



National Aeronautics and
Space Administration

On-orbit Servicing Assembly and Manufacturing (OSAM) Workshop
Technologies, Partnerships, and Opportunities

ENABLING SPACE INFRASTRUCTURE

Advanced Materials and Feedstock Development for On-orbit Manufacturing

Dr. Jennifer Edmunson





“If God wanted man to become a spacefaring species, He would have given man a Moon.”

- Krafft Arnold Ehricke

Artemis: Landing Humans on the Moon



Lunar Reconnaissance Orbiter: Continued surface and landing site investigation



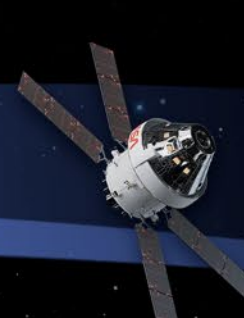
Artemis I: First human spacecraft to the Moon in the 21st century



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



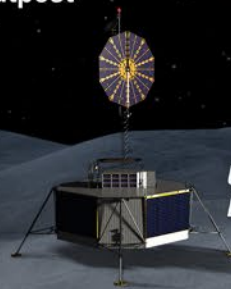
Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System



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



Uncrewed HLS Demonstration

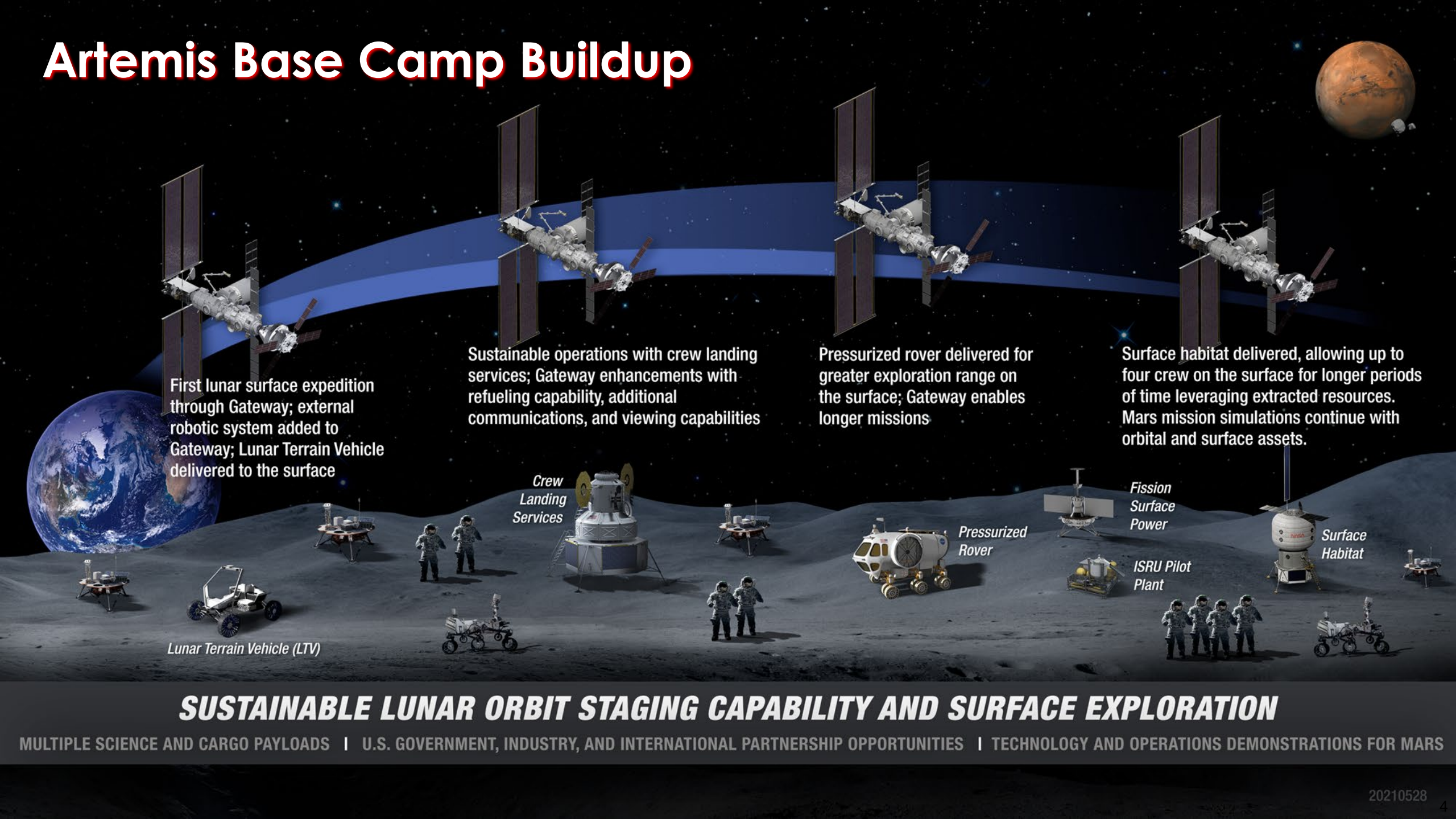


Humans on the Moon - 21st Century
First crew expedition to the lunar surface



LUNAR SOUTH POLE TARGET SITE

Artemis Base Camp Buildup

A diagram illustrating the four stages of the Artemis Base Camp buildup. The background shows a blue orbital path around the Moon, with Earth visible on the left and Mars on the right. Four Gateway stations are shown at different points along the path. Below the orbit, the lunar surface is depicted with various assets and astronauts. The assets include the Lunar Terrain Vehicle (LTV), Crew Landing Services lander, Pressurized Rover, Fission Surface Power reactor, ISRU Pilot Plant, and Surface Habitat. Astronauts are shown walking on the surface and operating the vehicles.

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.

Lunar Terrain Vehicle (LTV)

Crew
Landing
Services

Pressurized
Rover

Fission
Surface
Power

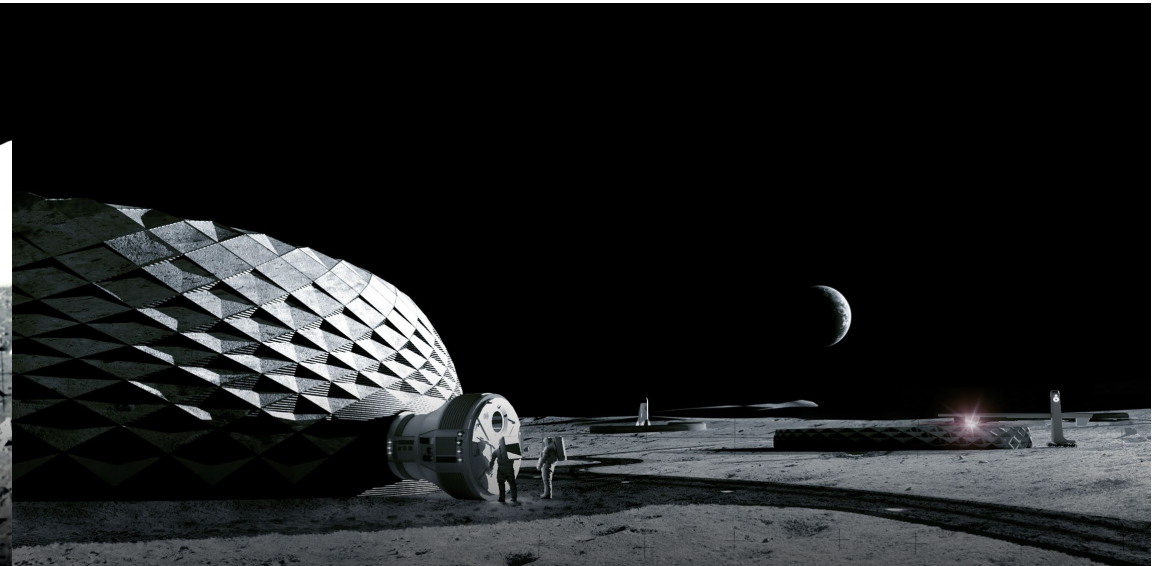
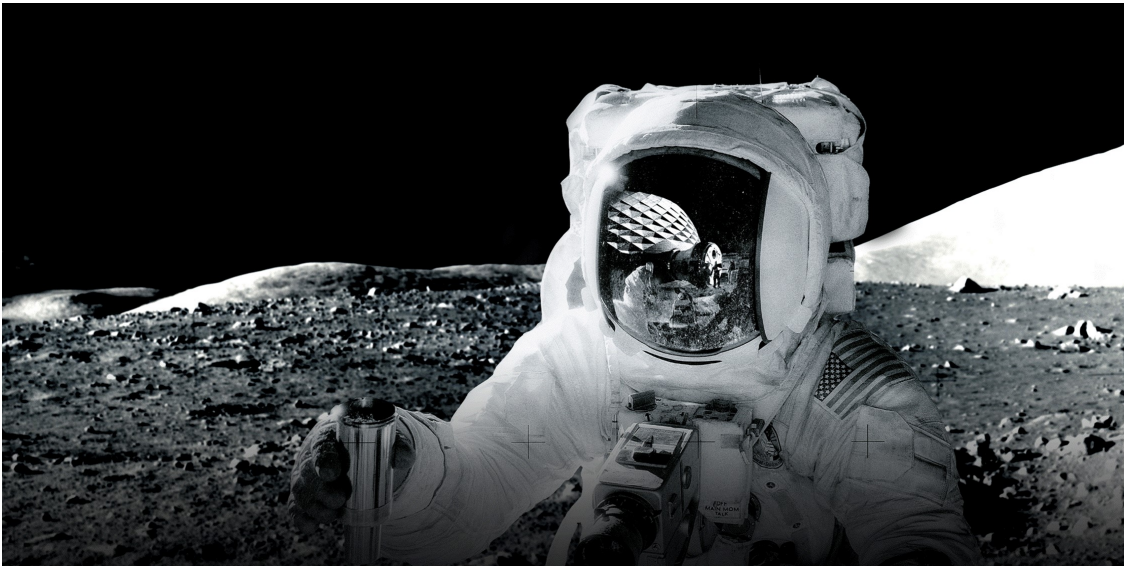
ISRU Pilot
Plant

Surface
Habitat

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

A Vision for a Sustainable Artemis Base



Images courtesy of ICON, the Bjarke Ingels Group, and Space Exploration Architecture

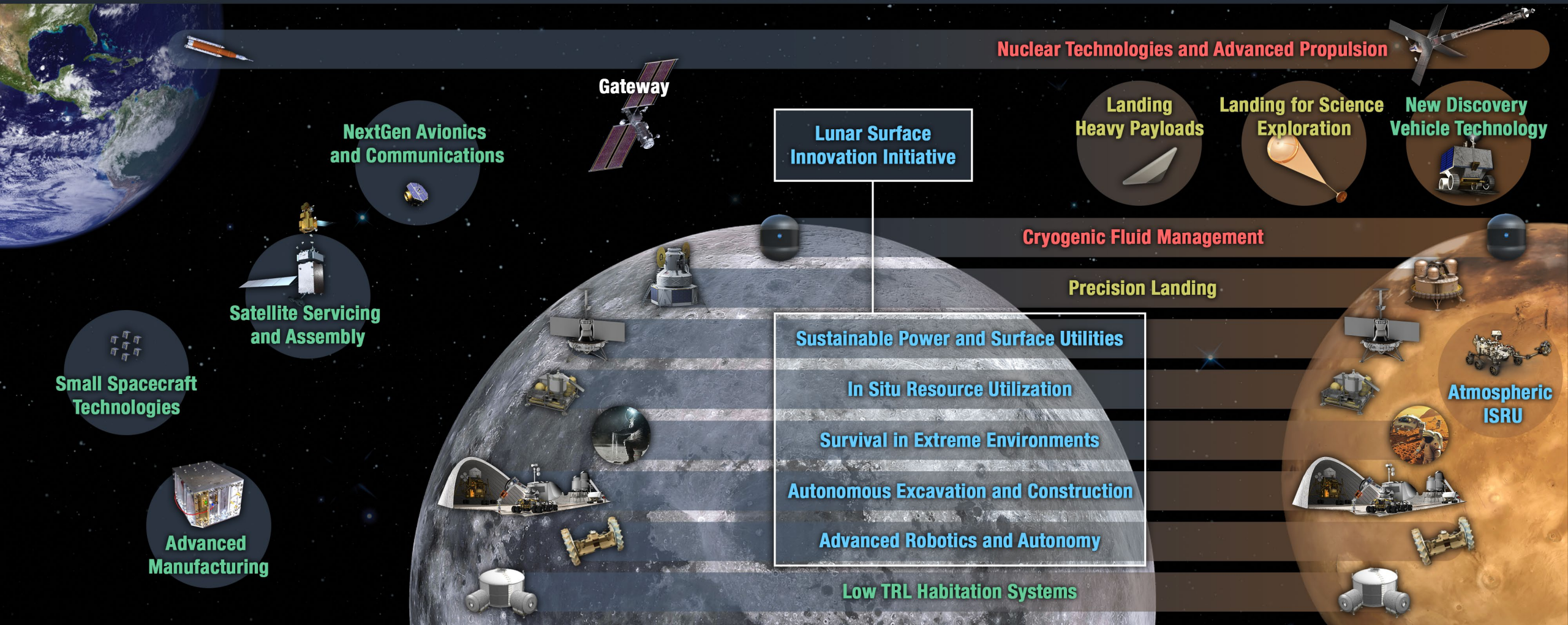
TECHNOLOGY DRIVES EXPLORATION

**Rapid, Safe, and Efficient
Space Transportation**

**Expanded Access to Diverse
Surface Destinations**

**Sustainable Living and Working
Farther from Earth**

**Transformative Missions
and Discoveries**



2020

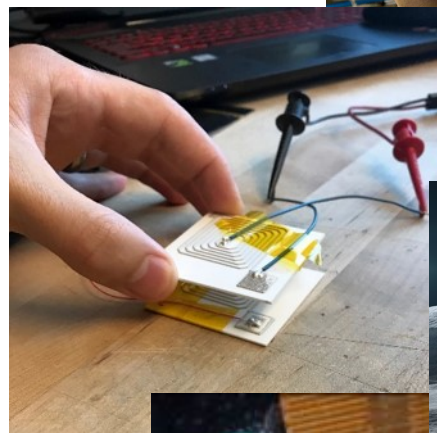
GO | LAND | LIVE | EXPLORE

203X

Manufacturing, Construction, and Outfitting



- Manufacturing (e.g., In-Space Manufacturing)
- Construction (e.g., Moon to Mars Planetary Autonomous Construction Technology (MMPACT) project)
- Outfitting (relatively new area!)



GOAL

Develop, deliver, and demonstrate on-demand capabilities to protect astronauts and create infrastructure on the lunar surface via construction of landing pads, habitats, shelters, roadways, berms, and blast shields using lunar regolith-based materials

APPROACH

MMPACT is comprised of 3 interrelated elements

- Olympus – Autonomous Construction System
- Construction Feedstock Materials Development
- Microwave Structure Construction Capability (MSCC)

High Level Capability Gaps (including those identified by the LSI Formulation Guidance for Lunar Surface Construction):

- Deposition processes and associated materials
- Increased autonomy of operations
- Hardware operation and manufacturing under lunar environmental conditions
- Long-duration operation of mechanisms and parts
- Scale of construction activities
- Material and construction requirements and standards



MMPACT – Current Partners



NASA Centers

- MSFC
- LaRC
- KSC
- JPL

OGA Leveraging

Potential:

- Innovation Unit US Air Force (AF)

Contributing:

- AF Civil Engineering Center
- AF Special Operations Command
- Defense Innovation Unit
- Texas Air National Guard
- USAF

Public/Private Partnerships

- Dr. Holly Shulman
- ICON Build
- Radiance Technologies
- RW Bruce Associates, LLC
- Blue Origin
- Jacobs Space Exploration Group
- JP Gerling
- Logical Innovations
- Microwave Properties North
- MTS Systems Corp.
- Southeastern Universities Research Association
- Southern Research
- Space Exploration Architecture (SEArch+)
- Space Resources Extraction Technologies
- Sioux Tribes
- Astroport

Technology Providers/ Contributing Partners: Academia

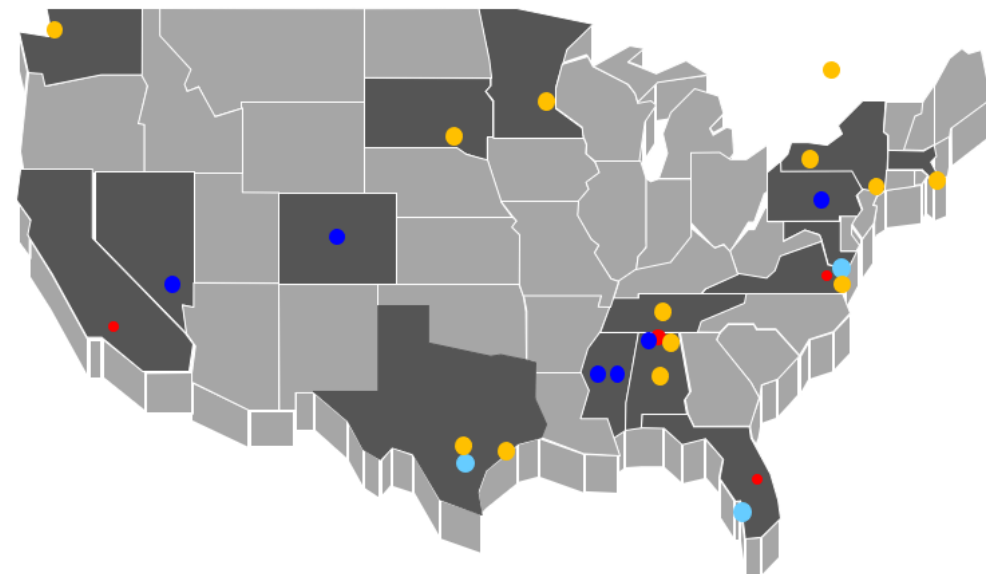
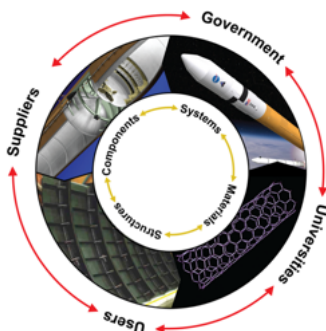
- Colorado School of Mines
- Drake State
- Mississippi State University
- Pennsylvania State University
- University of Mississippi
- University of Nevada Las Vegas

SBIR/STTR

- Construction Scale Additive Manufacturing Solution

Potential Customer

- Artemis



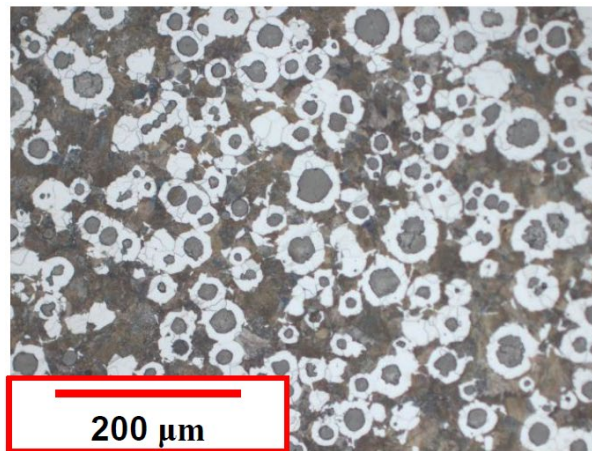
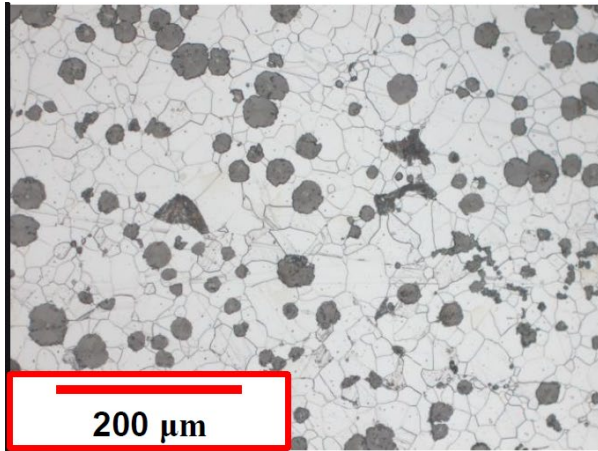
Collaborative multidisciplinary partnerships to leverage fiscal resources, ideas, knowledge & expertise.

MMPACT – In-Situ-Based Construction Materials

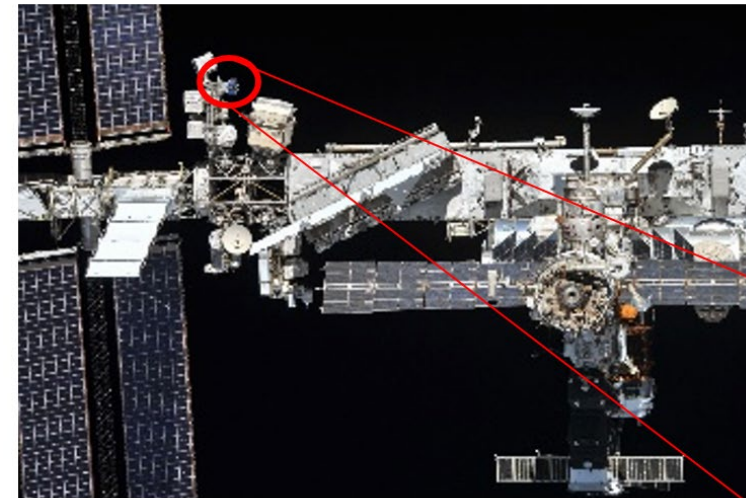


- Materials under study (including but not limited to)
 - Cement/regolith blends
 - Geopolymer
 - Ductile iron/steel
 - Microwave sintered regolith

Sulfur cement/regolith blend following impact testing. Image credit: NASA.



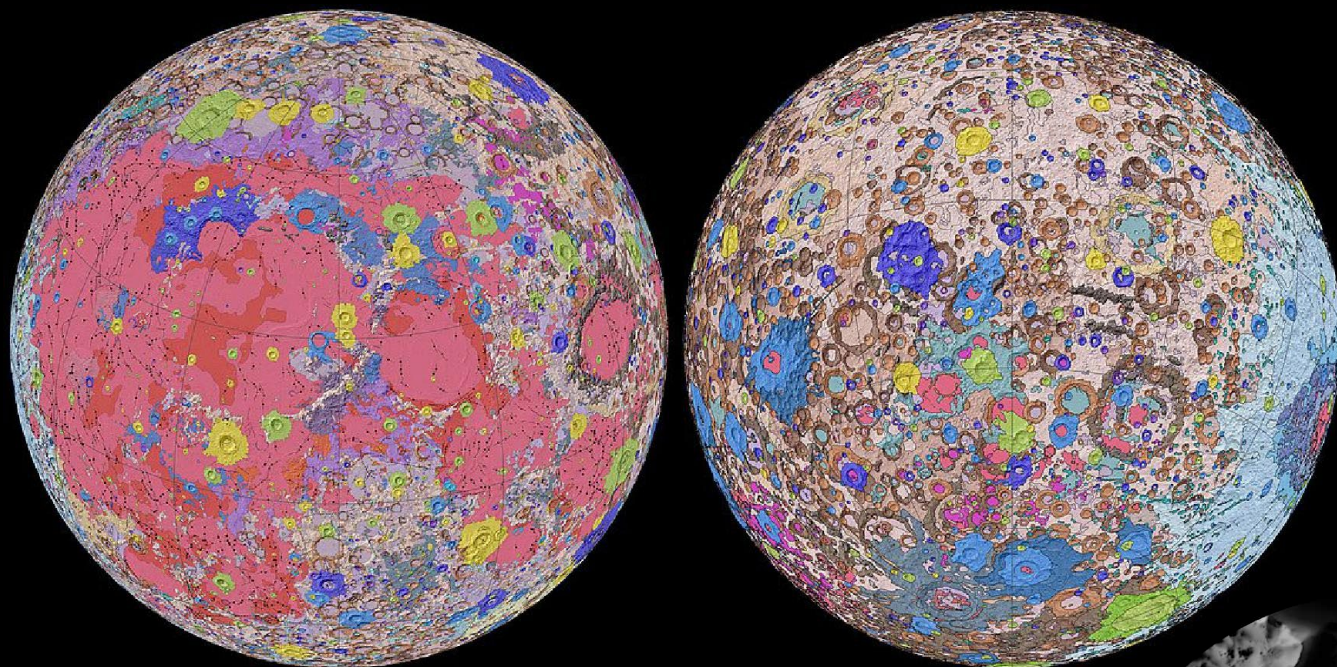
ISRU-based ductile iron cooled at 0.1°C/s (left) and 1.0°C/s (right). The difference is the formation of the harder phase, martensite (brown), at higher cooling rates. Images courtesy of Mississippi State/Blake Stewart.



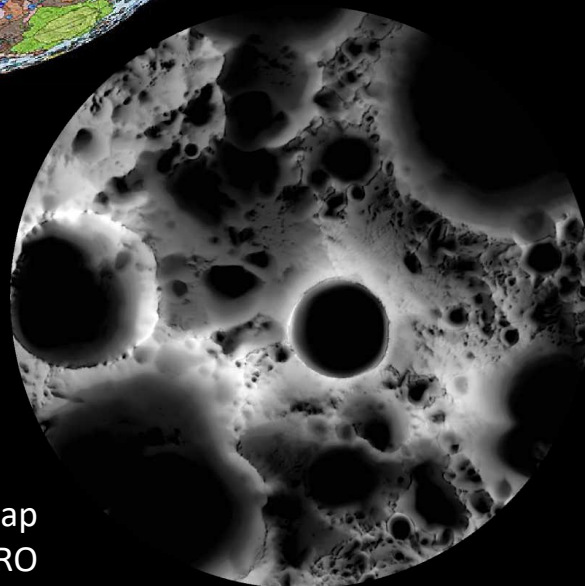
Materials ISS Experiment 15 contains multiple geopolymer samples. Image of geopolymer square courtesy of Penn State/Peter Collins and Aleksandra Radlinska.



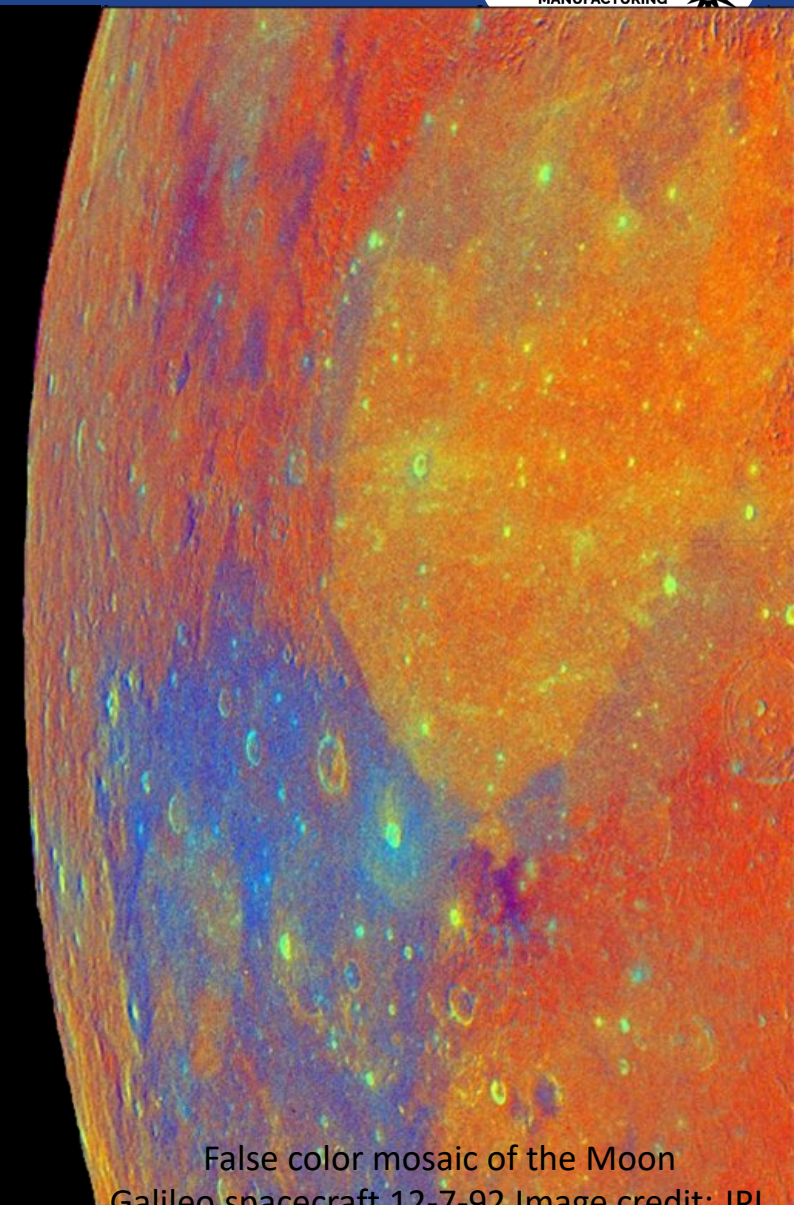
Leveraging Lunar Resources



Unified Geologic Map of the Moon orthographic projections
Image credit: NASA/GSFC/USGS

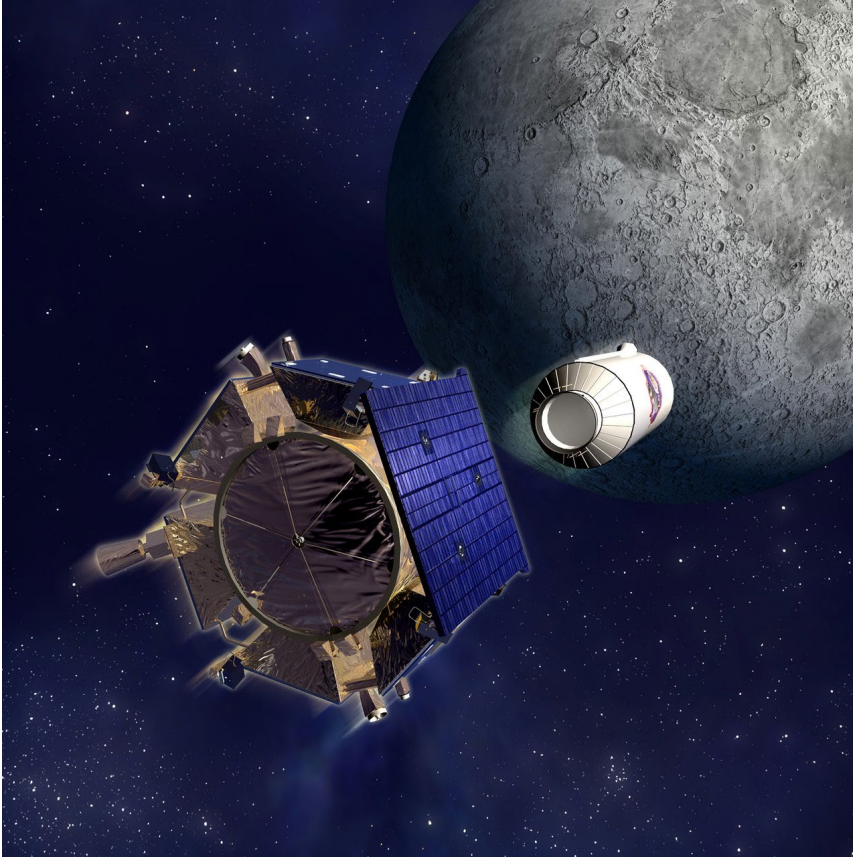


Lunar South Pole multi-temporal illumination map
Image credit: NASA/GSFC/Arizona State University/LRO

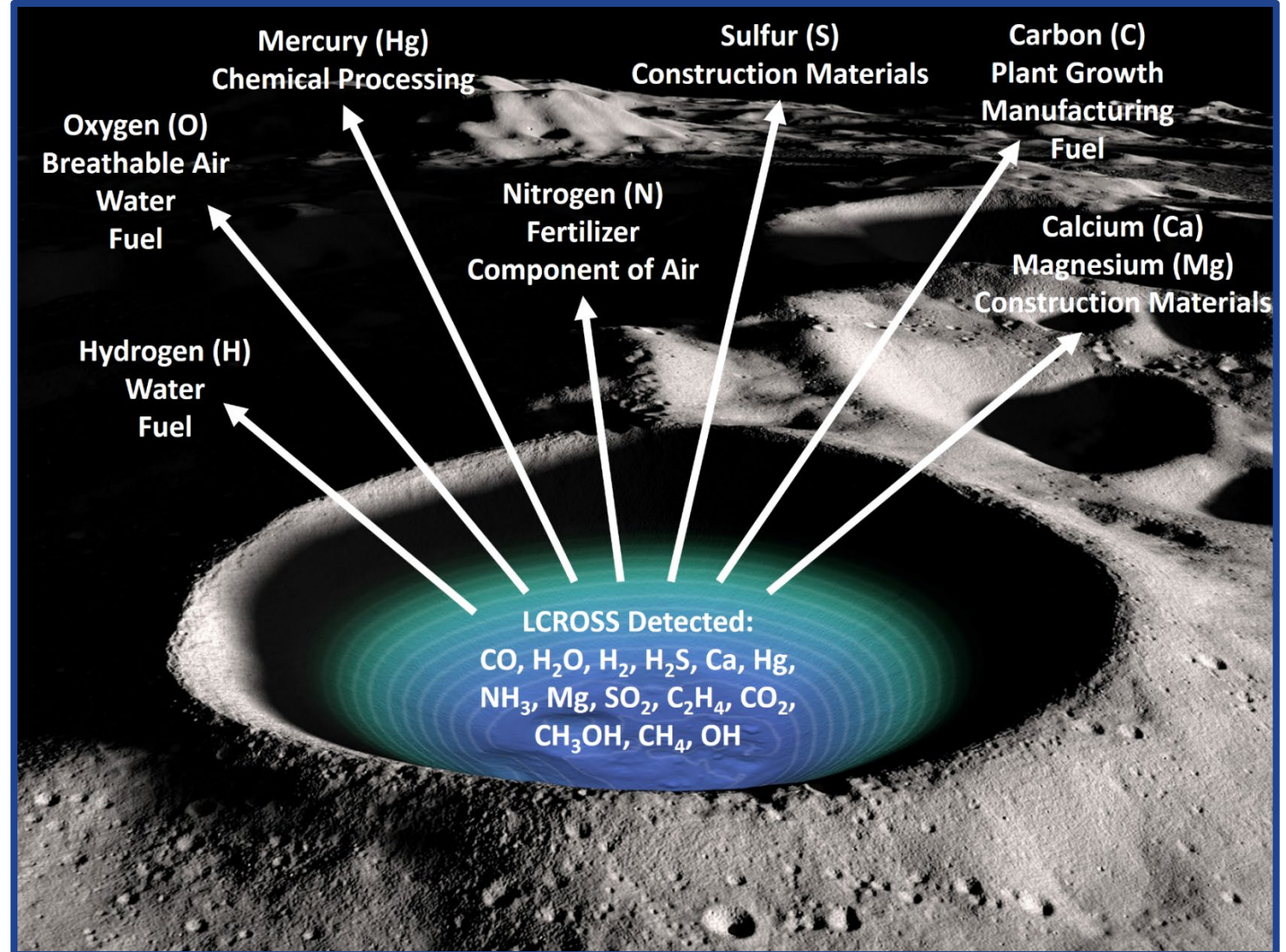


False color mosaic of the Moon
Galileo spacecraft 12-7-92 Image credit: JPL

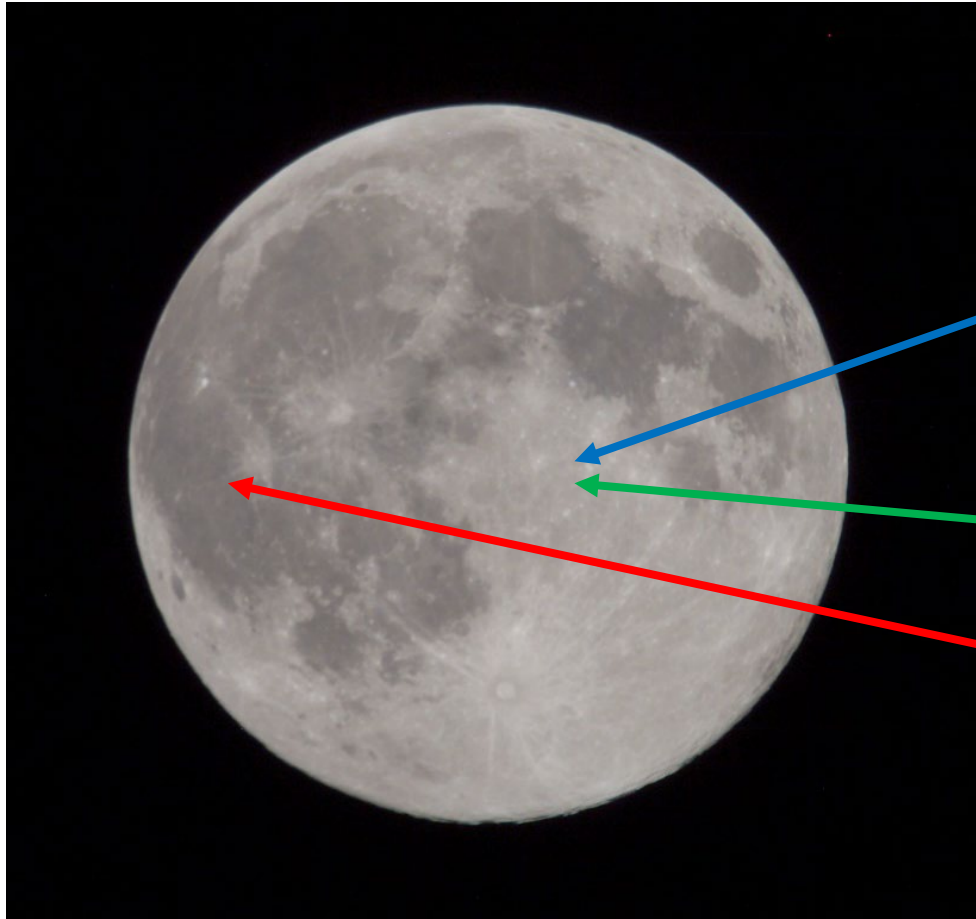
Leveraging Lunar Resources



Lunar **CR**ater **O**bservation and
Sensing **S**atellite (2009)



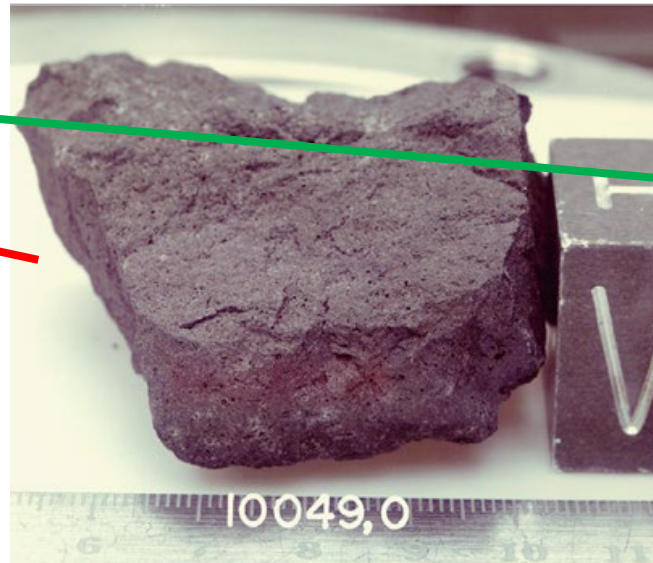
Leveraging Lunar Resources



anorthosite



basalt



norite



Leveraging Lunar Resources

Rocks

Minerals

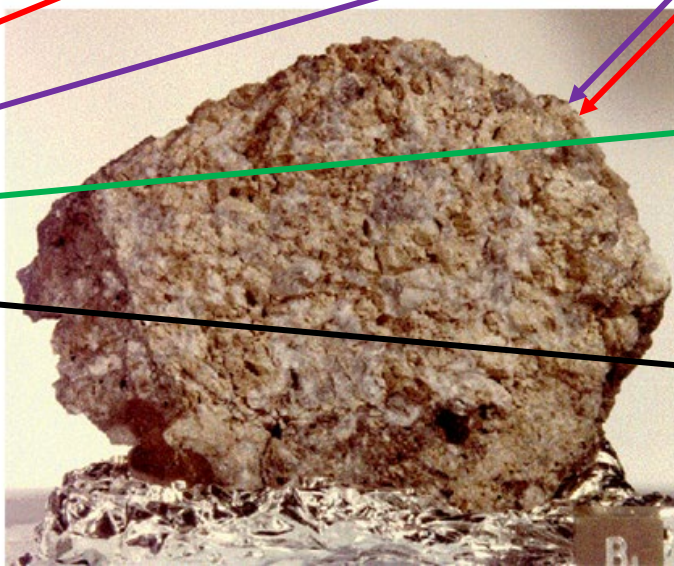
anorthosite



basalt



norite



Anorthite

Pyroxene



Olivine

Ilmenite



Leveraging Lunar Resources



Anorthite
 $\text{CaAl}_2\text{Si}_2\text{O}_8$



Pyroxene
 $(\text{Ca}, \text{Mg}, \text{Fe})\text{Si}_2\text{O}_6$



Olivine
 $(\text{Mg}, \text{Fe})_2\text{SiO}_4$



Ilmenite
 FeTiO_3

Al

Si

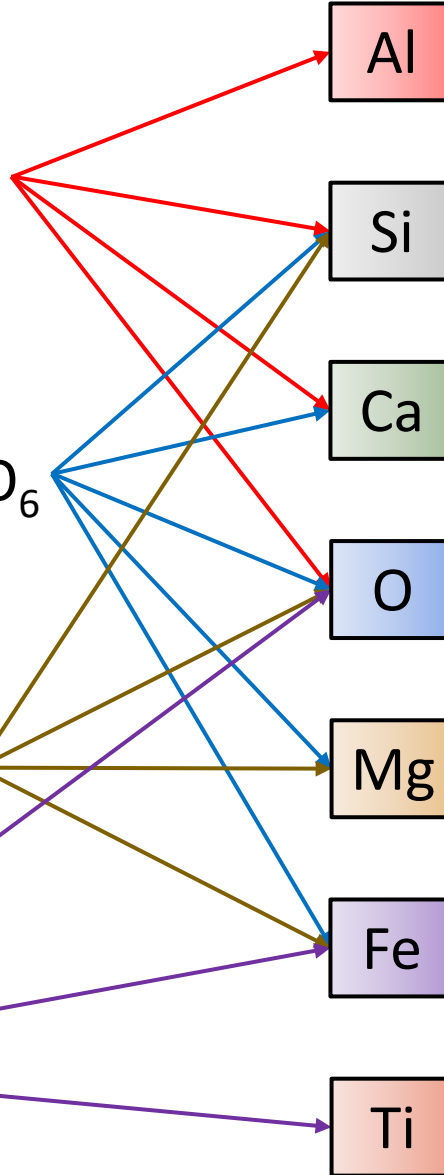
Ca

O

Mg

Fe

Ti



Leveraging Lunar Resources



Anorthite
 $\text{CaAl}_2\text{Si}_2\text{O}_8$



Pyroxene
 $(\text{Ca}, \text{Mg}, \text{Fe})\text{Si}_2\text{O}_6$



Olivine
 $(\text{Mg}, \text{Fe})_2\text{SiO}_4$



Ilmenite
 FeTiO_3

Al

Si

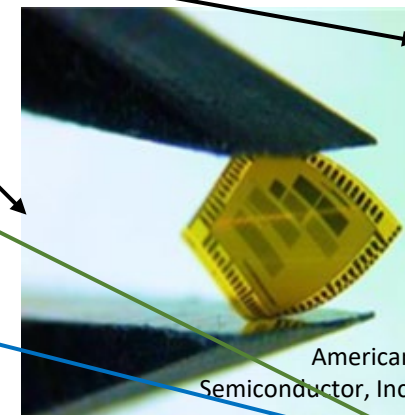
Ca

O

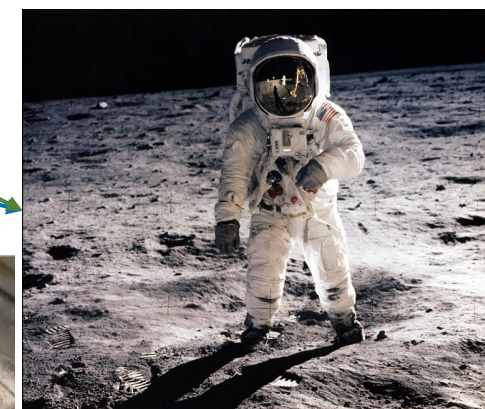
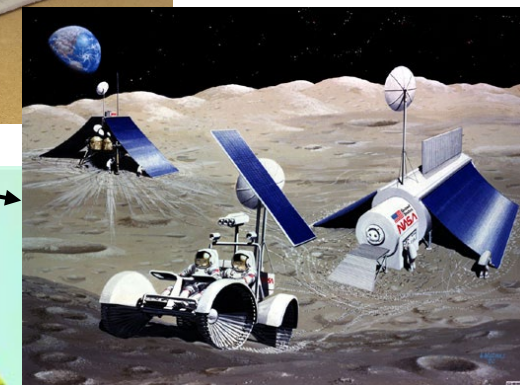
Mg

Fe

Ti



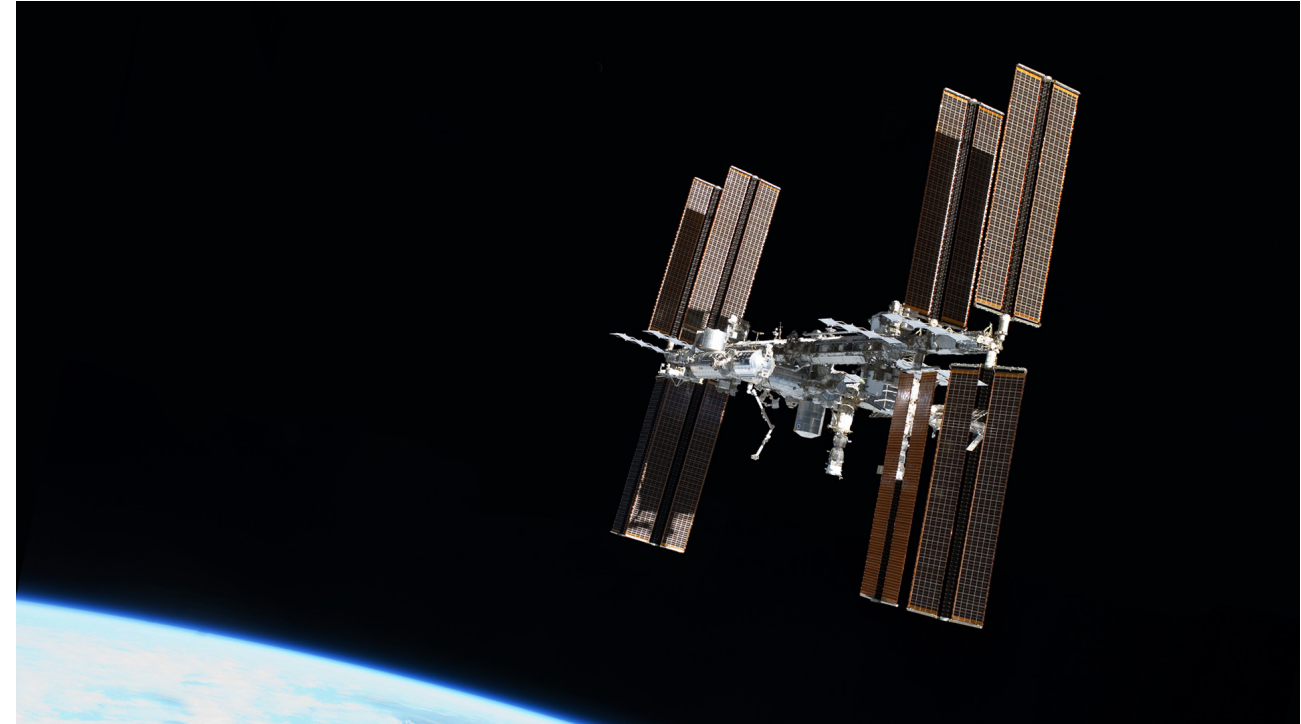
American
Semiconductor, Inc.



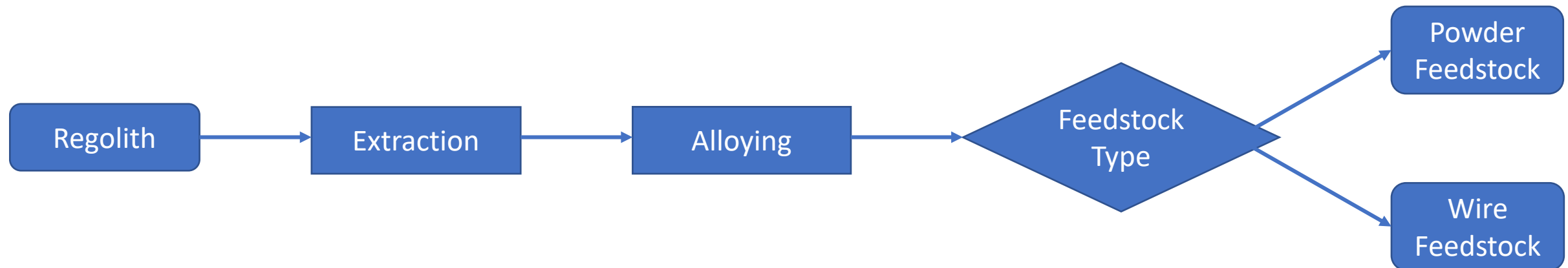
Made In Space

Additional Resources

- Crew waste
 - Polymers
 - Carbon
 - Human waste

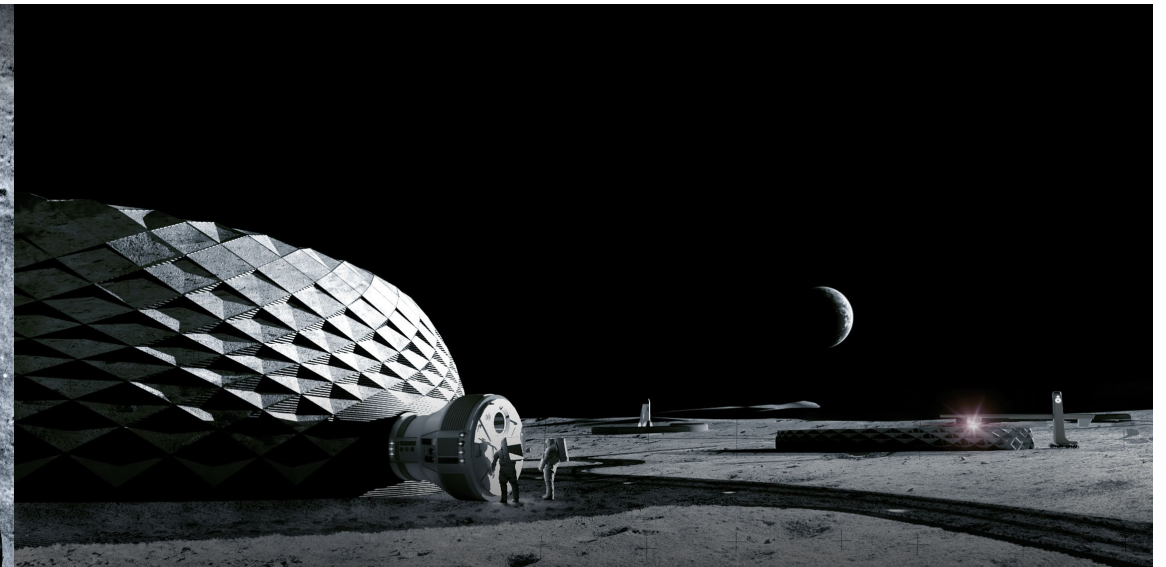


- Extraction of elements/compounds from regolith on an industrial scale
- Conversion of extracted elements/compounds into manufacturing or construction precursors (e.g., metal alloys, cement components)
- Production of usable manufacturing or construction feedstock (e.g., creating metal microspheres for powder bed fusion, metal wire for free form fabrication, or combining cement components into cement)

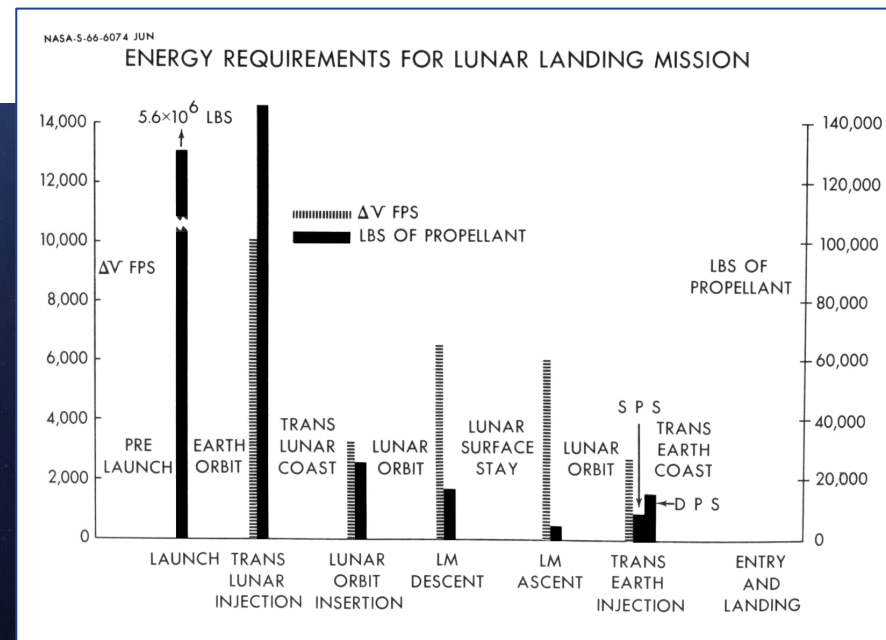
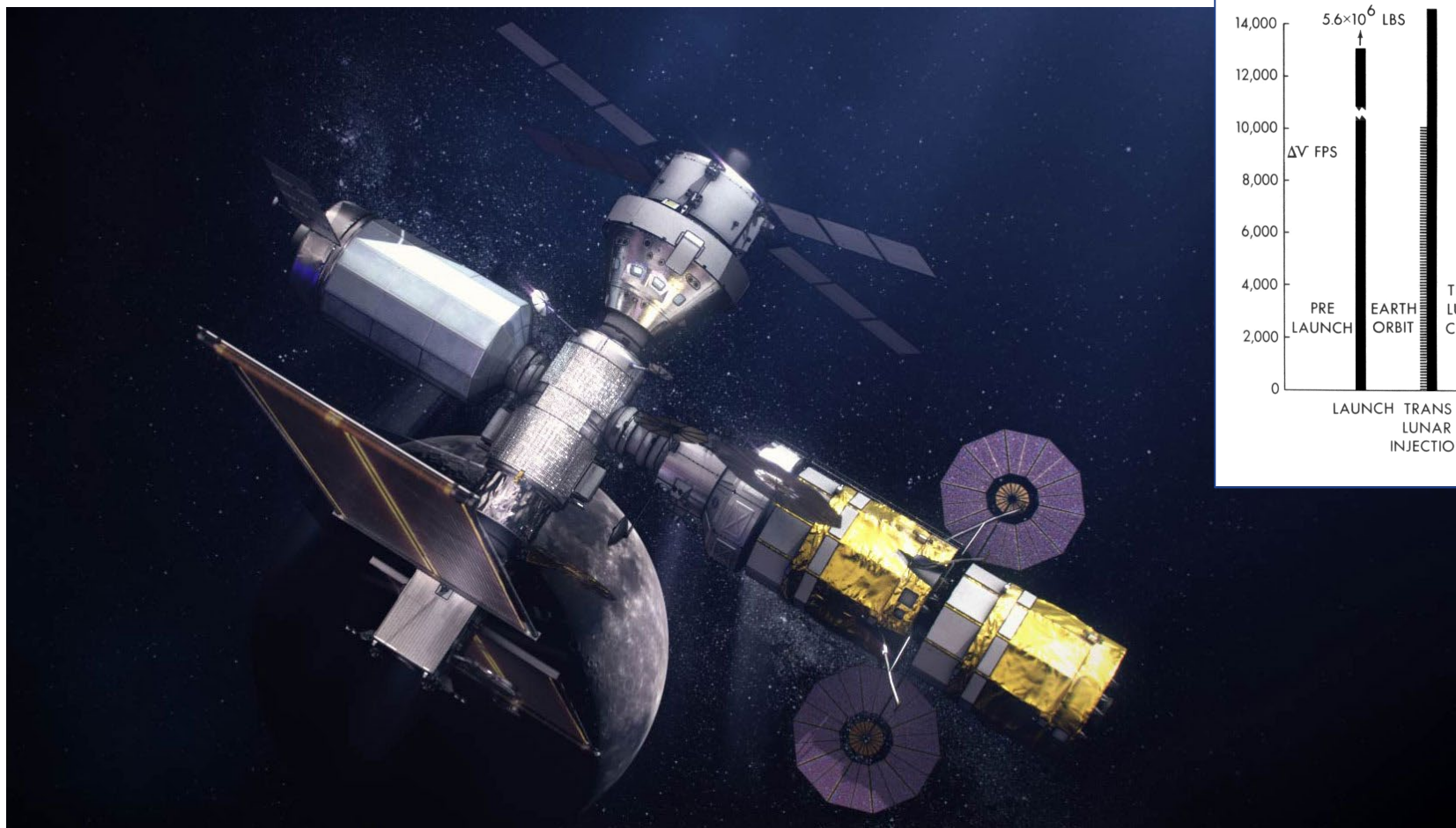


Items to Fabricate

Habitats, landing pads, furniture, plumbing, forks, truss structures, printed electronics, spare parts, batteries, garages, blast shields, ingress/egress ports, knives, telescopes, energy harvesting devices, thermal wadis, roads, storage tanks, spoons, greenhouses, solar panels/arrays, cabinets, countertops, partitions, sinks, toilets, etc.



Lunar Resource Utilization Benefit to OSAM



Maynard et al. (1966) Energy Requirements for Apollo Lunar Landing Mission (NASA-S-66-6074 fig. 2 in NASA TM X-58006)

Acknowledgements



- Space Technology Mission Directorate Game Changing Development Program
- Moon to Mars Planetary Autonomous Construction Technology (MMPACT) Team
- In-Situ Resource Utilization Community
- Planetary Science Community
- OSAM Team





National Aeronautics and
Space Administration

On-orbit Servicing Assembly and Manufacturing (OSAM) Workshop Technologies, Partnerships, and Opportunities

ENABLING SPACE INFRASTRUCTURE

NASA, industry, and other government agencies are making investments to establish the in-space infrastructure for services and utilities that extend satellite capabilities and expand the frontier for exploration and discovery. This shared vision will only be possible through an affordable commercial marketplace for OSAM services. NASA's Technology Transfer Program ensures that innovations for these capabilities are broadly available to the public, maximizing the benefit to the nation.

To arrange further discussion of OSAM technologies contact:

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