Moon to Mars Planetary Autonomous Construction Technology (MMPACT)

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National Aeronautics and Space Administration

The MMPACT goal is to 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

Image credit: SEArch+ and ICON

MMPACT: Moon to Mars Planetary Autonomous Construction Technology

Many infrastructure elements are required for a sustainable human presence on the Moon, and emplacement must be economical

Critical Technology Needs:

Excavation

In Situ Resource Utilization

Construction

Manufacturing

Power

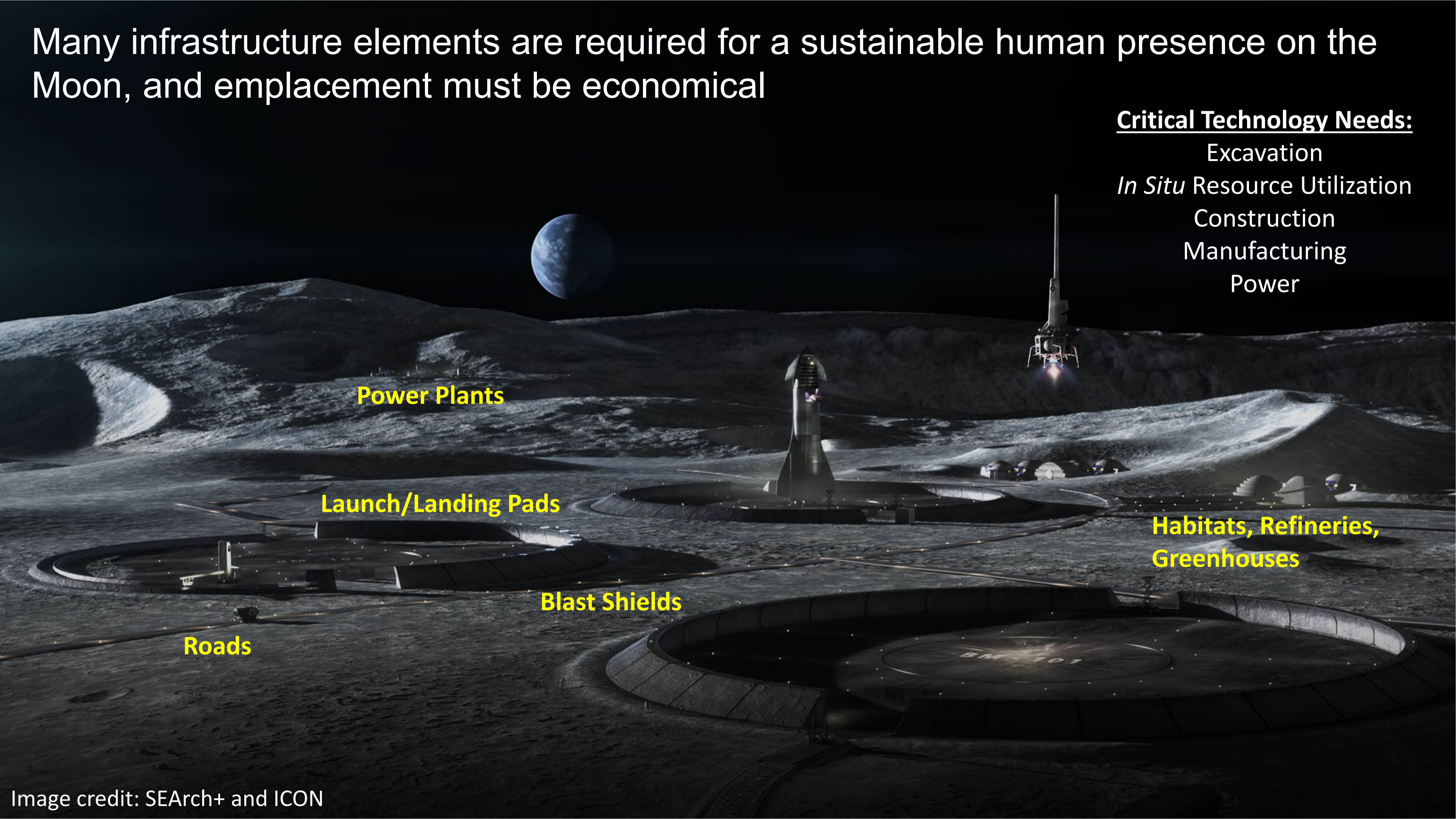
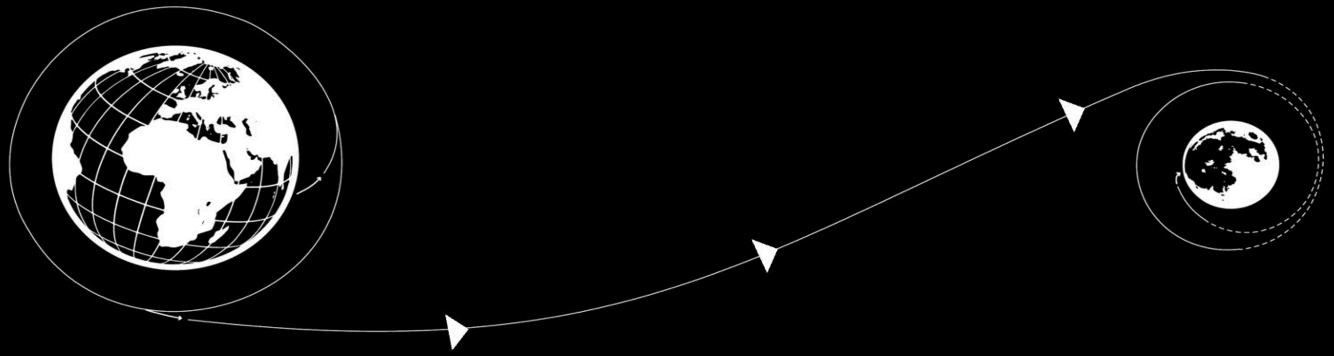


Image credit: SEArch+ and ICON

Rockets are not ***efficient*** movers of building materials.

Even with commercial space flight dramatically dropping the launch costs to all-time historic lows, flying pre-built structures doesn't make financial sense. Even flying building materials from Earth to the Moon is cost prohibitive.

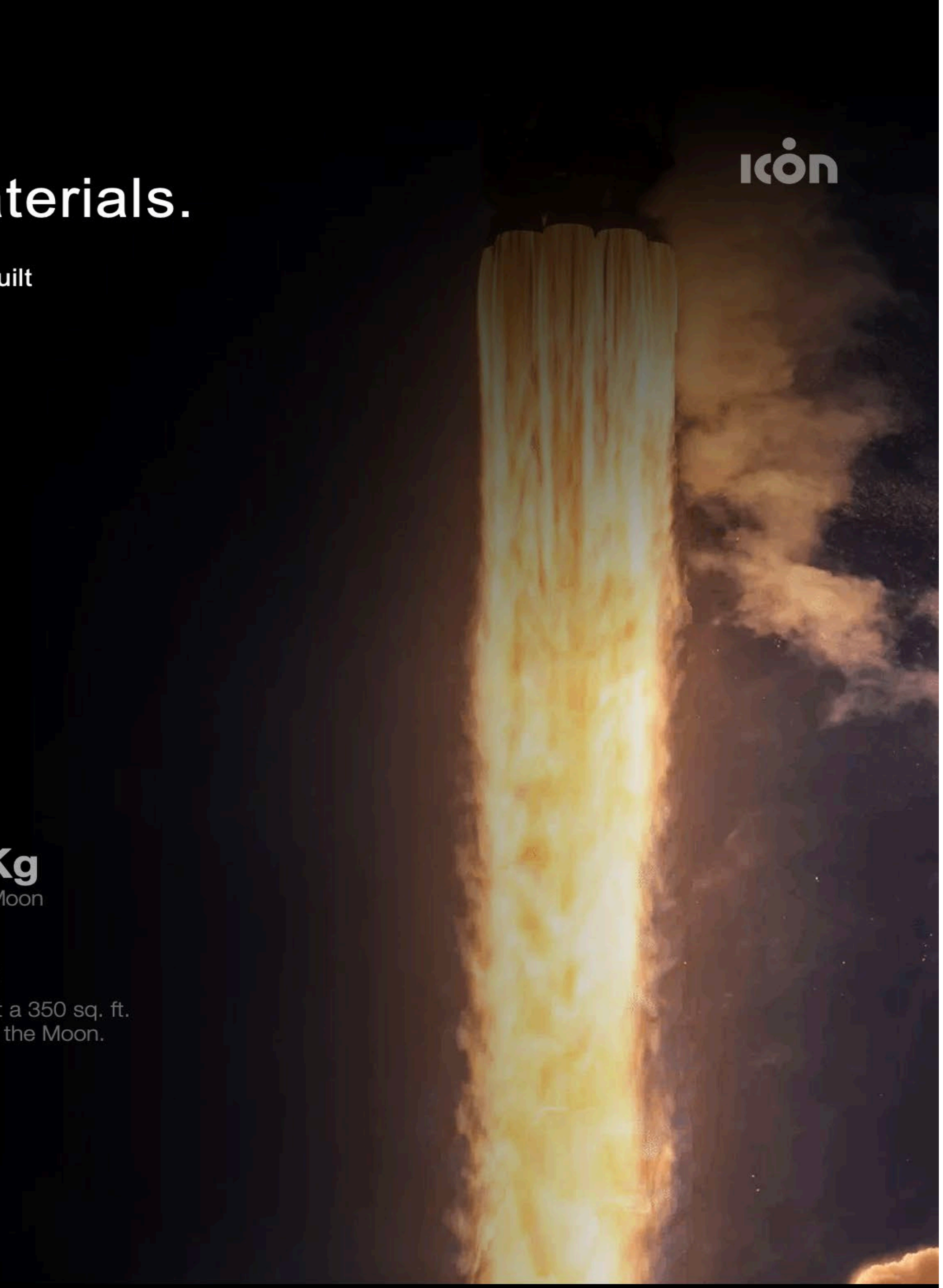


$ 0.11 per Kg
Costs of dry concrete on Earth

$ 1,200,000 per Kg
Cost to transport concrete to the Moon

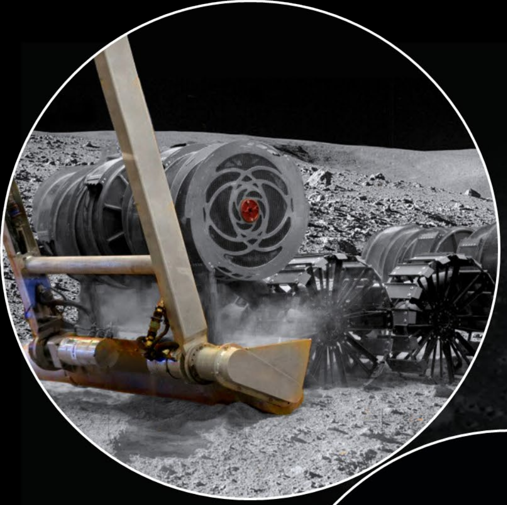
$ 96,000,000,000
Just the dry concrete costs to print a 350 sq. ft. structure like the Chicon House on the Moon.

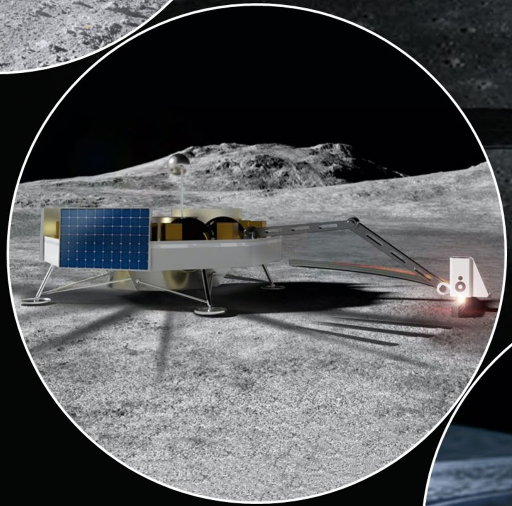
Source: Astrobotic Peregrine Lunar Lander Payload User's Guide:
https://explorers.larc.nasa.gov/2019APSMEX/MO/pdf_files/Astrobotic%20-%20Payload%20User%20Guide%20v3%202018-10.pdf

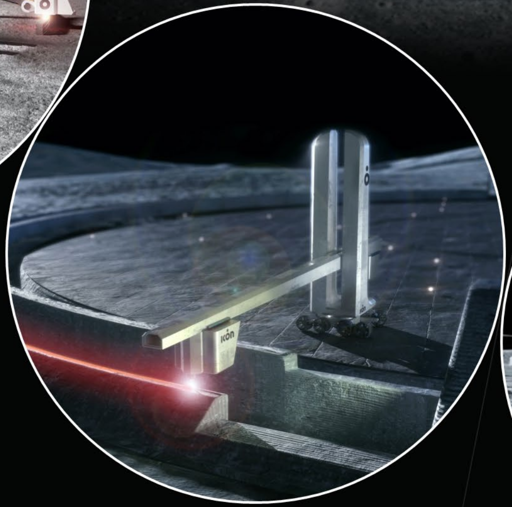


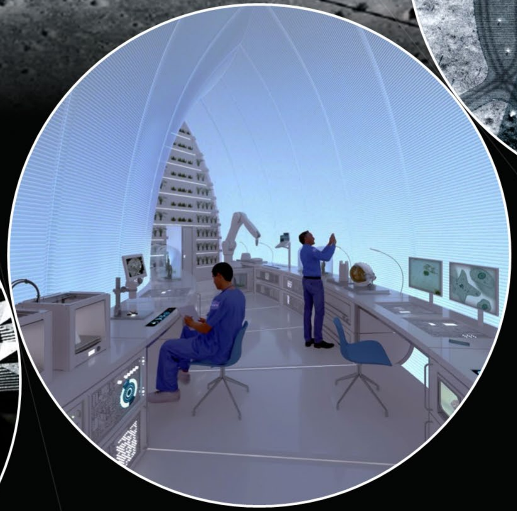
Lunar Construction Roadmap

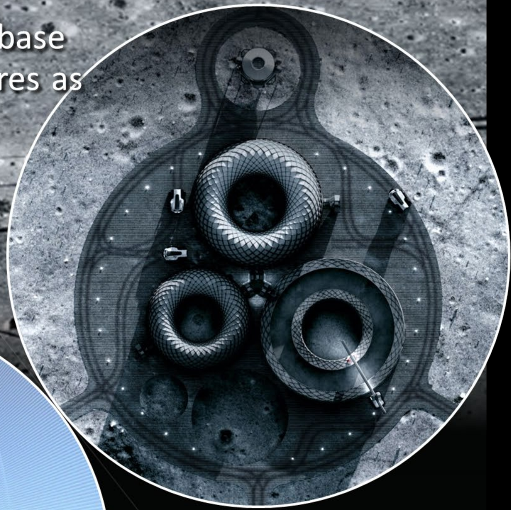
Phase 4: Complete build-out of the lunar base per the master plan and add additional structures as strategic expansion needs change over time.











Phase 1:
Develop & demonstrate excavation & construction capabilities for on-demand fabrication of critical lunar infrastructure such as landing pads, structures, habitats, roadways, blast walls, etc.

Phase 2: Establish lunar infrastructure construction capability with the initial base habitat design structures.

Phase 3: Build & Outfit the lunar base according to master plan to support the planned population size of the first permanent settlement (lunar outpost).

MMPACT Objectives

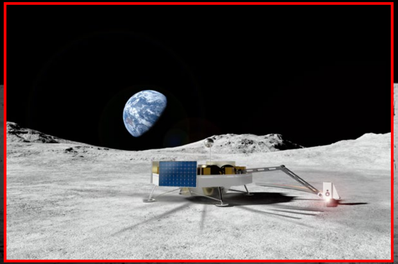
- Develop and demonstrate additive construction capabilities for various structures as materials evolve from Earth-based to exclusively *In Situ* Resource Utilization (ISRU)-based
- Develop and demonstrate approaches for integrated sensors and process monitoring in support of *in situ* verification & validation of construction system and printed structures
- Test and evaluate MMPACT hardware and materials products for use in the lunar environment
- Validate that Earth-based development and testing are sufficient analogs for lunar operations

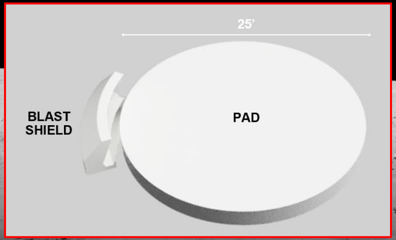
Demonstration Mission 1 (DM-1) — **2027**

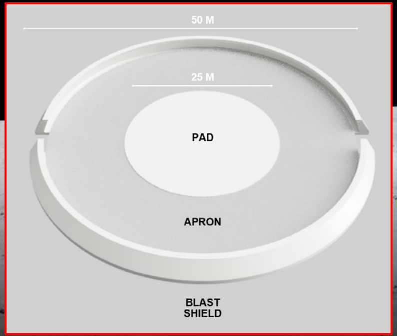
Demonstration Mission 2 (DM-2)

Qualification Mission 1 (QM-1) — **2030's**

Qualification Mission 2 (QM-2)







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MMPACT Requirements and Assumptions

- Level 1 requirements:
  - The system shall demonstrate lunar construction for future missions
  - The system shall additively construct structures using in-situ resources on the lunar surface
  - The system shall implement both autonomy and remote operations to carry out its tasks

- Mission success is defined as:
  - The ability to emplace a structural element with an observed material characteristic

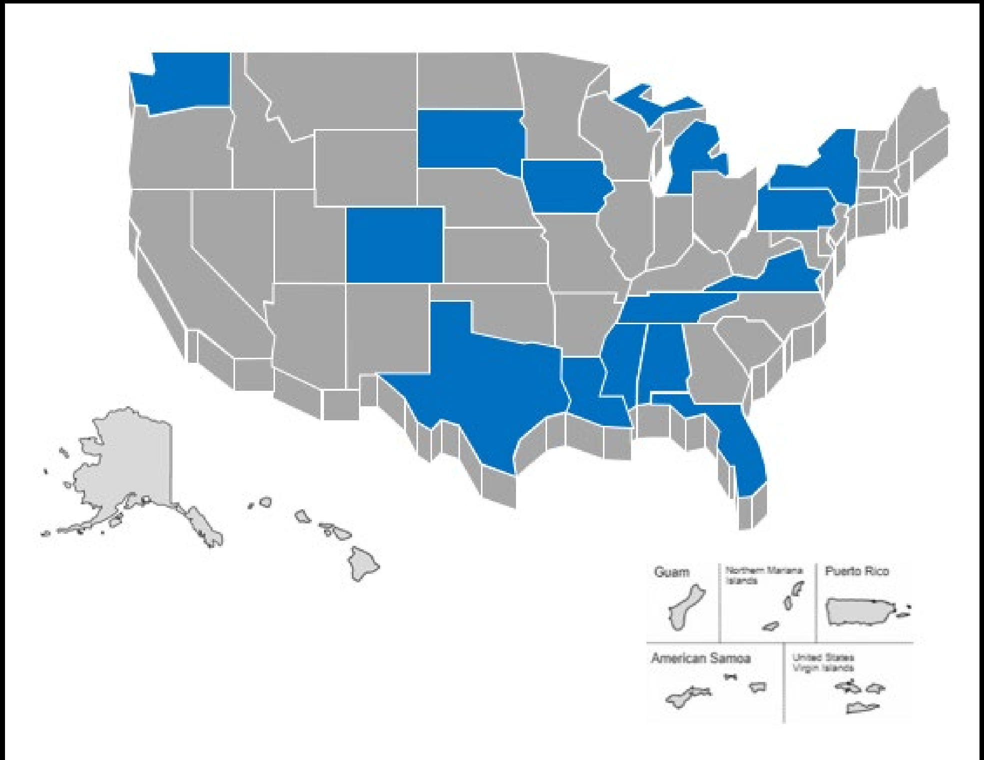
- Assumptions:
  - South polar region regolith
  - South polar region lighting

Image used with permission from ICON.

Collaborations and Partnerships

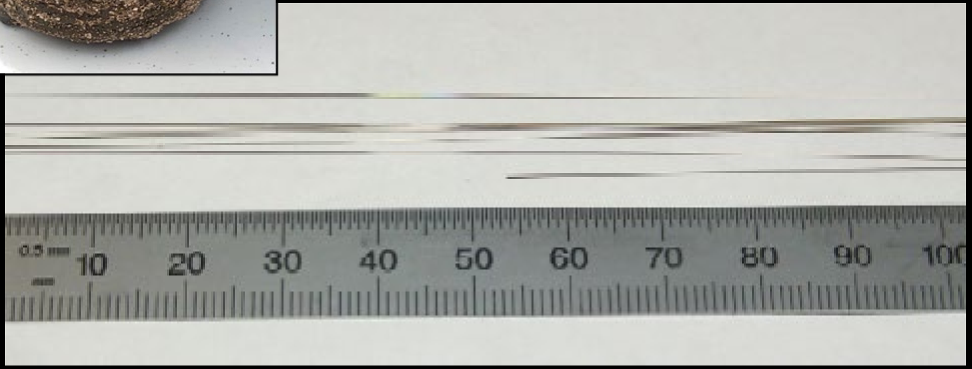
- Contributing partners and/or stakeholders
  - NASA Centers: MSFC, LaRC
  - OGA: AF Civil Engineering Center, Air Force Special Operations Command (AFWERX), Defense Innovation Unit (In Discussions), Texas Air National Guard, United States Air Force
  - Academia: Clarkson University, Drake State, Iowa State University, Mississippi State University, Pennsylvania State University, Sinte Gleska University, University of Alabama in Huntsville, University of Mississippi, University of Tennessee Knoxville
  - Industry: Blue Origin LLC, Dr. Holly Shulman, ICON Technology, Jacobs Space Exploration Group

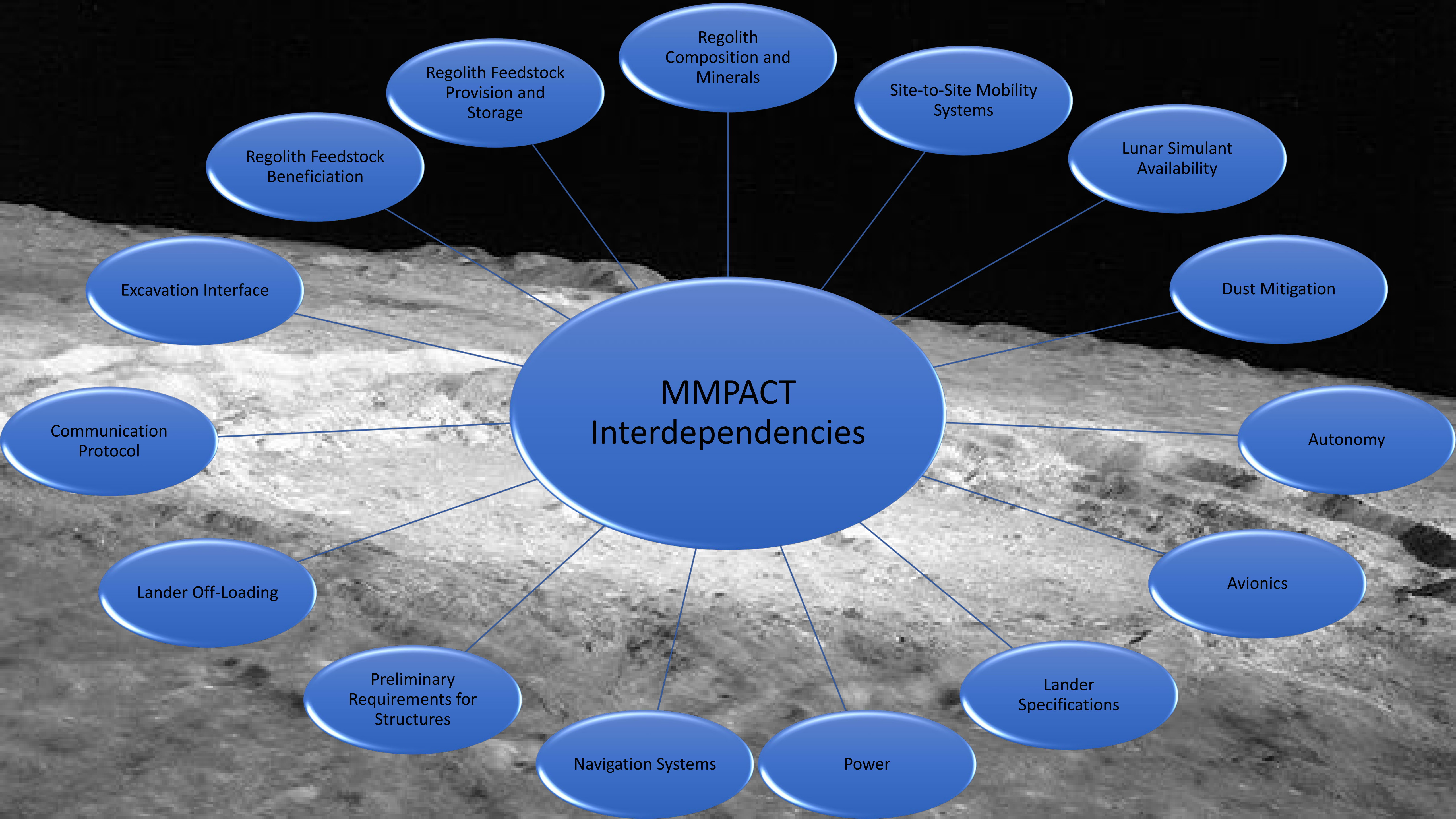
- Target applications
  - Industry partner plans to commercialize construction technology on the Moon
  - Potential application for Artemis and Space Force, construction of a sustainable human exploration base



MMPACT Materials

- Binder-Based Materials
  - Ordinary Portland Cement
  - Magnesium Oxide-Based Cements
  - Sodium Silicate
  - Calcium Sulfo-Aluminate
  - Geopolymers
  - Polymers
  - Sulfur Concrete
- 100% Regolith-Based Materials
  - Microwave Sintering
  - Laser Vitreous Material Transformation (VMX)
  - Molten Extrusion
  - Molten Casting




MMPACT Interdependencies
Regolith Composition and Minerals
Regolith Feedstock Provision and Storage
Site-to-Site Mobility Systems
Regolith Feedstock Beneficiation
Lunar Simulant Availability
Excavation Interface
Dust Mitigation
Communication Protocol
Autonomy
Lander Off-Loading
Avionics
Preliminary Requirements for Structures
Lander Specifications
Navigation Systems
Power

Technology Gaps

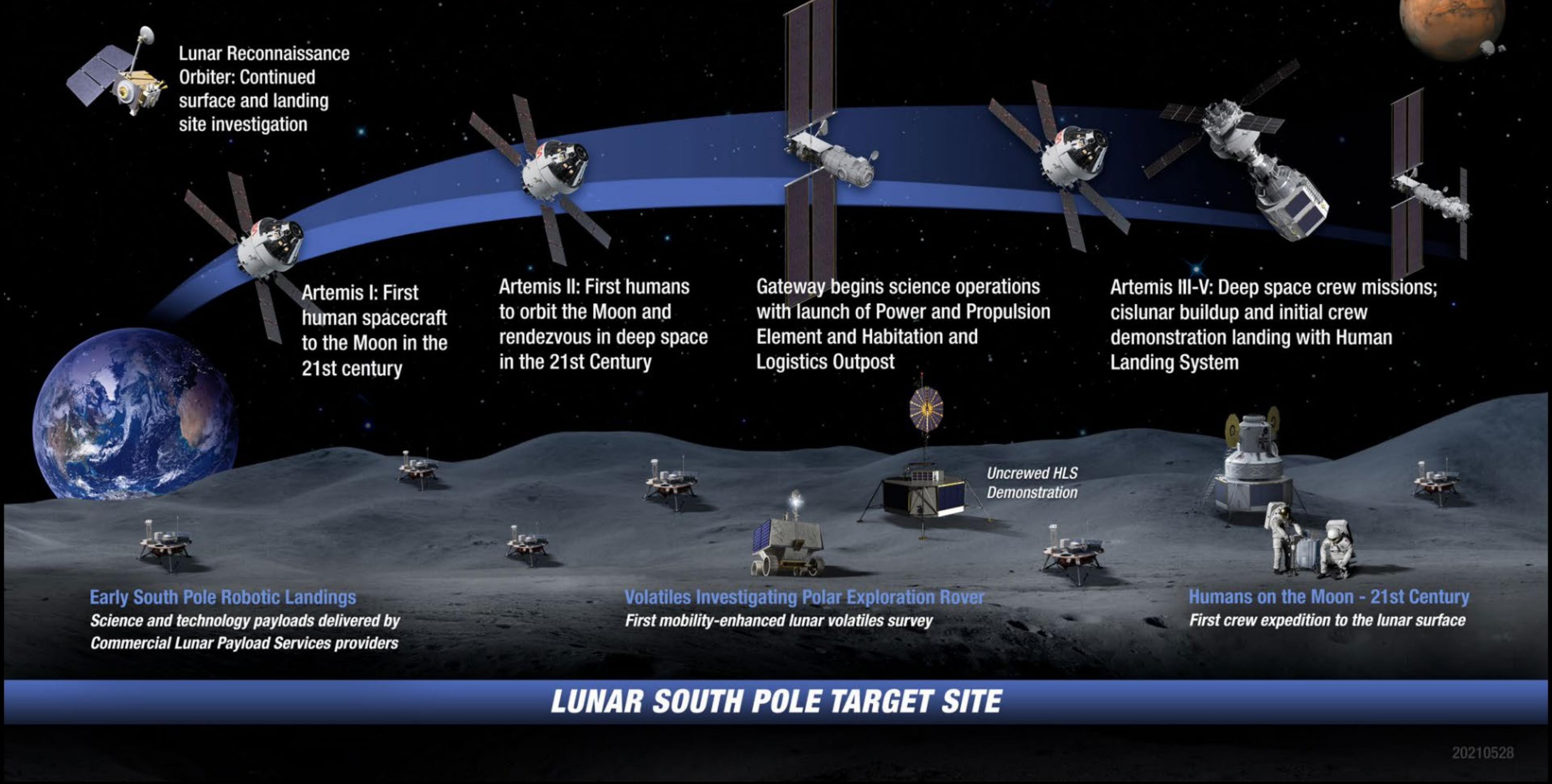
Primary source - https://www.globalspaceexploration.org/wordpress/wp-content/uploads/2021/04/ISECG-ISRU-Technology-Gap-Assessment-Report-Apr-2021.pdf (International Space Exploration Coordination Group ISRU Gaps)

- Scalable processes for extraction and/or purification (e.g., ionic liquids)
- Effective methods of dust mitigation
- Advanced materials for lunar and martian surface use
  - Controlled Coefficient of Thermal Expansion materials
  - Seals for hatches/penetrations
  - Composite parts (e.g., with regolith/basalt fibers)
  - Recyclable materials
  - Environmental durability
- Production of manufacturing and construction feedstock from in-situ resources
  - Creating additional alloys and binders (cements) from regolith
- Machining, joining, and assembly of ISRU-based materials
- Process monitoring and part verification
- Power infrastructure necessary for large-scale construction

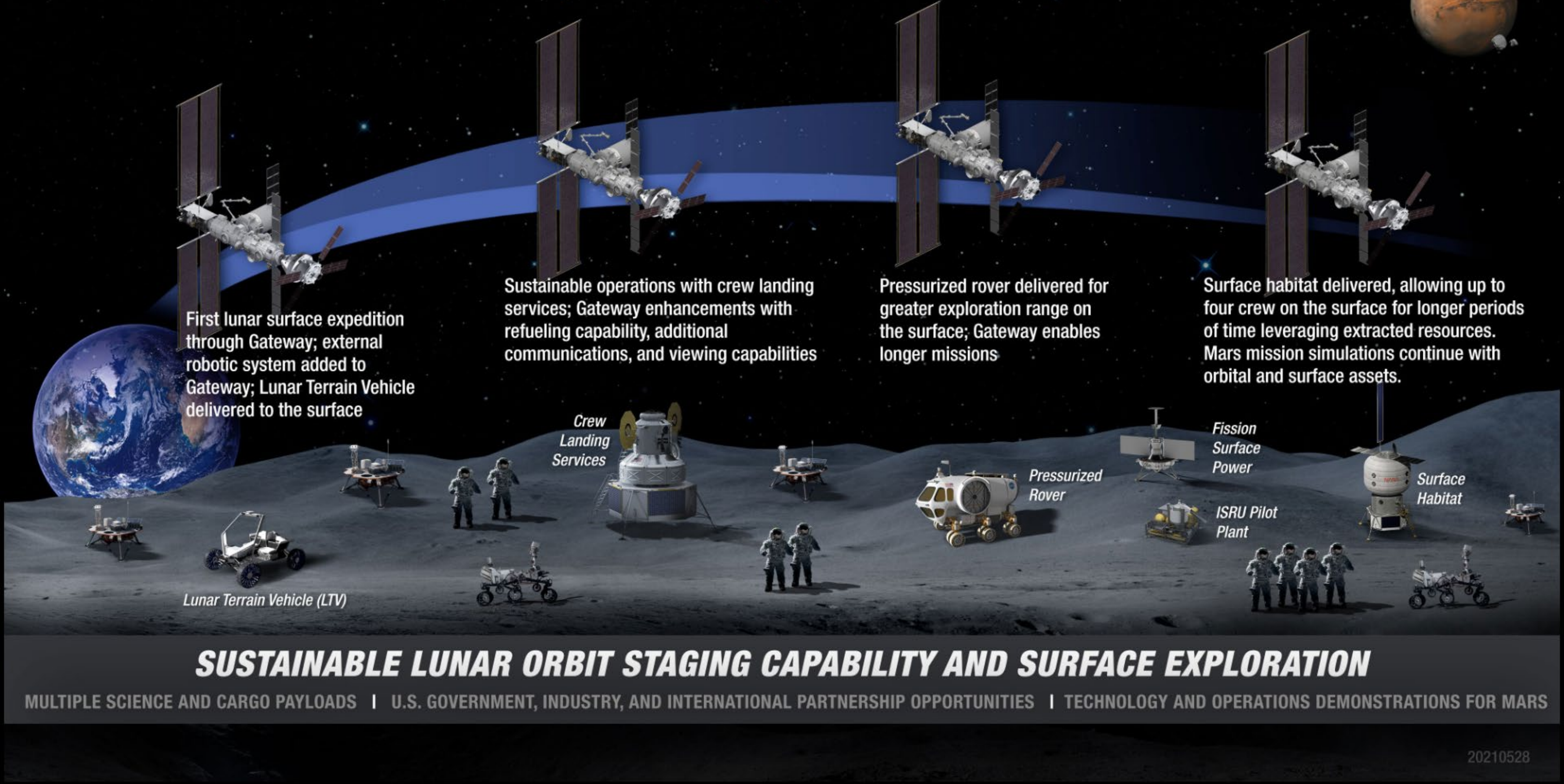
www.nasa.gov/spacetech

Backup

Artemis: Landing Humans On the Moon

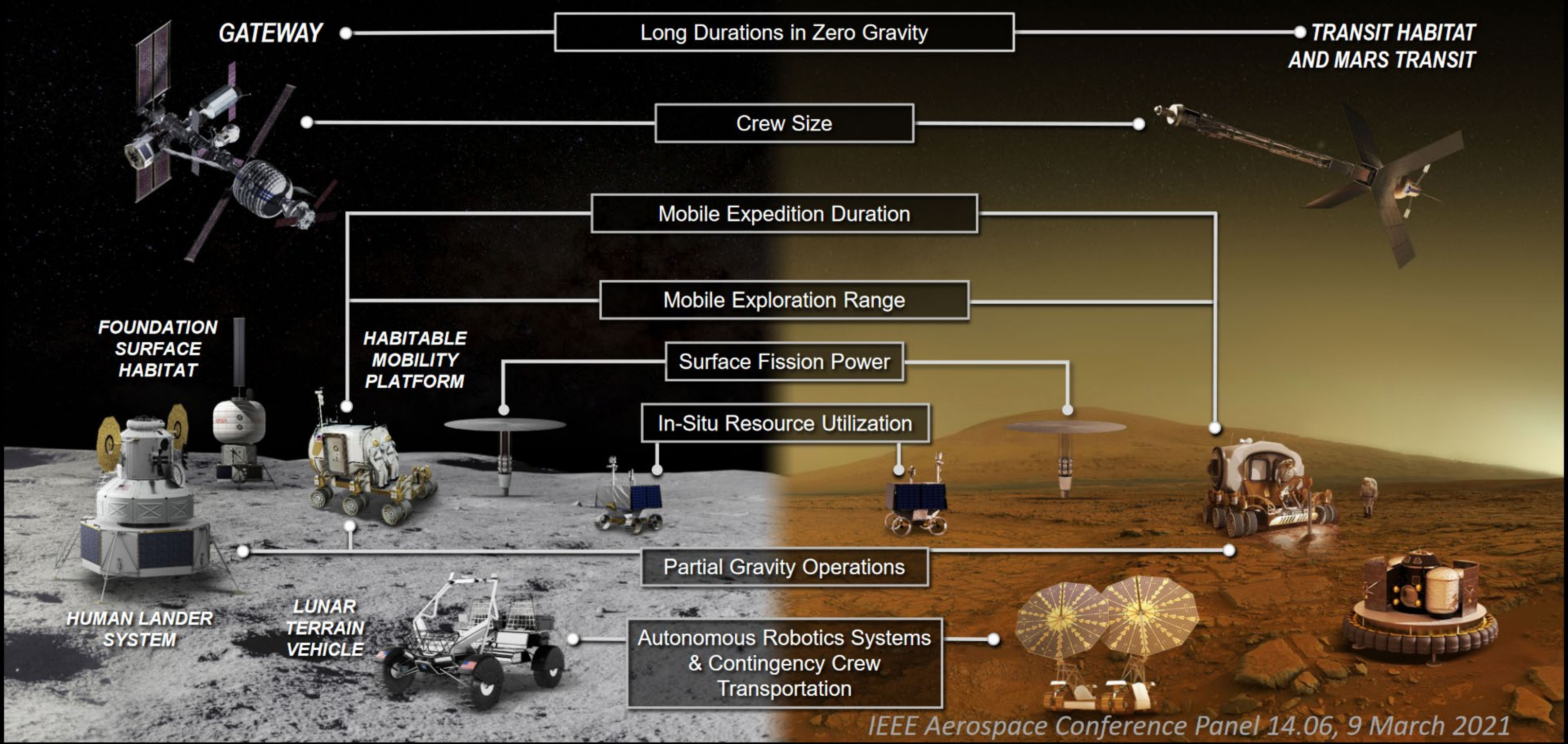


Artemis Base Camp Buildup

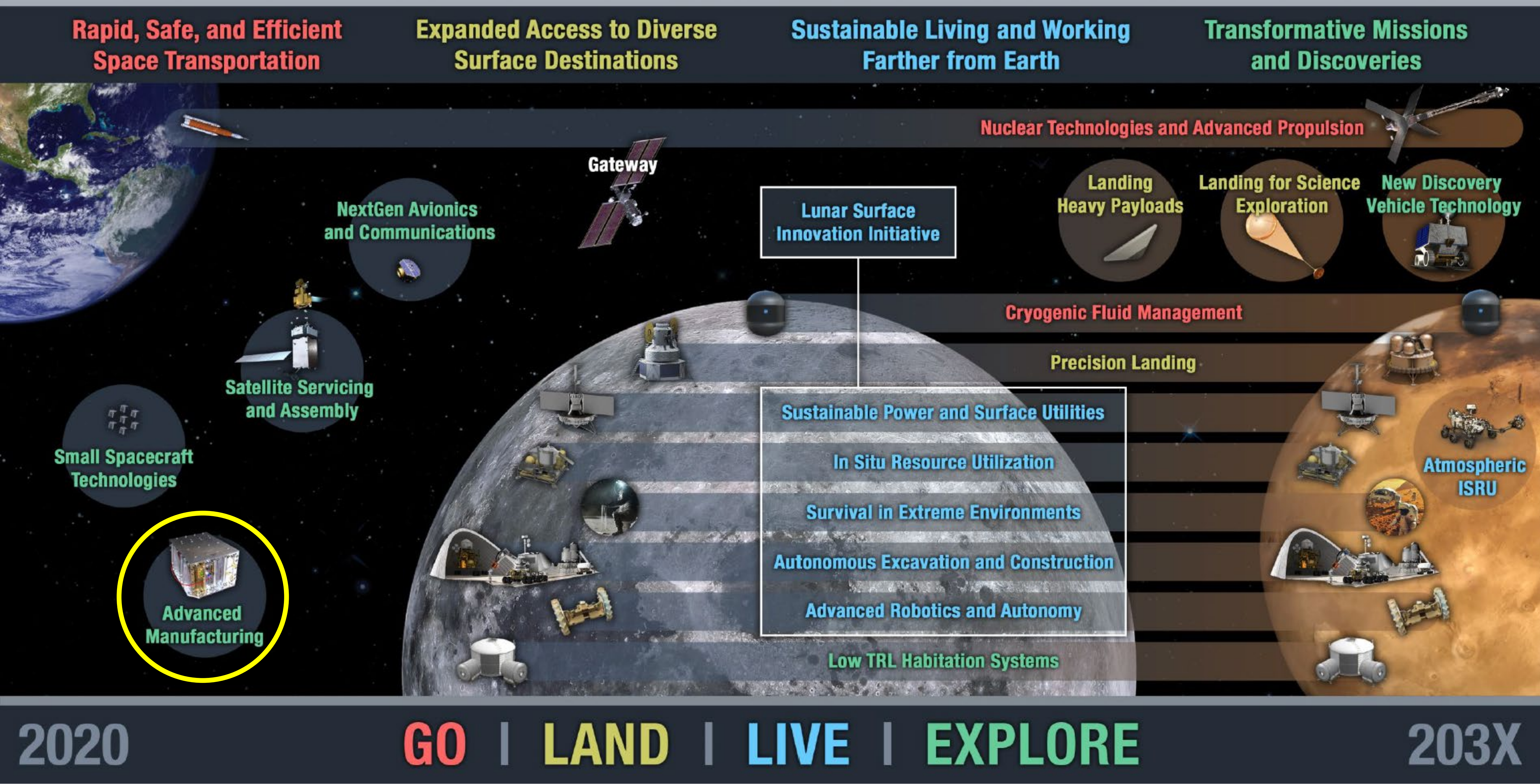


MOON AND MARS EXPLORATION

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



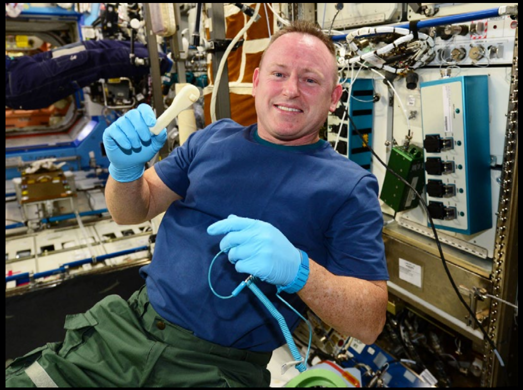
TECHNOLOGY DRIVES EXPLORATION



In-Space Manufacturing (ISM)

The goal of the ISM Project Portfolio is to provide a solution towards sustainable, flexible missions through the development of on-demand fabrication, replacement, and recycling capabilities

3D Printing In Zero-G



Demonstrate 3D printing of polymers on the International Space Station (ISS)

→

On-Demand Metals Manufacturing

Provide a capability for on-demand 3D printing of metal parts

Image courtesy of Made In Space / Redwire

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Recycling and Reuse

Develop materials and recycling technologies to create an on-orbit recycling ecosystem

Image courtesy of Cornerstone Research Group

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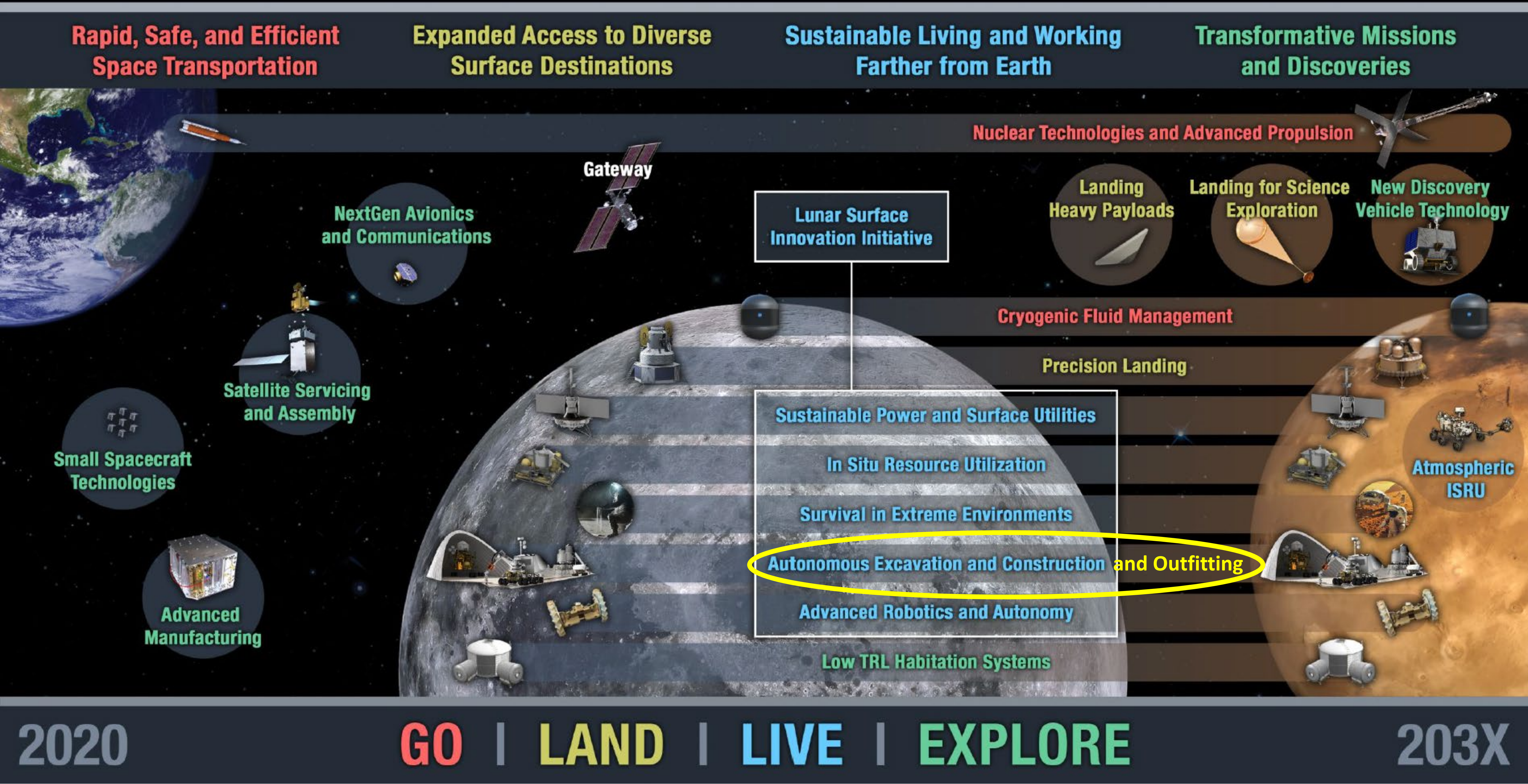
On-Demand Electronics Manufacturing

Develop printed electronics, sensors, and power devices for testing and demonstration on the ISS

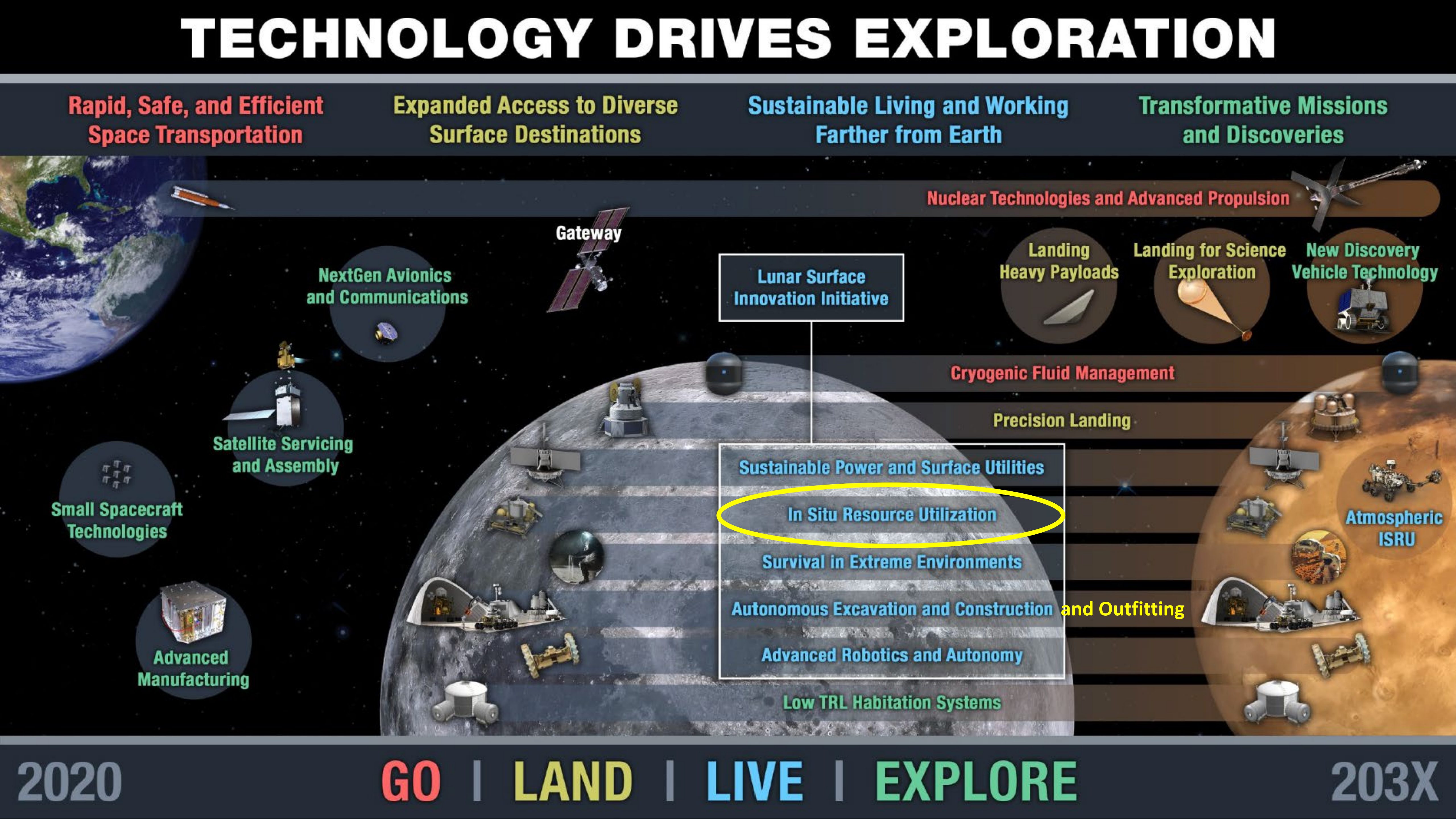
TECHNOLOGY DRIVES EXPLORATION



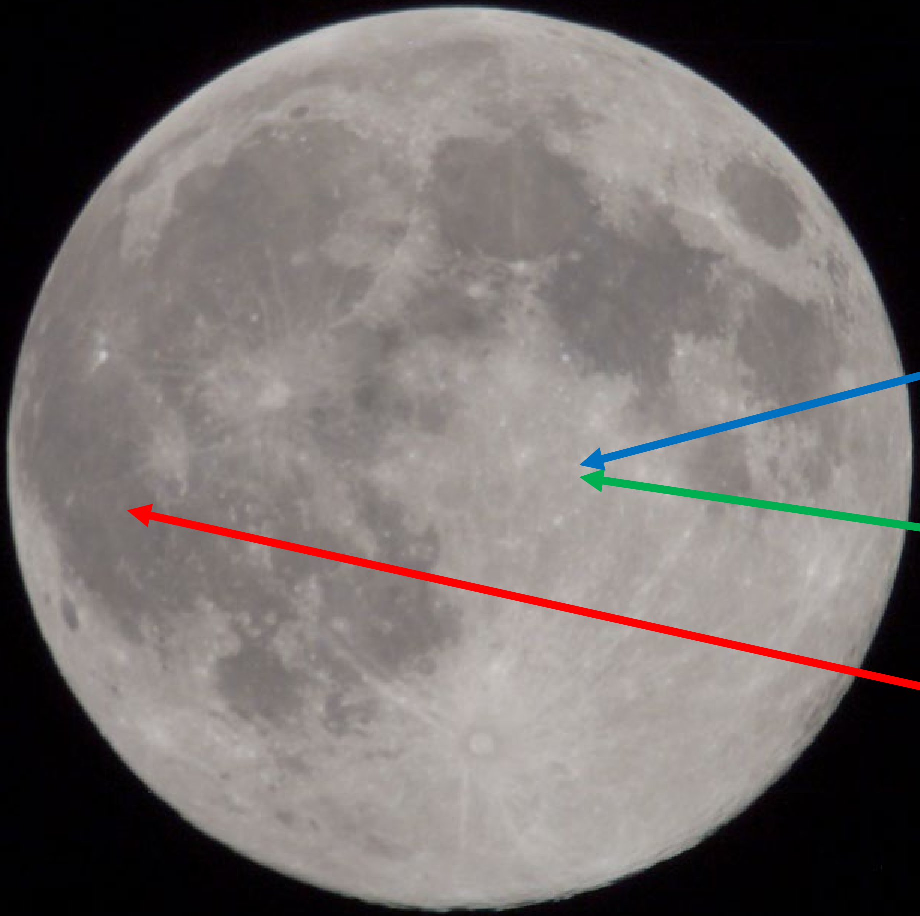
Outfitting Capability Development

- Outfitting encompasses the broad spectrum of capabilities to “turn a house into a home”
- In situ installation of subsystems
  - Mechanical
  - Electrical
  - Plumbing (ducting, piping, gas storage)
- Interior Furnishings Fabrication
  - Workbenches
  - Tables
  - Chairs
- Power, Lighting, Communications
- Enclosures (windows, hatches, bulkheads)
- Verification, Validation, and Inspection Technologies

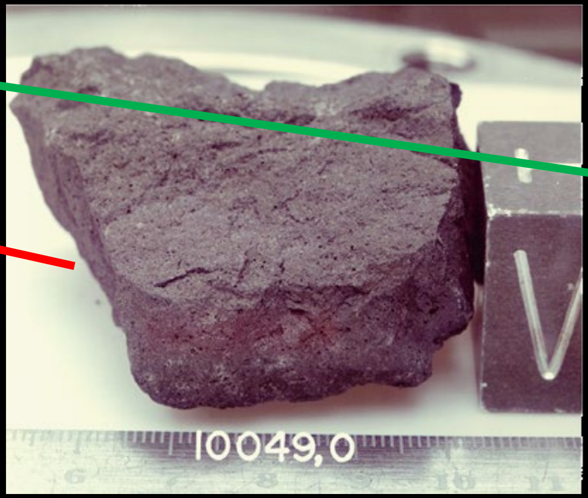
Image credit: ICON / Bjarke Ingels Group


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
Nuclear Technologies and Advanced Propulsion
Gateway
NextGen Avionics and Communications
Lunar Surface Innovation Initiative
Landing Heavy Payloads
Landing for Science Exploration
New Discovery Vehicle Technology
Cryogenic Fluid Management
Precision Landing
Satellite Servicing and Assembly
Small Spacecraft Technologies
Sustainable Power and Surface Utilities
In Situ Resource Utilization
Atmospheric ISRU
Survival in Extreme Environments
Autonomous Excavation and Construction and Outfitting
Advanced Robotics and Autonomy
Advanced Manufacturing
Low TRL Habitation Systems
2020
GO | LAND | LIVE | EXPLORE
203X

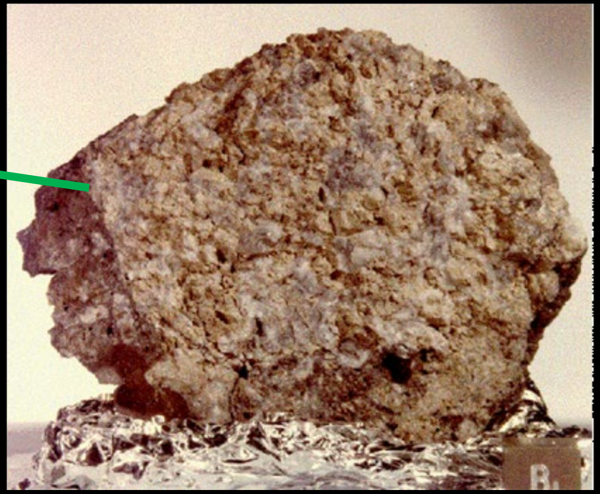
Apollo Samples – Defining Lunar Resources



Anorthosite

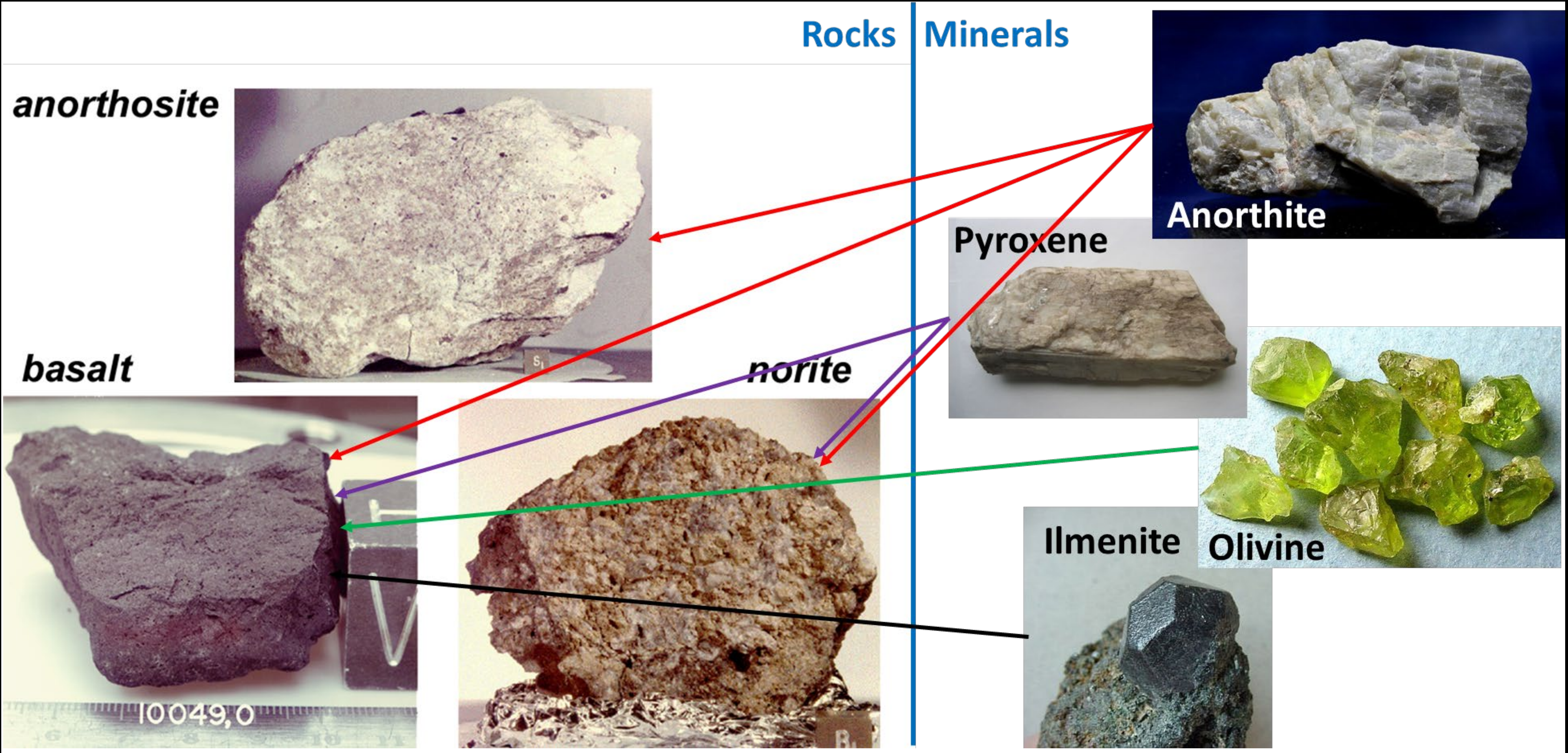


Basalt

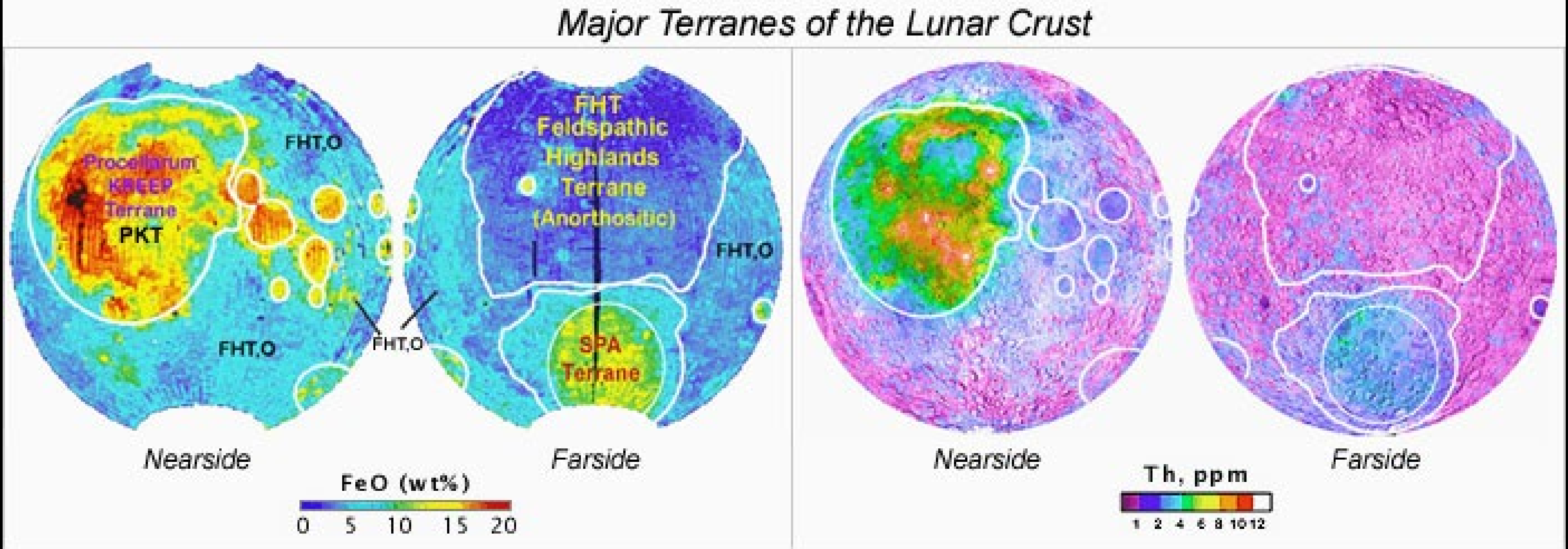


Norite

The Earth and Moon Have Common Minerals



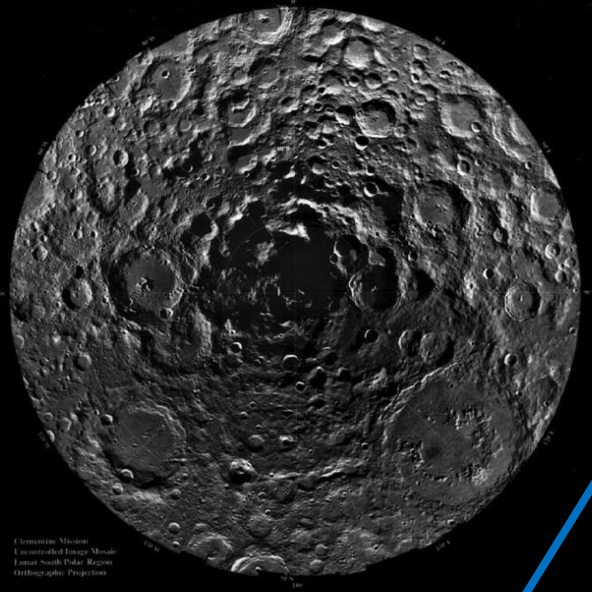
Global Remote Sensing

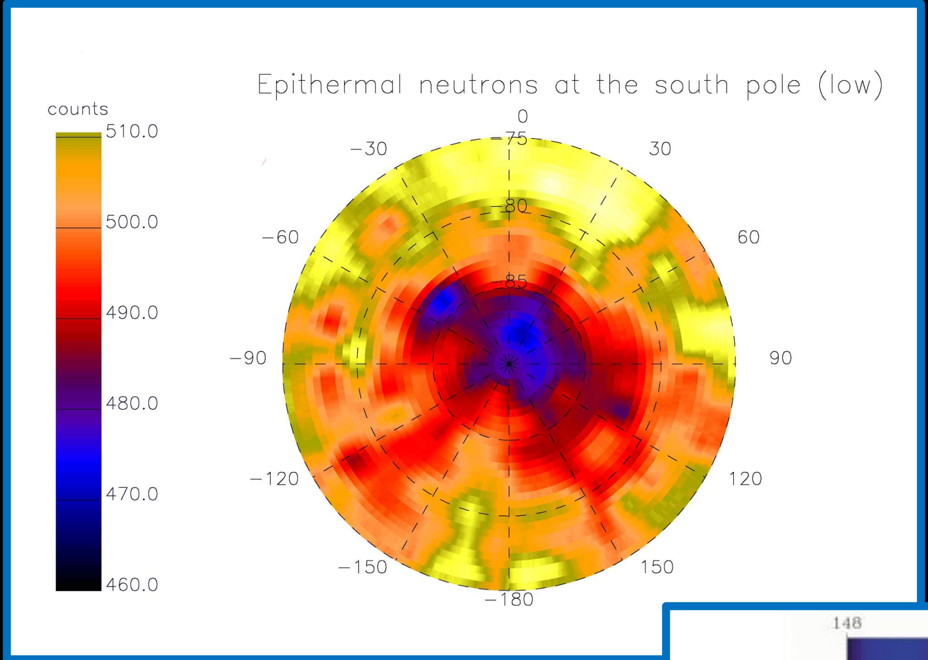


(From Jolliff et al., 2000.)
FeO (wt%) maps on the LEFT use a base image from Lucey et al. 1995. Th(ppm) maps on the RIGHT use Th concentrations from Lunar Prospector data, calibrated to landing site soils by Gillis et al., 2000.

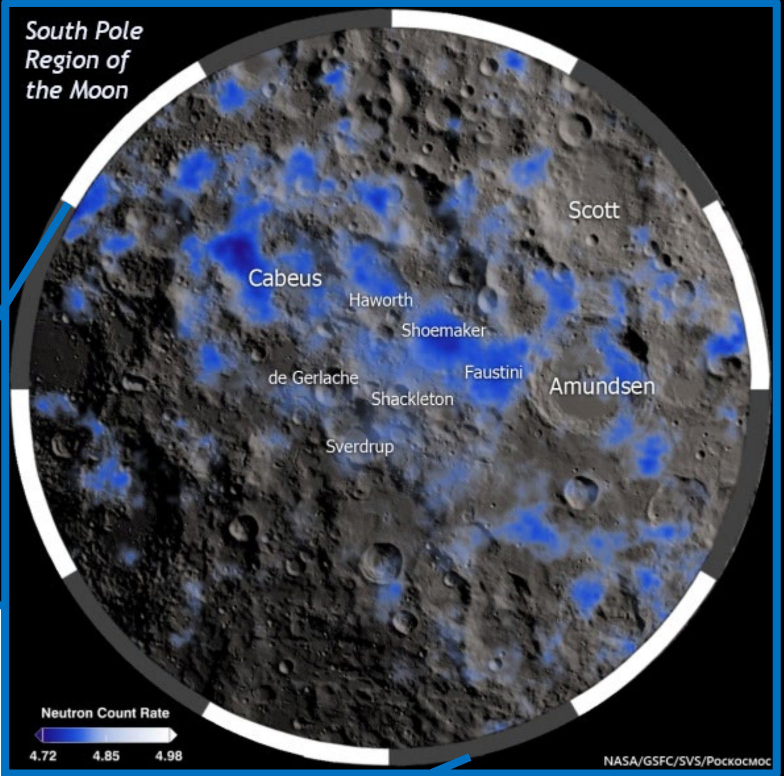
Global Remote Sensing

The Lunar South Pole

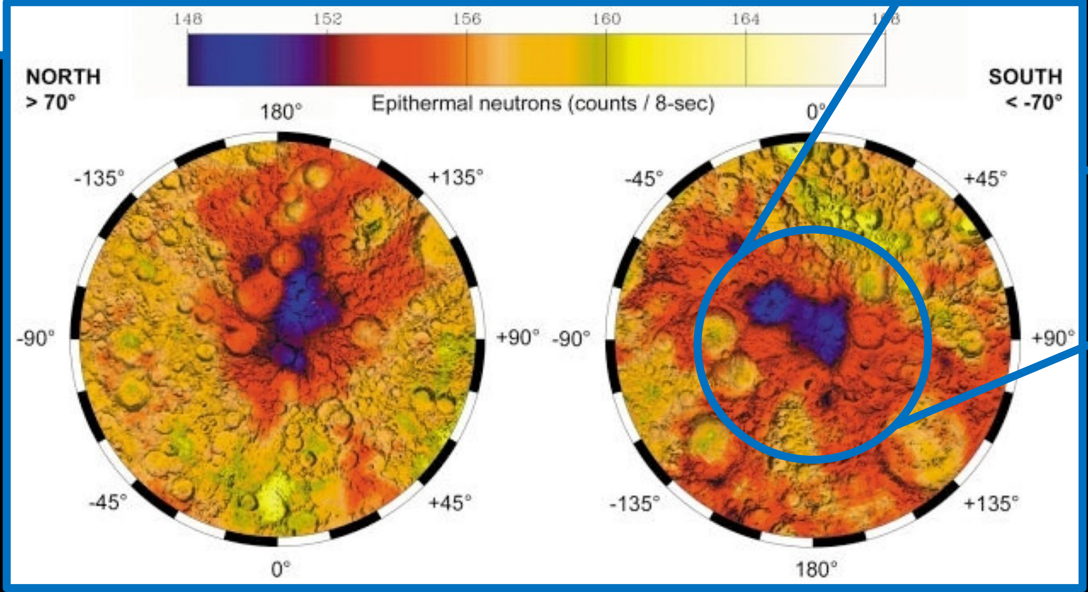




Clementine Orbiter Data
(Published in 1996)

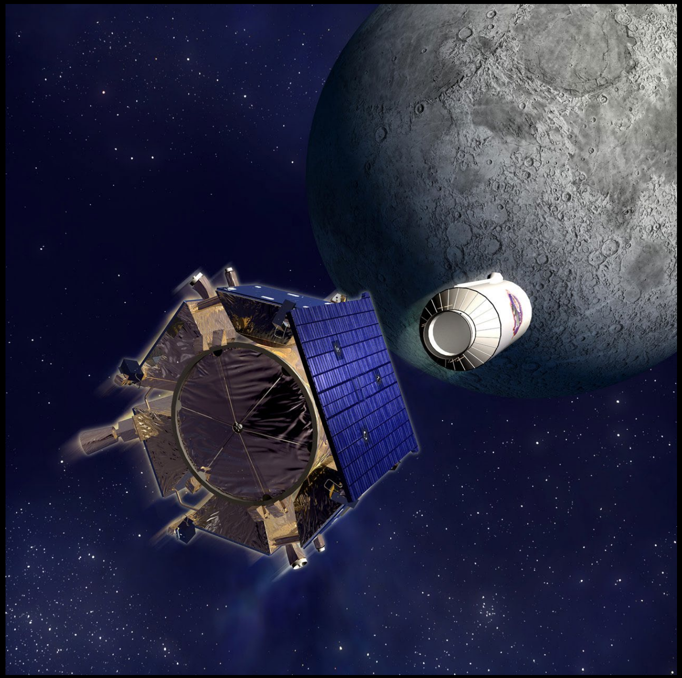


Lunar Reconnaissance Orbiter Data
(Published in 2012)

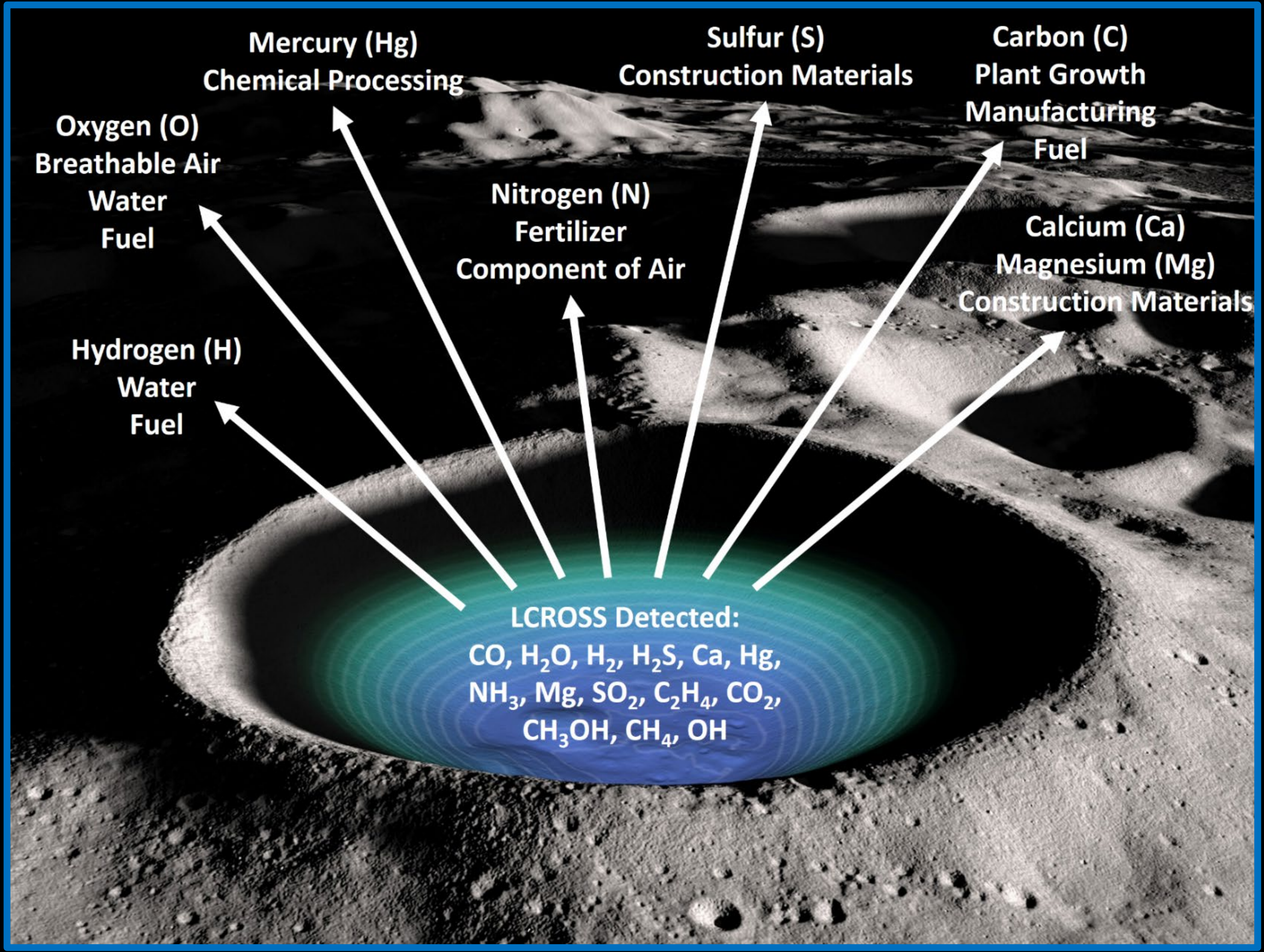


Lunar Prospector Data
(Published in 2006)

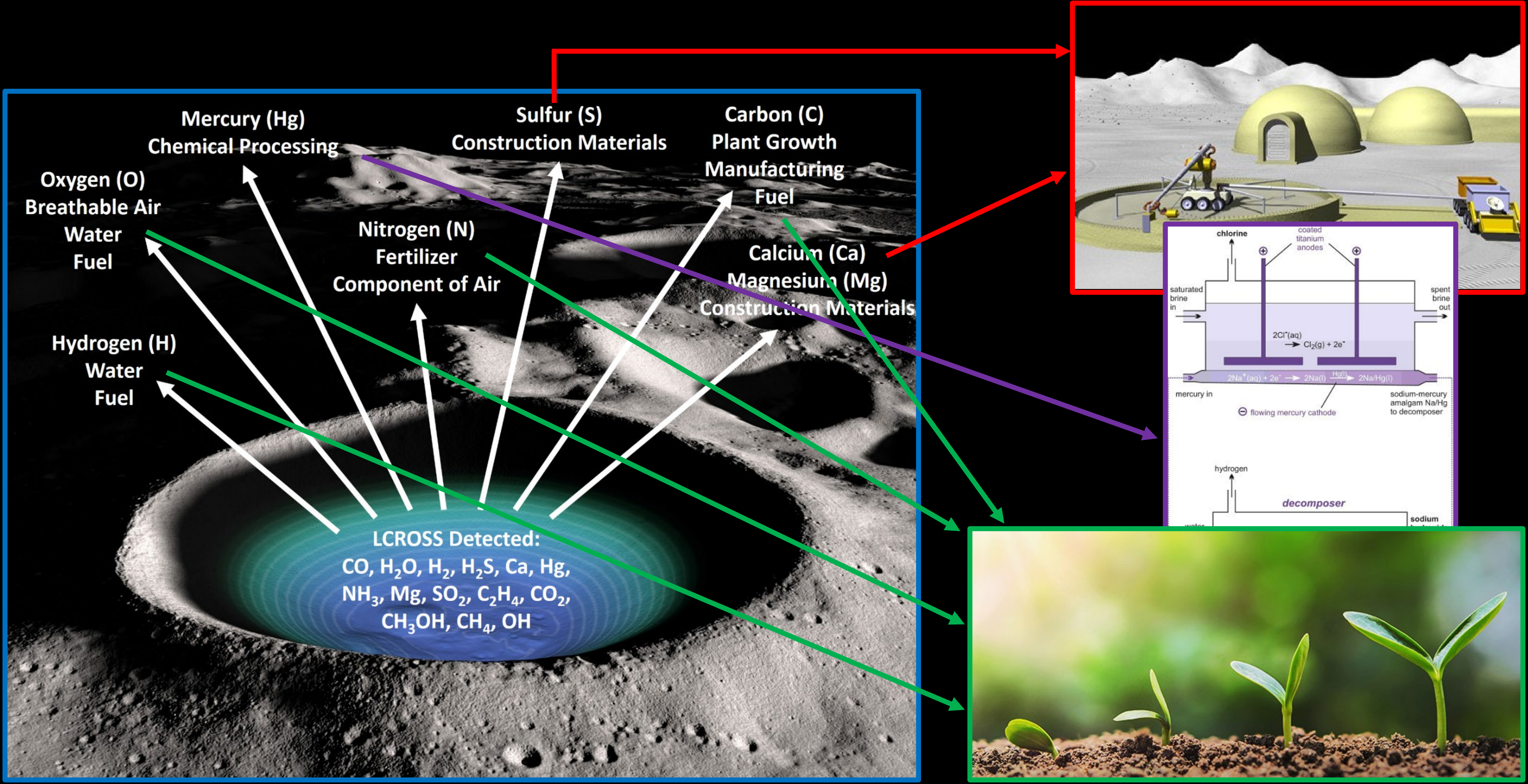
Resources in a Permanently Shadowed Region (PSR)



Lunar CRater Observation and Sensing Satellite (2009)



Applications of Resources



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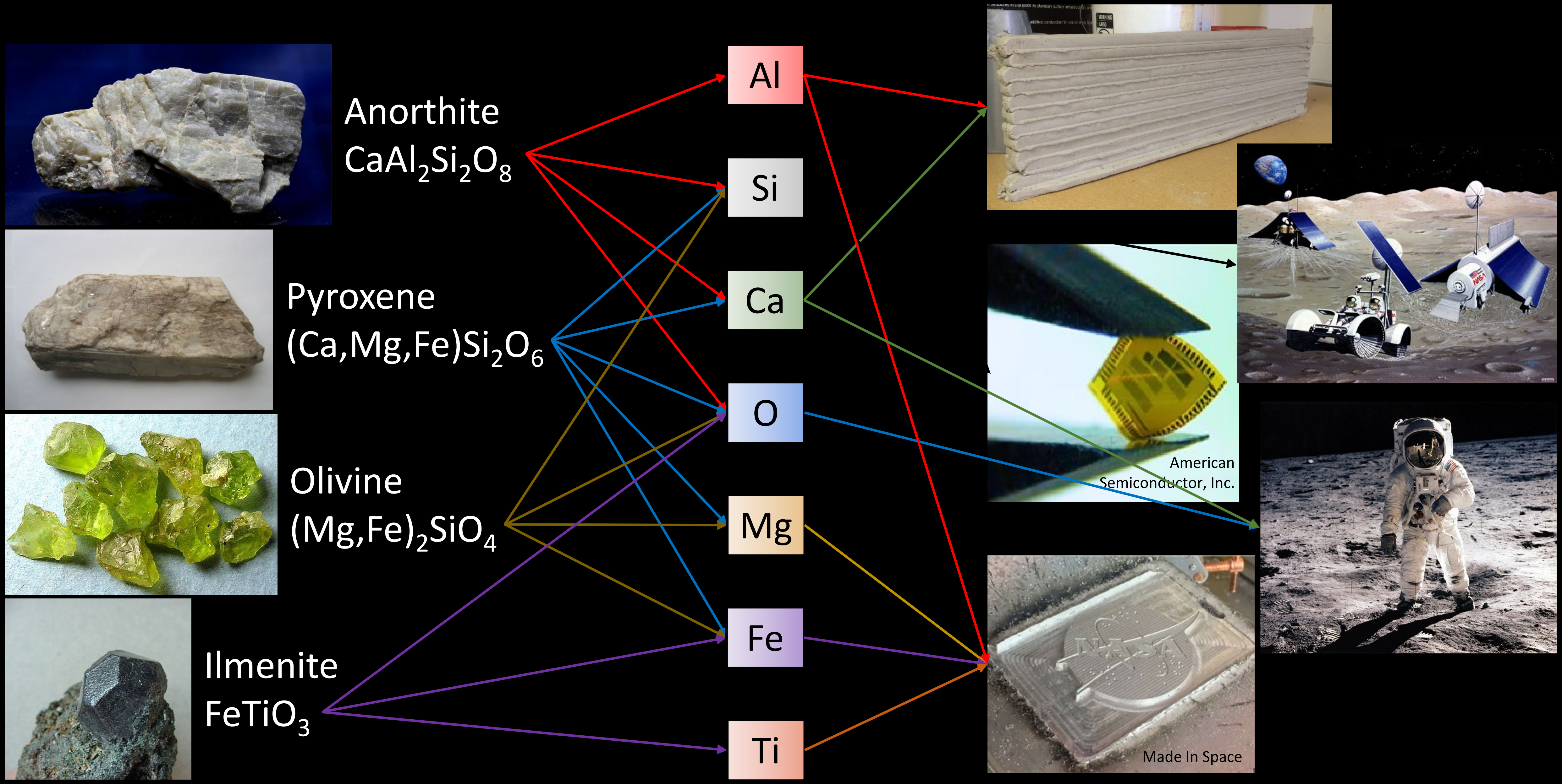


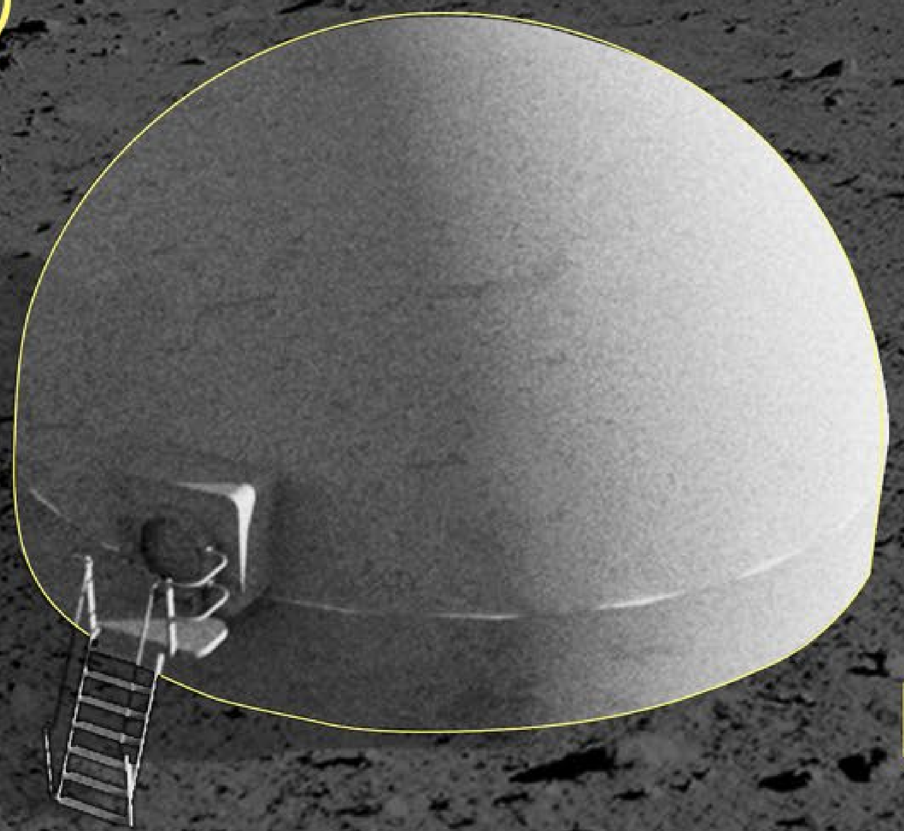
Lunar ISRU-based Habitats will be expected to meet a wide variety of environmental requirements

RADIATION

- Galactic Cosmic Rays (GCRs)
- Solar Particle Events (SPEs)
- Secondary Particles
- Albedo

METEOROID IMPACT

- Robust & durable shielding required. Composites and ballistic shielding preferred.
- Consideration of new failure modes due to impact
- Dust ramifications



SEISMIC ACTIVITY

- Deep Moonquakes lasting hours, even days
- Seismic Effects of Meteor Impacts

EXTREME TEMPERATURES

- Extreme Material Stresses
- Structural & Material Fatigue

Image courtesy of SEArch+

Architectural Design Strategies for Risk Mitigation

RADIATION

Shielding Mass & Thickness for Attenuation

Hydrogen-Rich Materials

Crew Operational Parameters; Habitat Protectiveness

SEISMIC ACTIVITY

Base Dampening & Isolation

Structural Reinforcement

EXTREME TEMPERATURES

High-Yield & Elastic Materials

Heat Transfer Strategies

Expansion Joints

METEOROID IMPACT

Ballistic Robustness & Durability

Structural Reinforcement

Whipple Shields

Structural Monitoring; Sensor Networks & Probabilistic Risk Assessment