An Overview of NASA’s Initiatives in Lunar Manufacturing, Construction, and Outfitting

National Space and Missile Materials Symposium (NSMMS)

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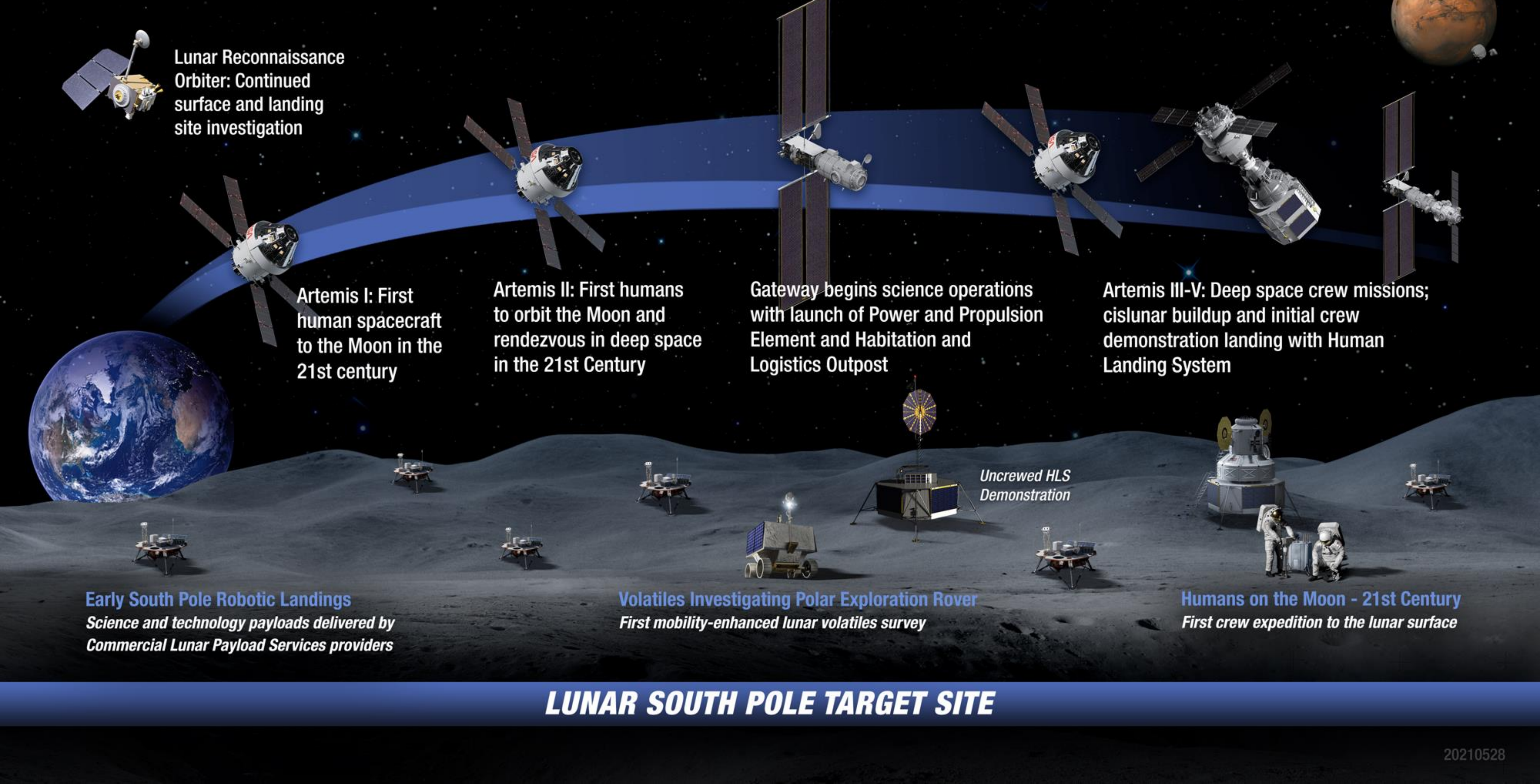
- Jason Ballard – CEO ICON Technologies
- Evan Jensen – ICON PM MMPACT
- SEArch+ - ICON/MMPACT Lunar Architectural Design Concepts
- Bjarke Ingels Group - ICON/MMPACT Lunar Architectural Design Concepts

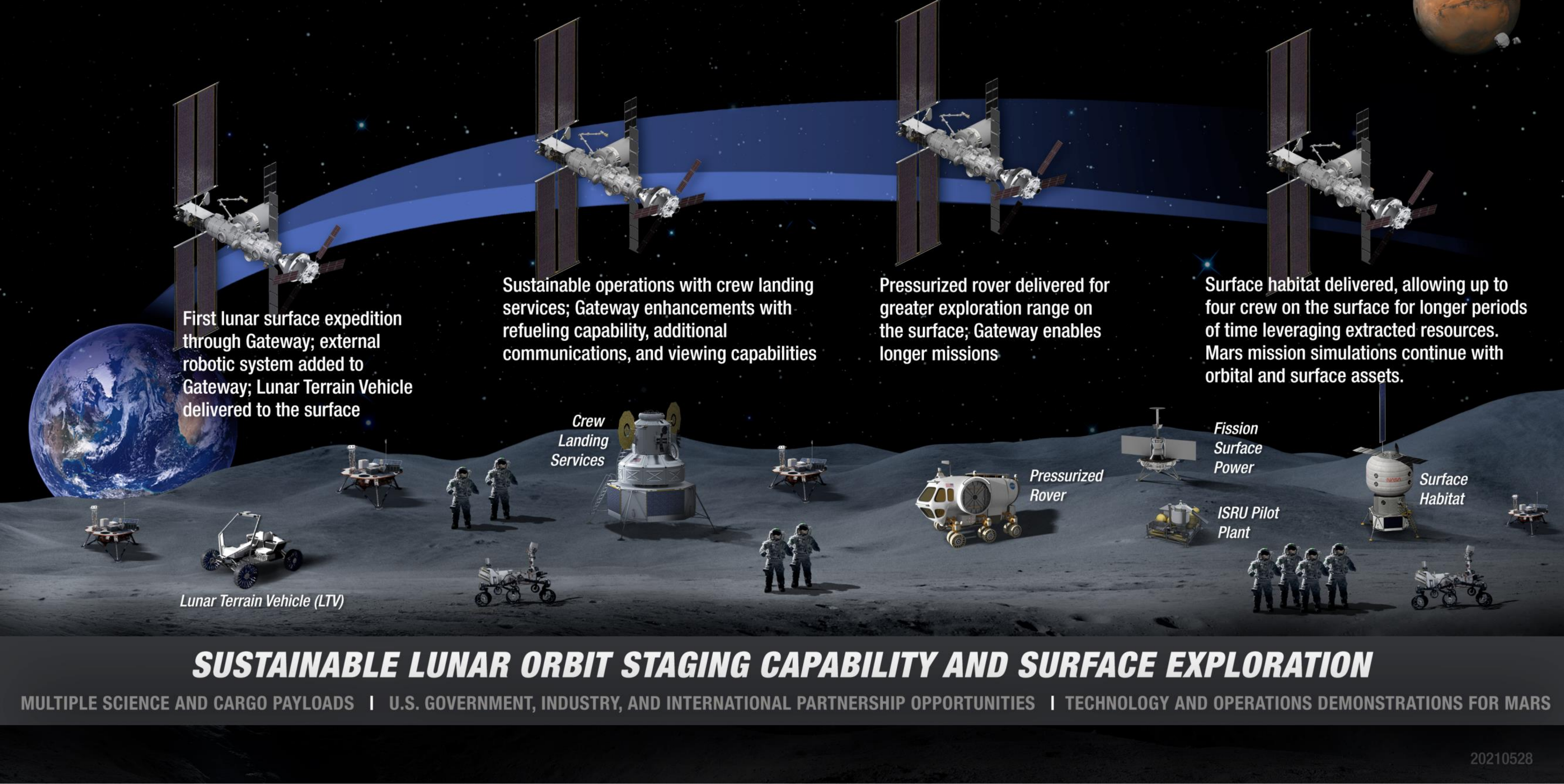
Agenda

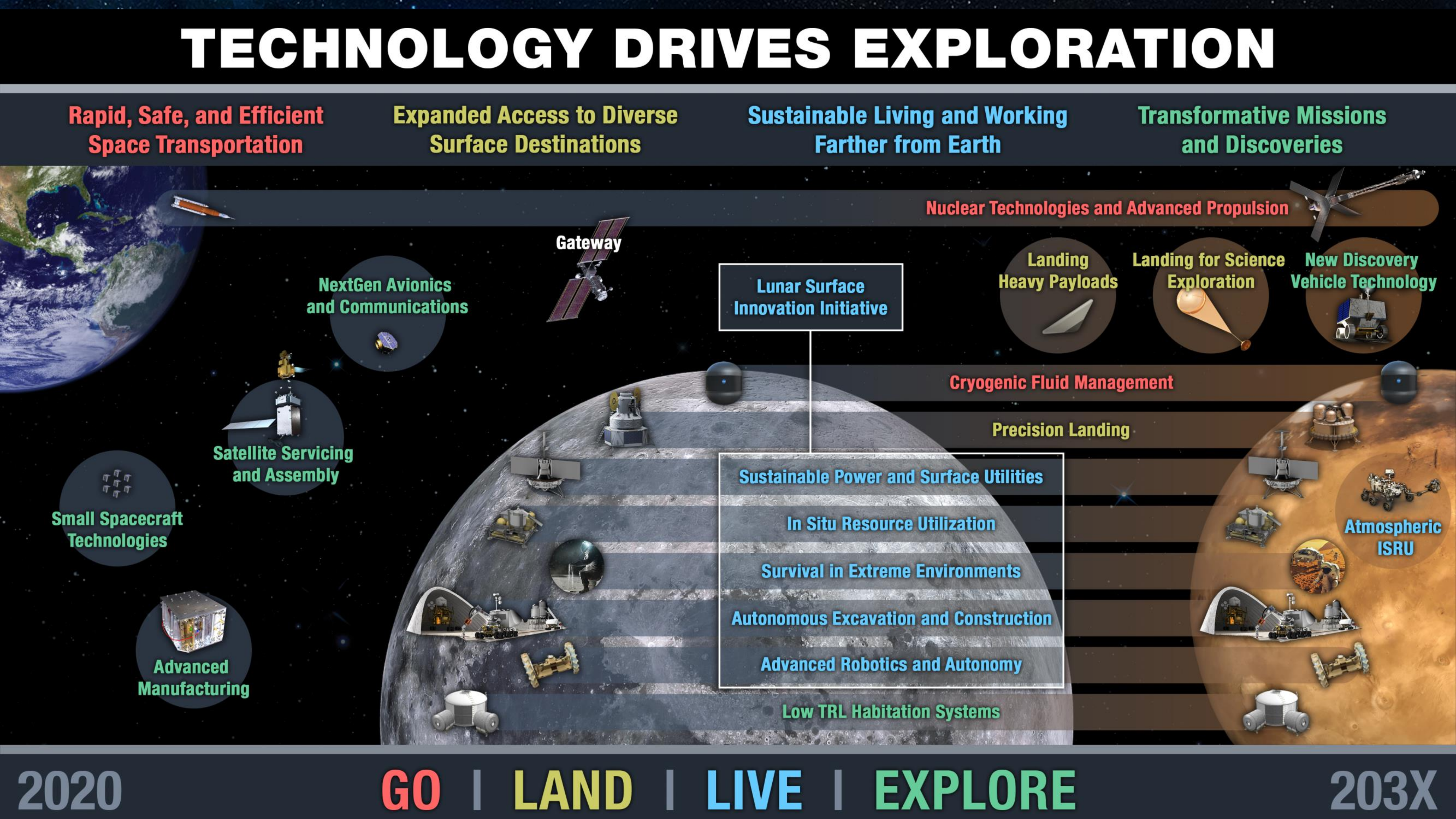
- Artemis: Phases 1 and 2
- Space Technology Mission Directorate: Technology Drives Exploration
    - Lunar Surface Innovation Initiative (LSII)
        - WHY: Out of Earth Manufacturing and Construction
        - Excavation, Construction, and Outfitting (ECO)
    - Advanced Manufacturing
        - In Space Manufacturing (ISM) – Portfolio and Challenges
- Questions

Artemis: Landing Humans On the Moon



Artemis Base Camp Buildup





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
Survival in Extreme Environments
Autonomous Excavation and Construction
Advanced Robotics and Autonomy
Low TRL Habitation Systems
Atmospheric ISRU
Advanced Manufacturing
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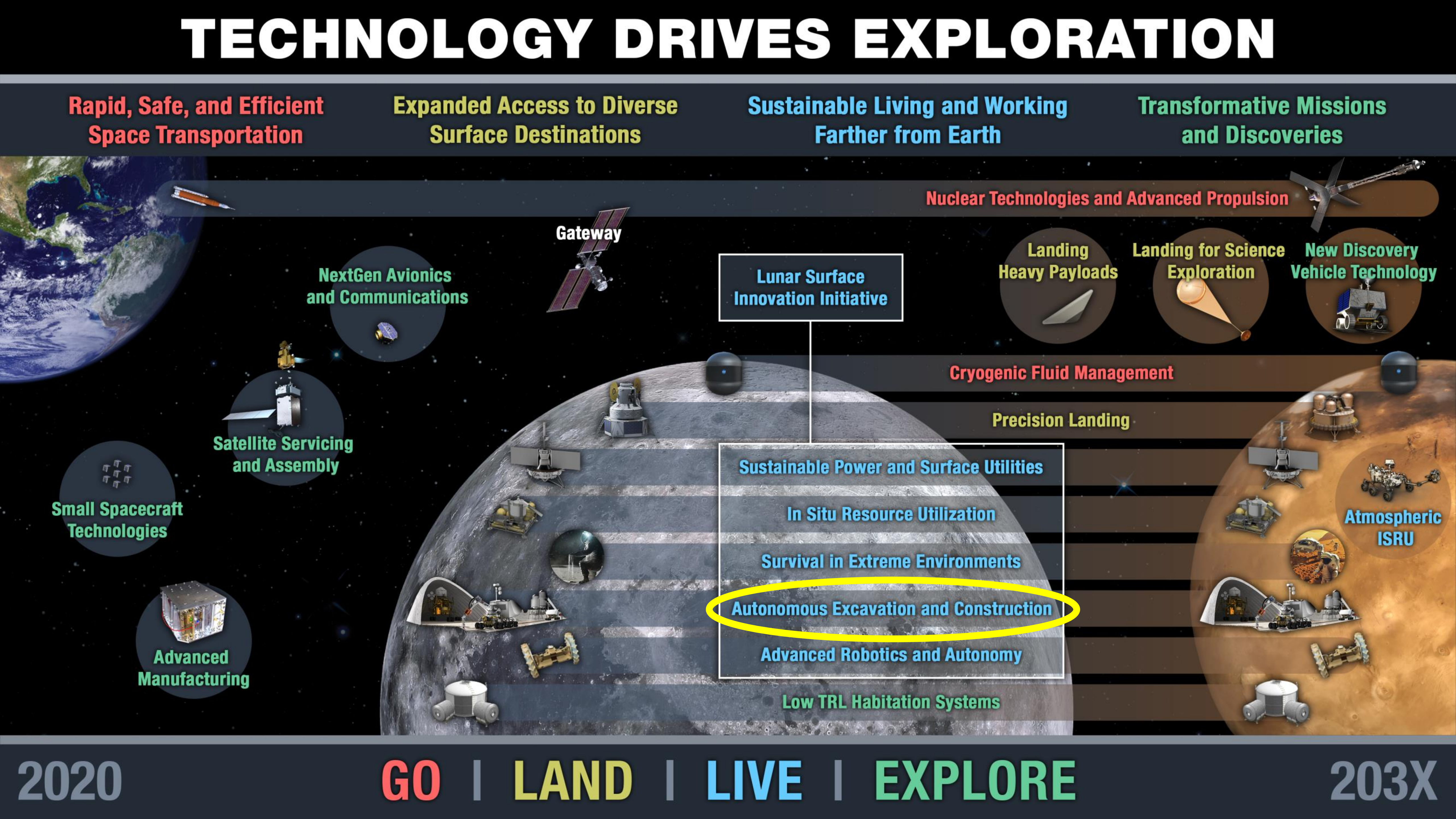

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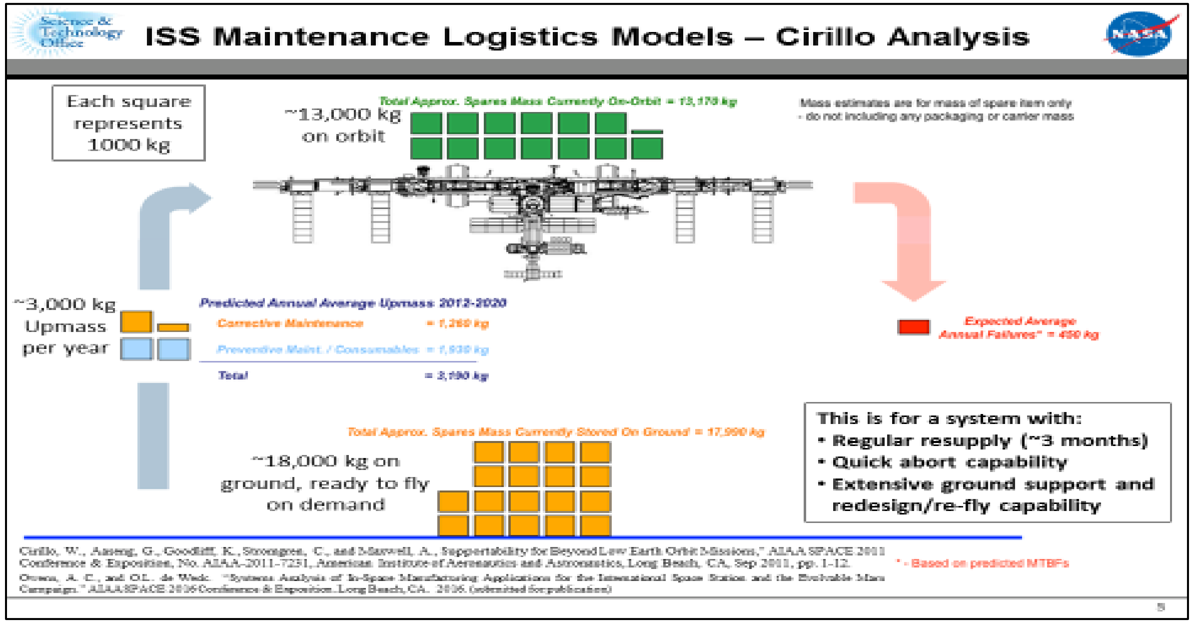
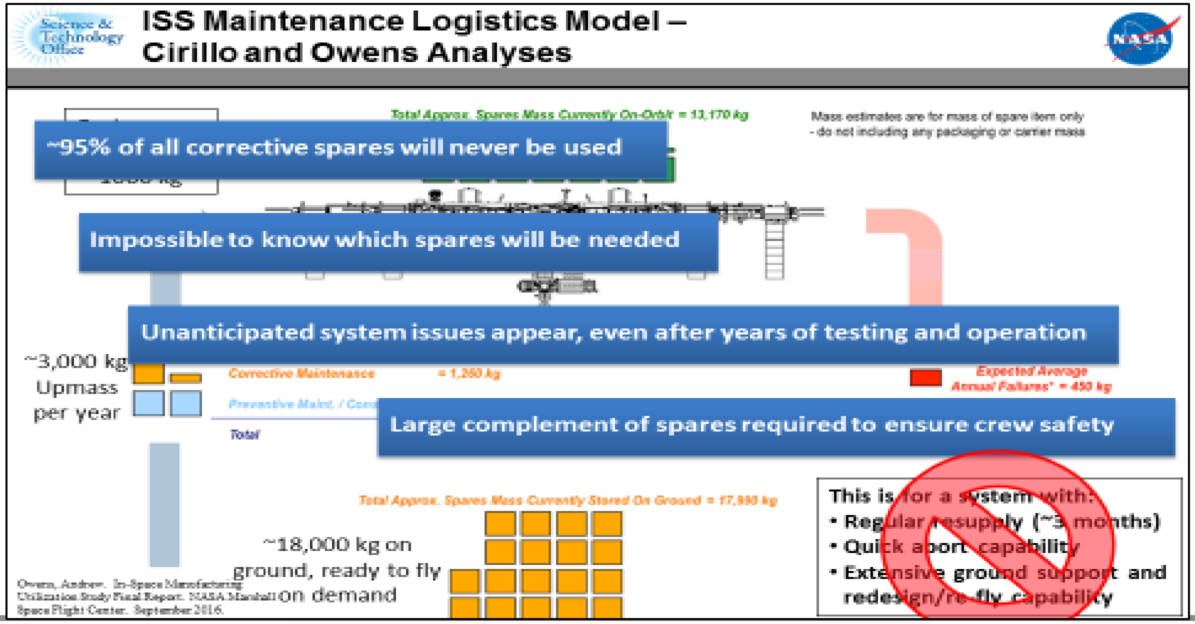
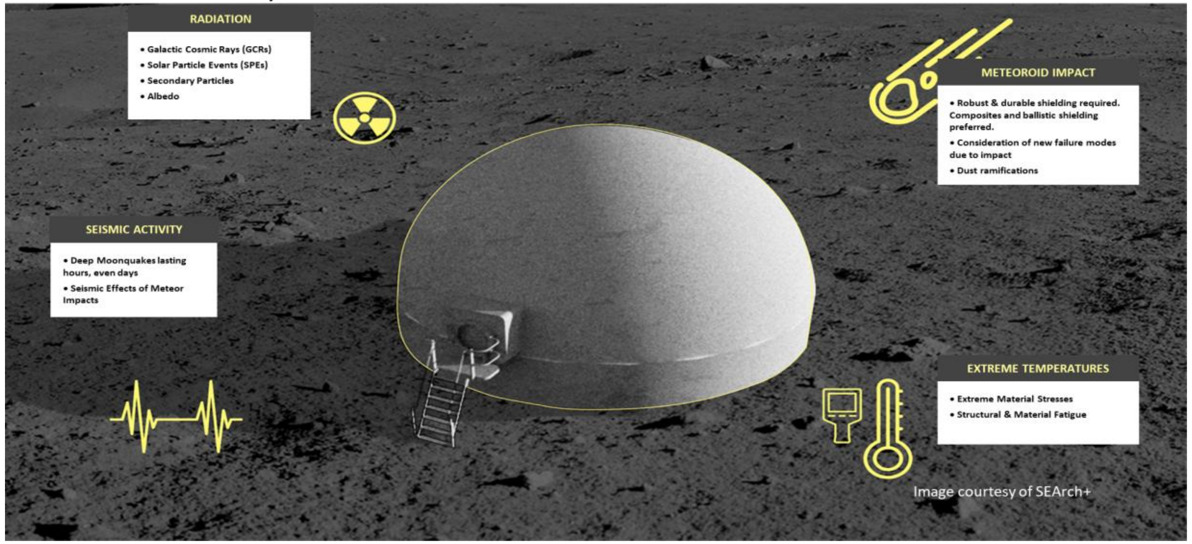
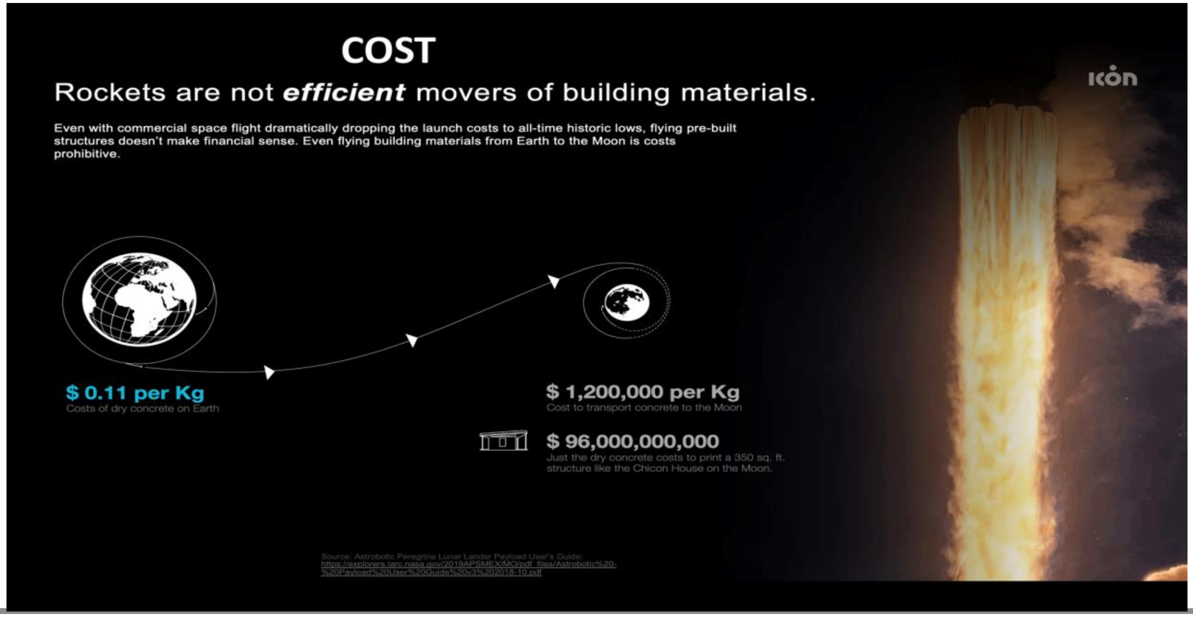
WHY: In Space Manufacturing   Extraterrestrial Construction





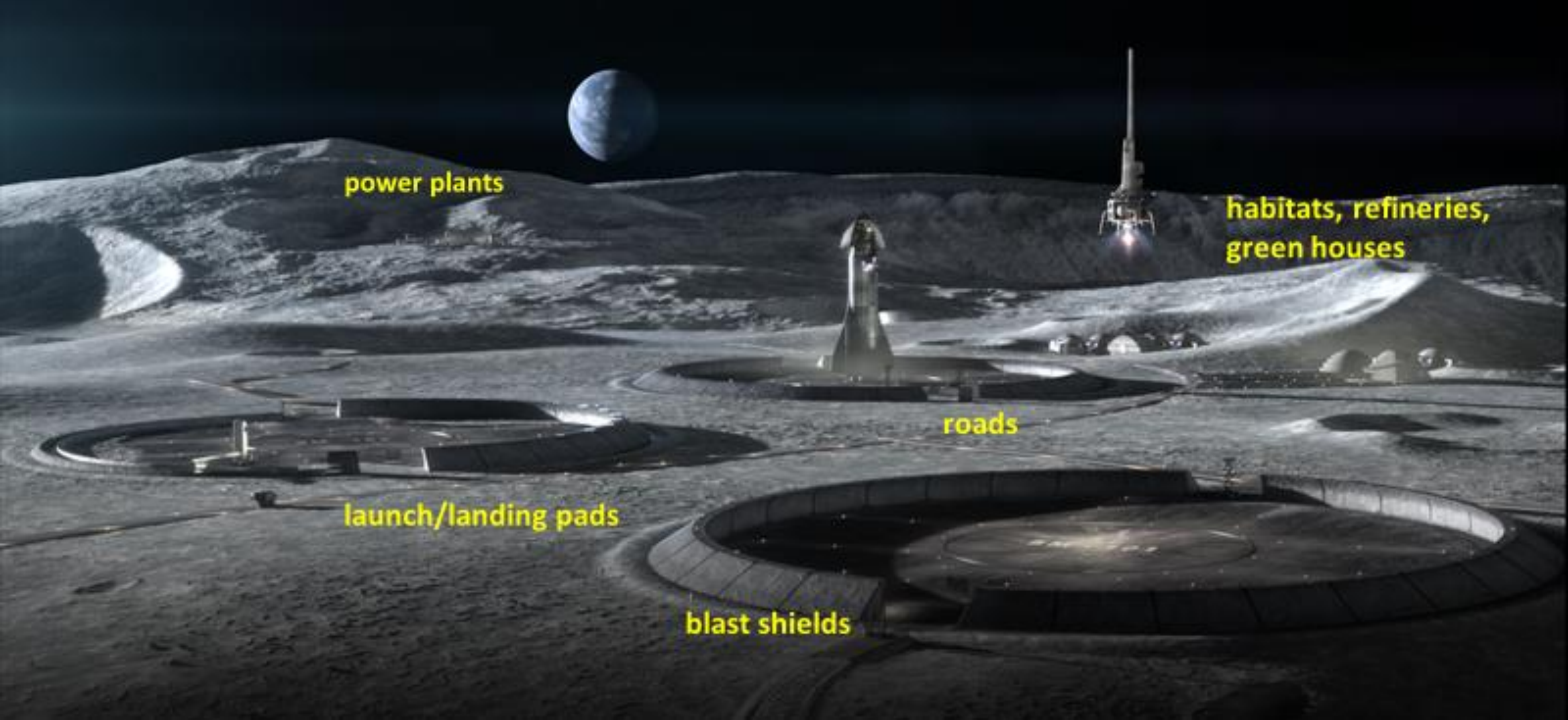
PROTECTION - Lunar ISRU-based infrastructure is expected to provide protection from a wide variety of environmental hazards.





Building a Sustainable Presence on the Moon

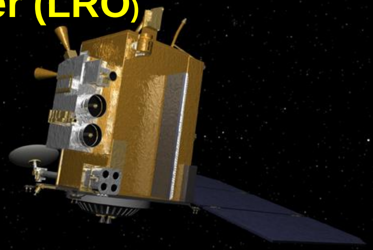
- **What infrastructure are we going to need?**

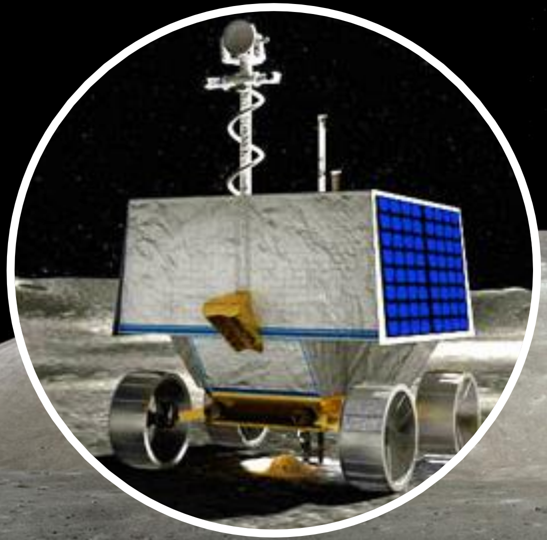


Excavation for ISRU and Construction:
Finding, Excavating and Transporting the Resources

Resource Prospecting – Looking for Resources

Lunar Reconnaissance Orbiter (LRO)





Volatiles Investigating Polar Exploration Rover (VIPER) ~2024 mission

Excavation & Processing for Aggregates and Binders

RASSOR Excavator Candidate for mid-to-late decade mission

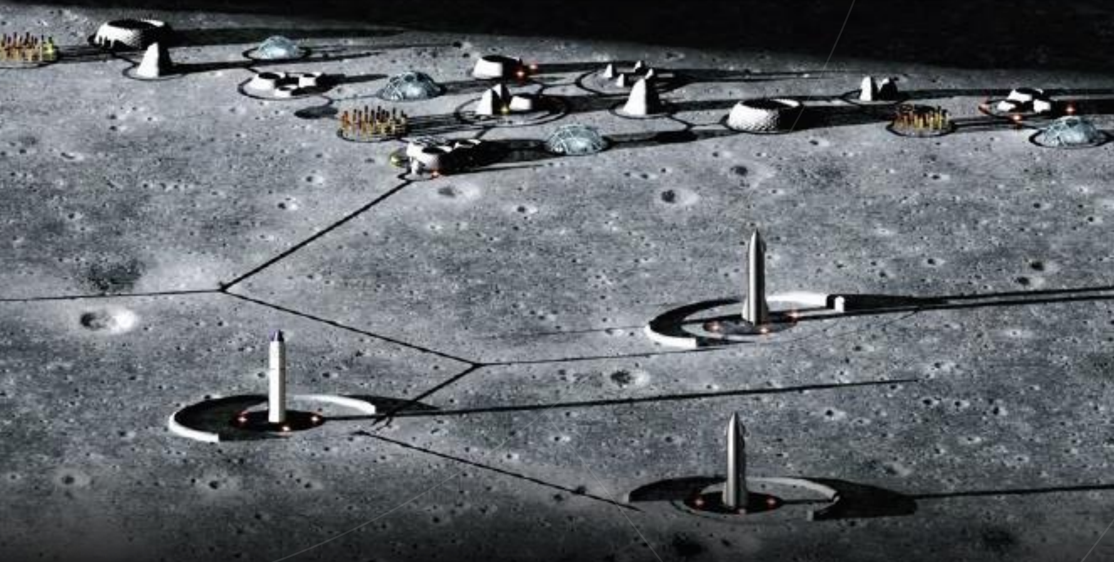
MMPACT

MOON TO MARS PLANETARY AUTONOMOUS CONSTRUCTION TECHNOLOGY

Moon-to Mars Planetary Autonomous Construction Technologies (MMPACT) Overview

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, and blast shields using lunar regolith-based materials.



MMPACT is structured into three interrelated elements:

1. Olympus Construction Hardware Development
2. Construction Feedstock Materials Development
3. Microwave Structure Construction Capability (MSCC)

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 Olympus and MSCC products for use in the lunar environment.
- Validate that Earth-based development and testing are sufficient analogs for lunar operations

MMPACT – Current Partners

NASA Centers
- MSFC
- LaRC
- KSC
- JPL

OGA Leveraging

Potential:
- Innovation Unit US Air Force (AF)

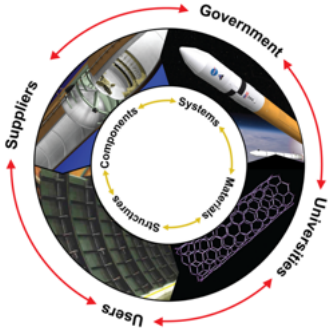
Contributing:
- AF Civil Engineering Center
- AF Special Operations Command
- Defense Innovation Unit
- Texas Air National Guard
- USAF

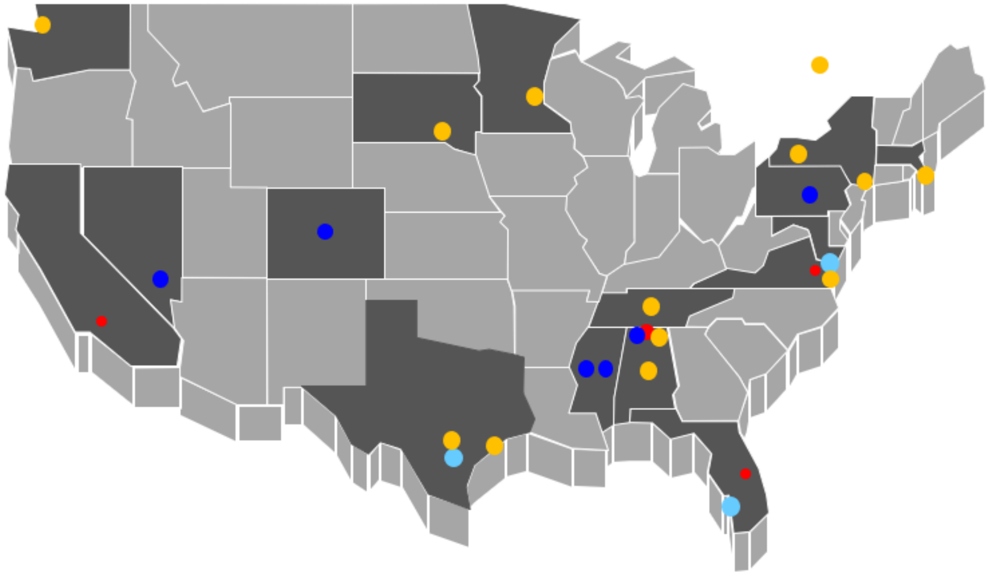
Public/Private Partnerships
- Dr. Holly Shulman
- ICON Build
- Radiance Technologies
- RW Bruce Associates, LLC
- Blue Origin
- Jacobs Space Exploration Group
- JP Gerling
- Logical Innovations
- Microwave Properties North
- MTS Systems Corp.
- Southeastern Universities Research Association
- Southern 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.

Autonomous Construction for the Lunar Outpost

Regolith-based Materials and Processes:

- Cementitious
- Geopolymers/Polymers
- Thermosetting materials
- Regolith Melting/Forming
- Laser sintered
- Microwave sintered

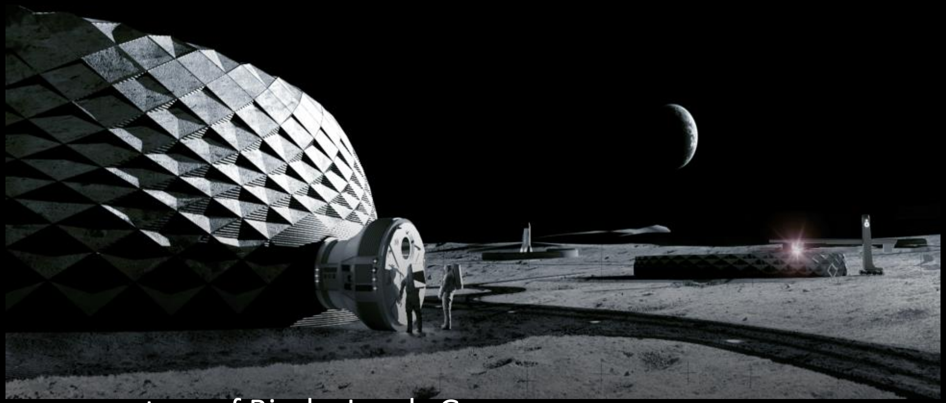


Image courtesy of Bjarke Ingels Group

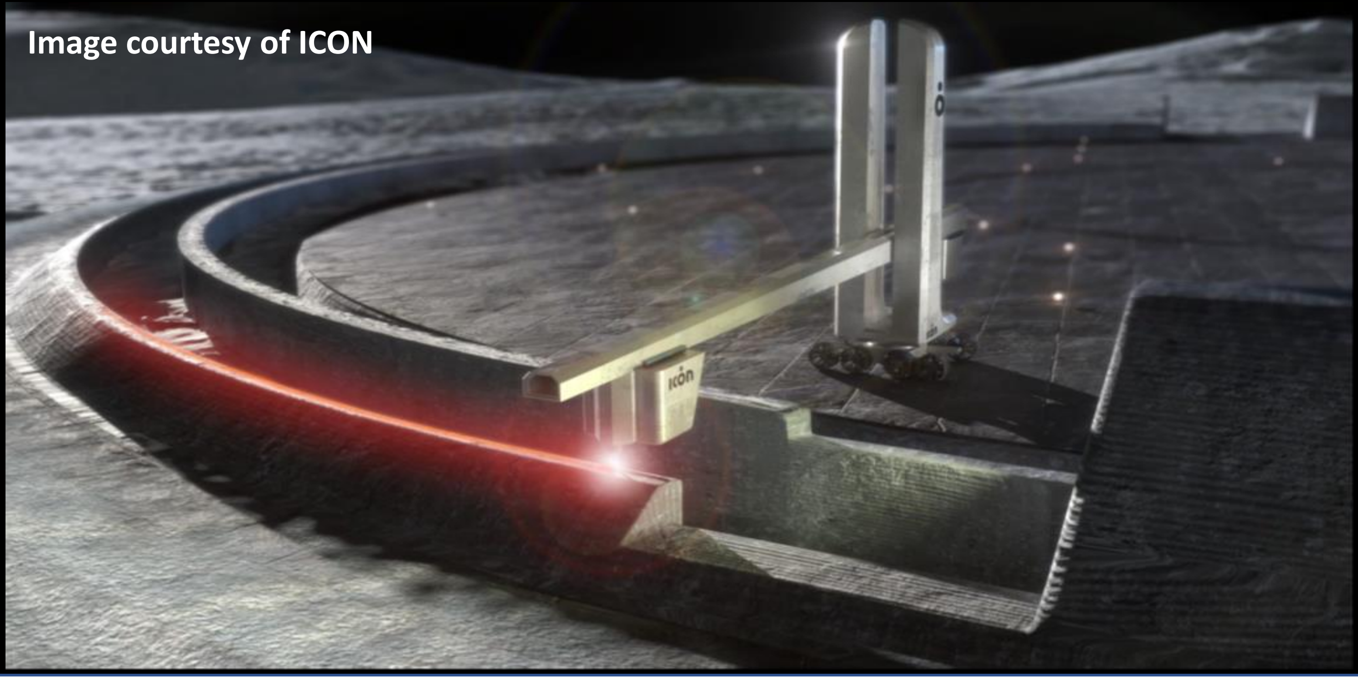


Image courtesy of ICON

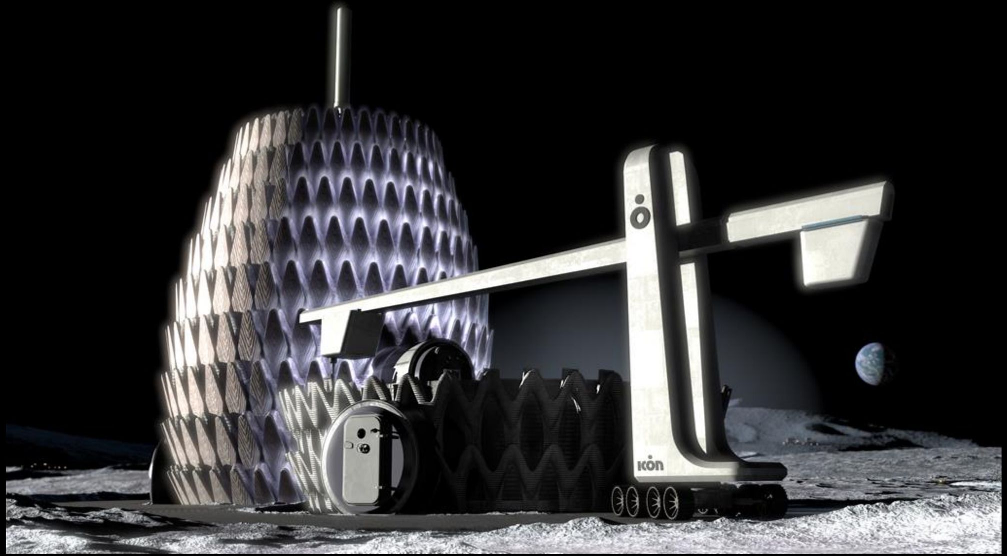
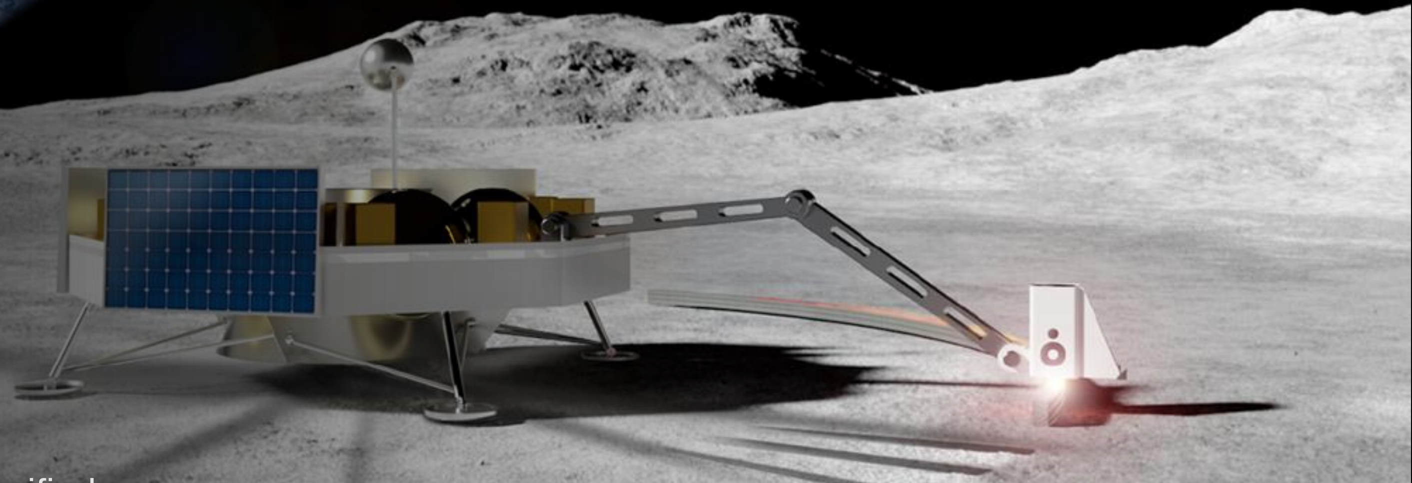


Image courtesy of SEArch+

Initial Candidate Construction Technology Demonstration Mission

Construction Roadmap

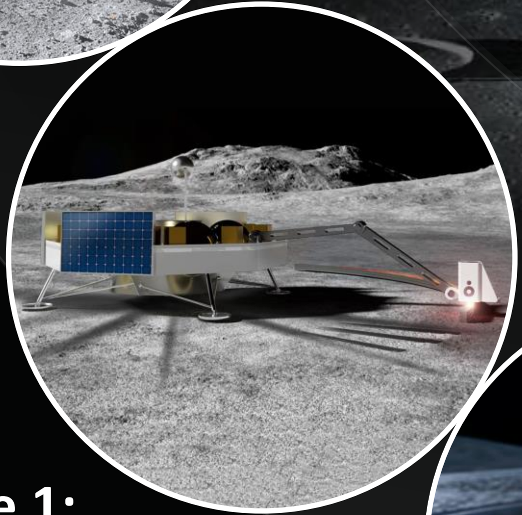
- Demonstrate downselected construction technique utilizing ISRU materials at small scale from lander base (horizontal and vertical subscale “proof of concept” elements)
- Results are critical to inform future construction demonstrations & characterize ISRU-based materials and construction processes for future autonomous construction of functional infrastructure elements
- Demonstration of remote/autonomous operations
- Initial demonstration of instrumentation and material
- Validation that Earth-based development and testing are sufficient analogs for lunar operations
- Anchors analytical models
- ***Rationale:*** *Must prove out initial construction concept in lunar environment*



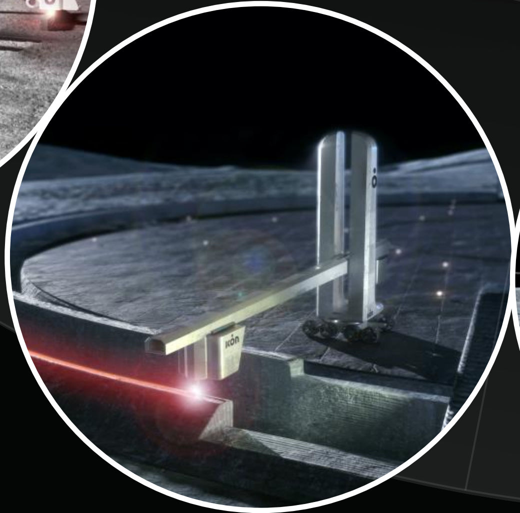
Outcome

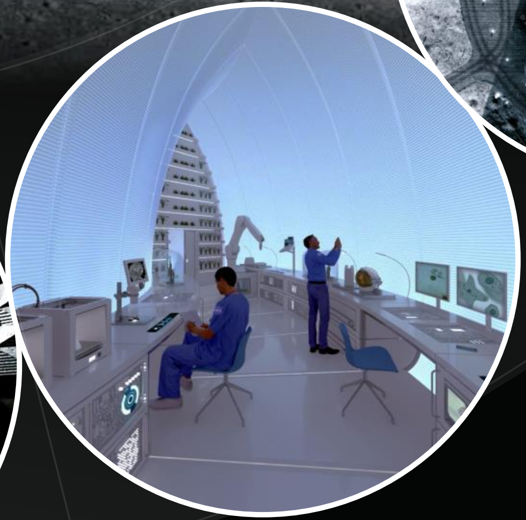
- **TRL 6** achieved for autonomous ISRU consolidation into densified, subscale horizontal and vertical demonstration products
- **TRL 9** for limited hardware and instrumentation that will be used on later missions

Lunar Construction Capability Development 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.





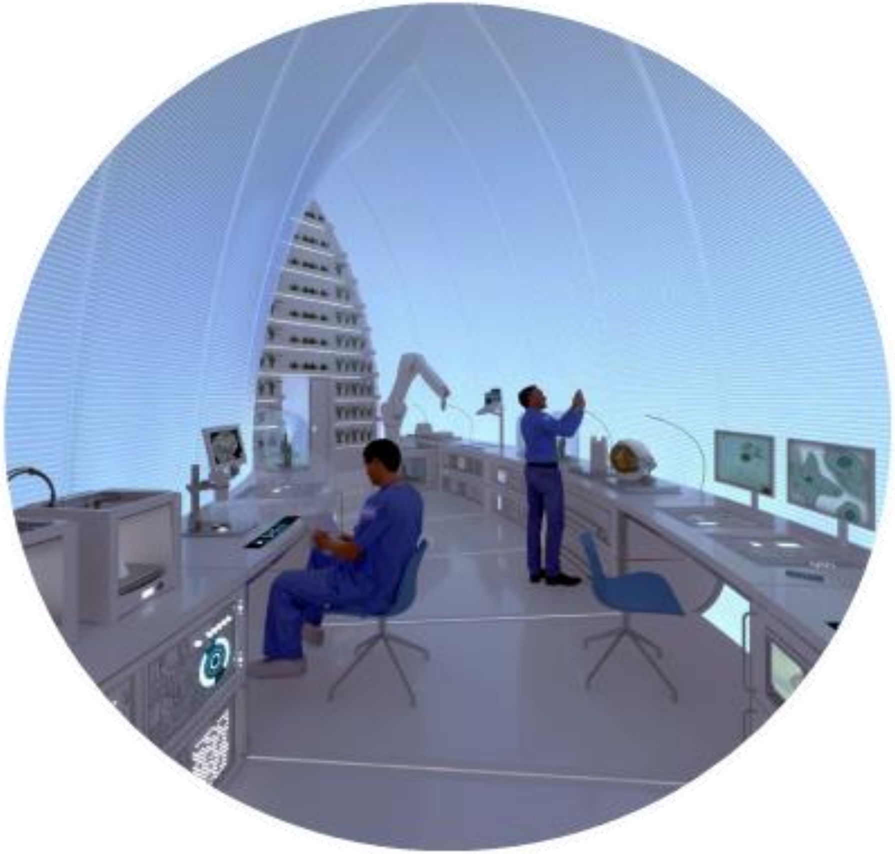
Phase 1:
Develop & demonstrate excavation & construction capabilities for on-demand fabrication of critical lunar infrastructure such as landing pads, structures, habitats, roadways, blast walls, etc.

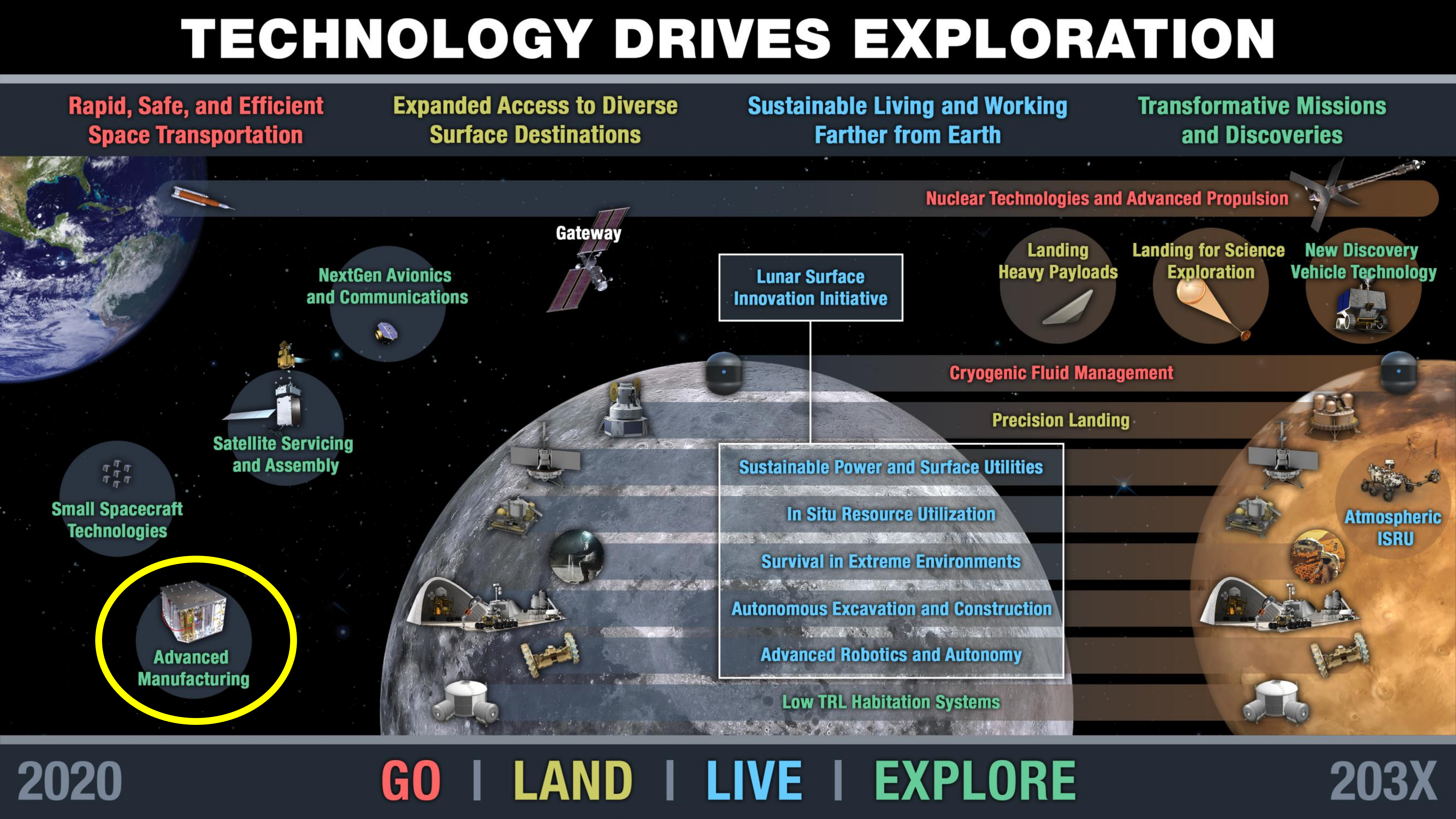
Phase 2: Establish lunar infrastructure construction capability with the initial base habitat design structures.

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

Lunar Outfitting Capability Development

- Outfitting: Broad spectrum of capabilities – “Turning 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





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In-Space Manufacturing Project Portfolio

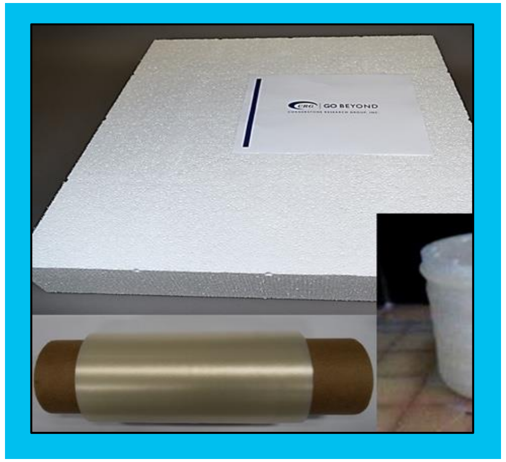
Objective: provide a solution towards sustainable, flexible missions through development of on-demand fabrication, replacement, and recycling capabilities

On Demand Metals Manufacturing

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

Image Courtesy of Made In Space (Redwire)

Recycling and Reuse



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

Image Courtesy of Cornerstone Research Group

On Demand Electronics Manufacturing

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

Development and Testing of Capabilities for On-Demand Spare Component Manufacturing

Techshot Fabrication Laboratory ground-based prototype for bound metal deposition. Image from Techshot, Inc. (Redwire)

Vulcan wire+arc hybrid additive manufacturing system from Made in Space, Inc. (Redwire)

Systems in development for future initial ISS demonstrations: 3D printing of metals

Adapting Metal AM for ISS and Lunar Surface

Environments (ISS and the lunar surface) impose unique constraints for manufacturing systems.

- Scale/scalability of hardware
  - Power (max power for ISS payload is 2kW)
  - Mass
  - Volume
- Safety (feedstock management, chip debris capture)
- Limited crew interaction
- Remote commanding
- Range of materials within processing capability
- Feedstock materials available, via beneficiation, on Moon
- Surface finish
- Operation in reduced gravity
  - Physics of deposition
  - Impact on material quality
  - Management of heat in absence of natural convective cooling

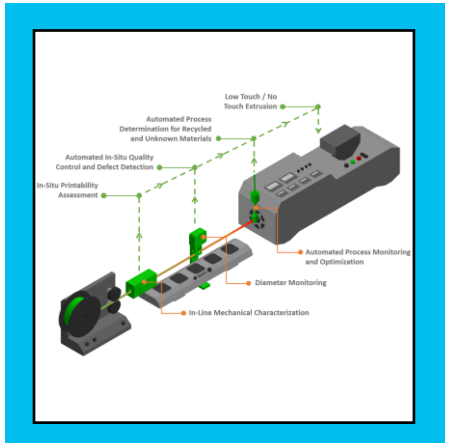
One of the pre-eminent ISM challenges is verification of parts produced on-orbit or on the lunar surface.

Recycling and Reuse (RnR)

The RnR project element develops materials and recycling technologies with the goal of creating an on-orbit ecosystem for repurposing waste products, such as packaging materials and defective components.

Cargo bags filled with trash on ISS for downmass in Cygnus cargo capsule. Image from NASA.

- Analyze historical waste streams and recycling technologies
- Development of “purpose-built” recyclable materials
- Development of in process monitoring technologies



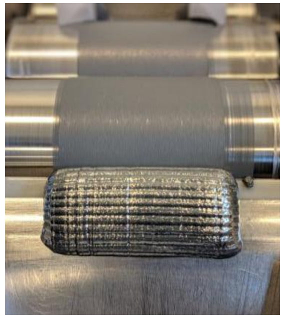
(LEFT) Thermally reversible packaging materials (which can also be used for 3D printing) and (RIGHT) in-process monitoring system for polymer filament production from Cornerstone Research Group (CRG). Images from CRG.

<u>Potential Areas for Future Exploration</u>

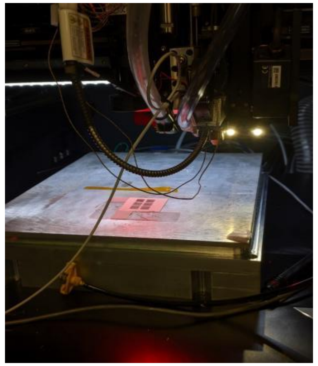
- Metals Recycling
- Sterilization and Sanitization Technologies
- Increased feedstock strength
- Validation and characterization of recycled feedstock
- In Situ Resource Extraction
- Disassembly of multi material products

On-Demand Manufacturing of Electronics (ODME)

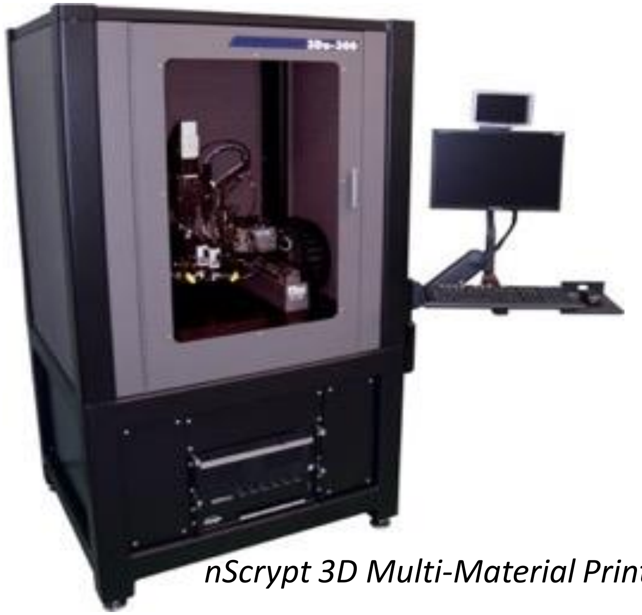
ODME is developing printed electronics, sensors, and power devices for initial testing and demonstration on ISS. In parallel, deposition processes used with printed electronics (direct write and plasma spray) are being matured for future flight demos.



Development of electronic inks



Development of laser sintering process



nScrypt 3D Multi-Material Printer

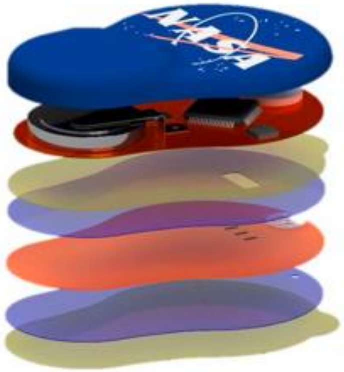
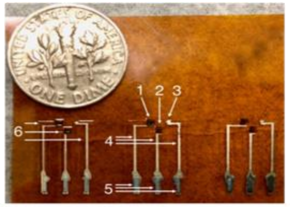


Diagram of AstroSense next-generation flexible, wireless, multi-sensor printed device for crew health monitoring. Image from Nextflex.

Development of photonic sintering process

Dimatix inkjet thin film printer

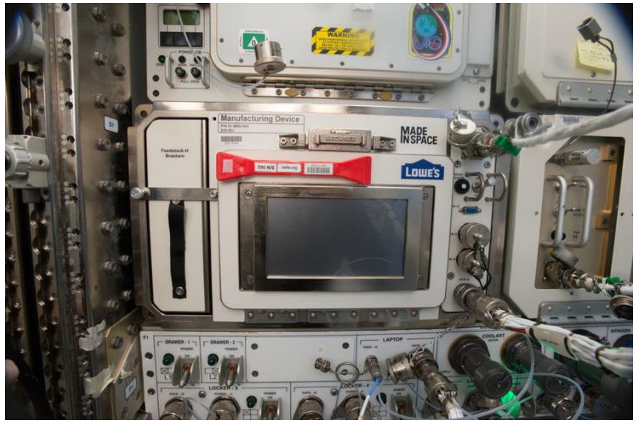


Printed cortisol (stress) sensor. Image from California Institute of Technology.

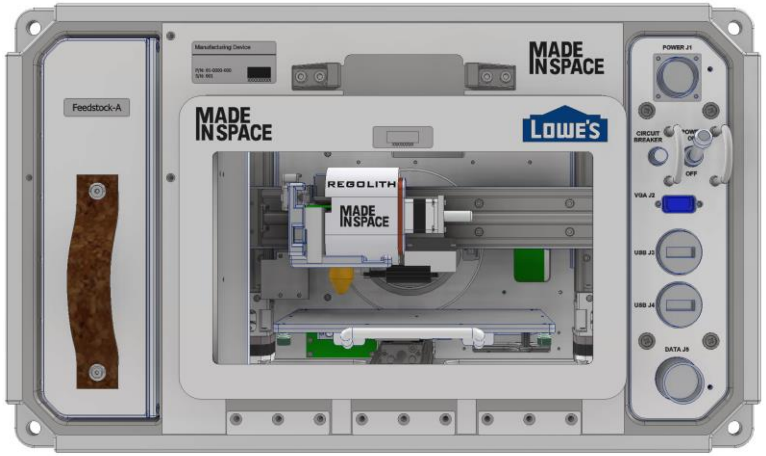
1st Generation Personal CO_2 Monitor

3D Printing and In Situ Resource Utilization (ISRU): Redwire Regolith Print (RRP)

RRP is an on-orbit demonstration of 3D printing with a polymer/regolith simulant feedstock blend. It was the first demonstration of manufacturing with ISRU-derived feedstocks on ISS.



Made in Space (MIS) (Redwire) owns and operates the Additive Manufacturing Facility (AMF).



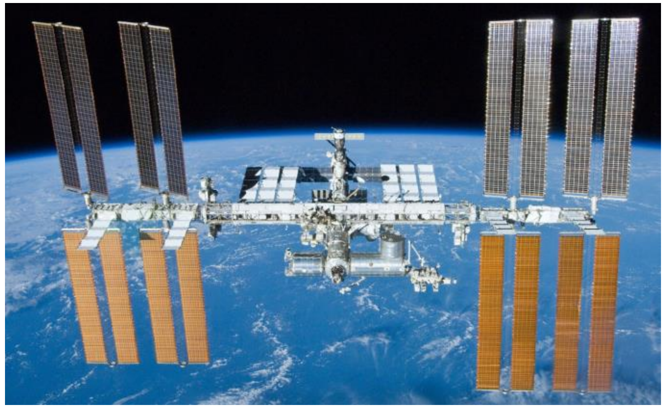
A previously flown version of AMF was modified to accommodate a new extruder and print with a feedstock consisting of regolith simulant and a thermoplastic.

- Launched 8/10/21
- Prints experienced off-nominal operations on ISS.
- RRP returned to Earth

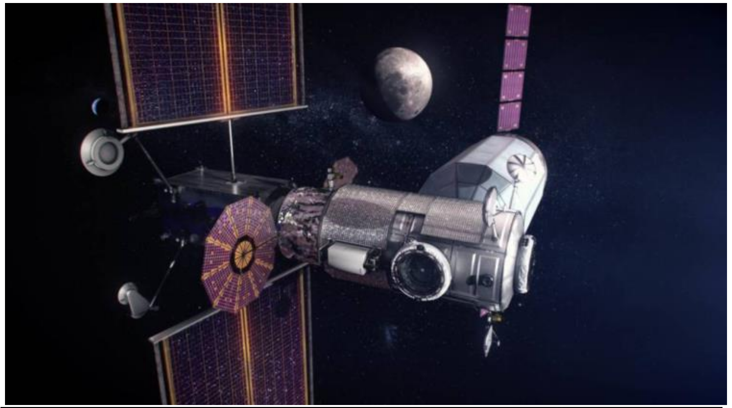
Printing (top) and testing (bottom) of a compression cylinder with a regolith simulant/polymer feedstock.

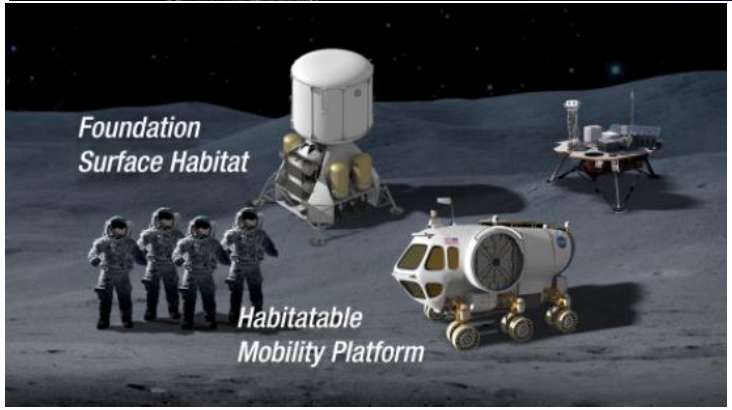
The Vision of Space Sustainability

Manufacturing in space is a destination-agnostic capability with clear mission benefits beyond low earth orbit. Cargo resupply opportunities are limited or nonexistent. These technologies are key enablers for sustainable space exploration.



DEMONSTRATE: *ISS is the testbed for ISM.*





USE: *ISM capabilities demonstrated on ISS are applicable to Gateway and the lunar surface.*

INSTITUTIONALIZE: *"Houston, we have a solution."*


NASA
www.nasa.gov/spacetech