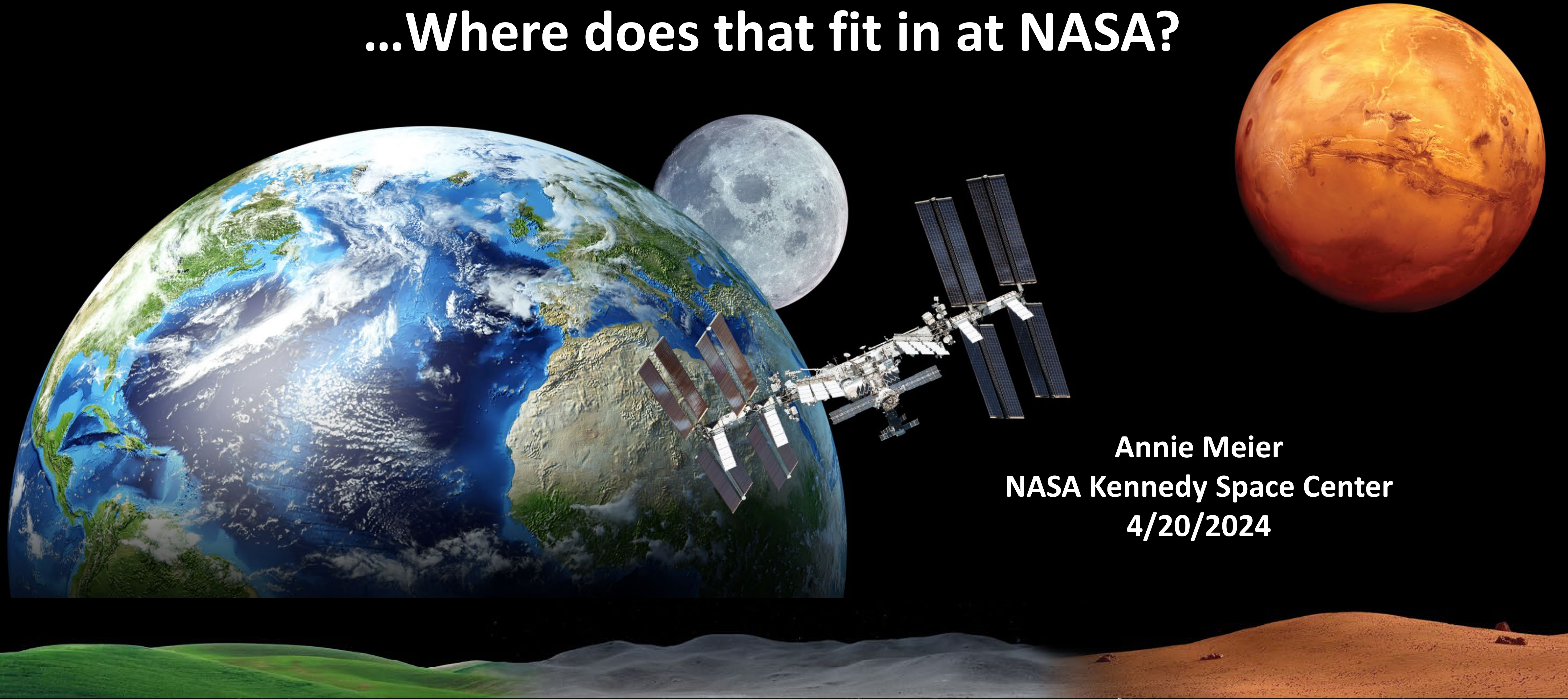
RESOURCE RECOVERY from TRASH …Where does that fit in at NASA?



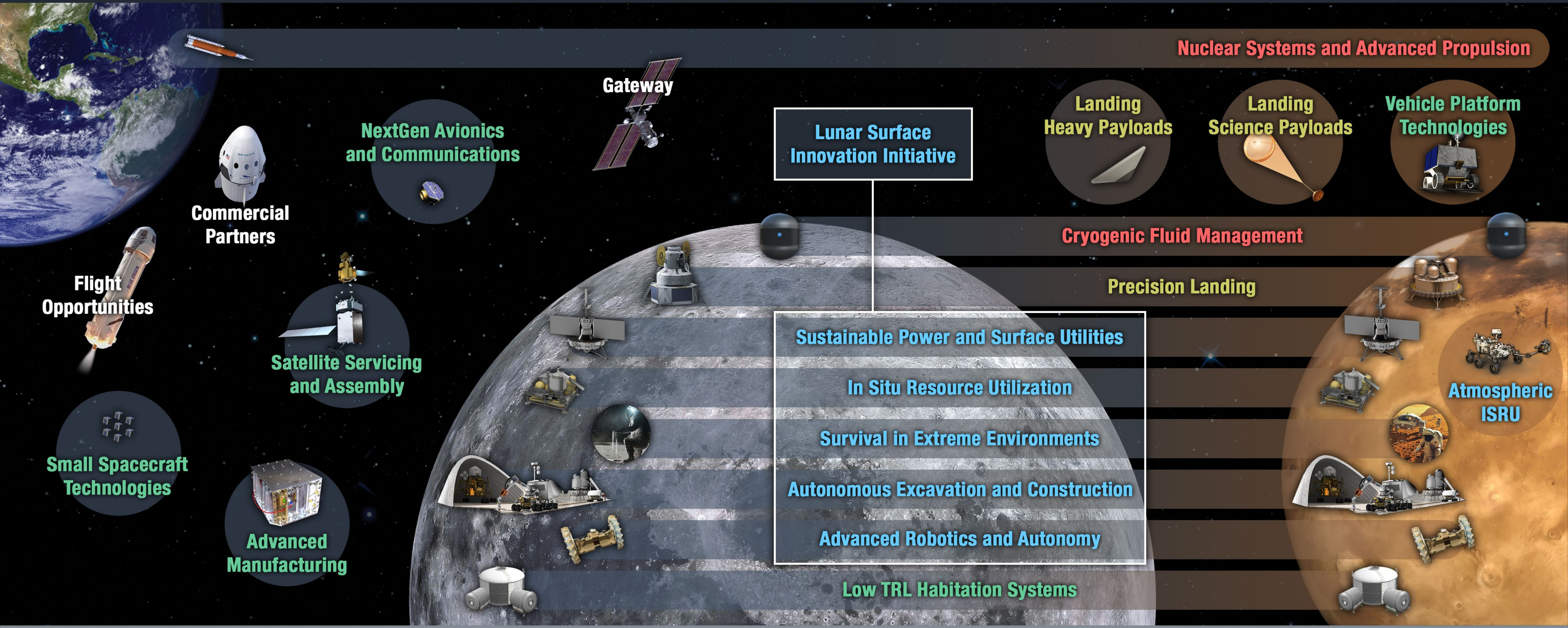
Annie Meier
NASA Kennedy Space Center
4/20/2024

Rapid, Safe, and Efficient Space Transportation

Expanded Access to Diverse Surface Destinations

Sustainable Living and Working Farther from Earth

Transformative Missions and Discoveries



Nuclear Systems and Advanced Propulsion

Commercial Partners

Flight Opportunities

NextGen Avionics and Communications

Gateway

Satellite Servicing and Assembly

Small Spacecraft Technologies

Advanced Manufacturing

Lunar Surface Innovation Initiative

Landing Heavy Payloads

Landing Science Payloads

Vehicle Platform Technologies

Cryogenic Fluid Management

Precision Landing

Sustainable Power and Surface Utilities

In Situ Resource Utilization

Survival in Extreme Environments

Autonomous Excavation and Construction

Advanced Robotics and Autonomy

Low TRL Habitation Systems

Atmospheric ISRU

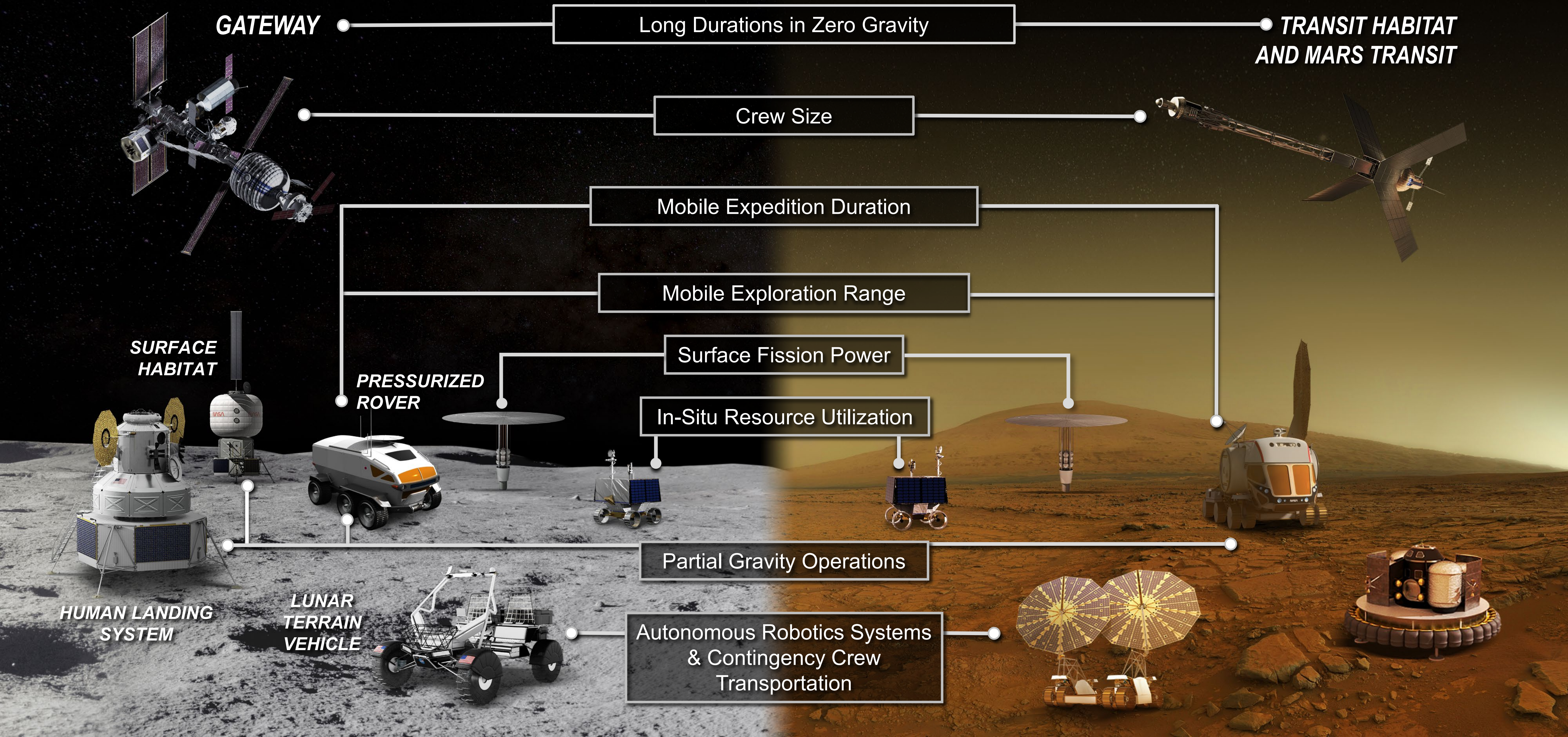
Mission Needs Drive Design

LOW EARTH RETURN	LUNAR RETURN	MARS RETURN
3 HOURS	3 DAYS	9 MONTHS
3,000°F	5,200°F	6,200°F
17,500 MPH	24,700 MPH	26,800 MPH
250 MILES	240,000 MILES	39,000,000 MILES

**Numbers are averages*

MOON AND MARS EXPLORATION

Operations on and around the Moon will help prepare for the first human mission to Mars



GATEWAY

Long Durations in Zero Gravity

TRANSIT HABITAT AND MARS TRANSIT

Crew Size

Mobile Expedition Duration

Mobile Exploration Range

SURFACE HABITAT

PRESSURIZED ROVER

Surface Fission Power

In-Situ Resource Utilization

Partial Gravity Operations

HUMAN LANDING SYSTEM

LUNAR TERRAIN VEHICLE

Autonomous Robotics Systems & Contingency Crew Transportation

Artemis: A Foundation for Deep Space Exploration

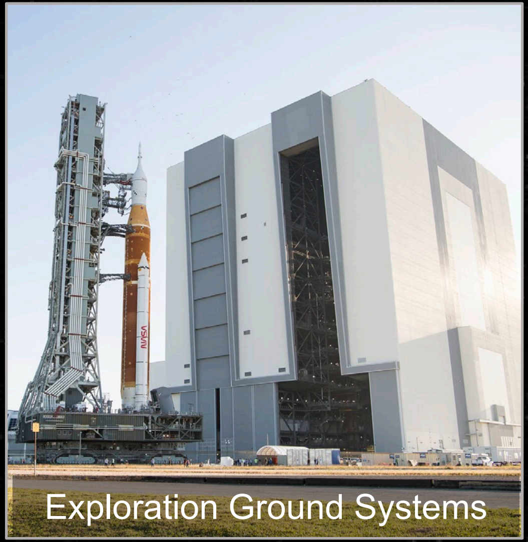

Space Launch System


Orion Spacecraft


Human Landing System


Surface Operations

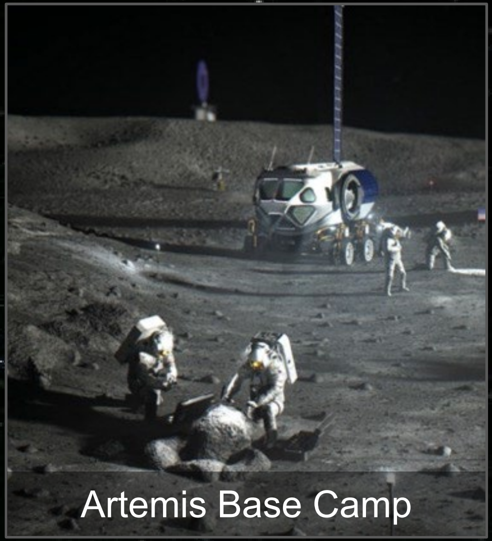

Gateway


Exploration Ground Systems


Space Communications & Navigation


Surface Mobility


Space Suits


Artemis Base Camp

ARTEMIS

ARTEMIS ACCORDS

- Australia
- Bahrain
- Brazil
- Canada
- Colombia
- Czech Republic
- Ecuador
- France
- India
- Israel
- Italy
- Japan
- Luxembourg
- Mexico
- New Zealand
- Nigeria
- Poland
- Republic of Korea
- Romania
- Rwanda
- Saudi Arabia
- Singapore
- Spain
- Ukraine
- United Arab Emirates
- United Kingdom
- The United States of America

United for Peaceful Exploration of Deep Space

Artemis I: 2022

Uncrewed flight test

COMPLETE

SLS, Orion, EGS

Artemis II: 2024

Crewed flight test

SLS, Orion, EGS

Artemis III: 2025

Crewed surface expedition

SLS, Orion, EGS, HLS

Artemis IV

Gateway assembly, crewed sustaining lander expedition

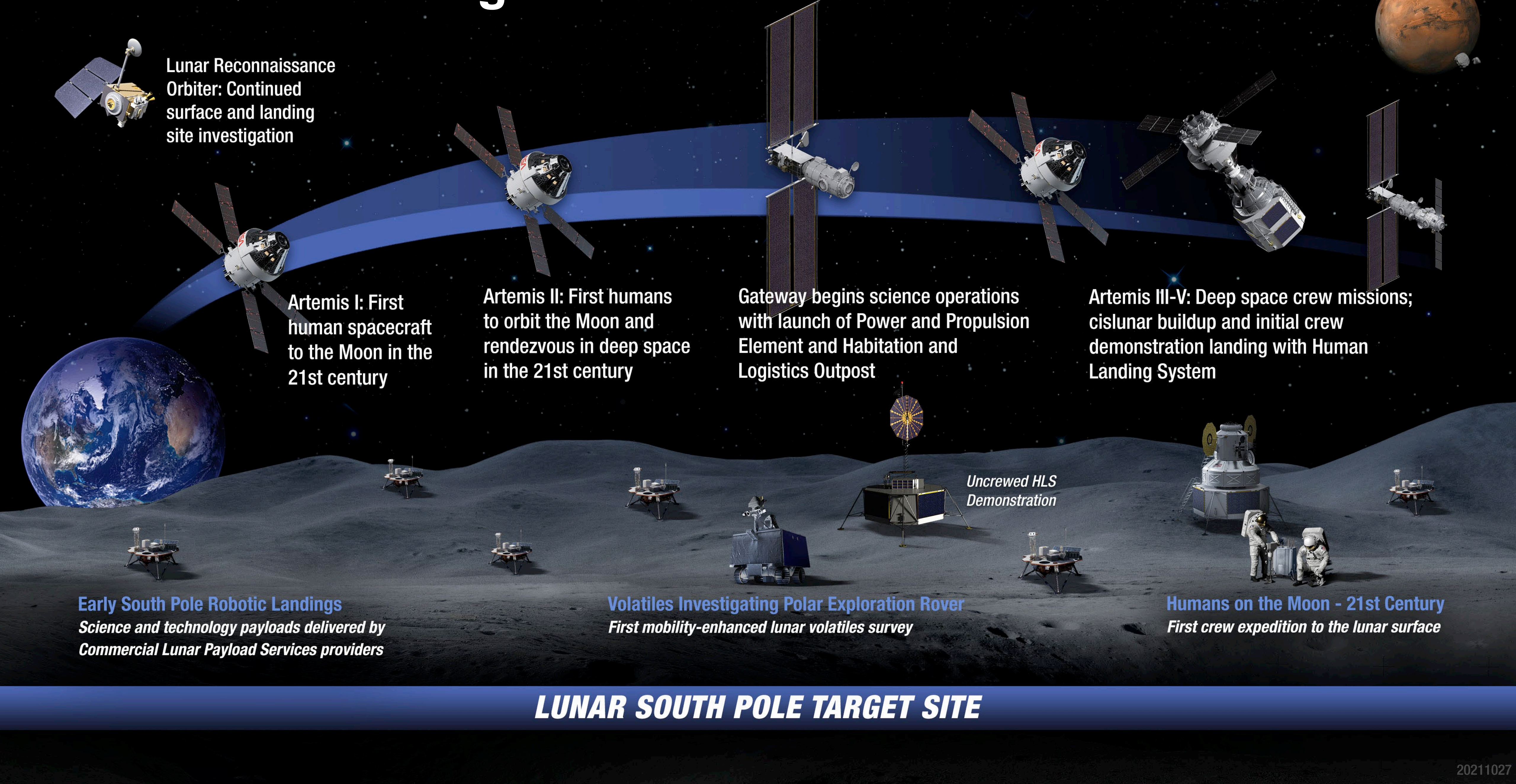
SLS, Orion, EGS,
HLS, Gateway
(PPE/HALO, I-HAB)

Artemis V

Crewed mobile surface exploration, Gateway expansion

SLS, Orion, EGS,
HLS, LTV, Gateway
(ESPRIT, Canadarm3)

Artemis: Landing Humans On the Moon



Lunar Reconnaissance Orbiter: Continued surface and landing site investigation

Artemis I: First human spacecraft to the Moon in the 21st century

Artemis II: First humans to orbit the Moon and rendezvous in deep space in the 21st century

Gateway begins science operations with launch of Power and Propulsion Element and Habitation and Logistics Outpost

Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System

Uncrewed HLS Demonstration

Early South Pole Robotic Landings

Science and technology payloads delivered by Commercial Lunar Payload Services providers

Volatiles Investigating Polar Exploration Rover

First mobility-enhanced lunar volatiles survey

Humans on the Moon - 21st Century

First crew expedition to the lunar surface

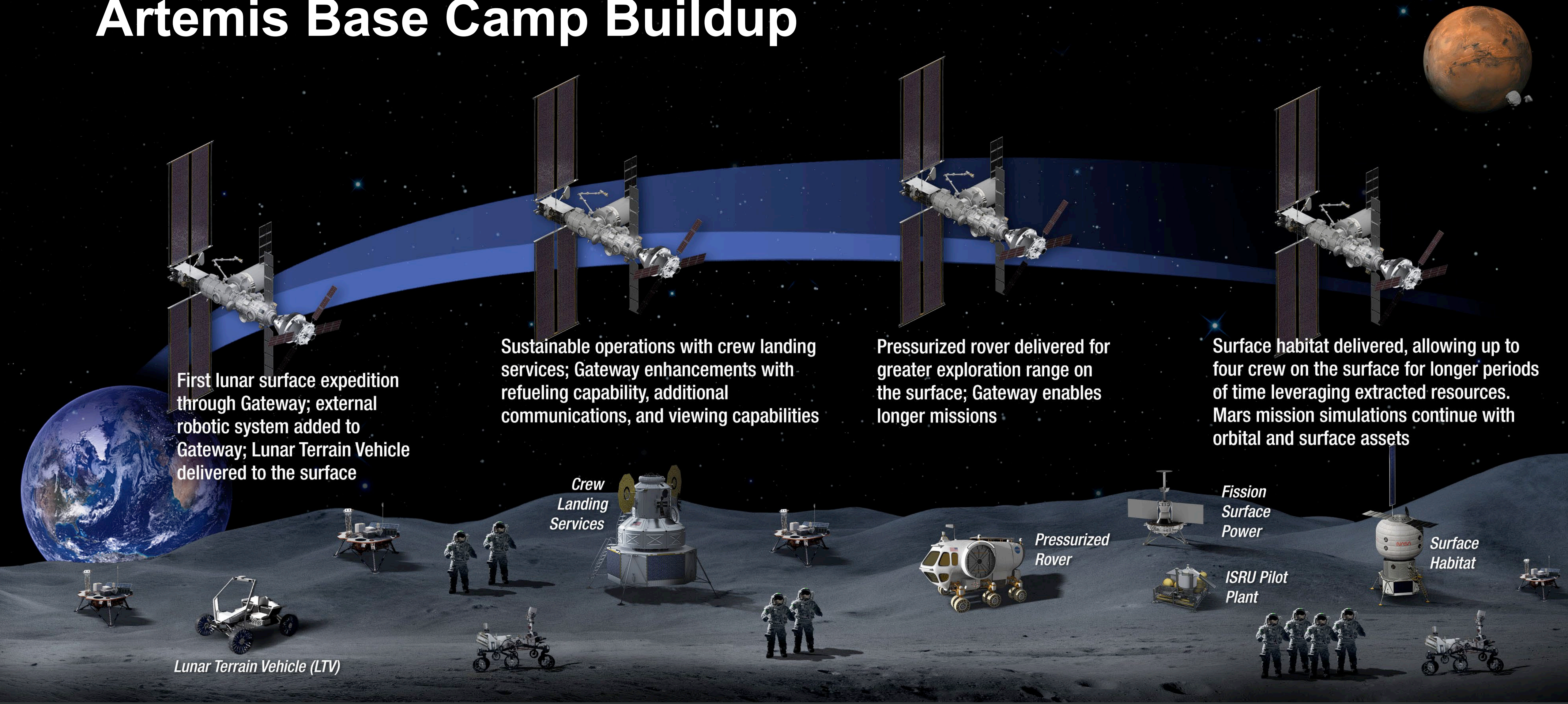
LUNAR SOUTH POLE TARGET SITE

20211027

Commercial Lunar Payload Services

14 CLPS providers are currently on contract and eligible to bid on payload deliveries to the Moon

Artemis Base Camp Buildup



First lunar surface expedition through Gateway; external robotic system added to Gateway; Lunar Terrain Vehicle delivered to the surface

Sustainable operations with crew landing services; Gateway enhancements with refueling capability, additional communications, and viewing capabilities

Pressurized rover delivered for greater exploration range on the surface; Gateway enables longer missions

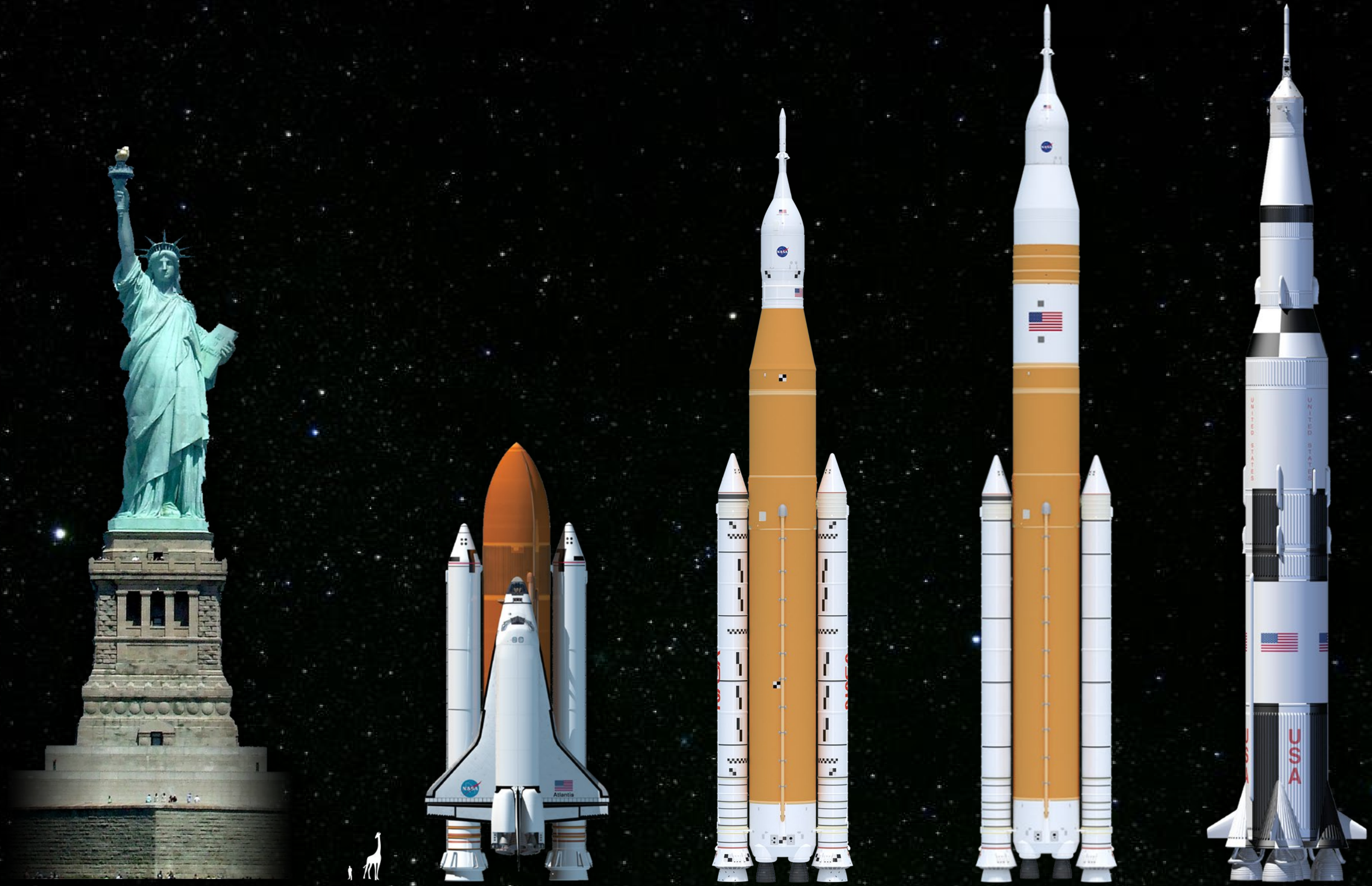
Surface habitat delivered, allowing up to four crew on the surface for longer periods of time leveraging extracted resources. Mars mission simulations continue with orbital and surface assets

SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

20211027

EGS



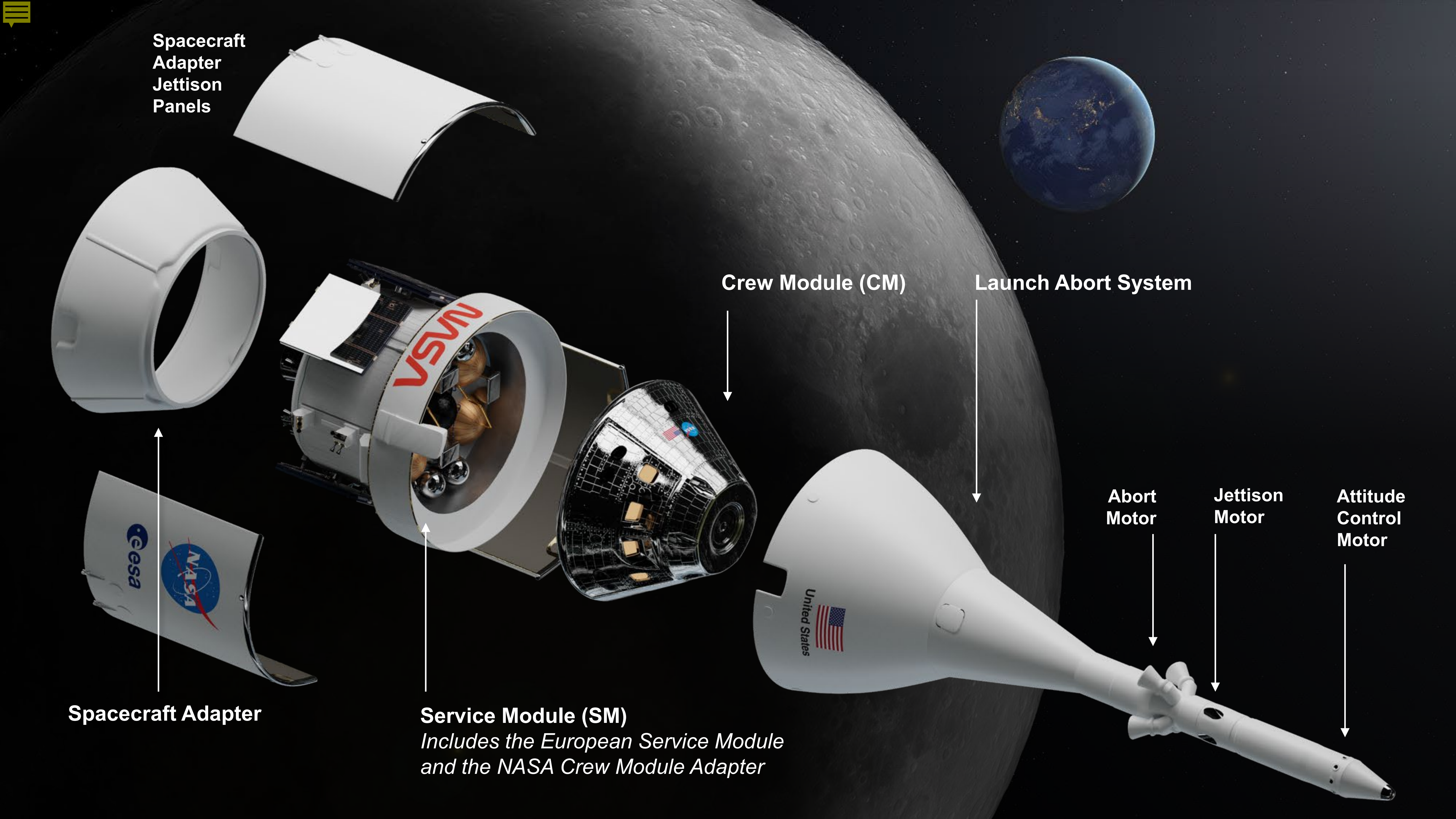
STATUE OF LIBERTY
305 ft.

SPACE SHUTTLE
184 ft.

SLS / ORION Block I
322 ft.

SLS / ORION Block II
364 ft.

SATURN 5
363 ft.



Spacecraft Adapter Jettison Panels

Crew Module (CM)

Launch Abort System

Abort Motor

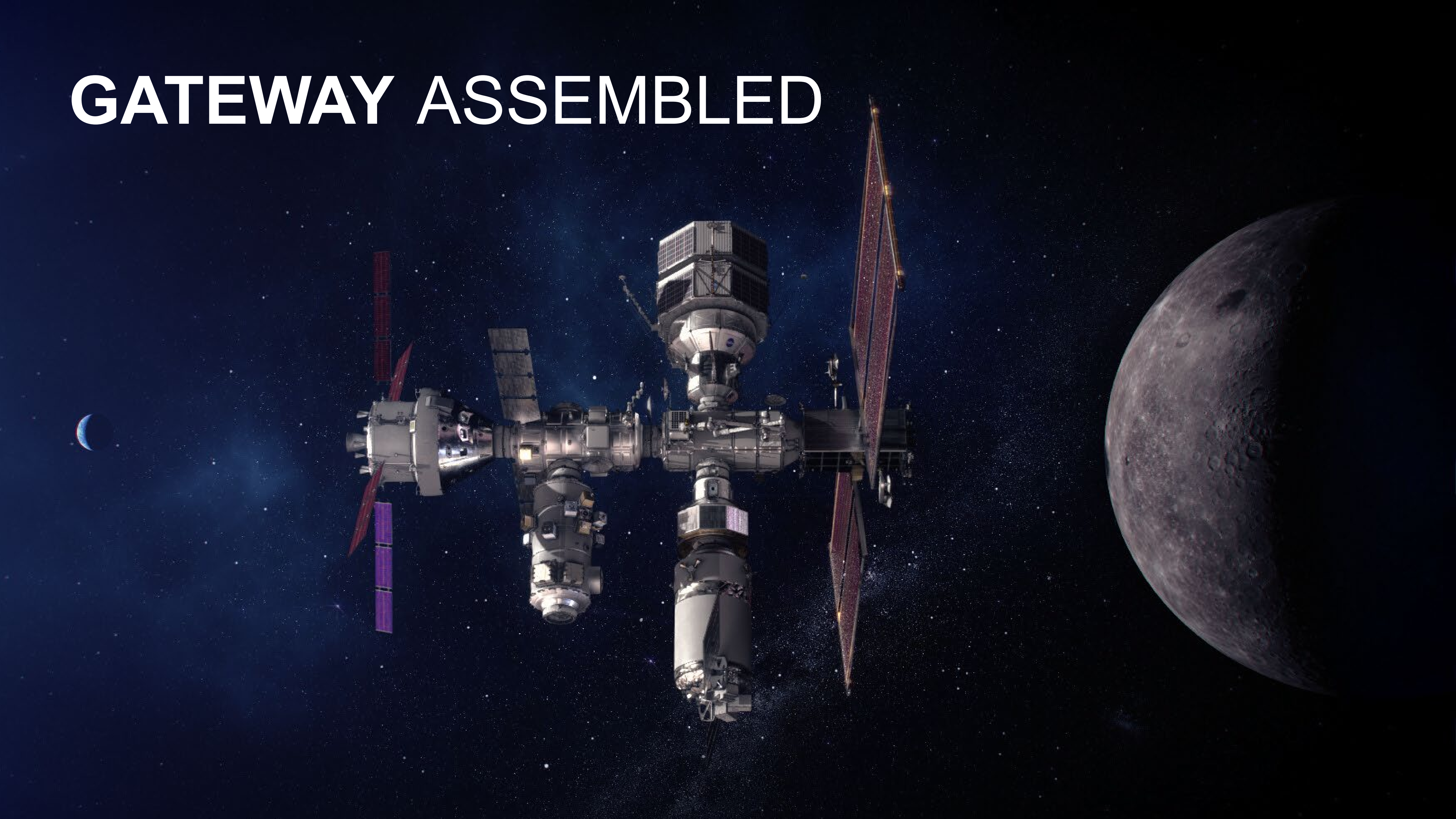
Jettison Motor

Attitude Control Motor

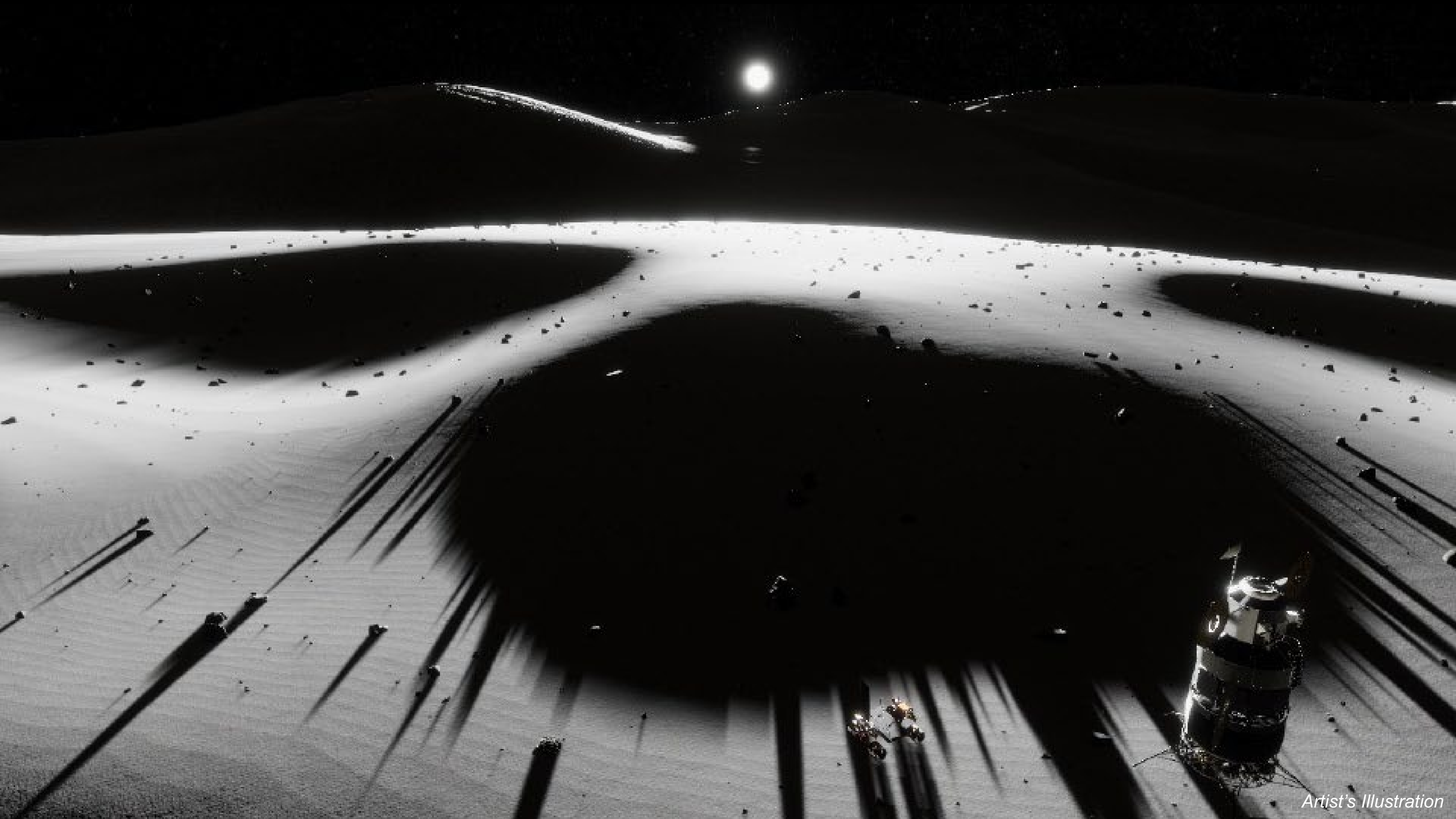
Spacecraft Adapter

Service Module (SM)
Includes the European Service Module and the NASA Crew Module Adapter

GATEWAY ASSEMBLED



HOW DO YOU LIVE AND WORK
BEYOND LOW EARTH ORBIT
UTILIZING as many of the RESOURCES around you?
How do we do this SUSTAINIBLY?



Artist's Illustration

LUNAR SURFACE SYSTEMS & INFRASTRUCTURE

Surface Habitat


Artist's illustration

Will be a primary asset to achieve a sustained lunar presence.

NASA is working with industry to develop conceptual designs for the Surface Habitat.

- 2-4 crew – medical, exercise, galley, crew quarters, stowage
- Houses 2 crew for 30 days
- EVA capable via suitports and includes airlock for suit maintenance capability
- Power generation, recharge capability for surface assets
- Communication hub for surface assets
- Reuse for multiple missions of 15-year lifetime

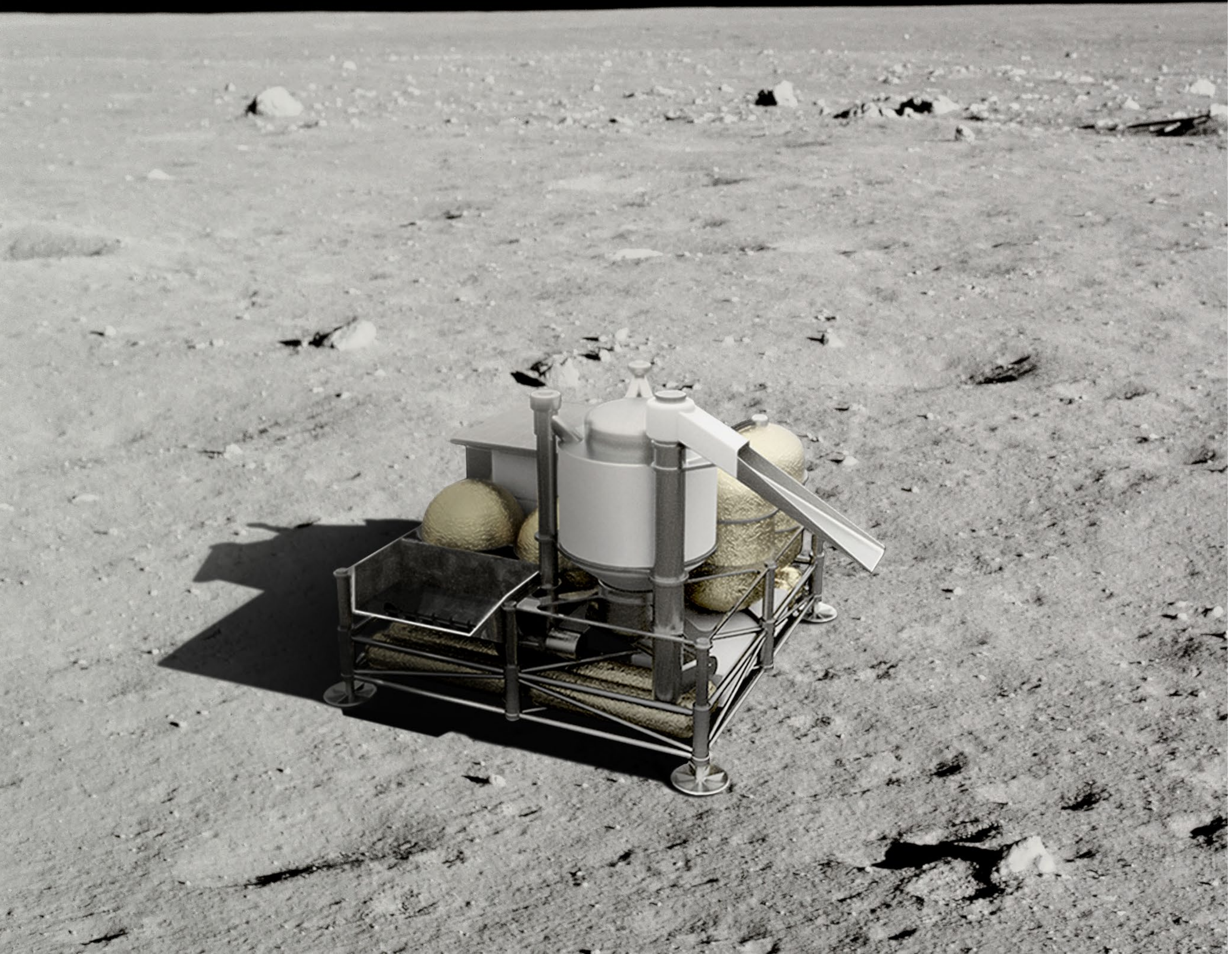
Pressurized Rover

Artist's illustration

Provides pressurized mobile habitation to enable long-range surface exploration in shirtsleeve environment and access to surface for exploration.

- Habitation for 30 days for 2 crew
- Allows astronauts to explore outside the vehicle in their spacesuits
- Provides volume for spares and logistics
- Power generation and energy storage for lunar environment
- Dust and radiation protection
- Reuse for multiple missions of 10-year lifetime
- Capability also identified in current concepts for first human mission to Mars

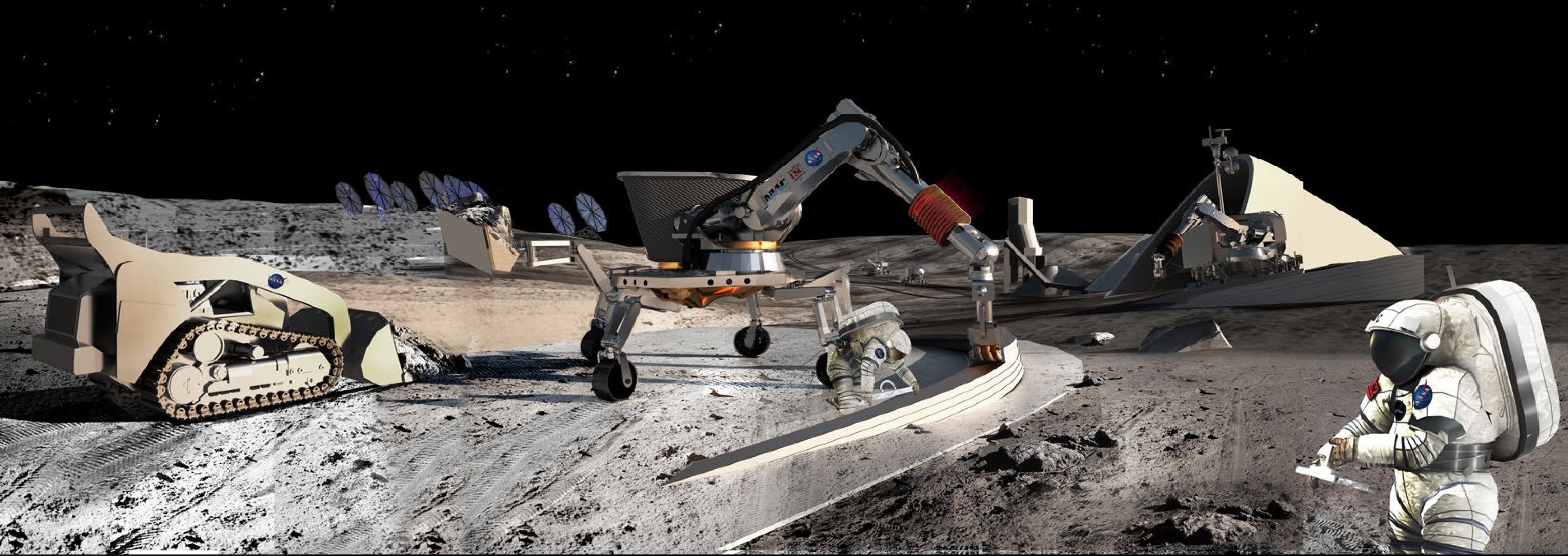
In-Situ Resource Utilization



Artemis ISRU systems to demonstrate resource mapping and a scalable capability to extract and use lunar-based resources

---

- **Resource Mapping/Estimation:** Enable global and detailed local and subsurface mapping of lunar resources and terrain, especially for water in permanently shadowed craters, for science, future exploration, and commercial use
- **Oxygen Extraction:** Enable extraction and production of oxygen from lunar regolith to provide 10’s of metric tons per year, for up to 5 years with little human involvement and maintenance, for reusable surface and ascent/descent transportation.
- **Water Mining:** Enable cislunar commercial markets through extraction of water resources to provide 100’s of metric tons of propellant per year for reusable landers and cislunar transportation systems
- **Lunar Surface Construction:** Building roads, launch/landing pads, dust free zones, foundations, blast protection, radiation shielding, shade structures, unpressurized shelters, and even pressurized habitats.



What is **ISRU?**

- “Living off the Land”
- Hardware & operations that harness and utilize ‘in-situ’ resources to create products and services for robotic and human exploration
    - Resource Assessment (Prospecting)
    - Resource Acquisition
    - Resource Processing/Consumable Production
    - In-Situ Manufacturing
    - In-Situ Construction
    - In-Situ Energy

LIVE: Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities

Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface*

Slide Credit: Jerry Sanders, Julie Kleinhenz and Diane Linne, NASA ISRU Presentation to COSPAR July 2022

Commercial Scale Water, Oxygen, Metals & Commodity Production

- Lunar resources mapped at meter scale for commercial mining
- Initial 10's of metric tons of commodities per year
- Scalable to 100's to 1000's metric tons of commodities per year

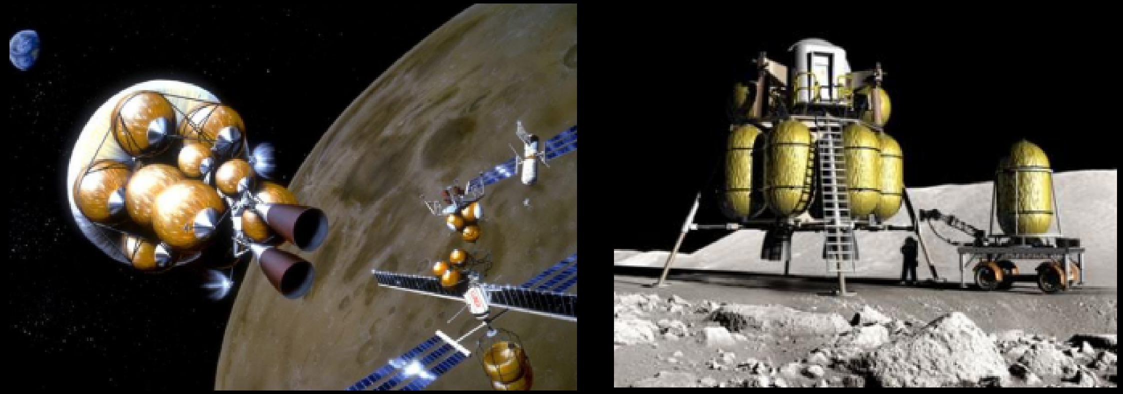
Commodities for Habitats & Food Production

- Water, fertilizers, carbon dioxide, and other crop growth support
- Crop production habitats and processing systems
- Consumables for life support , EVAs, and crew rovers/habitats for growing human space activities

In Situ Derived Feedstock for Construction, Manufacturing, & Energy

- Initial goal of simple landing pads and protective structures
- 100's to 1000's metric tons of regolith-based feedstock for construction projects
- 10's to 100's metric tons of metals, plastics, and binders
- Elements and materials for multi-megawatts of energy generation and storage
- Recycle, repurpose, and reuse manufacturing and construction materials & waste

Commodities for Commercial Reusable In-Space and Surface Transportation and Depots

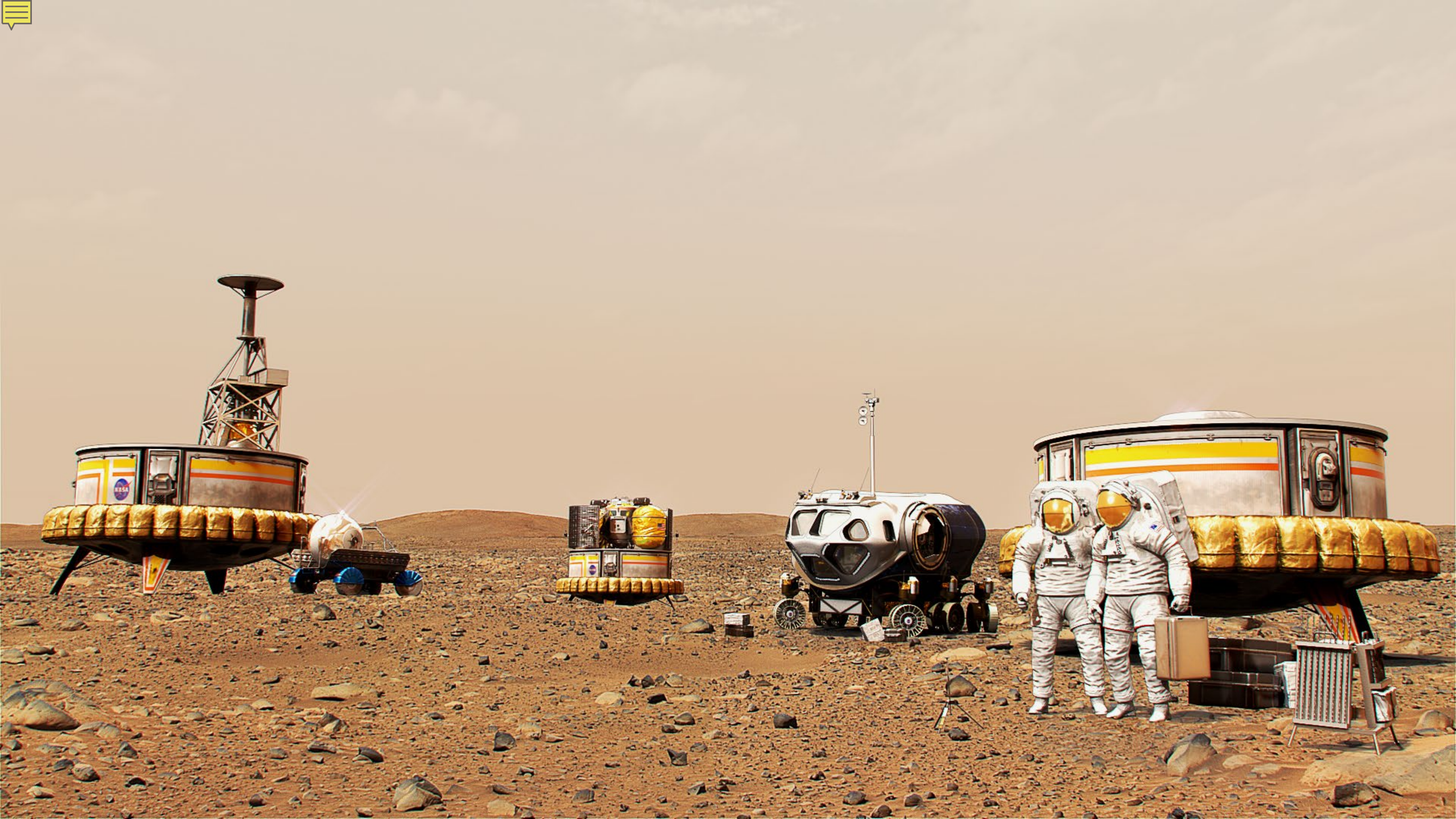


- Initially 30 to 60 metric tons per lander mission
- 100's to 1000's metric tons per year of for Cis-lunar Space
- 100's metric tons per year for human Mars transportation

All activities depicted not currently funded or approved. Depicts "notional future" to guide technology vision.

*Commodities are items and consumables that can be eventually sold


NASA

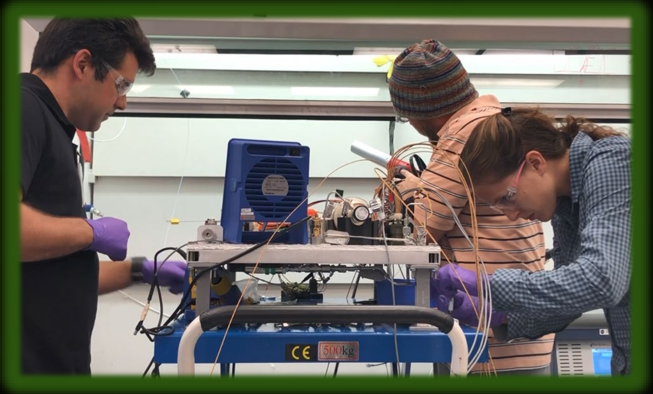


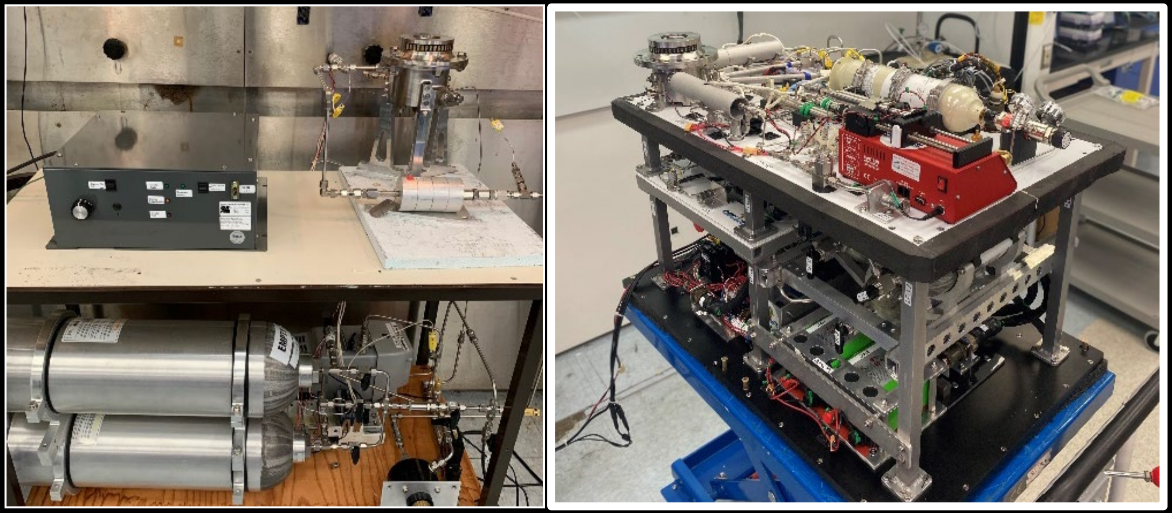
NASA Kennedy Space Center
APPLIED CHEMISTRY LABORATORY

Exploration Systems and Development Office

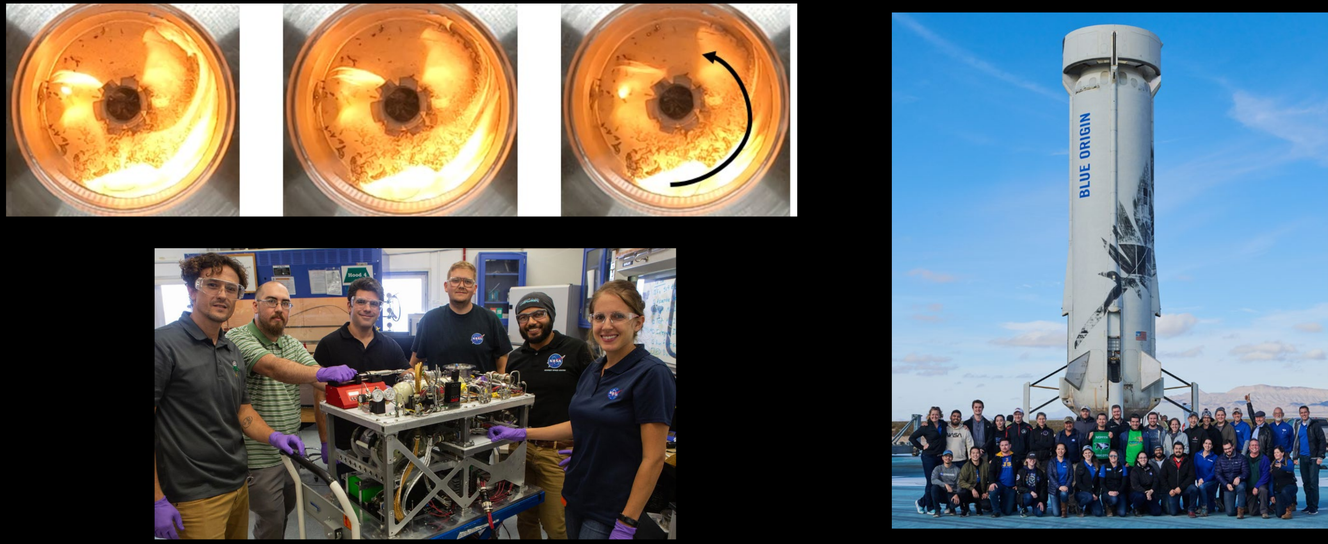
SWAMP WORKS
NASA KENNEDY SPACE CENTER

Exploration Systems and Development Office



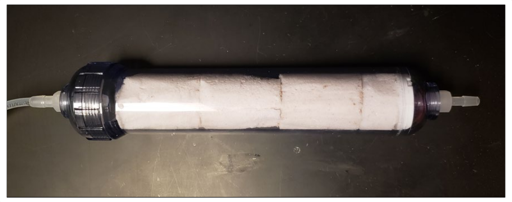


HEOMD AES – Logistics Reduction Trash Venting. Left: Plasma gasification/pyrolysis reactor; Right: OSCAR combustion/gasification/incineration Trash to Gas test rig.



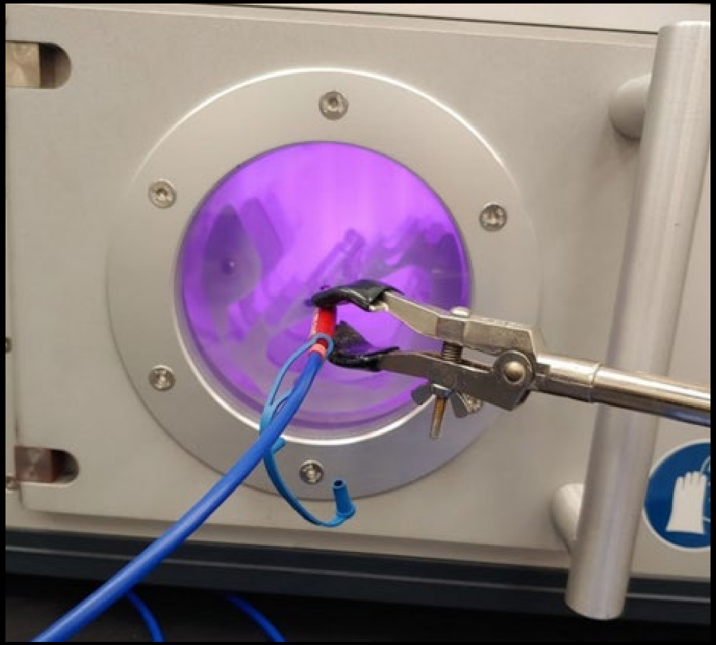
STMD, ECI and Flight Opportunities Orbital Syngas/ Commodity Augmentation Reactor (OSCAR): Waste processing in microgravity suborbital payload.

STMD CIF : CO_2 Plasma Gasification

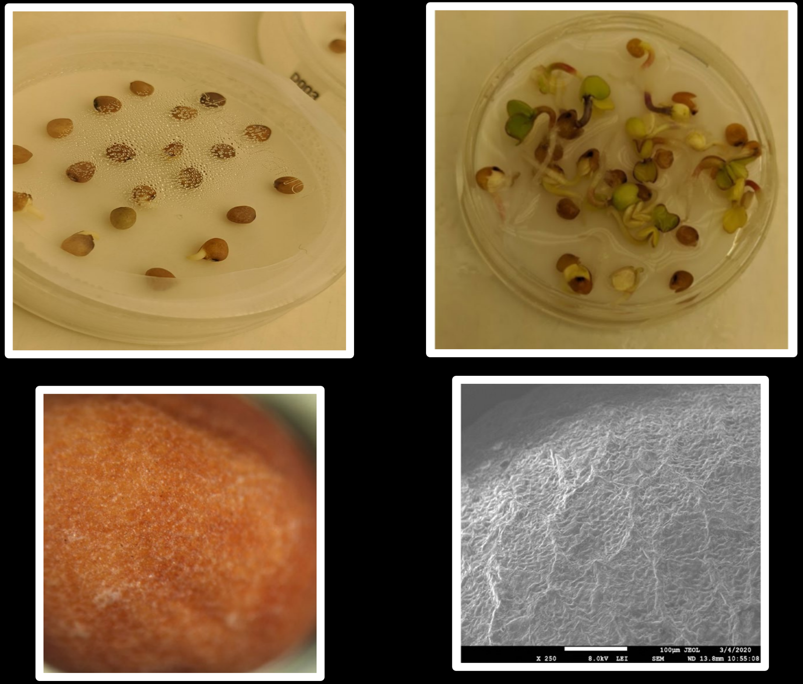


HEOMD AES - Water Silver Biocide, Passive silver ion releasing composite foam

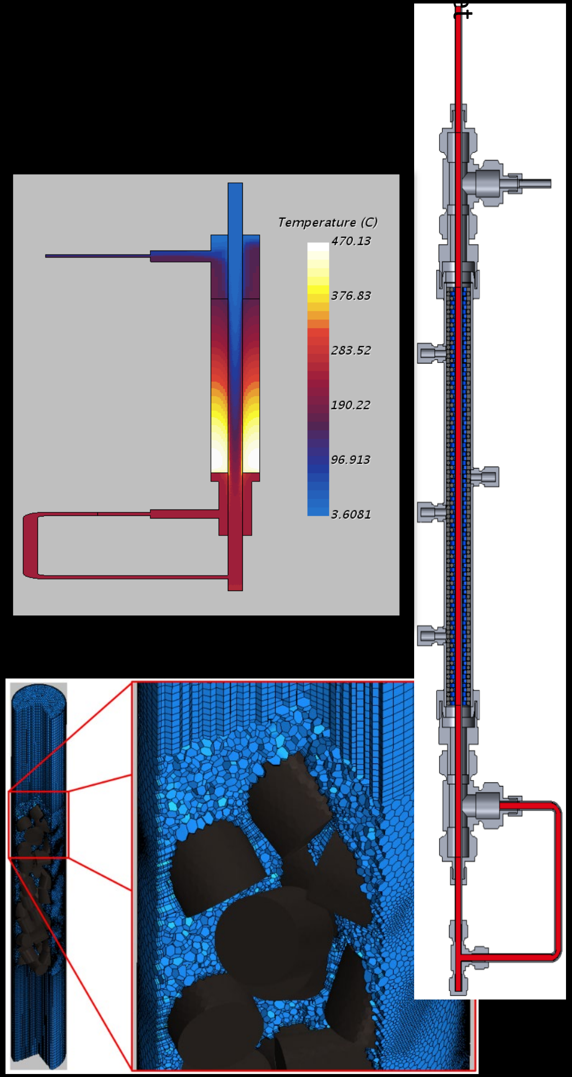
STMD Plasma Precision Cleaning Robot



Hydrogen Plasma Reduction of Lunar Regolith for Oxygen Liberation



Plasma Agriculture Sanitization, IR&TD



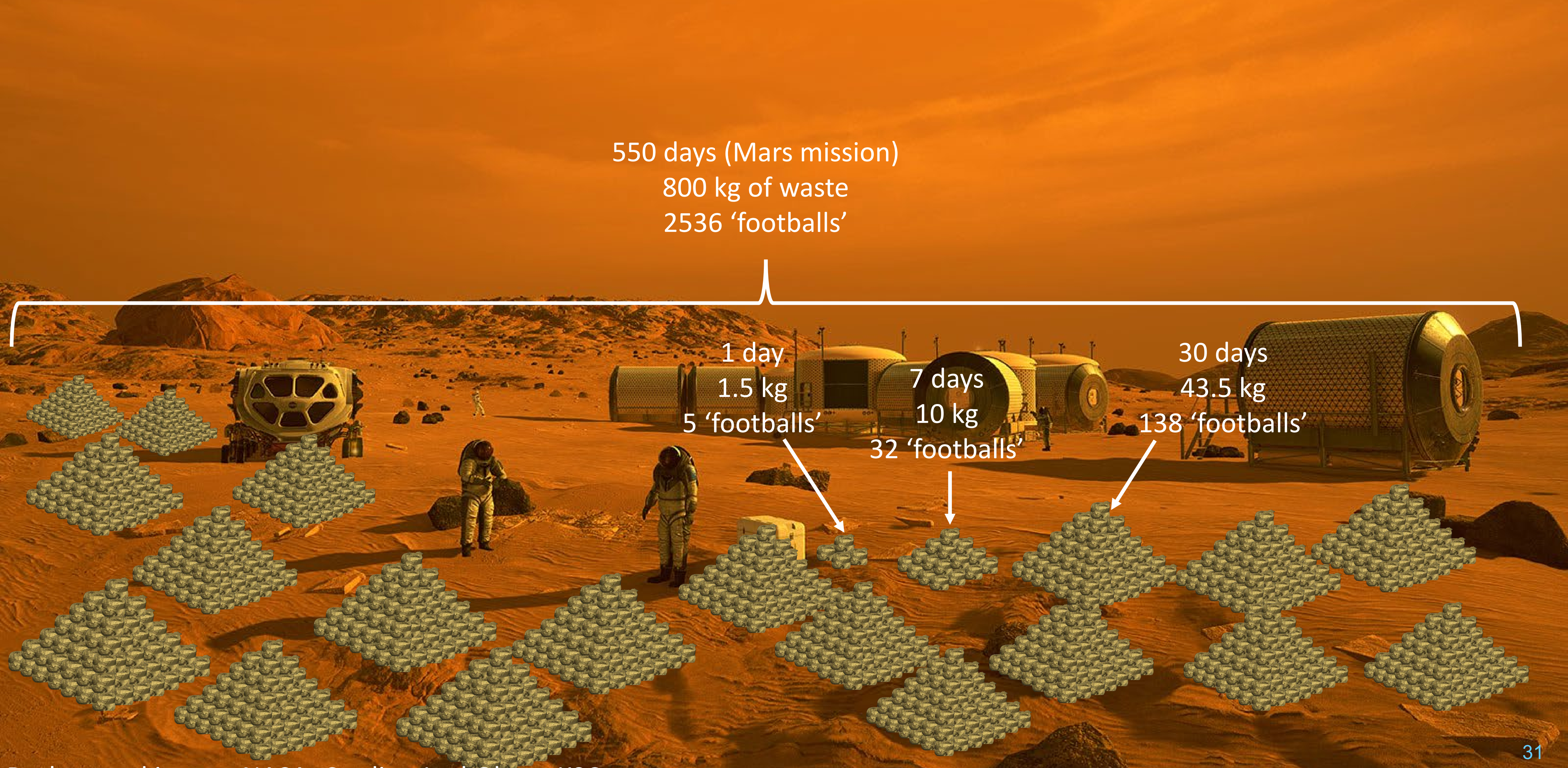
Computational Modeling

Relevant Environment Testing

Payload Qualification Testing


Artist's Illustration

NASA’s Trash Strategy…



550 days (Mars mission)
800 kg of waste
2536 ‘footballs’

1 day
1.5 kg
5 ‘footballs’

7 days
10 kg
32 ‘footballs’

30 days
43.5 kg
138 ‘footballs’

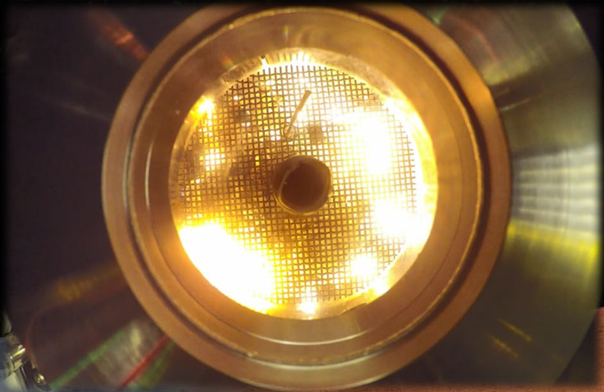
Background image: NASA; Credits: Joel Olson, KSC

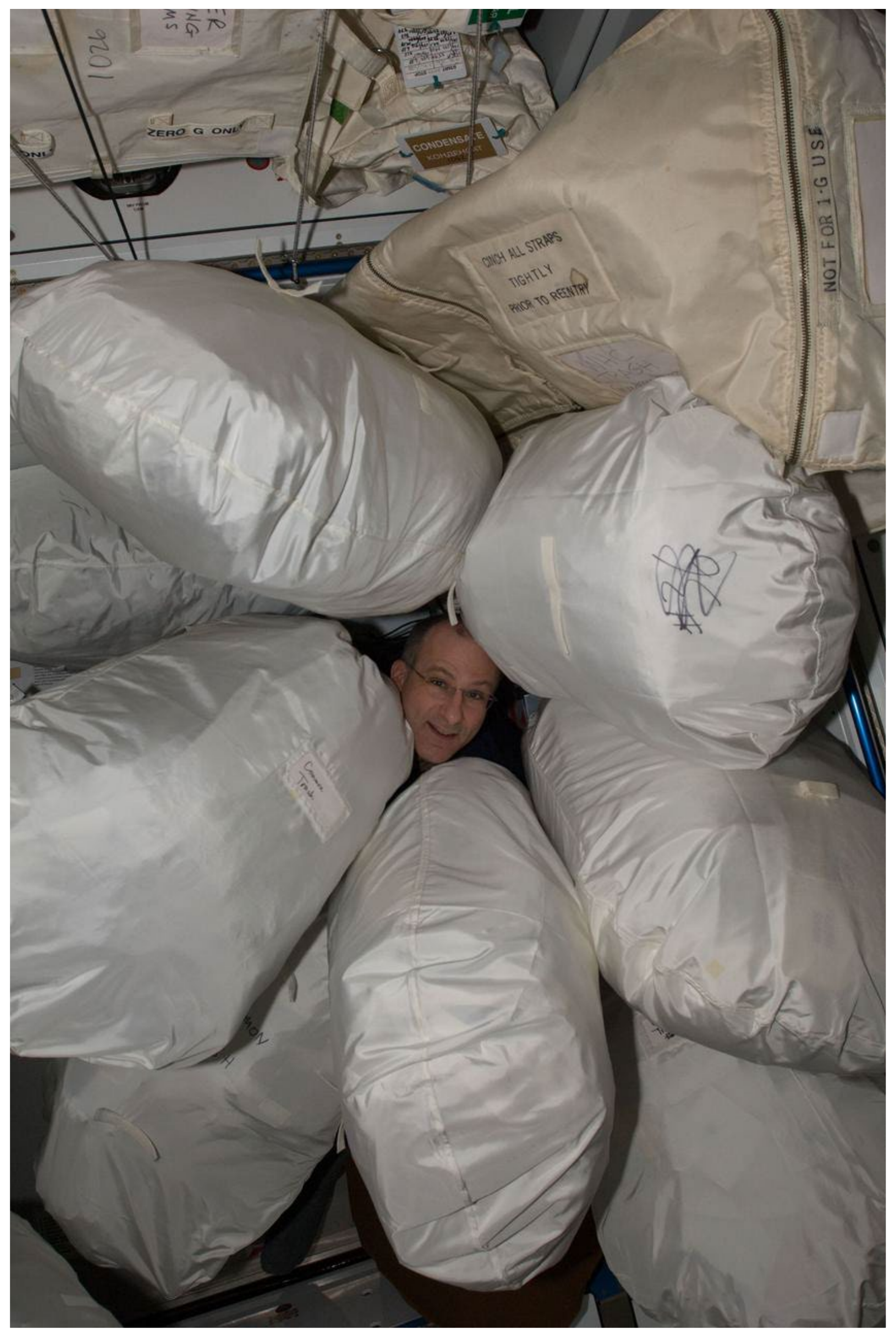
ESDMD Waste Strategy

Keep

Throw out (Mass Jettison)

Throw out (Mass Venting)




ZERO G ONLY
CONDENSATE
CINCH ALL STRAPS TIGHTLY PRIOR TO REENTRY
NOT FOR 1-G USE


ZIPLOCK, USOS CLOTHING BAG 1
528-21059-436

6.4 kg/day of trash
Crew of 4

Toothpaste

Nitrile Gloves

Shampoo

Clothing

Toilet Paper

Fecal Stimulant

Food Stimulant

Tech Wipes

Wet Wipes

Food Packaging

6.4 kg/day of trash
Crew of 4

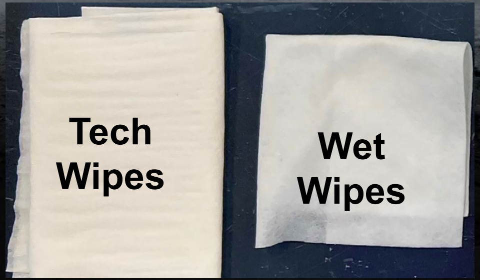
Toothpaste

Nitrile Gloves

Shampoo

Clothing

Toilet Paper



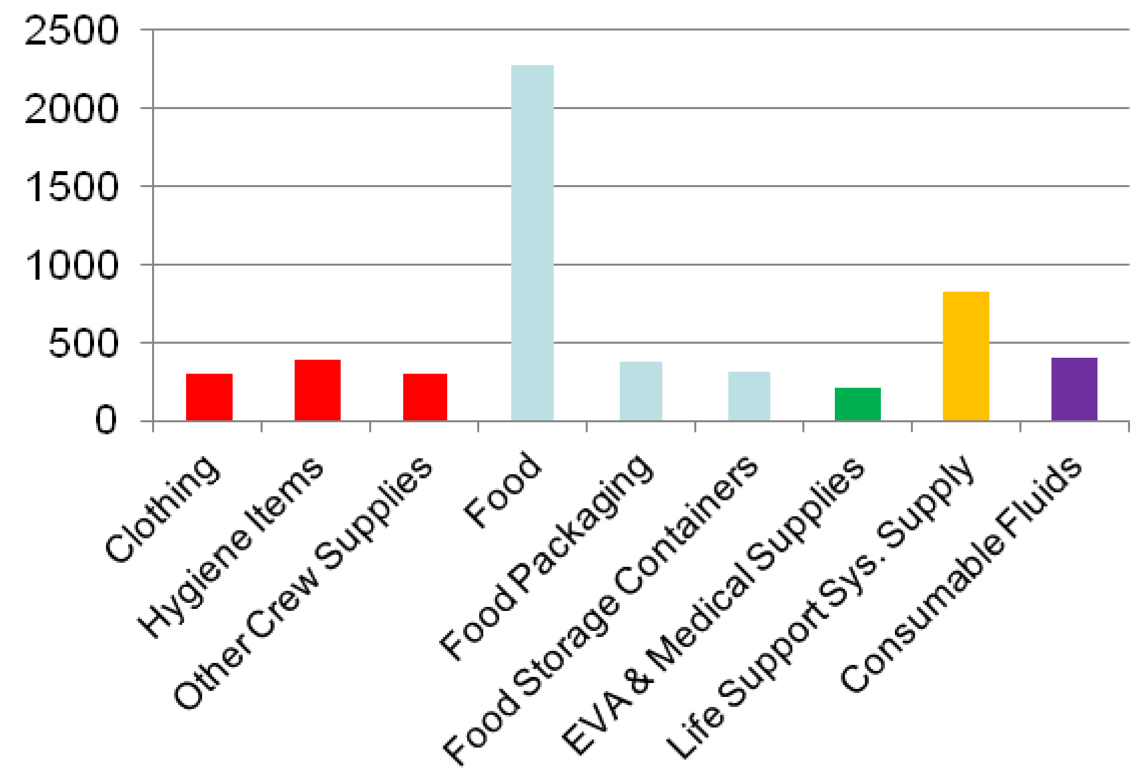
Food Packaging

Trash Feedstock Simulant Recipes

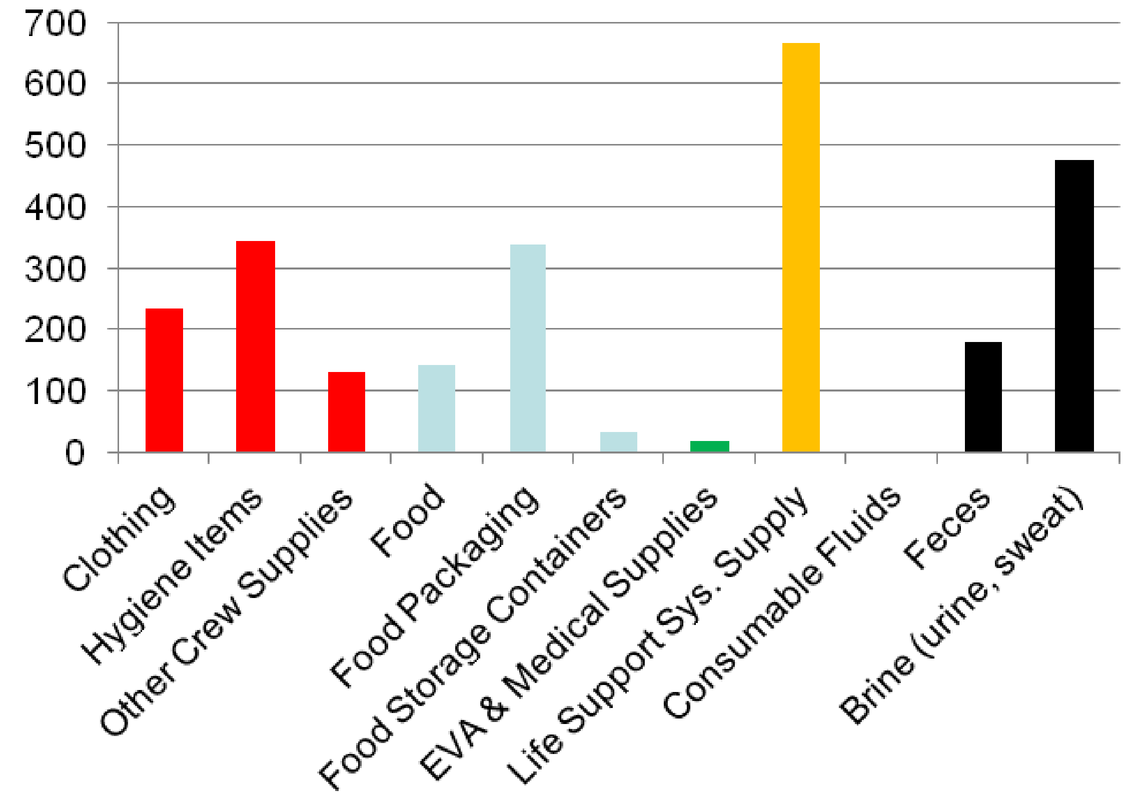
Component of OWS	OWS (Mass %)	Component of HFWS	HFWS (Mass %)
Clothing/Cotton	17.9	Urine Brine	21.3
Food Packaging (FP)	13.4	Polyethylene sheet	16.2
FP Overwrap	13.4	Clothing/Cotton	12.6
Hygiene towels	9.5	Fecal Simulant	11.2
Tech Wipes	3.6	Food Simulant	8.9
Toilet Paper	3.6	Hand/face wipes	5.5
Nitrile Gloves	1.6	Tissues	4.9
Fecal Simulant	13.4	Hygiene towels	4.8
Hand/face Wipes	10.8	Nylon sheet	4.6
Toothpaste	1.2	Shampoo	2.4
Shampoo	1.2	Aluminum foil	2.3
Food Simulant	10.6	Nitrile gloves	2.1
Fecal Simulant	11.2	Toothpaste	1.2
		Paper	0.6
		Maximum absorbency garments (MAG)	0.5
		Disinfecting wipes	0.4
		Duct tape	0.4

Logistics Waste Model – 1 year, 4 people

Launch Mass (kg)

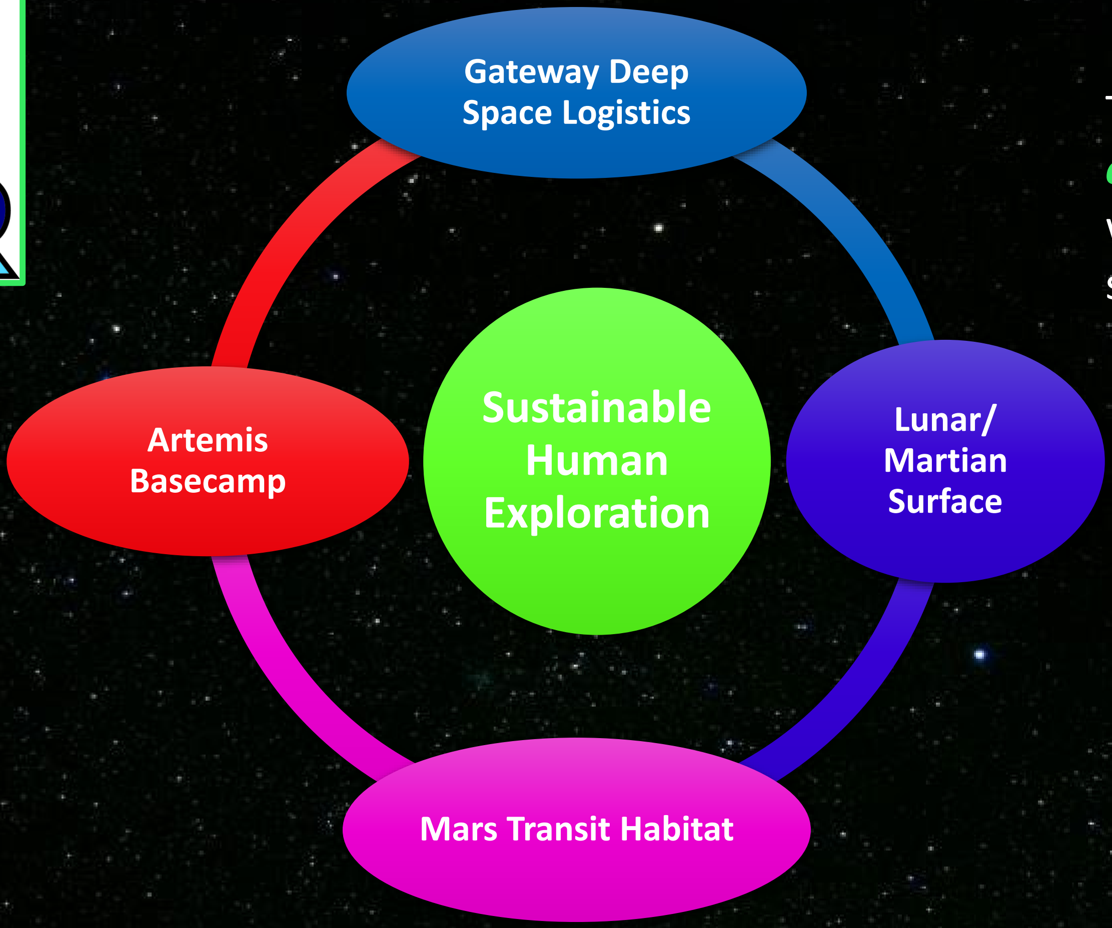


Waste Mass (kg)



M. K. Ewert and J. L. Broyan, "Mission Benefits Analysis of Logistics Reduction Technologies," in 43rd International Conference on Environmental Systems, 2013.

NASA Sustainable Trash Processing



Gateway Deep Space Logistics

Lunar/ Martian Surface

Mars Transit Habitat

Artemis Basecamp

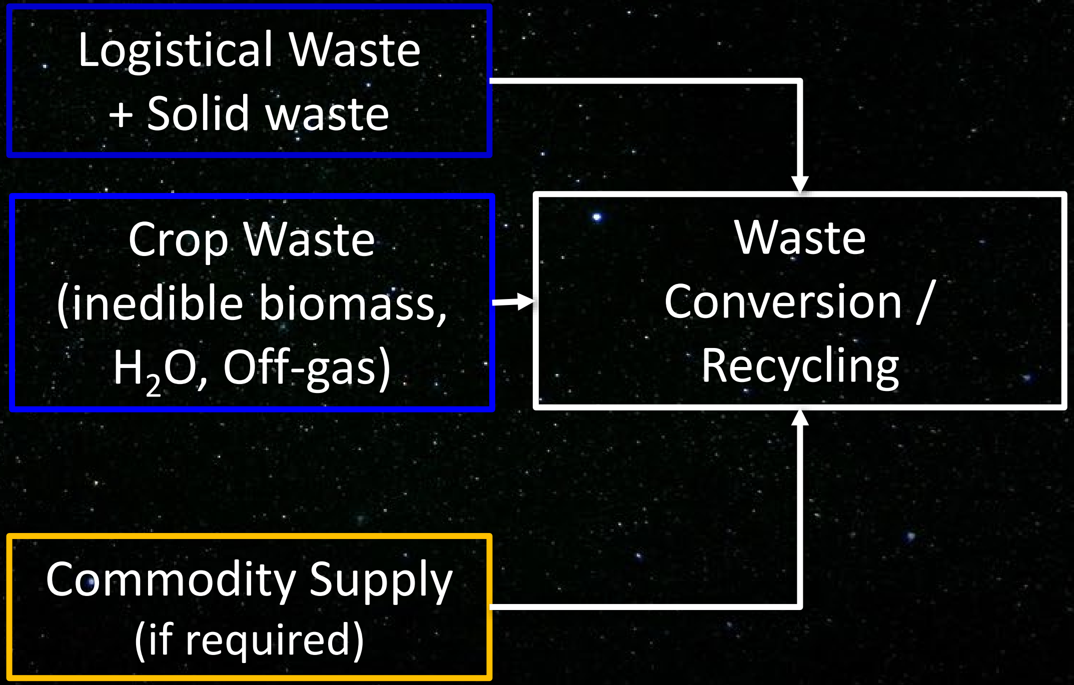
Sustainable Human Exploration

This work lays the framework for ***earnest spaceflight sustainability*** within next generation of human spaceflight & exploration.

Moon 2 Mars Objectives

- **Trash Conversion/ Trash-to-Gas considers NASA’s sustainable architecture for recycling/reuse of on-orbit M2M Objectives:**
  - **OP-12:** Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration.
  - **RT-5:** Maintainability and Reuse: when practical, design systems for maintainability, reuse, and/or recycling to support the long-term sustainability of operations and increase Earth independence.
  - **RT-6:** Responsible Use: Conduct all activities for the exploration and use of outer space for peaceful purposes consistent with international obligations, and principles for responsible behavior in space.

Concept: Trash Processing & Reuse Systems / Trash-to-Gas+



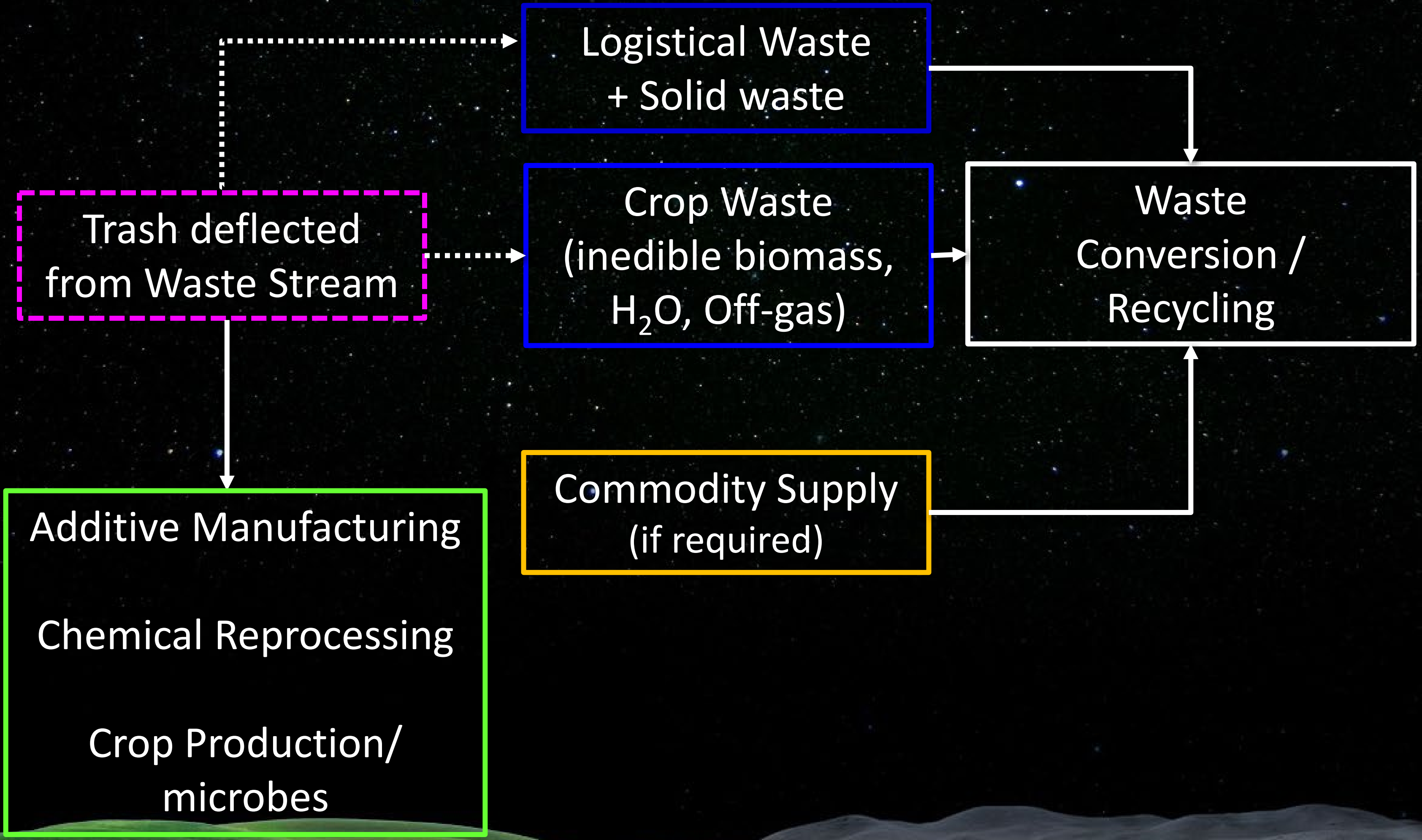
Logistical Waste
+ Solid waste

Crop Waste
(inedible biomass, H_2O, Off-gas)

Commodity Supply
(if required)

Waste
Conversion /
Recycling

Concept: Trash Processing & Reuse Systems / Trash-to-Gas+



Logistical Waste
+ Solid waste

Trash deflected
from Waste Stream

Crop Waste
(inedible biomass,
H_2O, Off-gas)

Waste
Conversion /
Recycling

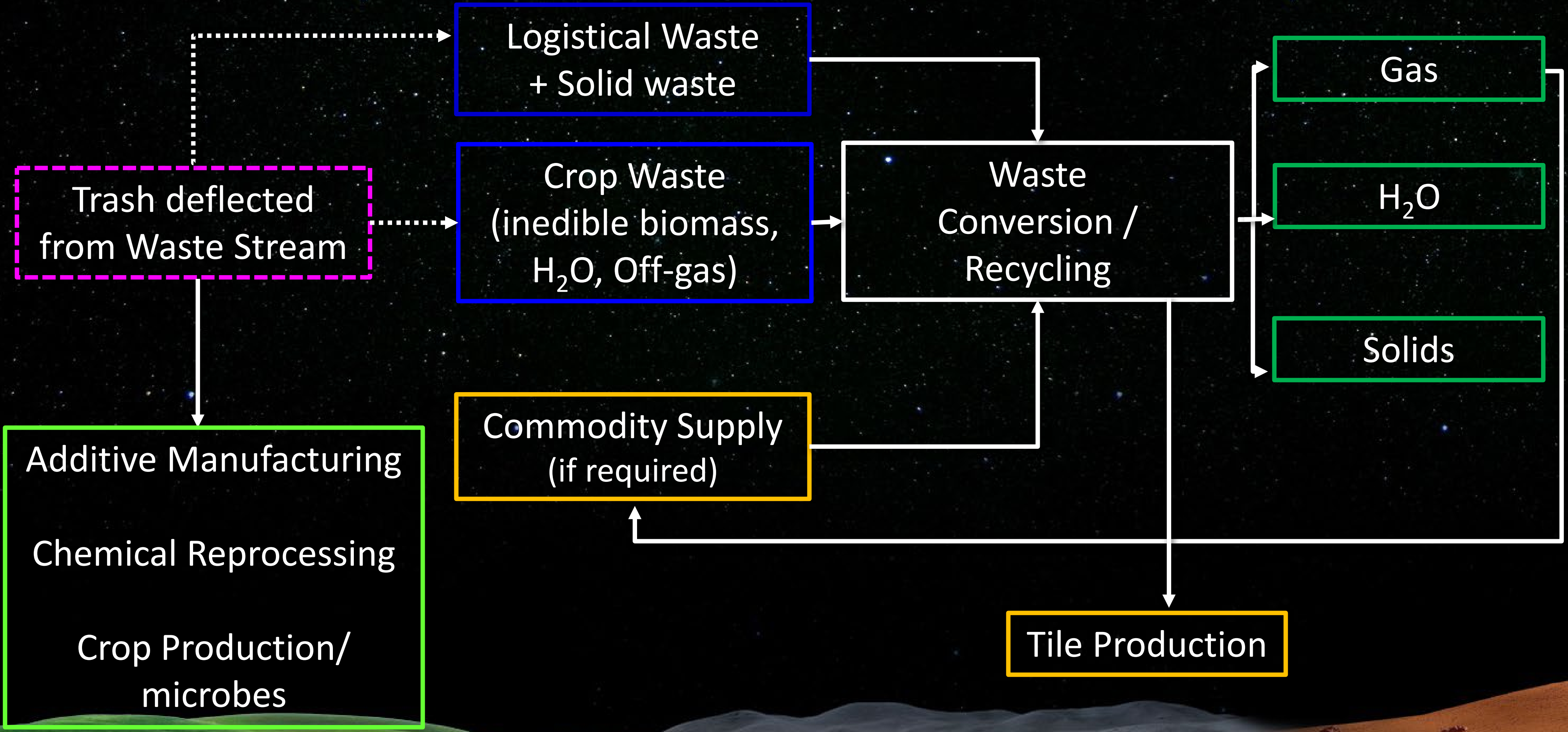
Commodity Supply
(if required)

Additive Manufacturing

Chemical Reprocessing

Crop Production/
microbes

Concept: Trash Processing & Reuse Systems / Trash-to-Gas+



Trash deflected from Waste Stream

Logistical Waste + Solid waste

Crop Waste (inedible biomass, H_2O, Off-gas)

Commodity Supply (if required)

Waste Conversion / Recycling

Gas

H_2O

Solids

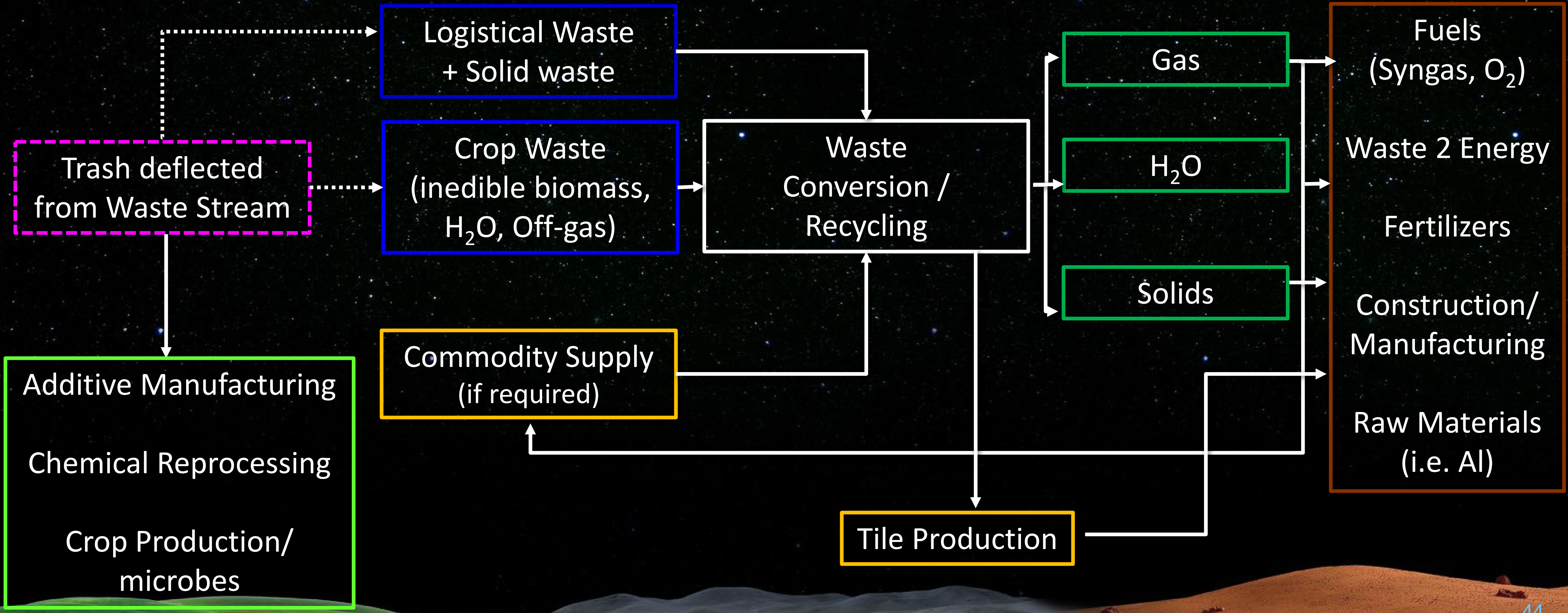
Tile Production

Additive Manufacturing

Chemical Reprocessing

Crop Production/ microbes

Concept: Trash Processing & Reuse Systems / Trash-to-Gas+



Trash deflected from Waste Stream

Logistical Waste + Solid waste

Crop Waste (inedible biomass, H_2O, Off-gas)

Waste Conversion / Recycling

Commodity Supply (if required)

Gas

H_2O

Solids

Tile Production

Fuels (Syngas, O_2)

Waste 2 Energy

Fertilizers

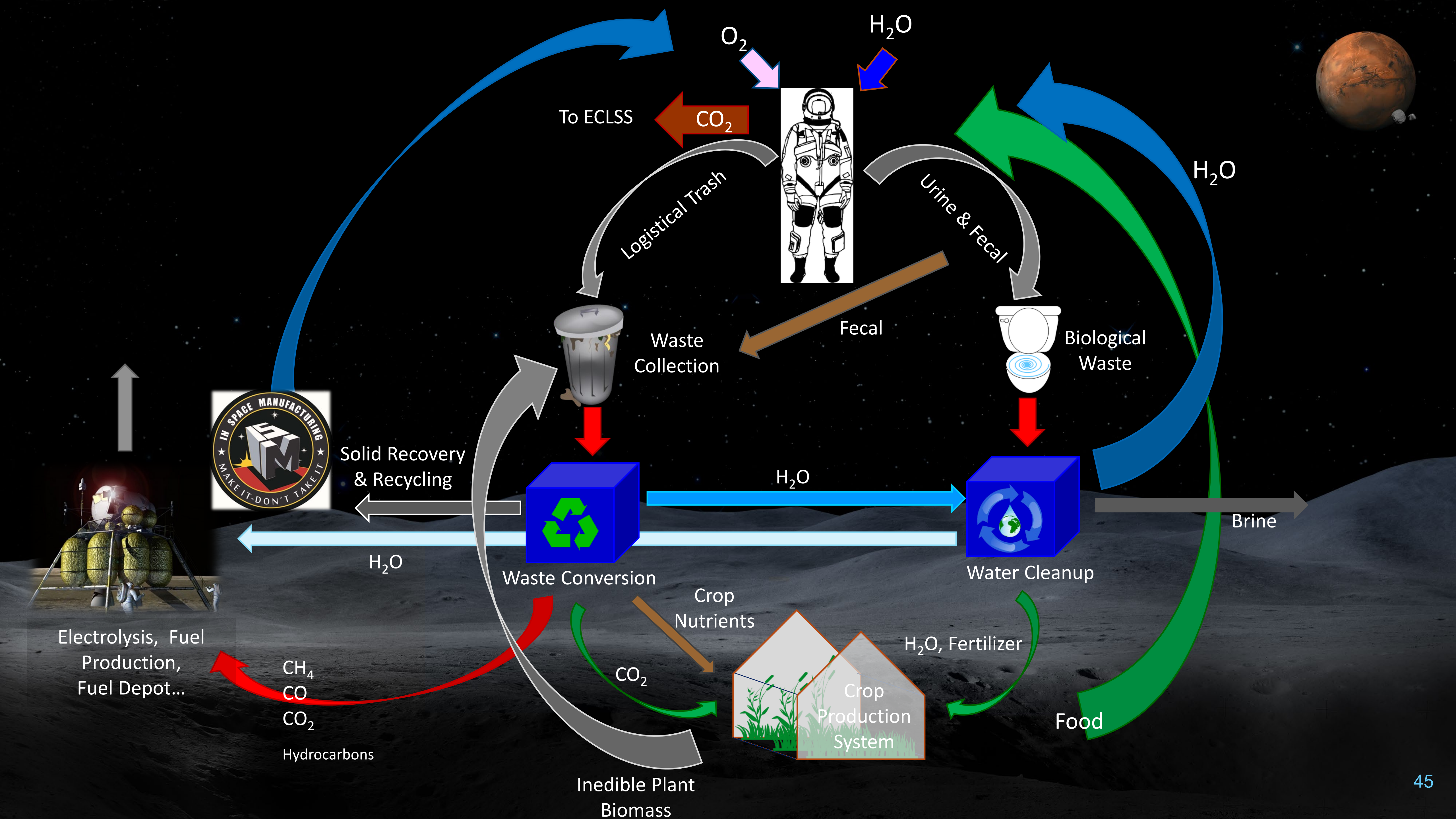
Construction/ Manufacturing

Raw Materials (i.e. Al)

Additive Manufacturing

Chemical Reprocessing

Crop Production/ microbes



O_2

H_2O

To ECLSS

CO_2

Logistical Trash

Urine & Fecal

Fecal

Waste Collection

Biological Waste

H_2O

Solid Recovery & Recycling

H_2O

Brine

H_2O

Waste Conversion

Water Cleanup

Electrolysis, Fuel Production, Fuel Depot…

CH_4

CO

CO_2

Hydrocarbons

Crop Nutrients

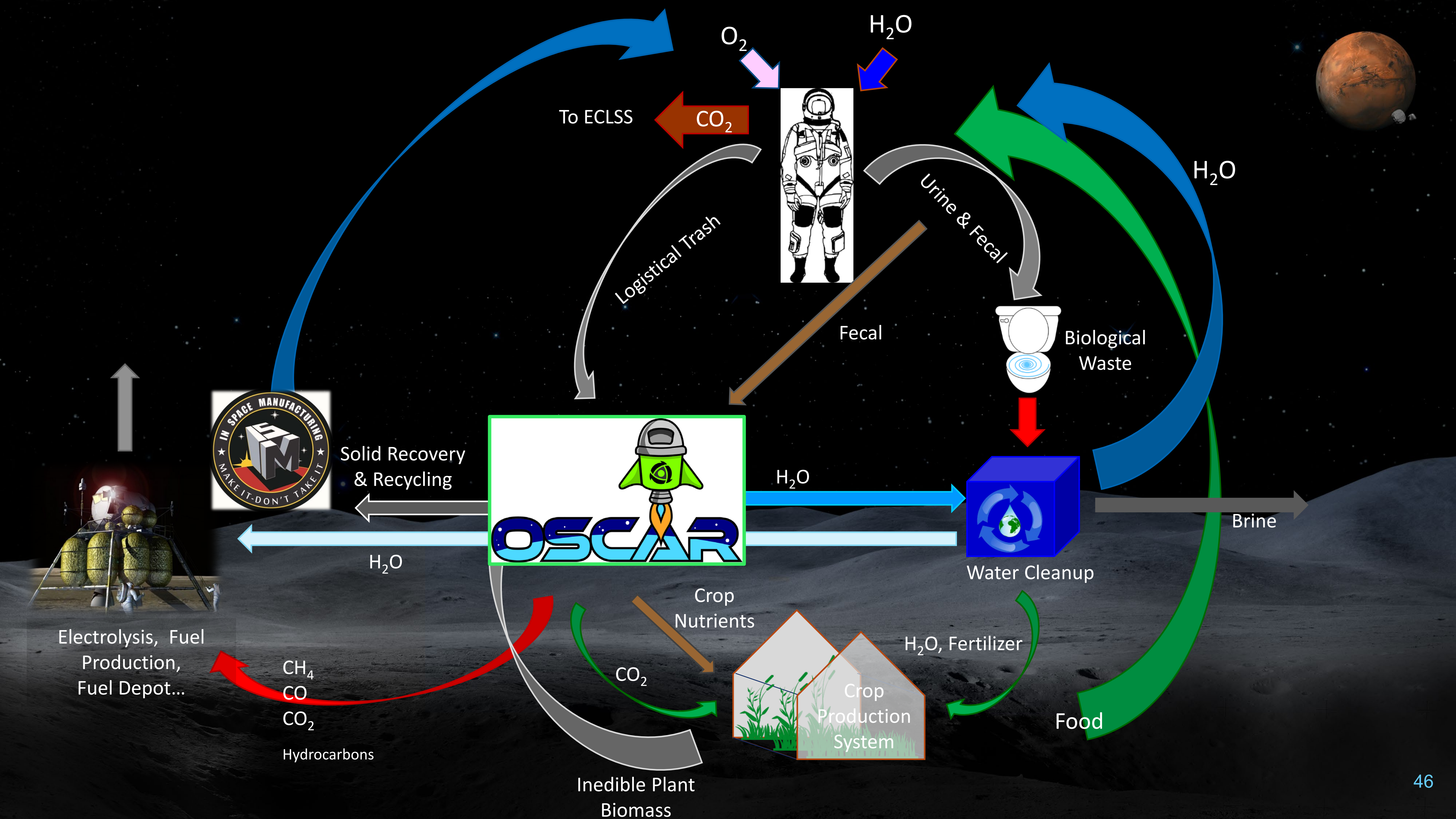
CO_2

H_2O, Fertilizer

Crop Production System

Food

Inedible Plant Biomass


O_2

H_2O

To ECLSS

CO_2

Logistical Trash

Urine & Fecal

Fecal

Biological Waste

H_2O

Solid Recovery & Recycling

H_2O

Brine

Water Cleanup

H_2O

Electrolysis, Fuel Production, Fuel Depot…

CH_4

CO

CO_2

Hydrocarbons

Crop Nutrients

CO_2

H_2O, Fertilizer

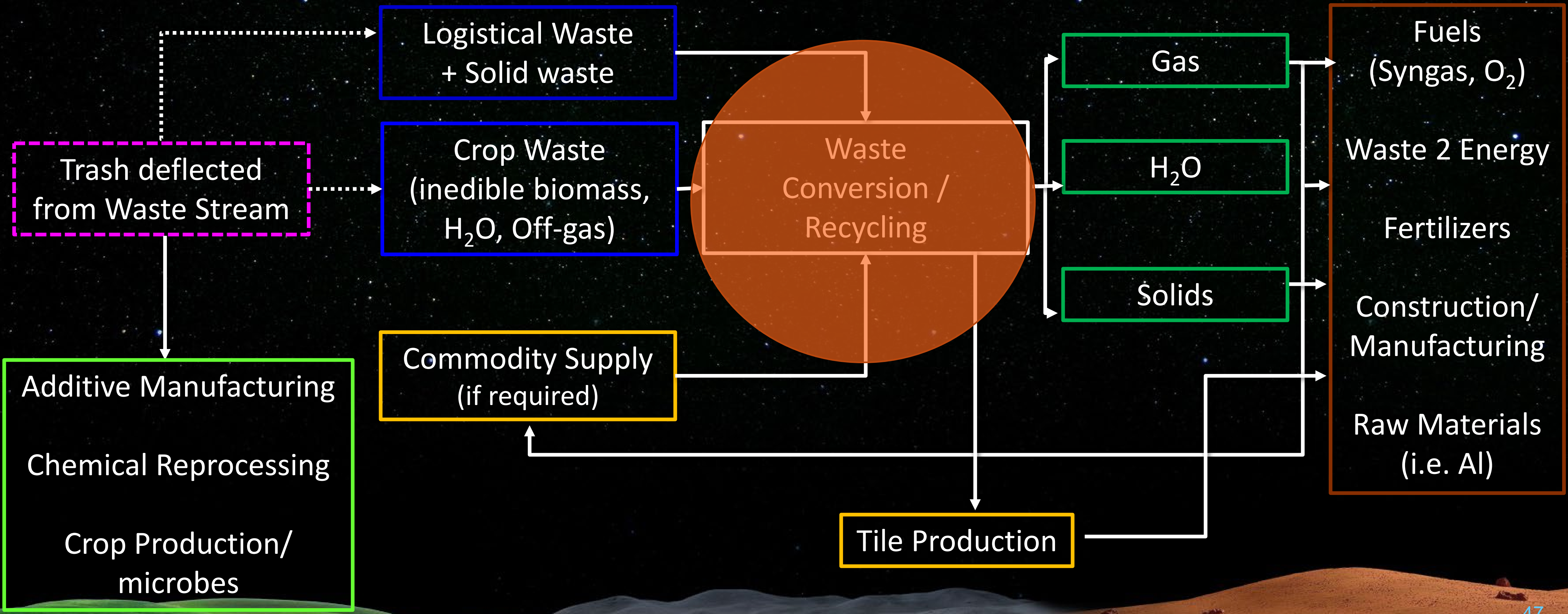
Crop Production System

Food

Inedible Plant Biomass

Concept: Trash Processing & Reuse Systems / Trash-to-Gas+

Have flown sub-scale trash conversion unit. Other units need fundamental research for advancing the circular process.



Trash deflected from Waste Stream

Logistical Waste + Solid waste

Crop Waste (inedible biomass, H_2O, Off-gas)

Commodity Supply (if required)

Waste Conversion / Recycling

Gas

H_2O

Solids

Tile Production

Fuels (Syngas, O_2)

Waste 2 Energy

Fertilizers

Construction/ Manufacturing

Raw Materials (i.e. Al)

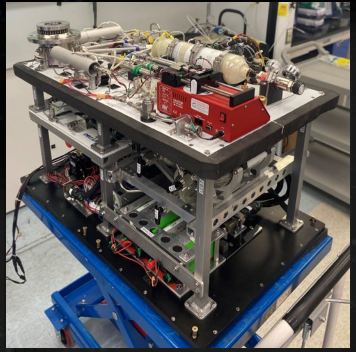
Additive Manufacturing

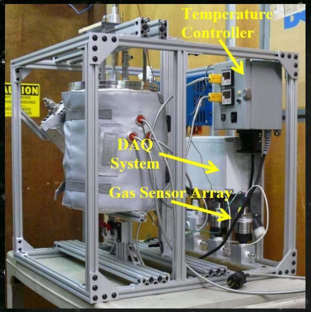
Chemical Reprocessing

Crop Production/ microbes

Evaluated Trash-to-Gas Systems evaluated in trade studies from 2020+ (does not include all from 2011-2019)

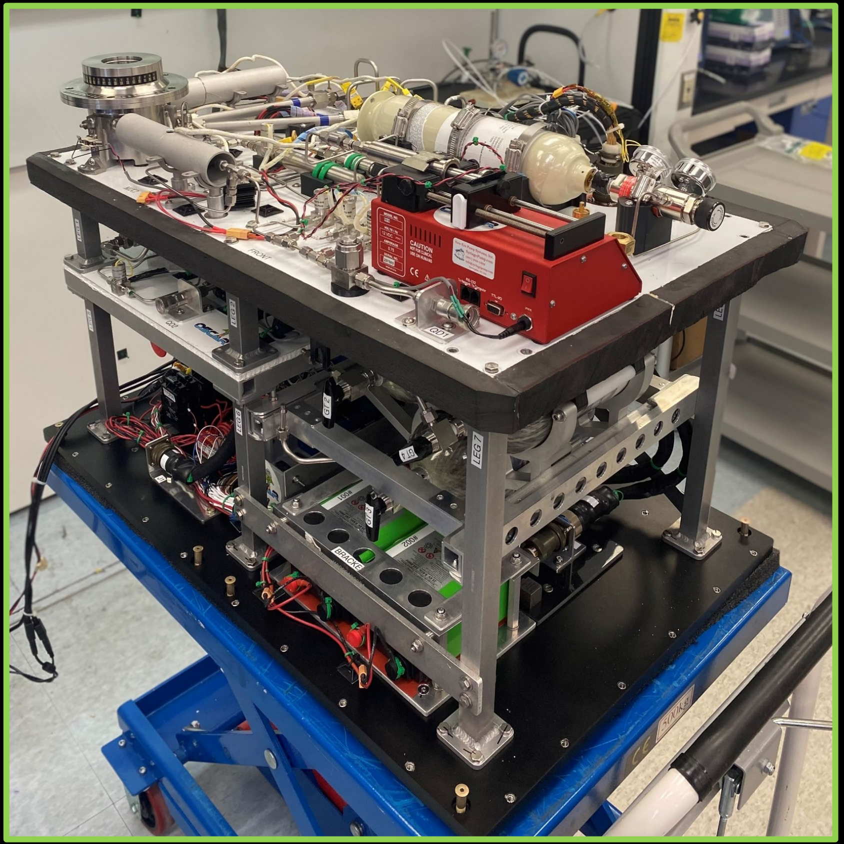
- Incineration/gasification (**Inc-Gas**; NASA/KSC; Anthony and Hintze, *44th ICES*, 2014, 016).
- Plasma gasification (**Plas-Gas**; NASA/KSC).
- Advanced Organic Waste Gasifier (**AOWG**); Pioneer Astronautics, Inc.).
- Orbital Syngas Commodity Augmentation Reactor (**OSCAR**; NASA/KSC).
- Microwave Assisted Pyrolysis (**MAP**; Advanced Fuel Research Corporation).
- Plasma Pyrolysis (**Plas-Pyro**; NASA/KSC).
- Torrefaction Processing Unit (**TPU**; Advanced Fuel Research Corporation).



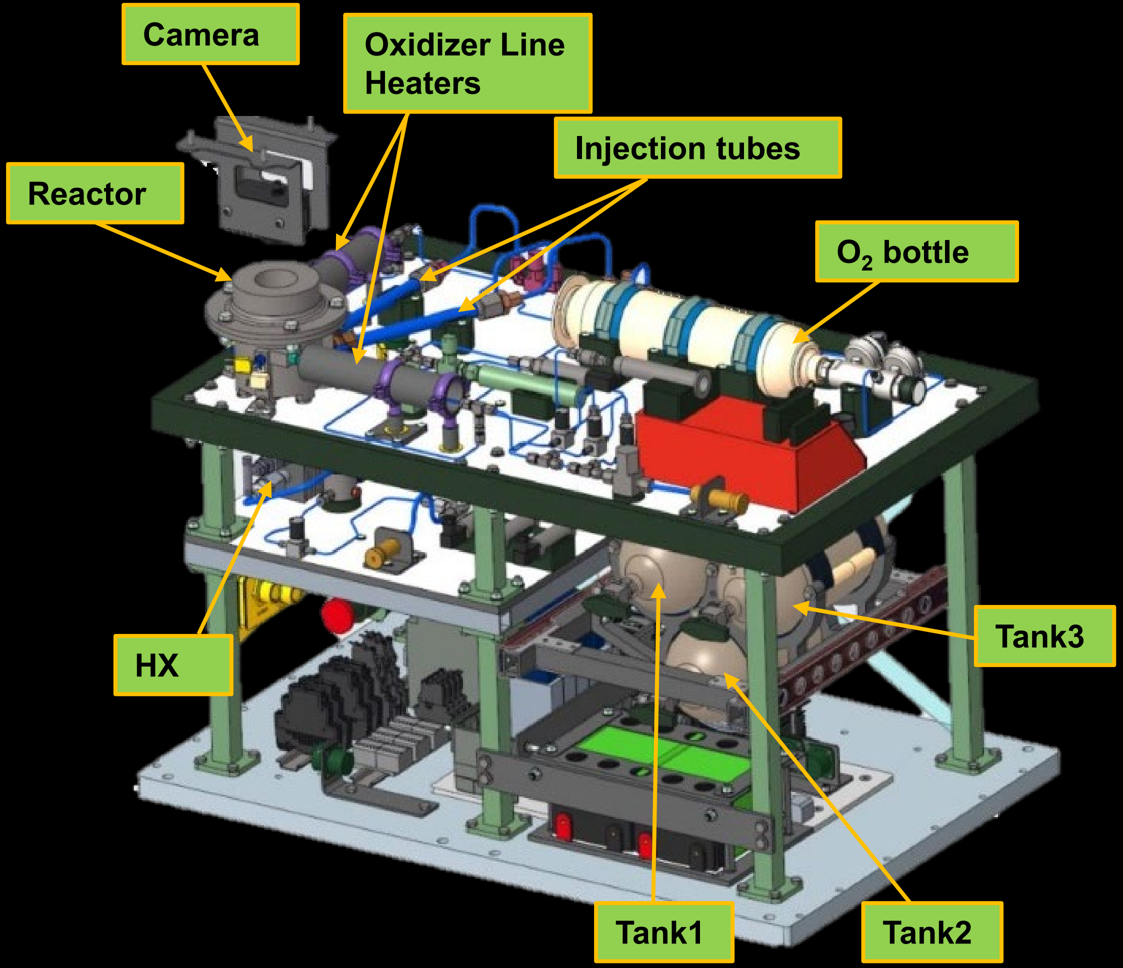


Olson, J.; Rinderknecht, D.; Essumang, D.; Kruger, M.; Golman, C.; Norvell, A.; Meier, A. A Comparison of Potential Trash-to-Gas Waste Processing Systems for Long-Term Crewed Spaceflight. **2021**.

Trash Processing & Reuse Systems / Trash-to-Gas / OSCAR



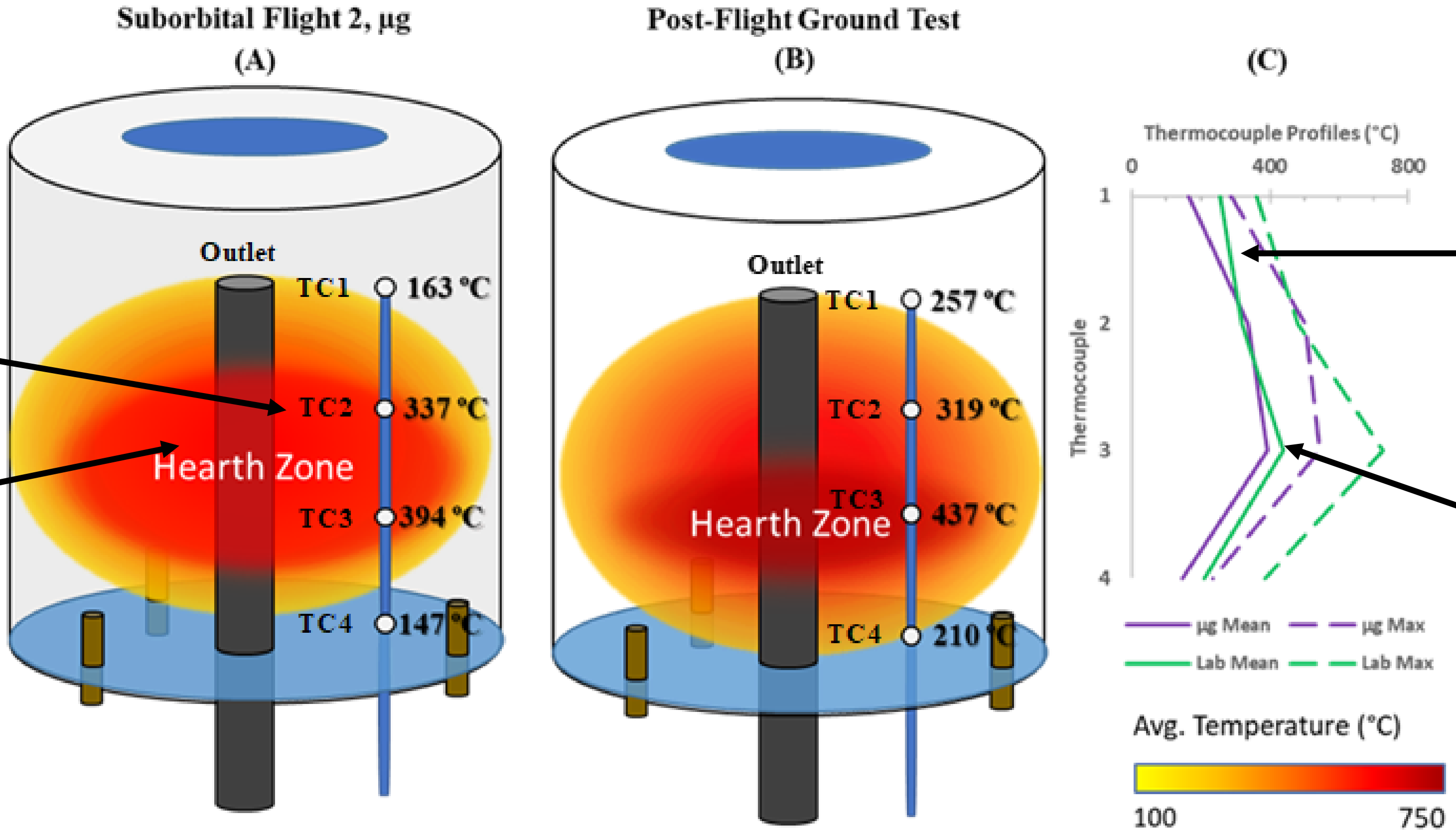
- "OSCAR" (Orbital Syngas Commodity Augmentation reactor) was for suborbital flight subscale demonstration only.
  - (15 min flight time with 3 minutes microgravity).
- Sub-scale: 10g processed in 3 minutes.
- 0.5 L reactor w/trash injection tubes
- 100% O2 feed gas at 1 SLPM
- 308 kPa / 45 PSIG



OSCAR Sub-scale System for Suborbital Flight

Warmer TC2 due to torch behavior

Trash floating



More efficient heat transfer in lab

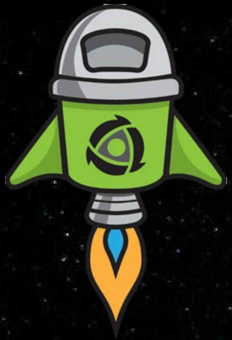
Lab temperatures warmer overall

Trash-to-Gas systems evaluated Mars transit propellant requirements

TtG System Name, Year of Operational Report	Thermal Process Technology	Total Vehicle Mass (kg)	Total Mass Reduction (kg)
Baseline (Stowage Model)	n.a.	309,296	--
NASA Incinerator/Gasifier (Inc-Gas), 2014 [23]	Incineration and Gasification	303,074	6,222
NASA Plasma Gasification [30] (Plas-Gas), 2019	Plasma-Induced Incineration and Gasification	303,145	6,151
Advanced Organic Waste Gasifier (AOWG), Pioneer Astronautics, Inc. (developed under NASA SBIR.) 2020 [23]	Oxygen-Enhanced Steam Reforming	303,391	5,905
Orbital Syngas Commodity Augmentation Reactor (OSCAR), 2021 [28], [48]	Oxygen-Enriched Combustion	303,141	6,155
Microwave Assisted Pyrolysis (MAP), (Advanced Fuel Research (AFR) Corporation (developed under NASA SBIR)) 2014 [23]	Microwave-Induced Pyrolysis	303,430	5,866
(Plas-Pyro), 2020 [45]	Plasma-Induced Pyrolysis	303,511	5,785
Torrefaction Processing Unit, (TPU), AFR Corporation (NASA SBIR), 2019 [40]	Torrefaction	305,597	3,699

J. A. Olson, P. Chai, D. Rinderknecht, and A. J. Meier, "A Comparison of Propellant Requirements for Crewed Mars Missions Incorporating Different Waste Processing Technologies," presented at the ASCEND, Las Vegas, Nevada & Virtual, 2021. doi: 10.2514/6.2021-4080.

Resources Available for Future Mission Scenarios in Trash



850-Day Mars Mission

- Mission duration: 850 days
- Mission location: Mars
- Crew size: 4
- Trash production rate: 1.607 kg/CM-d
- Trash composition: OSCAR-FS

30-Day Lunar Mission

- Mission duration: 30 days
- Mission location: Moon
- Crew size: 4
- Trash production rate: 1.607 kg/CM-d
- Trash composition: OSCAR-FS

Resources Available in (Crew Consumable) Waste Stream (kg)

Mission Type	Trash Total	Oxygen	Water	Polyethylene	Polyester	Polypropylene	Nylon	Aluminum
850-Day Mars	5463.8	1148.9	628.3	968.7	535.4	299.6	916.6	173.6
30-Day Moon	192.8	40.6	22.2	34.2	18.9	10.6	32.4	6.1

R.Pitts et.al. “Development of a Predictive Model for In-Situ Resource Utilization of Space Exploration Waste”, ASCEND 2023

Pending Publication ICES-2024-288
“Thermal Degradation and Rapid Composting of Inedible Biomass and Logistical Waste for Crop Production and Resource Recovery in Space Applications”

Innovations/Future Focus:

- Large scale demonstrations
- Integration into crop/LSS
- Full Scale OSCAR/ Trash-to-Gas Demonstration
  - OSCAR-Full Scale
  - crew of 4 on 1 year mission
  - ~6.5 kg/day for 30 days demo
  - Large reactor to accept 1 kg / batch of trash.
- Crop infusion with solids/ash nutrient tuning
- Water, ash and gas recovery
- Plasma VOC mitigation
- High throughput plasma gasification system.
- CHAPEA Mars Analog Habitat trash and data collection
- Alternative material selection for logistics packaging
- Additive manufacturing with polymers or recovered metals from logistics materials/packaging


Hood 3
NASA Kennedy Space Center
Applied Chemistry Laboratory

THANK YOU

NASA Kennedy Space Center

Applied Chemistry Laboratory

BACKUP SLIDES

Other papers for data on waste processing for space applications:

1. McKinley, M. K., Ewert, M. K., Borrego, M. A., Orndoff, E., Fink, P., Sepka, S., Richardson, J., and Meier, A. **Advancements in Logistics Reduction for Exploration Missions.** Presented at the 52nd International Conference on Environmental Systems, Calgary, Canada, 2023.
2. Olson, J. A., Chai, P., Rinderknecht, D., and Meier, A. J. A Comparison of Propellant Requirements for Crewed Mars Missions Incorporating Different Waste Processing Technologies. Presented at the ASCEND, Las Vegas, Nevada & Virtual, 2021.
3. Olson, J., Rinderknecht, D., Essumang, D., Kruger, M., Golman, C., Norvell, A., and Meier, A. A Comparison of Potential Trash-to-Gas Waste Processing Systems for Long-Term Crewed Spaceflight. Presented at the 50th International Conference on Environmental Systems, 2021.
4. Chen, T., et al. **Benefits of Trash-to-Gas versus Jettison of Waste via Trash-Lock for Mars Transit.** Presented at the 52nd International Conference on Environmental Systems, Calgary, Canada, 2023.
5. Linne, D. L., Palaszewski, B. A., Gokoglu, S. A., Balasubramaniam, B., Hegde, U. G., and Gallo, C. Waste Management Options for Long-Duration Space Missions: When to Reject, Reuse, or Recycle. Presented at the 7th Symposium on Space Resource Utilization, AIAA SciTech Forum, 2014.
6. Shah, M. G., Pitts, R. P., Benson, M. A., and Gleeson, J. R. **Investigating Waste Preparation Methods for Trash-to-Gas Technologies.** Presented at the 51st International Conference on Environmental Systems, St. Paul, Minnesota, USA, 2022.
7. Meier, A., Rinderknecht, D., Olson, J., Shah, M., Toro Medina, J., Pitts, R., Carro, R., Gleeson, J., Hochstadt, J., Forrester, E., Kruger, M., and Essumang, D. "Pioneering the Approach to Understand a Trash-to-Gas Experiment in a Microgravity Environment." *Gravitational and Space Research*, Vol. 9, No. 1, 2021, pp. 68–85. https://doi.org/10.2478/gsr-2021-0006.

Expected Trash Production Rate for Exploration

6.4 kg/day of trash
Crew of 4

TOP DOWN

Estimate production rates of each high-level waste category (refer to "Logistics Rates and Assumptions for Future Human Spaceflight Beyond LEO" (AIAA Control ID: 3907708)

Waste Category	*Production Rate ($kg*CM^{-1}*day^{-1}$)*
Food Packaging and Adhered Food	0.56
Waste & Hygiene Consumables	0.30
Wipes and Gloves	0.20
Fecal/Urine Collection Bags	0.17
Healthcare Consumables	0.09
Hygiene Kits	f(crew size, duration)*
Used Clothing	f(crew size, duration)*
Used Towels	f(crew size, duration)*

Notes:
* Hygiene kits, clothing, and towel waste productions vary per item and are a function of crew size and mission duration. Refer to the ELPG for discrete production rates for each item type.

Trash to Supply Gas – General Sys. Analysis

Waste Volume Reduction: 19 m^3

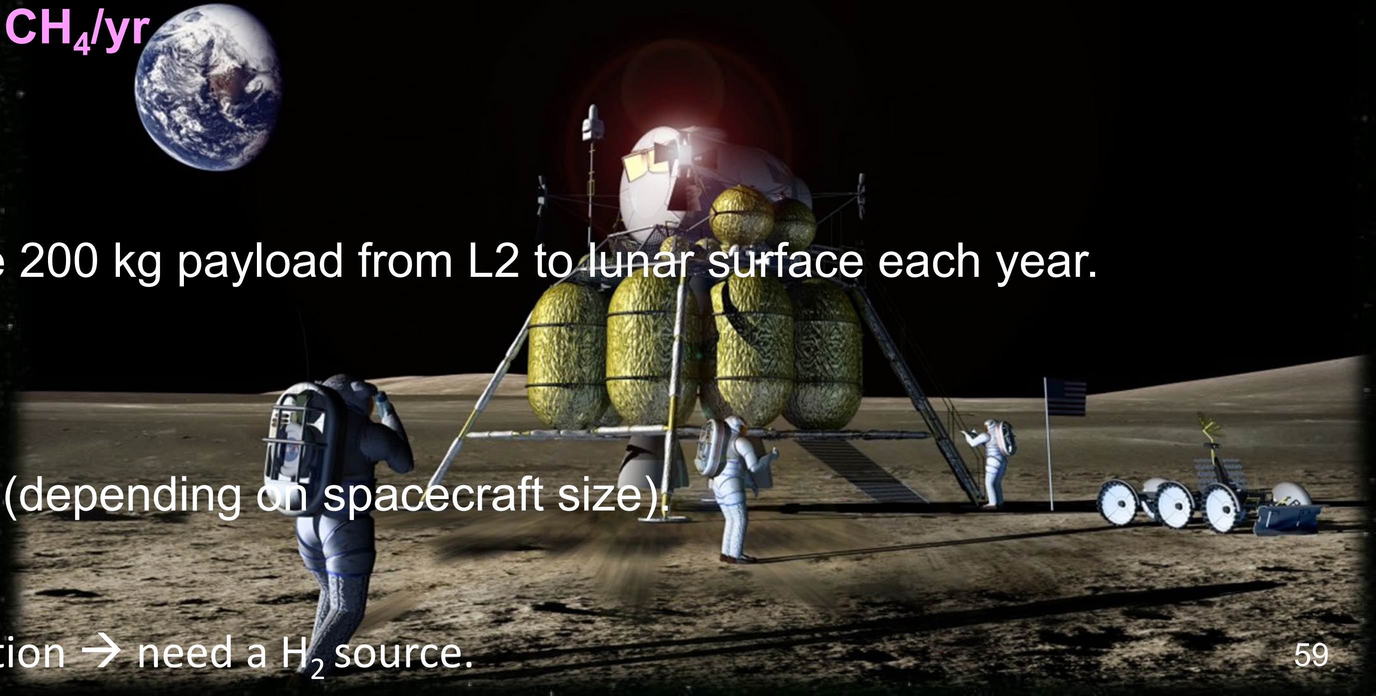
Equivalent to pressurized volume of one Orion Spacecraft.

Enough delta-V for yearly station keeping at Earth-Moon Lagrange point.

Production:

~800 kg of O_2 , ~900 kg of H_2O, 1,100 kg of CO_2

~800 to 1500 kg of CH_4/yr



Lunar:

Enough to send one 200 kg payload from L2 to lunar surface each year.

Mars:

Course Corrections (depending on spacecraft size).

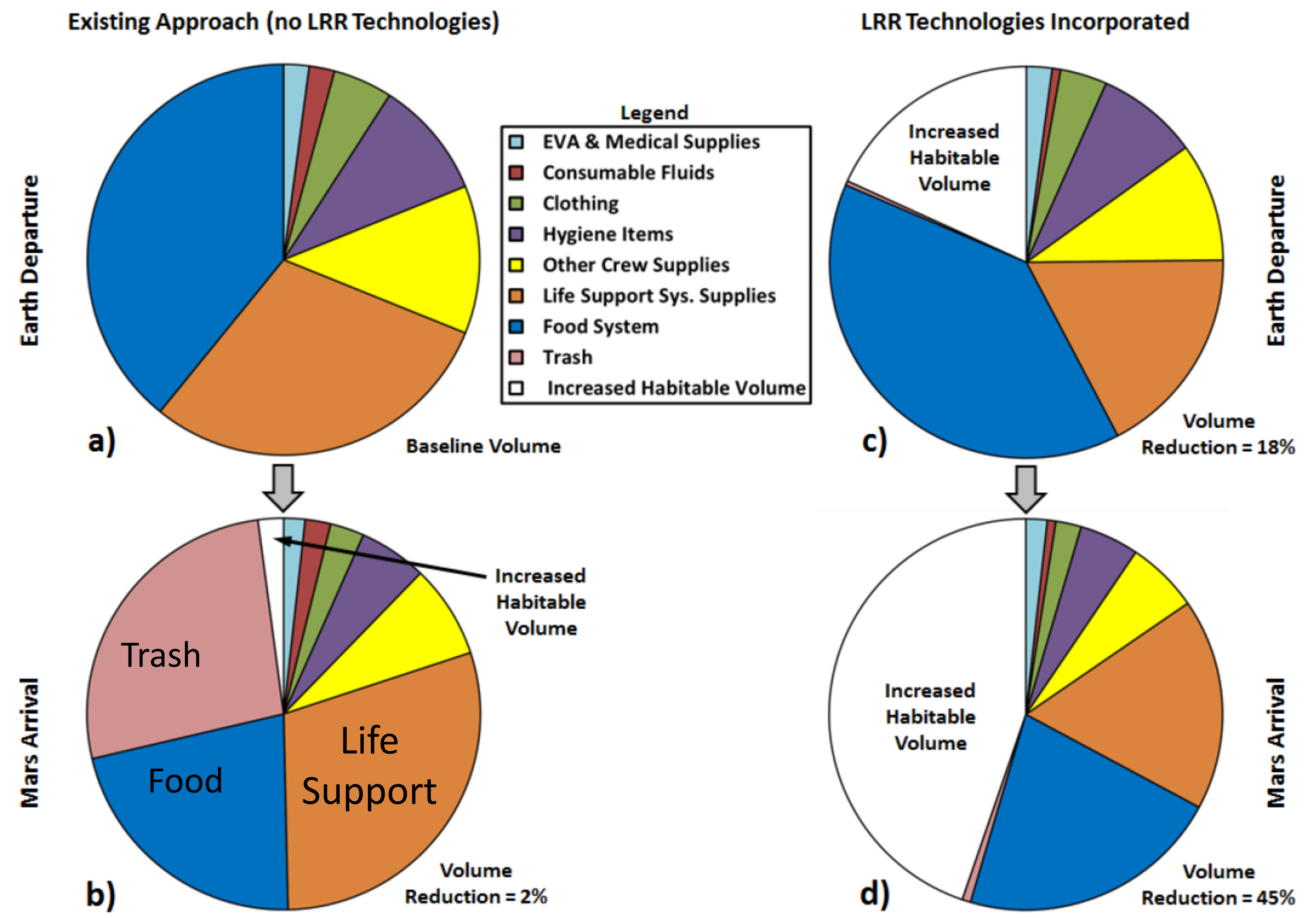
C is limiting reagent.

If CO_2 used for CH_4 production → need a H_2 source.

ISRU Challenges

- Landing site
- Maximize performance / Reduce mass
- Reliability
- Thermal management
- Extreme environments (dust, radiation, temperature, pressure)
- Microgravity environment
- Long duration operation, autonomy, failure recovery
- Interfaces
- Planetary protection

Logistics Reduction Mission Impacts - Volume



J. L. Broyan, et. Al, “Logistics reduction technologies for exploration missions,” presented at the AIAA SPACE 2014.