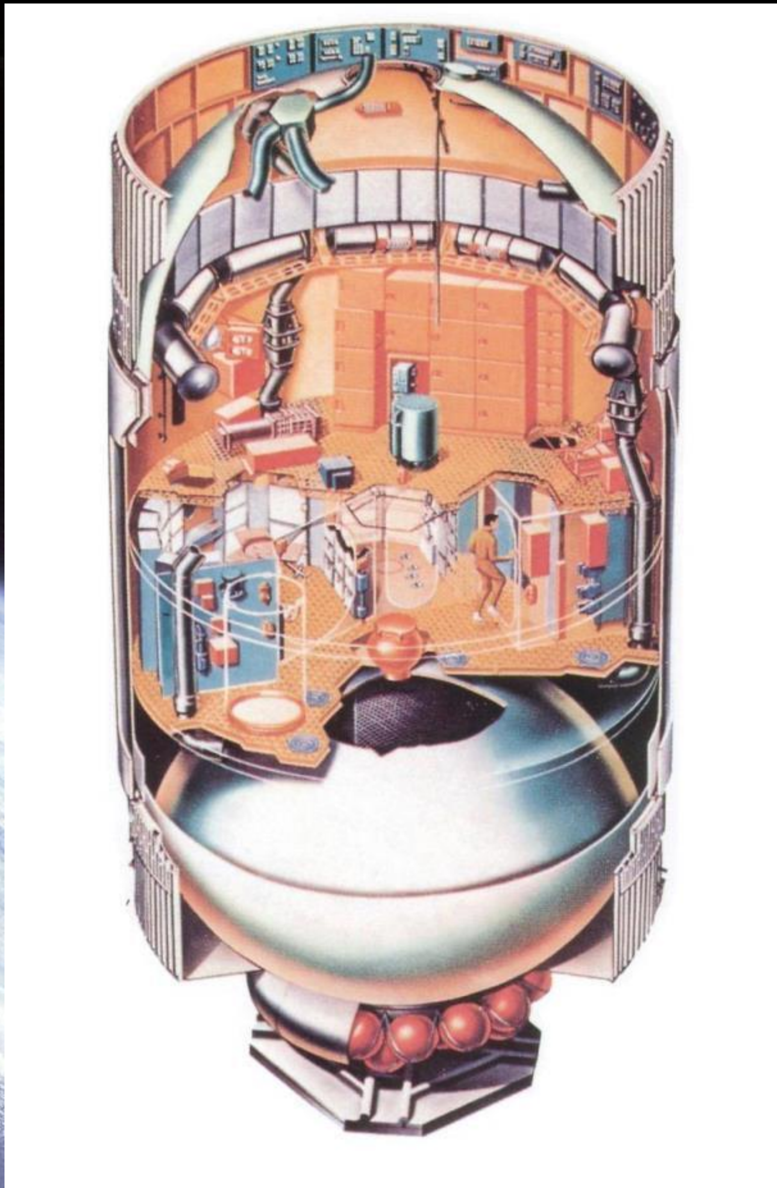






SKYLAB

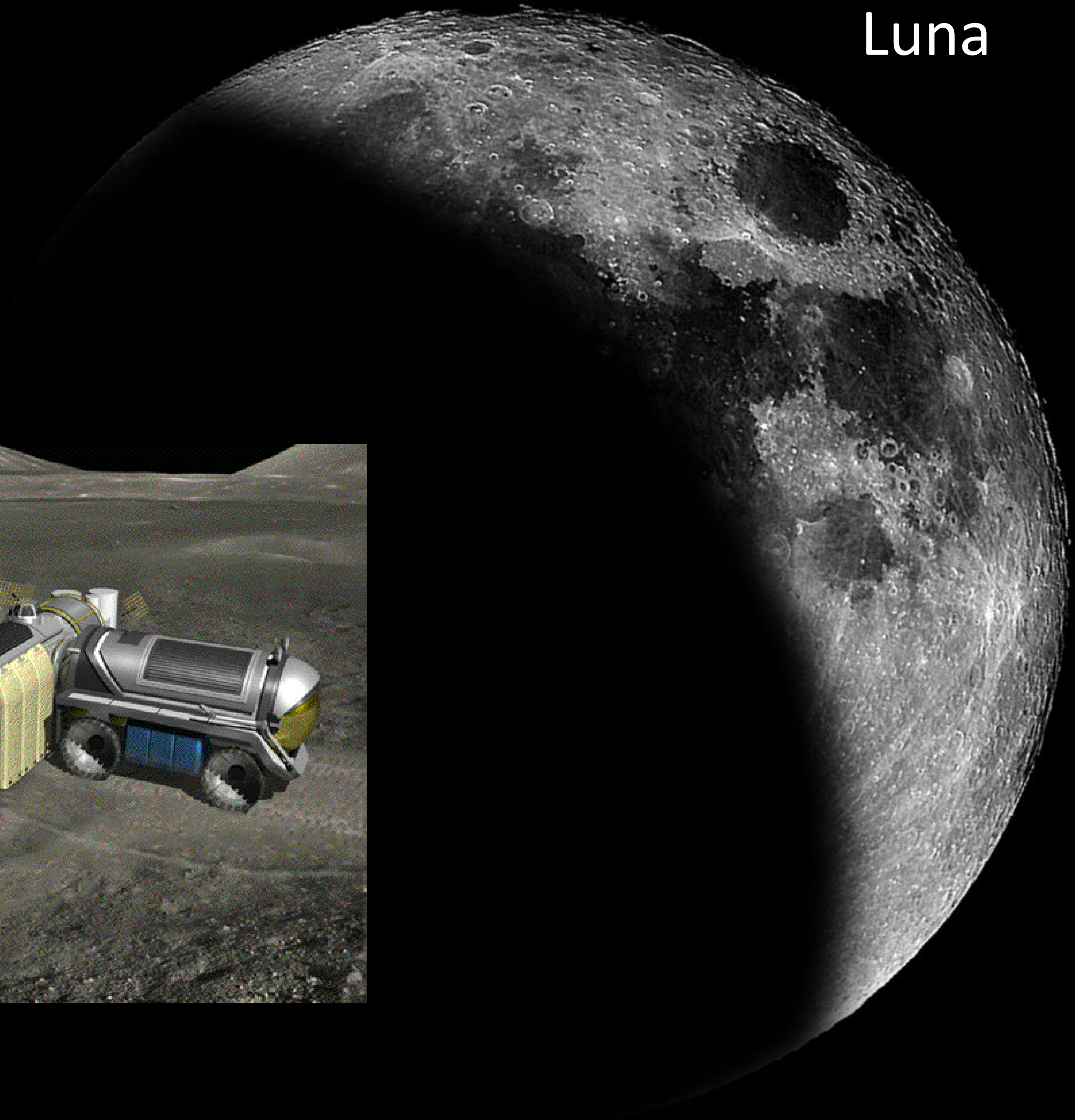
3 Missions - 28, 59, 84 days

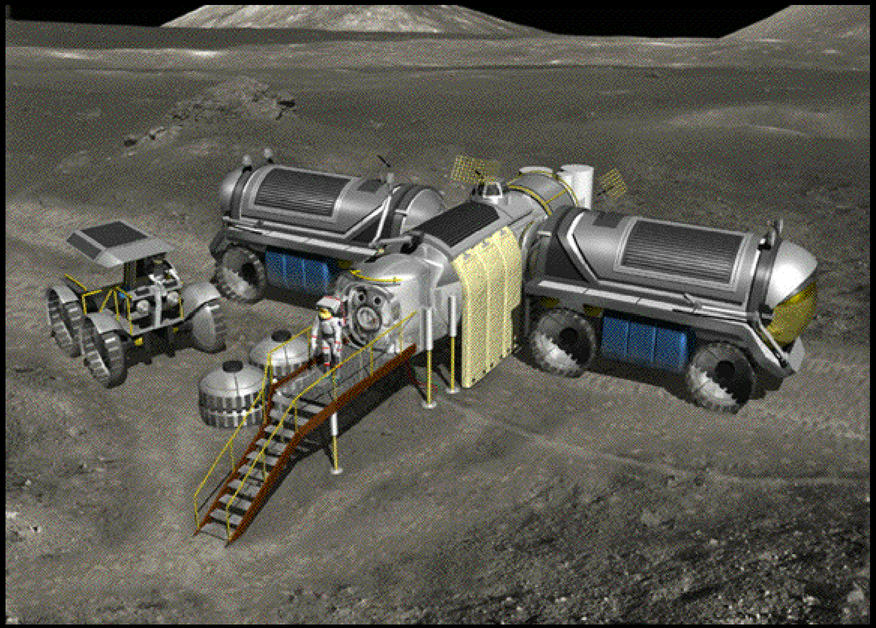



STS

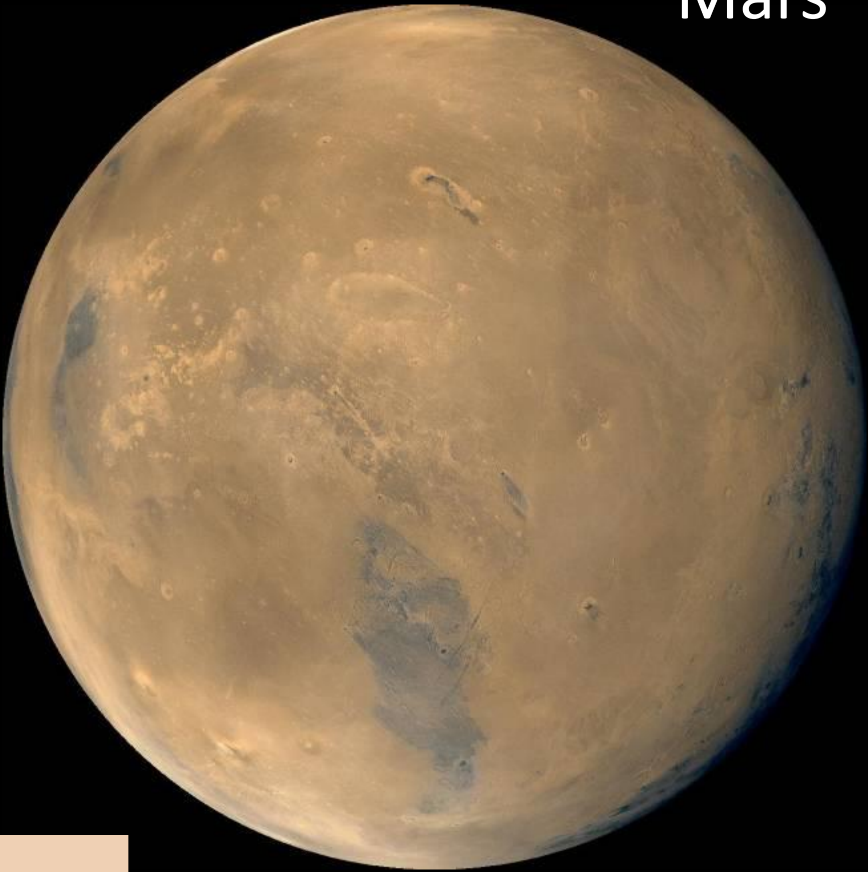
ISS

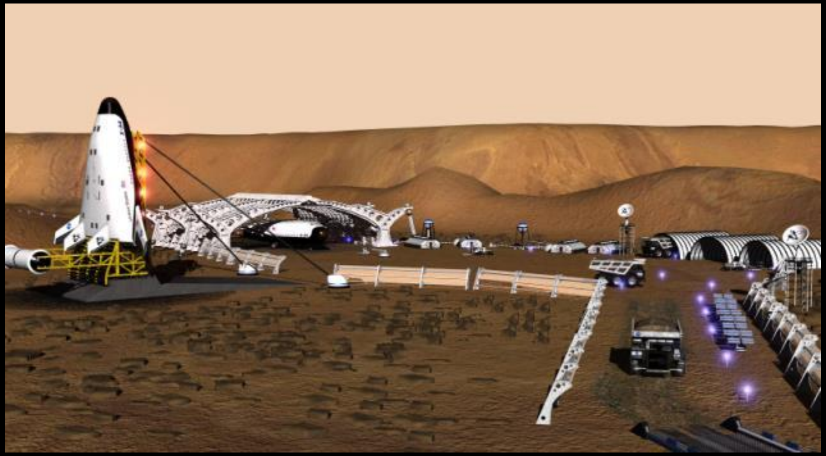
Luna





Mars





Life Support Requirements Mass Breakdown

(Per Person-Day)

DAILY INPUTS - NOMINAL

	kg
Oxygen	0.84
Food Solids	0.62
Water in Food	1.15
Food Prep Water	0.79
Drink	1.62
Hand/Face Wash Water	1.82
Shower Water	5.45
Clothes Wash Water	12.50
Dish Wash Water	5.45
Flush Water	0.50
TOTAL	30.74

5.02 - 30.74 kg per person-day

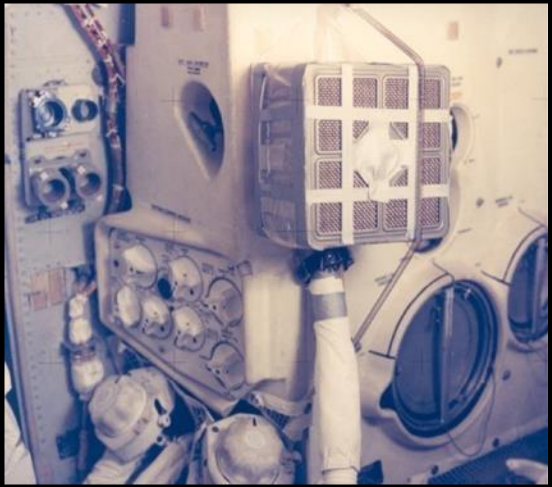
11.3 Metric Tons Per Person-Year

DAILY OUTPUTS - NOMINAL

	kg
Carbon Dioxide	1.00
Respiration and Perspiration Water	2.28
Urine	1.50
Feces Water	0.09
Sweat Solids	0.02
Urine Solids	0.06
Feces Solids	0.03
Hygiene Water	6.68
Clothes Wash Water	11.90
Clothes Wash Latent Water	0.60
Other Latent Water	0.65
Dish Wash Water	5.43
Flush Water	0.50
TOTAL	30.74

Atmosphere Management

Air Revitalization



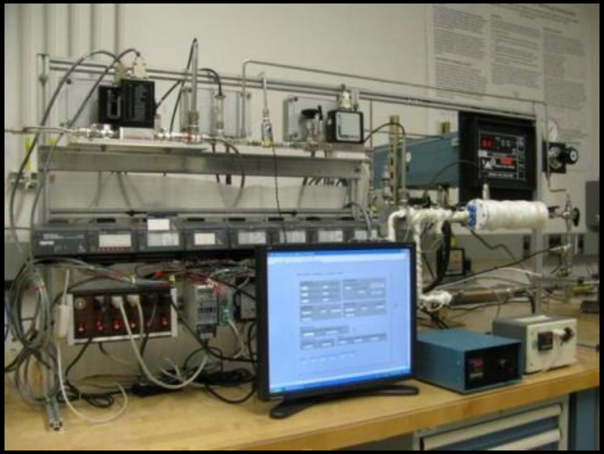
Functions

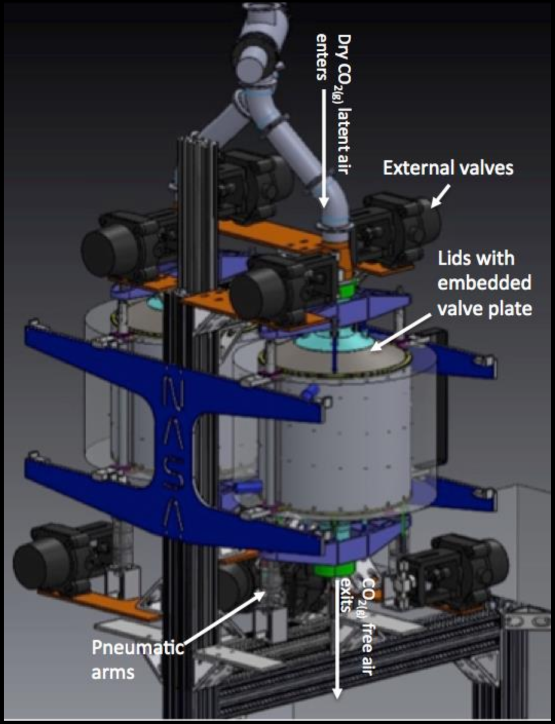
- O_2 Generation
- CO_2 Removal
- Contaminant Control
- Particulate Control

Current = 47% O_2 Recovery from CO_2
Goal = >75%

CO_2 Capture and Sequestration

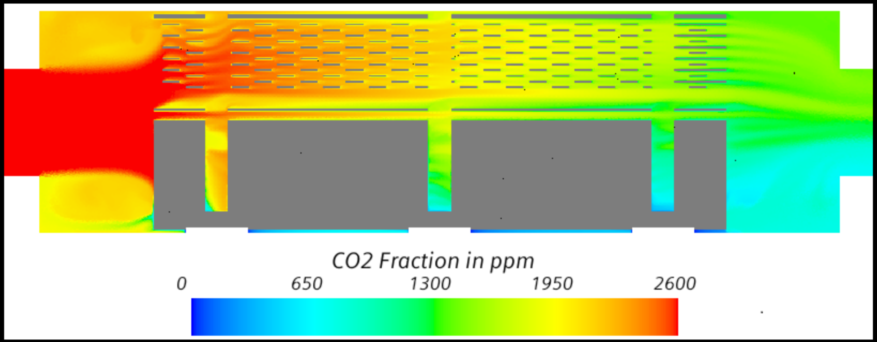
Temperature Swing Adsorption Compression



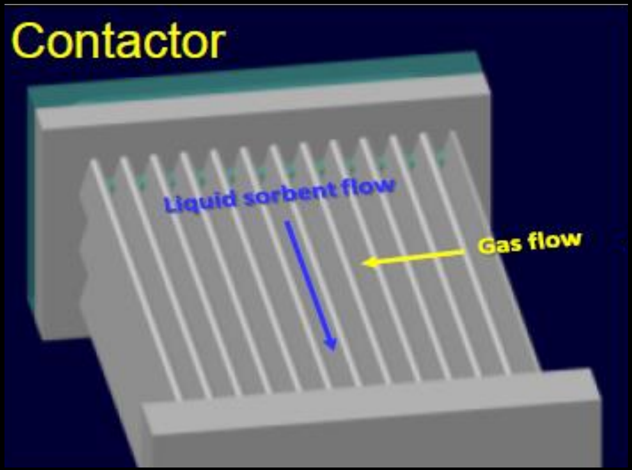


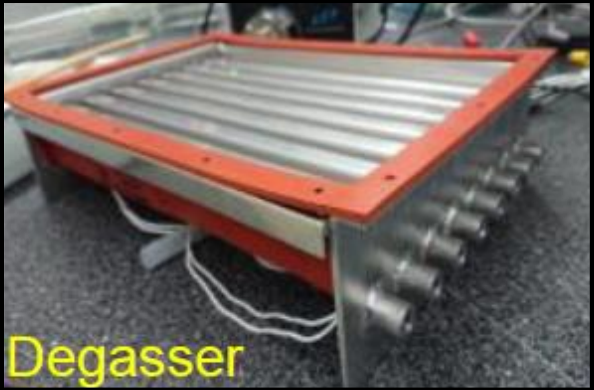
CO_2 Capture and Sequestration

CO_2 Cold Deposition (CDep)



Liquid Amines/CapiSorb





CO_2-Based Biomanufacturing

Objective: Use rapid physico-chemical methods to convert CO_2 to an organic media that is used by heterotrophic microbes to produce mission-relevant products in space.

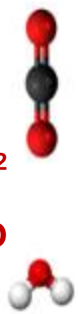
Concept Example:

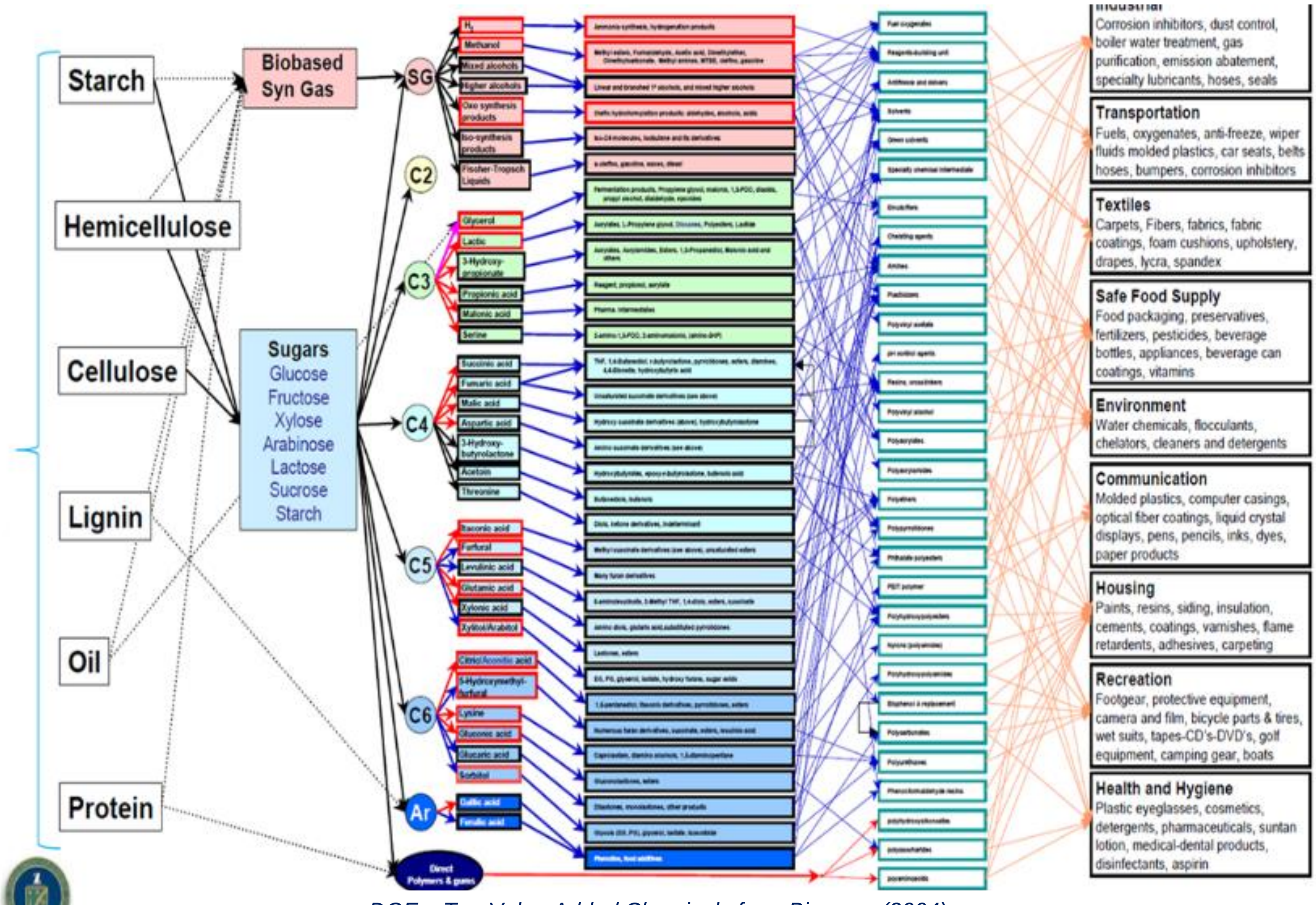
$CO_2 + H_2$

P/C Conversion System → Microbial Medium → Growth System → Product

Biomass-Based Manufacturing

CO_2
+
H_2O

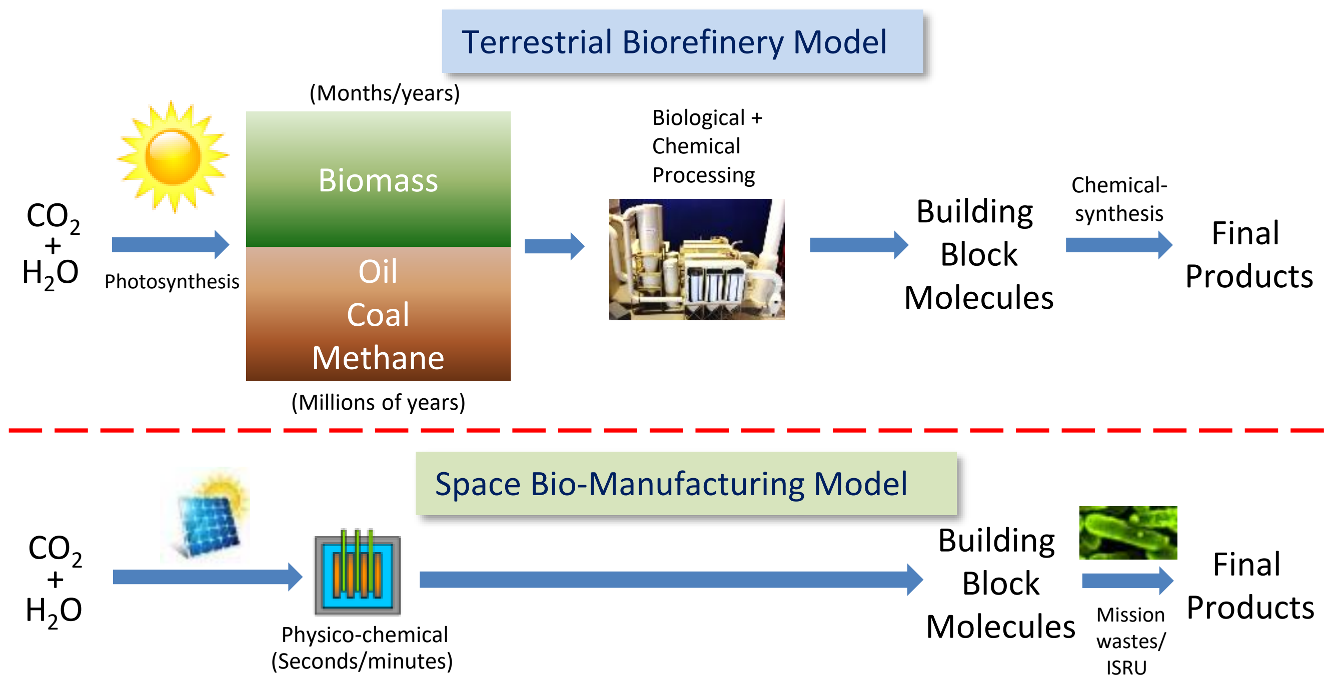




DOE – Top Value Added Chemicals from Biomass (2004)

Biomanufacturing Approaches

- Long duration missions/settlements require extensive loop closure, *in situ* resource utilization and *in situ* manufacturing
- Terrestrial “biorefineries” use low-efficiency biomass processes - not viable in space



CO_2-Based Manufacturing Project

CO_2 conversion

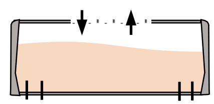
$CO_2 \rightarrow$ Formic Acid

$CO_2 \rightarrow CO \rightarrow$ Acetate

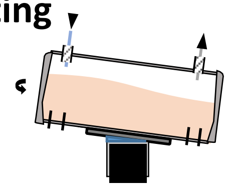
CO_2 Conversion Challenge

$CO_2 \rightarrow$ Glucose

Bioreactor development and testing



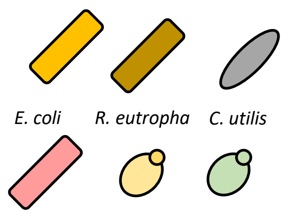
Passive membrane diffusion system



Rocking system

Products and applications

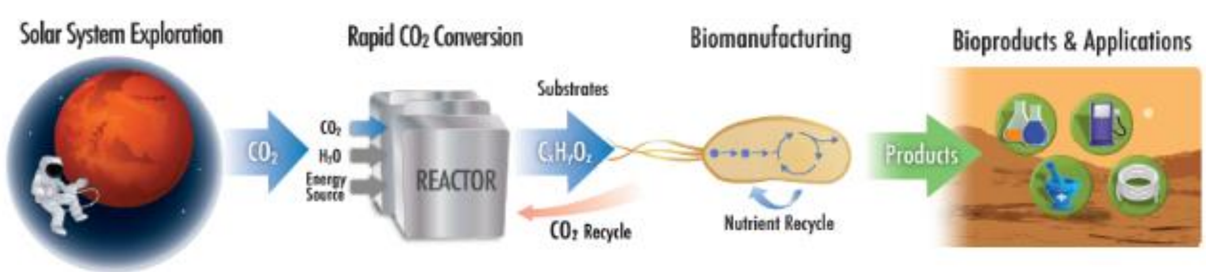
Microorganism engineering and testing



Pathway engineering
Metabolize uncommon substrates

Genetic Tools
Development of expression systems

Products
Carbonic Anhydrase



Funded by STMD Game Changing Division

NASA CO_2 Conversion Centennial Challenge

NASA
CO_2 Conversion
Challenge

GOAL: Abiotic production of sugars from CO_2 to support to feed heterotrophic microbial biomanufacturing operations

PHASE 1: CONCEPT

Goal: Provide a preliminary design schematic and description of the physicochemical conversion system the competitor(s) could construct to demonstrate the production of selected carbon-based molecular compounds.

Duration: 8 Months

Participation: Submissions from 20 teams were evaluated for a Prize

Awards: $250,000 Prize Purse
Five teams were awarded $50,000 each

COMPLETE

PHASE 2: DEMONSTRATION

Goal: Demonstrate a physicochemical system that is able to produce one or more of the targeted compounds.

Competitors will: Build a system; submit video evidence of their successful process; host the Challenge judges for an on-site evaluation and submit a sample for analysis.

Duration: 12 months

Awards: $750,000 Prize Purse

1st Place - $400,000
2nd Place - $250,000
3rd Place - $100,000

PHASE 1 AWARDS

5 Winning Teams each received $50,000

Dioxide Materials	Boca Raton, Florida
Lotus Separations	Princeton, New Jersey
Peidong Yang Group	Berkeley, California
RenewCO_2 LLC	Jersey City, New Jersey
The Air Company	Brooklyn, New York

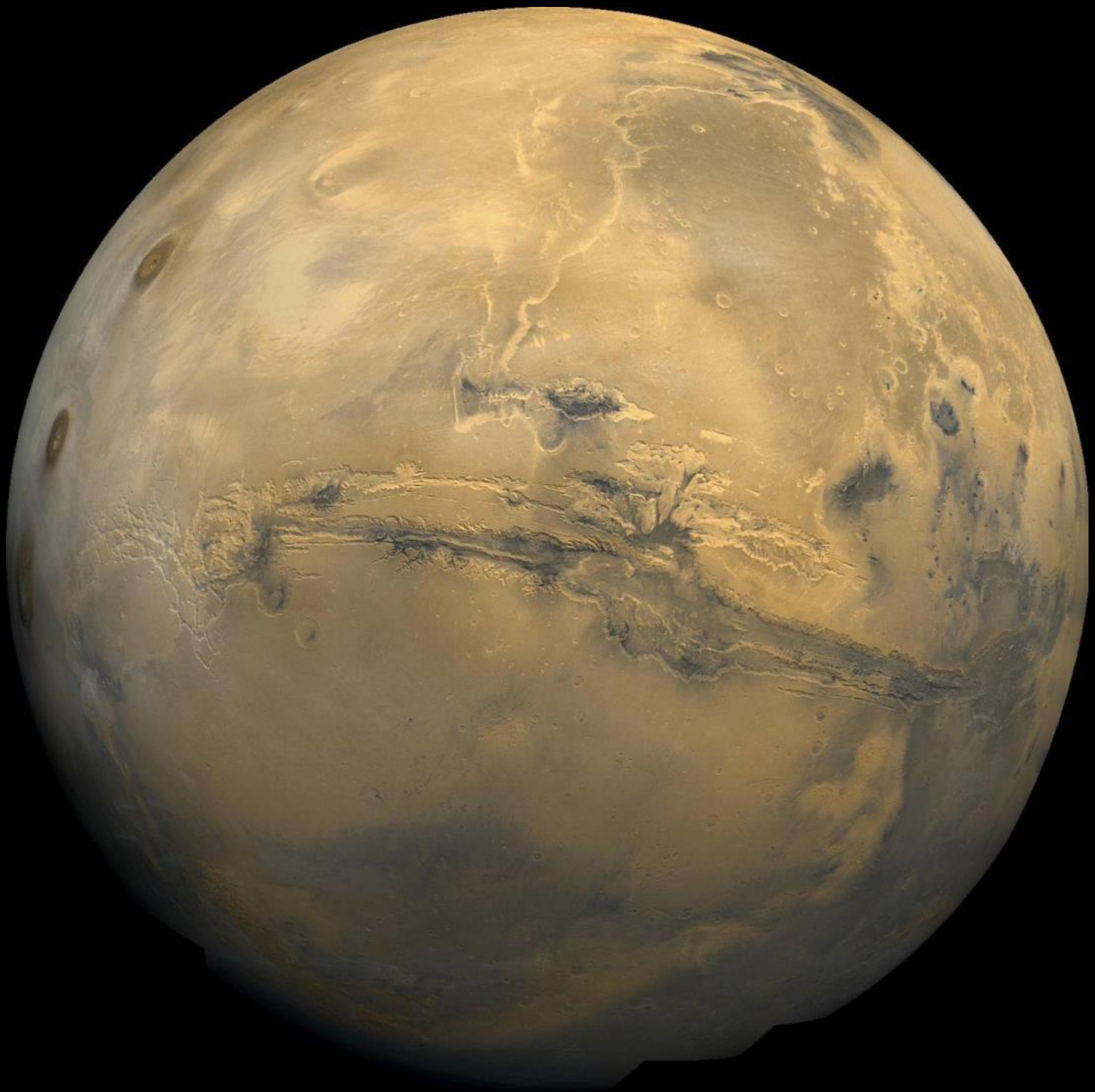
Criteria for Judging

- **Technology overview-** Description of Physiochemical Overview and its Chemistry
- **Assumptions**- Operations/Tactics Critical to Overcoming Implementation Challenges
- **Design Schematic-** Can operate continuously for 7 hours, produce product sufficient for analysis
- **Physical Properties-** Physical characteristics of system
- **Data Analysis-** Supporting calculations/preliminary laboratory analysis data
- **Project Plan-** Milestones for building the technology

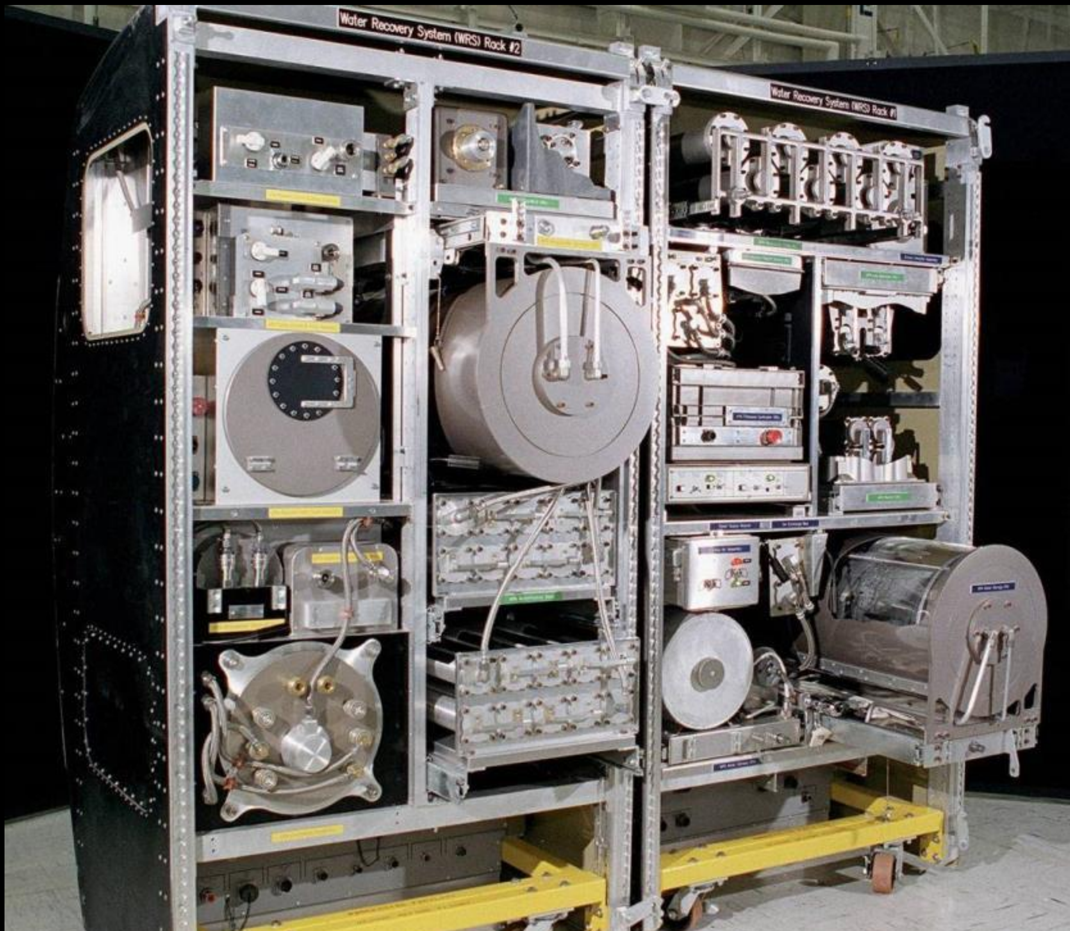
Challenge Target Compounds

Product Constituent	Weight Factor
D-Glucose	100
Other 6-carbon Sugars (hexoses)	80
5-carbon sugars (pentoses)	50
4-carbon sugars (tetroses)	10
3-carbon sugars (trioses)	5
Glycerol	5

Water Treatment



Wastewater to Drinking Water



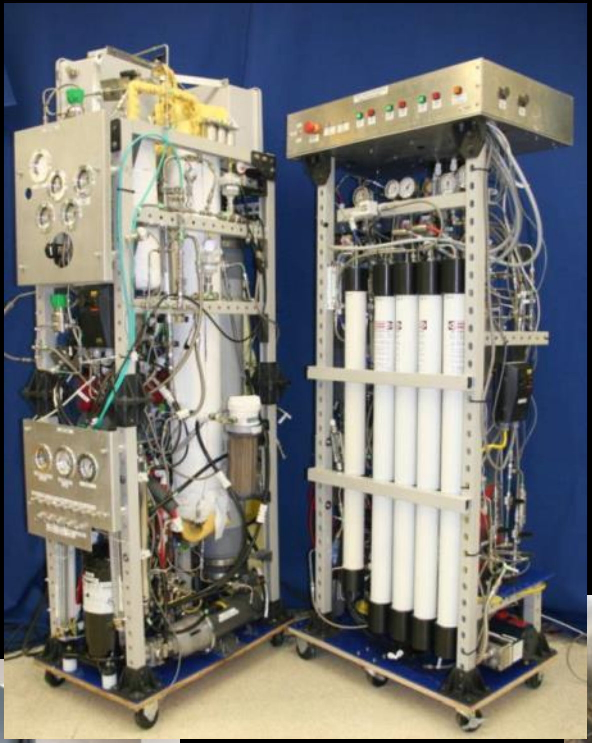
ISS Water Recovery Subsystem

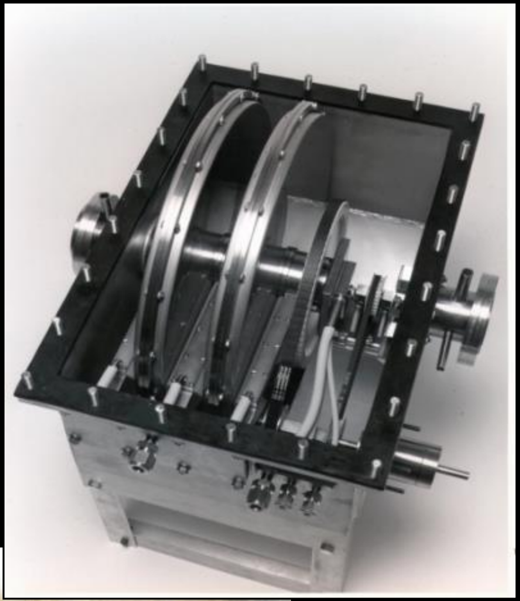
<u>Functions</u>

- Disinfection
- Organic Removal
- Inorganic Removal
- Maximize Recovery

- Current = 90% water recovery
- Goal = 98% Water recovery

Closed-Loop Water Treatment





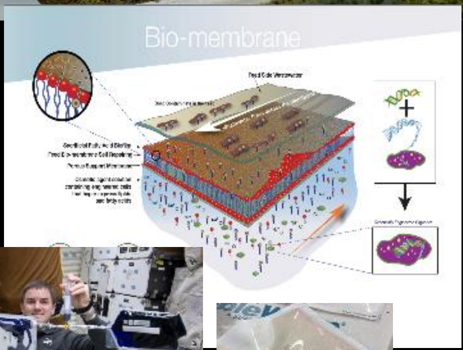
ARC Water Recovery Systems

- Forward Osmosis Secondary Treatment (AWP)
  - Removal of ammonia, salts and solids from the effluent of the TTU/JSC/KSC bioreactor system.

- ARC Sustainability Base Grey Water Recycling System
  - Long duration membrane testing in operational environment.
  - Operating since 2014 treating gray water from NASA office building.
  - Transferred to Army as forward operating base water recycling system.

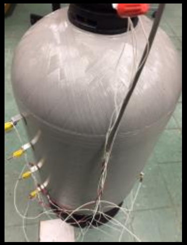
Sustainability Base

- Bio-membrane “living” water purification membrane.
  - Membrane capable of self repair and self cleaning.
  - Based on the integration biomaterials and living organisms.
  - Extends membrane life indefinitely, fully regenerable.



- Emergency Water Recycling System
  - Water recycling bag that requires no power or control to produce engineered food/water solution designed to keep crew alive.
  - Modified to produce baby formula for developing world applications.
  - Three flight experiments completed through NASA/ESA collaborations.

- Spectral Mass Gauging
  - Measuring tank water volumes with external sensing



- Silver-based Disinfection
  - Developing alternatives to iodine-based systems

Waste Management

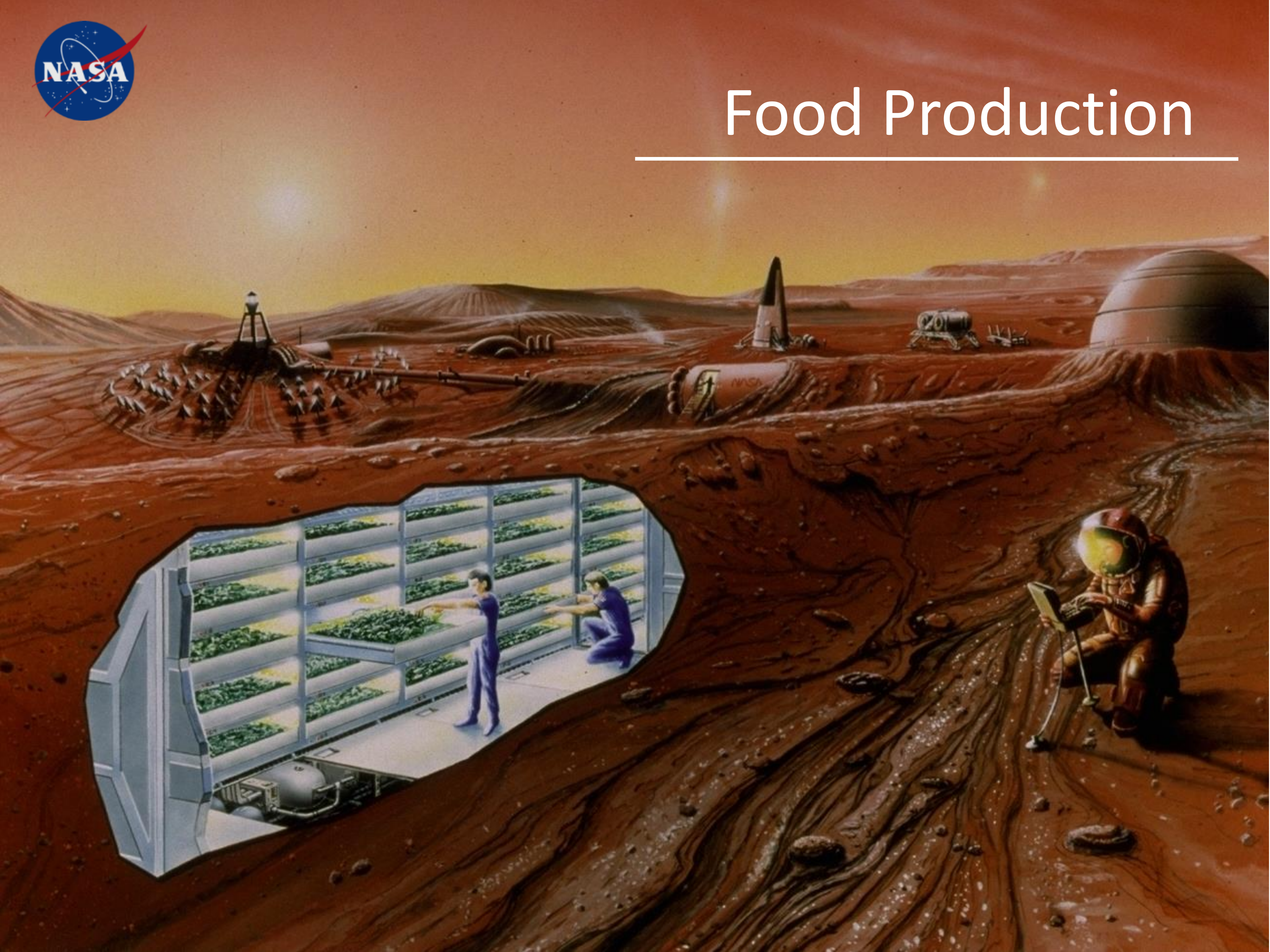
“Waste” Conversion and Reuse

Functions

- Volume Reduction
- Odor Control
- Sanitization
- Recover H_2O, O_2, CO_2, Fuel, Nutrients, Building Materials

ARC Heat Melt Compactor System

Food Production




Mercury and Gemini Food (1961-1966)


Apollo Food (1968-1972)


Skylab Food and Tray (1973 - 1974)


Shuttle Food Tray


Freeze-Dried Foods

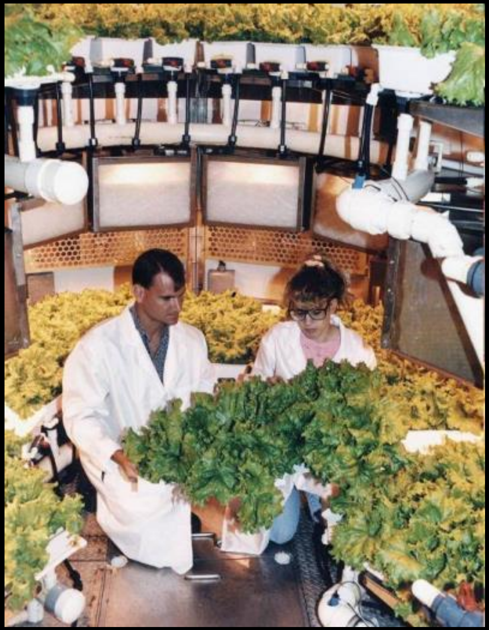

Thermostabilized Foods

Beverages


Natural Form Foods and Condiments


International Space Station Food Container

Food and Nutrition



Food Stores Goals

- > 5 year Shelf life
- Cold storage
- Acceptability
- Nutritional stability

Closed Agriculture Goals

- Maximize Yield
- Low Water
- Efficient Lighting
- Use recovered nutrients

BioNutrients: Overall Project Concept

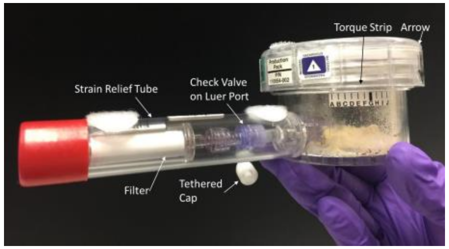
5-Year ISS Storage-Reactivation Demonstration – NG-11 (04/17/19)

Develop and Demonstrate an on-demand nutrient production system for long duration missions.

Deliverables:

- Flight tested nutrient production system that can be evolved for future surface missions, and serve as basis for producing other mission-relevant compounds.
- Potential space-adapted microbial hosts for future genetic engineering.
- Identify on-orbit safety and operational needs for future implementation.

Future Implementation Concept



BioNutrients Flight Production Pack for on-orbit testing

Engineering yeast to produce nutrients on-demand

Developing microbes adapted for use in space

BioNutrients Production Pack w/ media and yeast

Also developing yogurt-based production systems

BioNutrients Flight Ops

Crew member David Saint-Jacques hydrating BioNutrients-1 production pack aboard ISS - First BioNutrients crew operations (June 2019).

Production packs in SABL incubator.

BioNutrients production packs removed from incubator after initial growth phase for second agitation.

3 On-orbit operations performed: 2 years completed.

The Center for the Utilization of Biological Engineering for Space

CUBES

Lead Institution:
University of California – Berkeley; Dr. Adam Akin, PI

Vision:
- Support biomanufacturing for deep space exploration;
- Create an integrated, multi-function, multi-organism biomanufacturing system for a Mars mission; and
- Demonstrate continuous and semiautonomous biomanufacture of materials, pharmaceuticals, and food in Mars-like conditions.

5 years - up to $3M/year budget

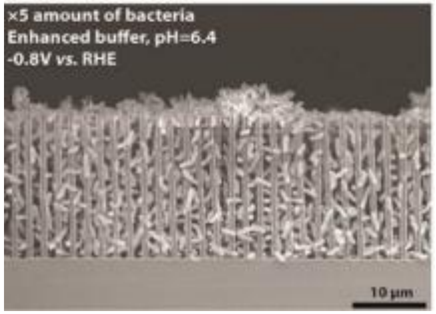
https://cubes.space

Berkeley University of California — Stanford University — Utah State University — UC Davis — UF University of Florida

Bio-Manufacturing for Deep Space Exploration – CUBES Activities

Use of Local Resources to Support Biomanufacturing

- Conversion of carbon dioxide, water, and other needed local resources to support rapid plant and microbial growth systems
- Develop nanowire/bacteria hybrids for solar-driven CO_2 fixation to organic substrates for microbial growth
- Develop novel hybrid N_2 fixation methods for nitrogen capture/supply



Nanowire/Bacteria Hybrid Reactor for acetate feedstock production

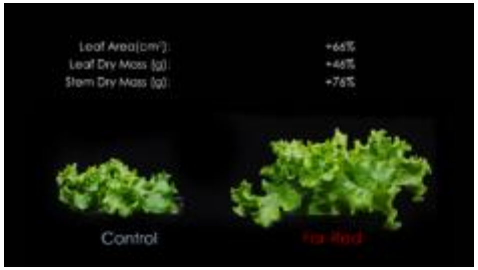
Biomanufacturing of Mission Products

- Optimize media/microbial engineering to produce bioplastics
- Advanced additive manufacturing techniques for mission products
- Increase yield, volume efficiency, and photosynthetic efficiency
- Pharmaceutical synthesis in plants and cyanobacteria
- Microbiome engineering for enhanced plant growth/performance

In-Space Bioplastic synthesis and product manufacturing

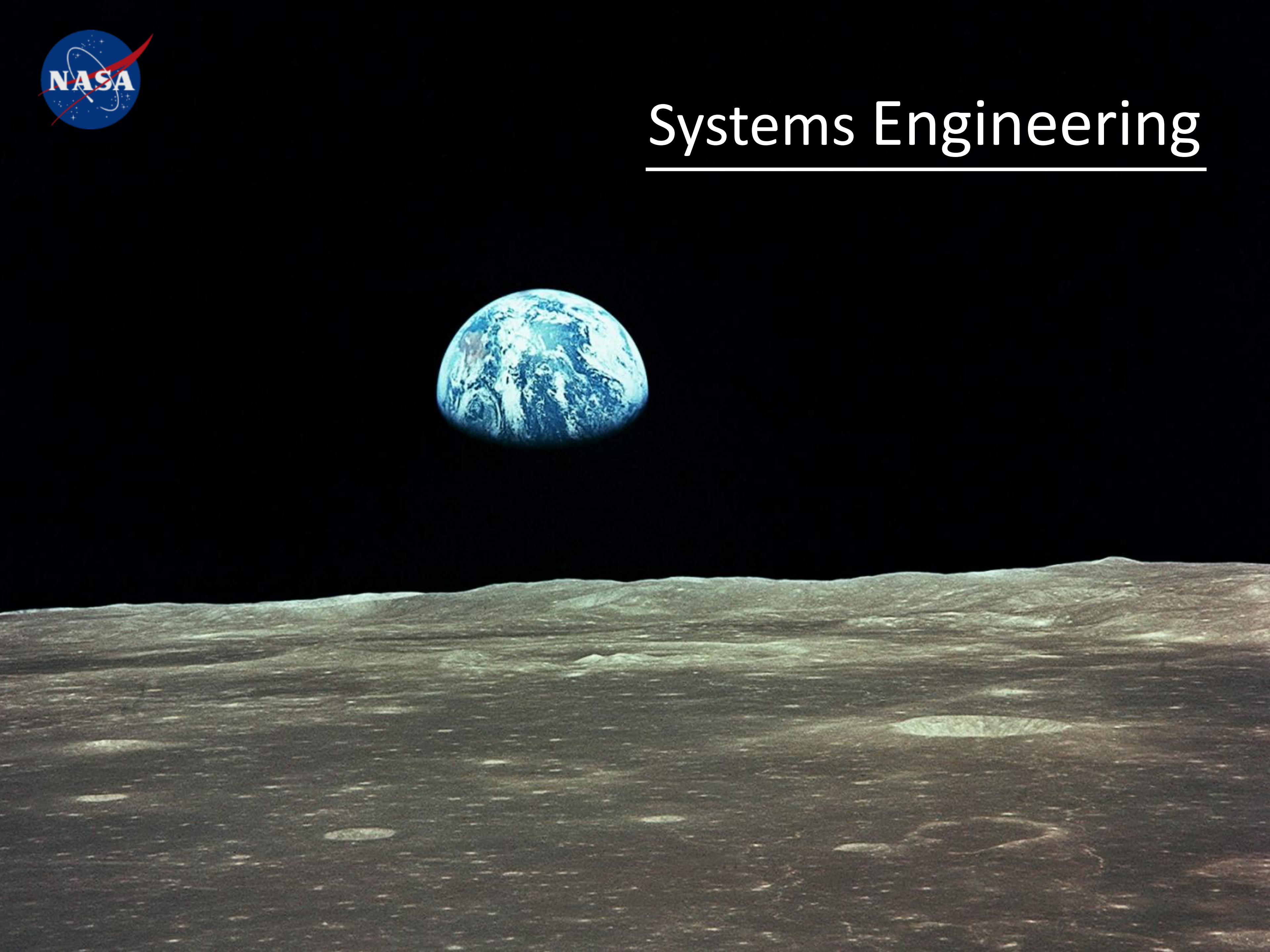
Systems Analysis, Integration and Demonstration

- Determine resource availability to guide technology development efforts
- Develop performance requirements, architecture and process models
- Integrate components for a scaled biomanufacturing demonstrationand assist in fabrication/testing

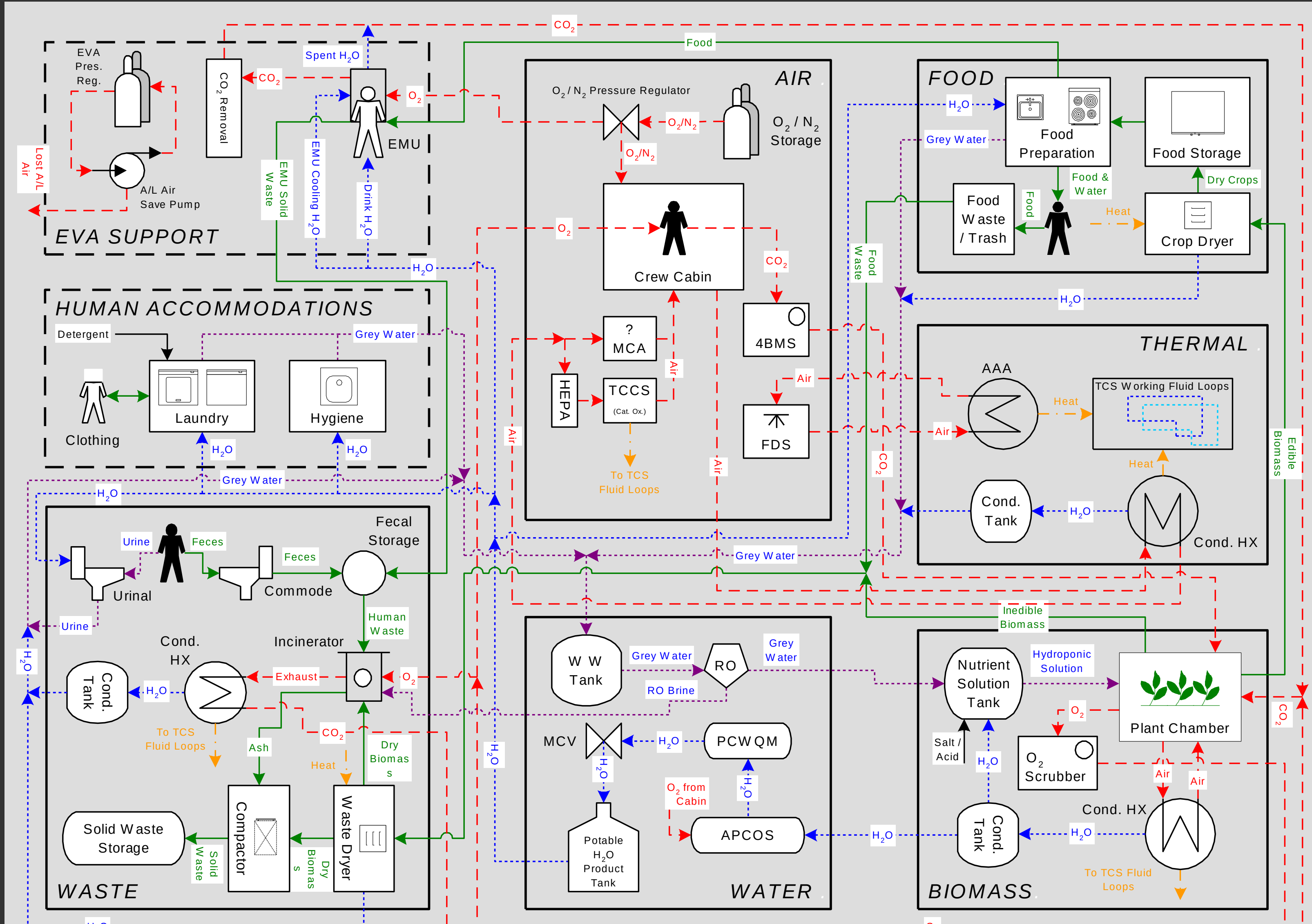


Far-red wavelength benefits

Systems Engineering



Systems Engineering



From: NASA ALS Reference Missions Document

Forward Challenges

- Optimizing system closure
- Mass, power, and volume reduction
- System reliability
- Food systems for long duration missions
- Meeting planetary protection regulations
- Scaling processes for long-term concepts

Thank You

john.a.hogan@nasa.gov