National Aeronautics and
Space Administration

Make It – Don’t Take It: NASA’s Vision for Extraterrestrial Manufacturing and Construction

National Space and Missile Materials Symposium

June 26, 2023

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AGENDA

- NASA’s Moon to Mars Exploration Strategy Overview
- NASA’s Space Technology Mission Directorate (STMD): Technology Drives Exploration
- Lunar Surface Innovation Initiative (LSII)
  - Excavation, Construction and Outfitting Focal Area Summary
    - Moon to Mars Planetary Autonomous Construction Technology (MMPACT) Project Overview
- Advanced Manufacturing Focal Area Overview
  - In Space Manufacturing Portfolio
- Summary

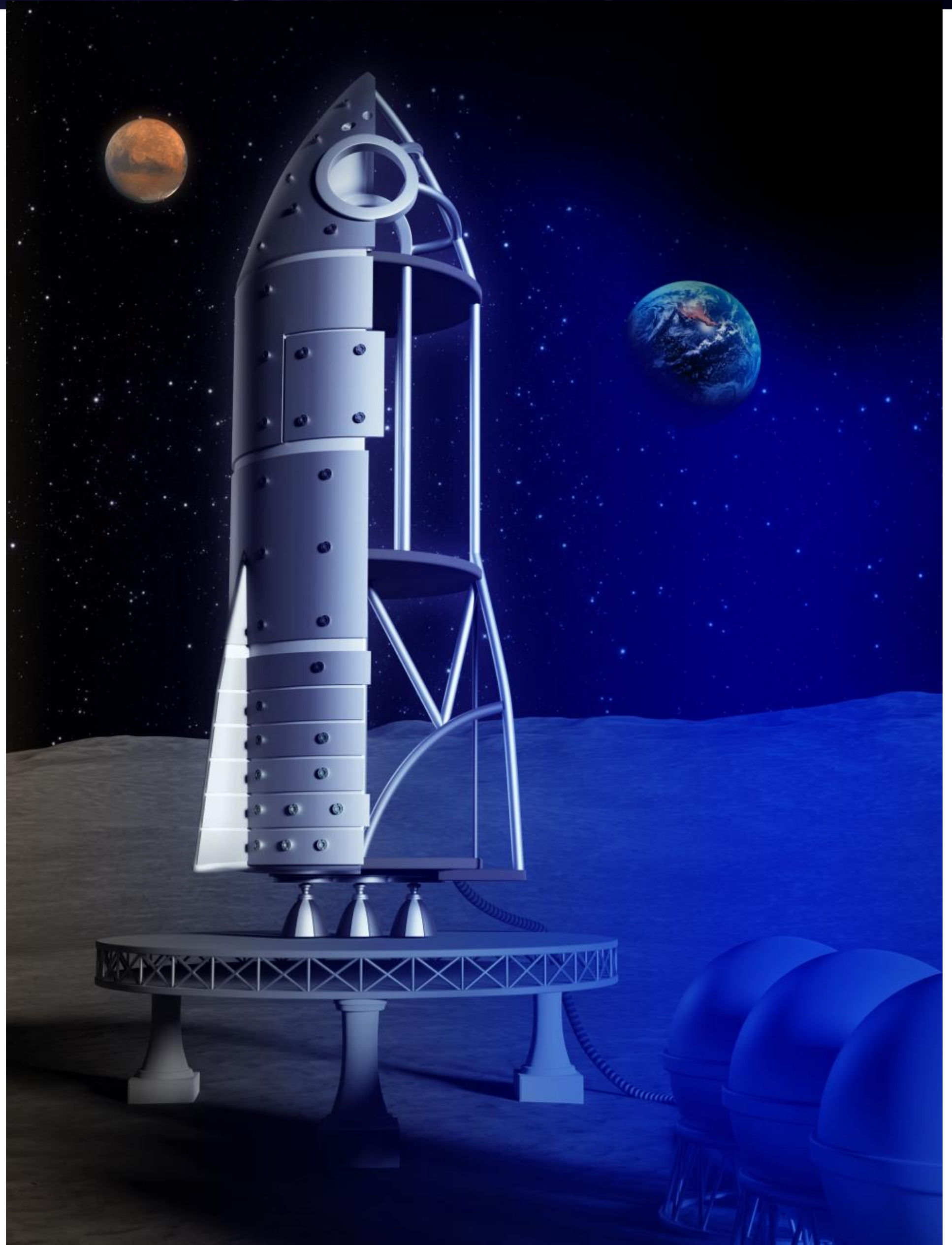
NASA's Moon to Mars Exploration Strategy

- NASA's Moon to Mars Strategy and Objectives Development document is available online at:

  https://go.nasa.gov/3zzSNhp

- There are multiple resources available to provide additional information on the background and development of the strategy:
  - Architecture Definition Document
  - NASA's Moon to Mars Architecture: A Summary of the 2022 Architecture Concept Review
  - Architecture Concept Review 2022 White papers:
    - Systems Analysis of Architecture Drivers
    - Why NRHO: The Artemis Orbit
    - Why Artemis will Focus on the Lunar South Polar Region
    - Gateway: The Cislunar Springboard for International and Sustainable Human Deep Space Exploration
    - Mars-Forward Capabilities to be Tested at the Moon
    - Mars Transportation

    - **https://www.nasa.gov/feature/nasa-details-strategy-behind-blueprint-for-moon-to-mars-exploration**
    - **https://www.nasa.gov/sites/default/files/atoms/files/acr22-wp-why_nrho-the-artemis-orbit.pdf**



Moon to Mars Strategy: Manufacturing and Construction Examples
Objective-based Approach – Architect from the Right - Stick with the Plan

LI-4L: Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-8L: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, needed for continuous human/robotic presence.

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.

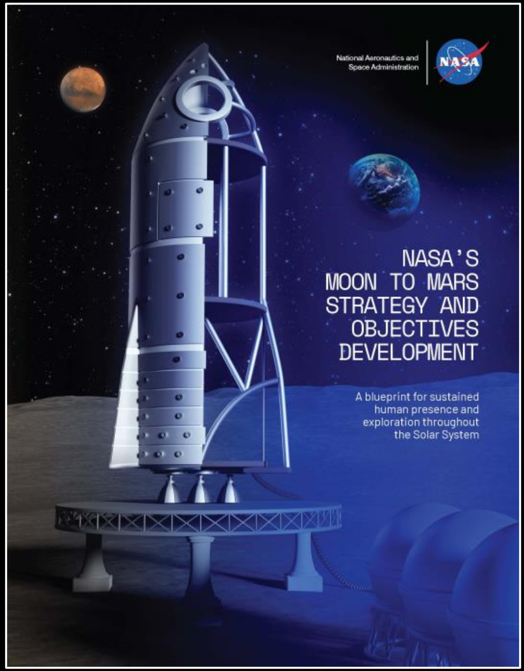
PPS-2LM: Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.

AS-6LM: Advance understanding of how physical systems and fundamental physical phenomena are affected by partial gravity, microgravity, and general environment of the Moon, Mars, and deep space.

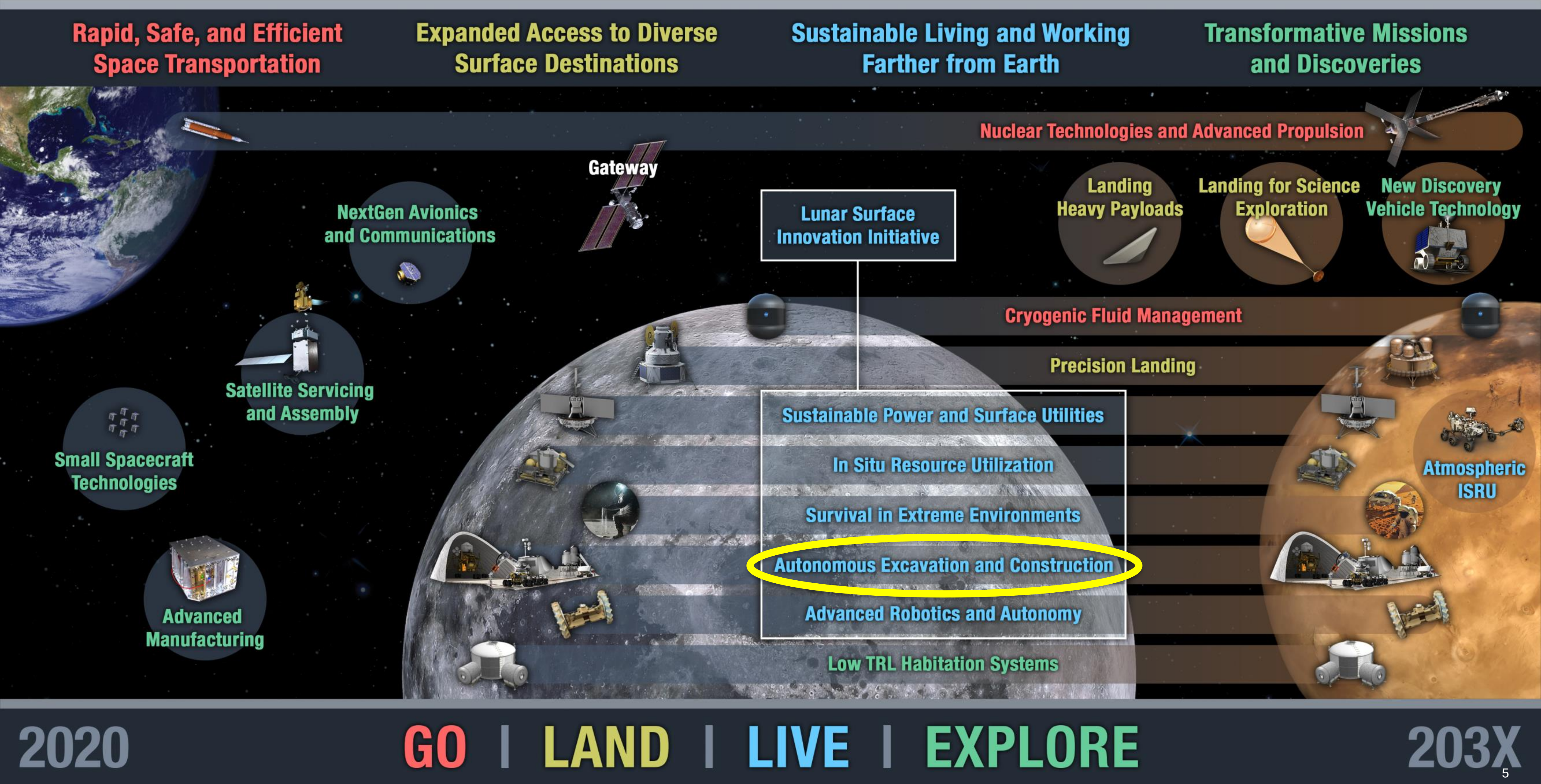
TH-4LM: Develop in-space and surface habitation system(s) for crew to live in deep space for extended durations, enabling future missions to Mars.

OP-11LM: Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.

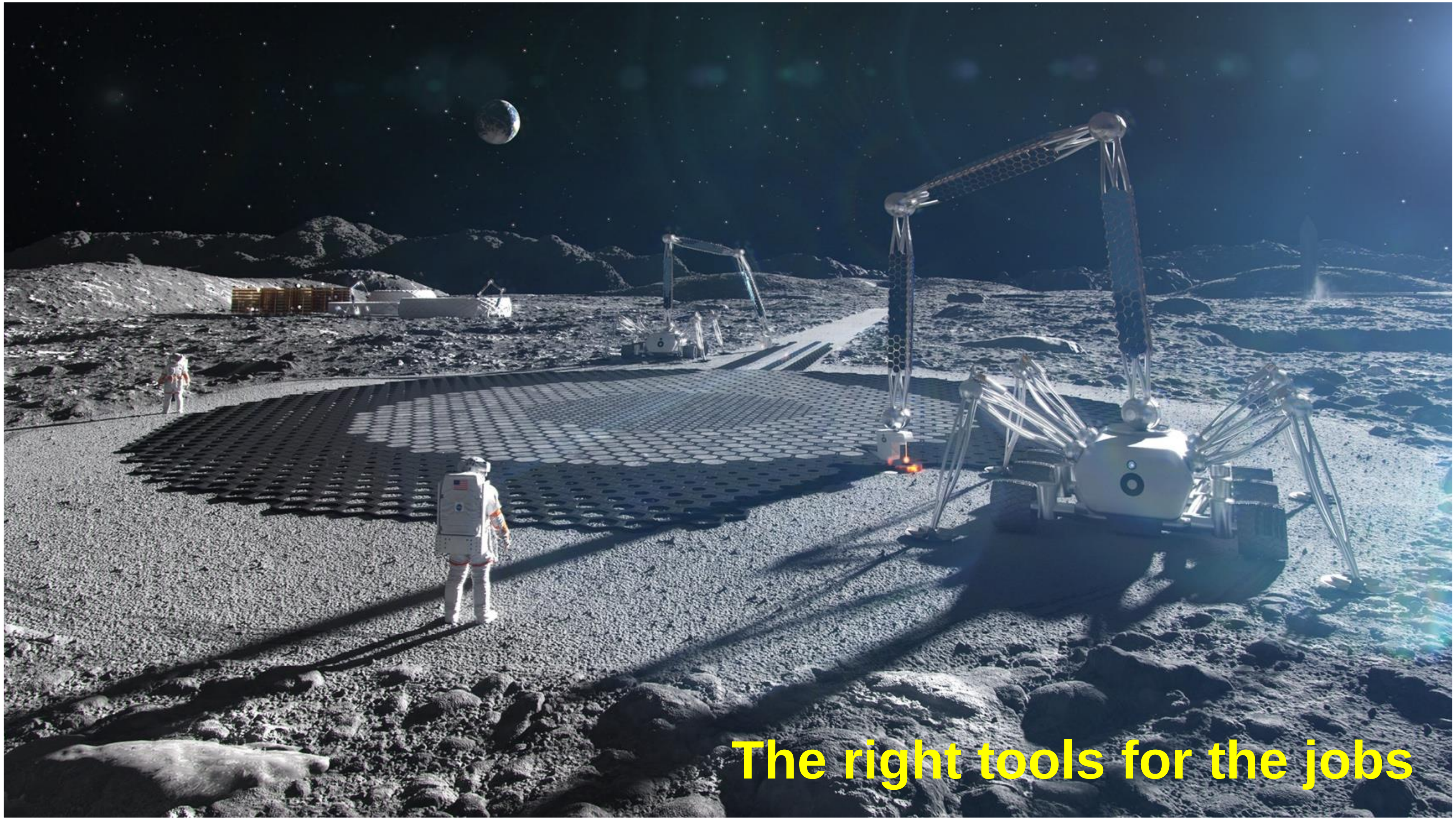
OP-12LM: Establish procedures and systems that will minimize the disturbance to the local environment and allow for reuse/recycling of material transported from Earth.



TECHNOLOGY DRIVES EXPLORATION



How We Explore… Lunar Construction Technology

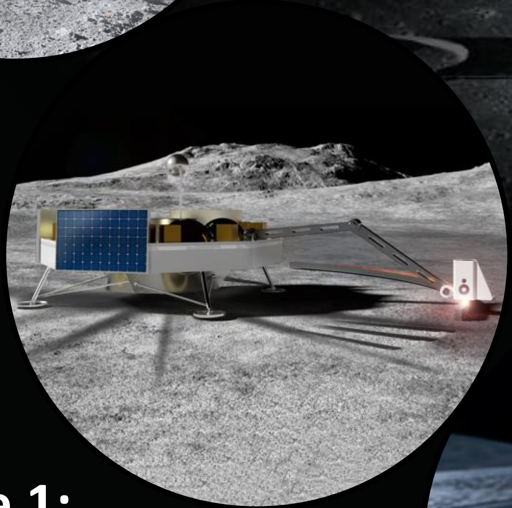


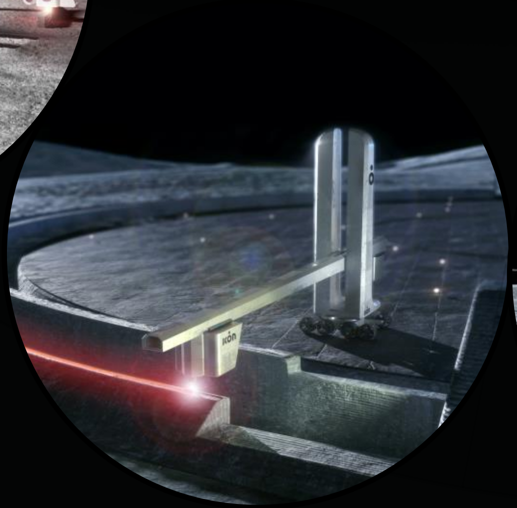
Credit: ICON/BIG-Bjarke Ingels Group

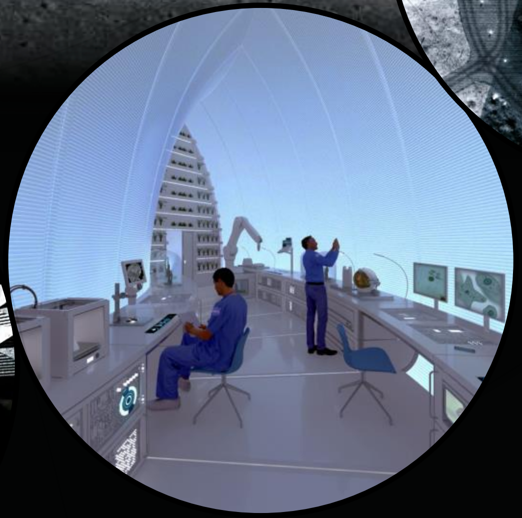
GRAND VISION

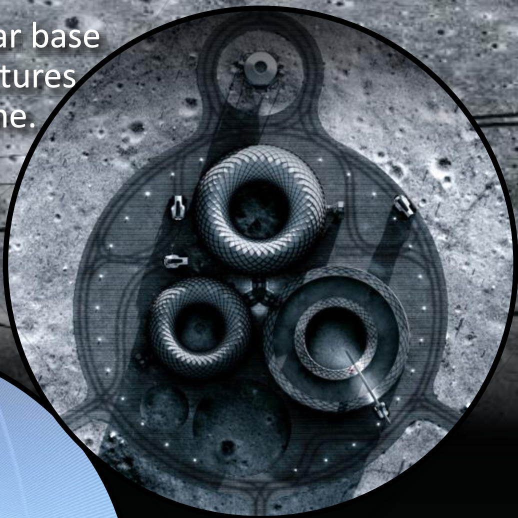
- MMPACT will enable the development of a lunar economy by providing an on-demand construction capability for multiple infrastructure elements (habitats, launch/landing pads, roads, blast shields, and other structures)
- MMPACT will enable sustainable human presence on the Moon
  - Customization of infrastructure based on application
  - Construction of a suitable location for new crew members, new rovers/spacecraft, or facilities based on need
- MMPACT's industry partner is expected to be commercially viable on the Moon in the 2030's or potentially earlier
- Demonstrations begin with a CLPS proof-of-concept mission (STMD)
- Partnerships with other NASA Centers and members of industry and academia
- Technology Capability at the End State of Phase II of the Project:
  - A flight-ready proof-of-concept technology demonstration for construction on the Moon

Lunar Construction Capability Development Roadmap









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).

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

Space Tech Lunar Surface Demonstration Strategy

ISRU, power, excavation, and construction utilizing cross-cutting technologies

Reconnaissance, Prospecting, Sampling

Sub-system demonstrations:
Investigate, sample, and analyze the environment for mining and utilization.

Oxygen extraction ground demo

IM-2

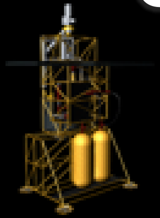
PRIME, Hopper, LTE Demos

VIPER (SMD)

Resource Acquisition & Processing

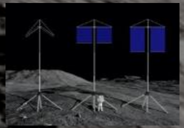
Follow the natural resources:
Demonstrations of systems for extraction and processing of raw materials for future mission consumables production and storage.

CT-1



ISRU O2 Demo

ISRU Pilot Excavator

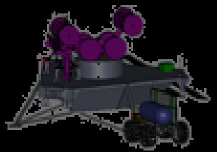


Surface Power Demo (VSAT, RFC)

Construction Demo 1

CT-2

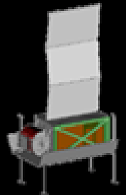
ISRU Subscale Demo



Construction Demo 2

Pilot Consumable Production

Sustainable exploration:
Scalable pilot systems demonstrating production of consumables from in-situ resources in order to better support sustained human presence.



Fission Surface Power

ISRU Pilot System*

* ISRU Pilot Plant demo will use Fission Surface Power

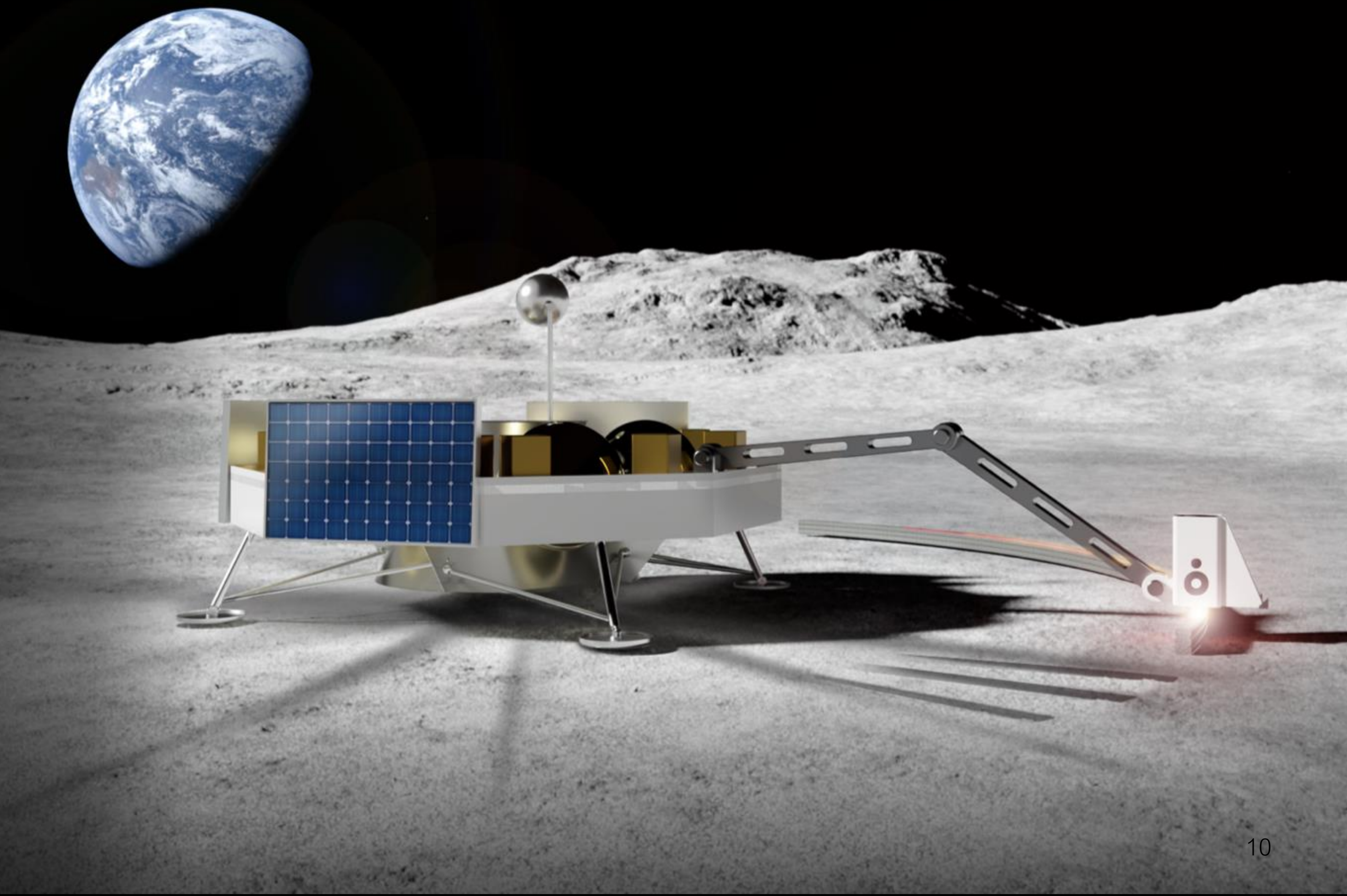
Moon-to-Mars Planetary Autonomous Construction Technologies (MMPACT) Initial Construction Technology Demonstration Concept

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.

Objectives:

- Demonstrate "proof of concept" for downselected construction technology utilizing ISRU materials at small scale from lander base
- Characterize ISRU and ISRU-based materials
- Demonstrate remote/autonomous operations
- Demonstrate instrumentation operations
- Validate that Earth-based development and testing are sufficient analogs for lunar operations
- Anchor analytical models
- Address technology gaps and inform construction processes for future construction of functional infrastructure elements

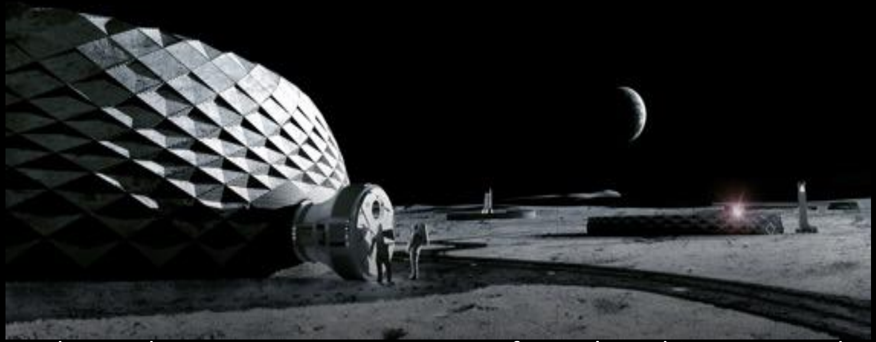


Materials and Concepts for the Lunar Outpost

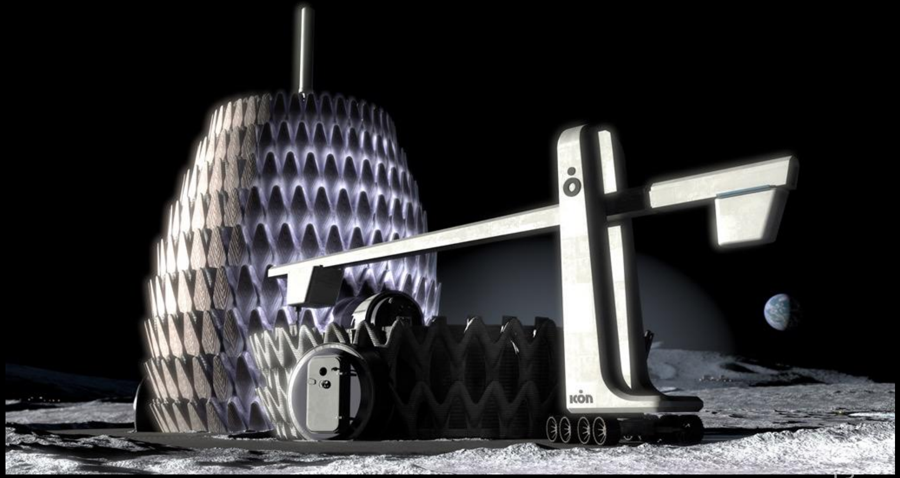
Regolith-based Materials and Processes:

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

Image courtesy of ICON



Bjarke Ingels Group Concept courtesy of ICON’s Architecture Study



SEArch+ Concept courtesy of ICON’s Architecture Study

Screening Test Matrix for Selection of Initial Demonstration Mission Material/Process

Compression Strength	Mortar	ASTM C0109	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars	STP
	Ceramic	ASTM C1424	Standard Test Method for Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature	STP
Compression at Cold Temperature (lunar night)	Mortar	ASTM C0109	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars	-192°C
	Ceramic	ASTM C1424	Standard Test Method for Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature	-192°C
Compression at Elevated Temperature (lunar day)	Mortar	ASTM C0109	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars	57°C
	Ceramic	ASTM C1424	Standard Test Method for Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature	57°C
Compression After Thermal Cycling Under Vacuum2	Mortar	ASTM C0109	Standard Test Method for Compressive Strength of Hydraulic Cement Mortars	STP
	Ceramic	ASTM C1424	Standard Test Method for Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature	STP
Layer to Layer Adhesion	Both	ASTM C297	Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions	STP
4 Point Bend Flexural Test	Mortar	ASTM C78	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)	STP
	Ceramic	ASTM C1161	Standard Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature	STP
Ablation3	Both	EM40-OWI-013	EM40 Non-Metallics & Advanced Manufacturing Division Plasma Torch Test Facility Operation Procedure	TBD

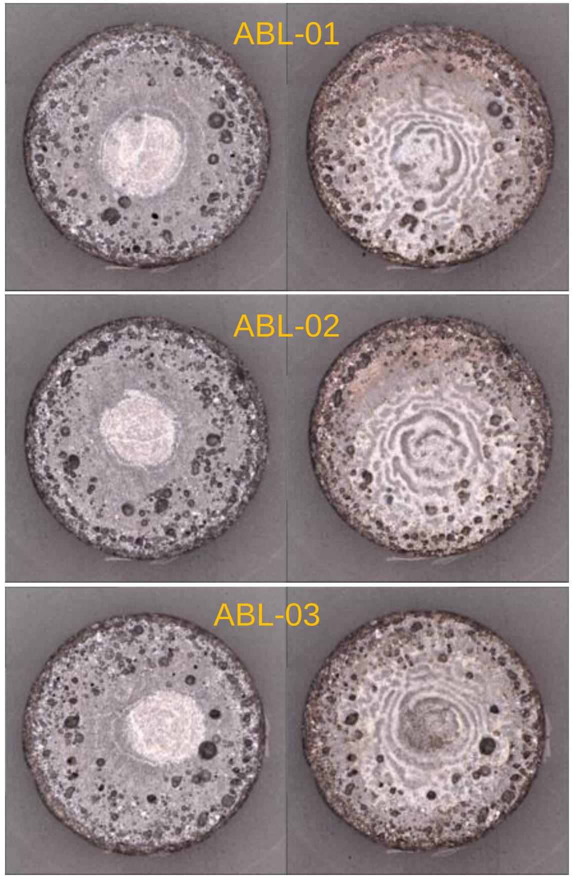
1All test specimens will have more than 1 horizontal layer, with the knitline(s) perpendicular to the loading axis.
2One thermal cycle is defined as room temperature to -192°C, -192°C to 57°C, 57°C to -192°C and back to room temperature. Vacuum level used will be 10-4 to 10-3.
3Two configurations of ablation specimens will be tested: an as-built surface facing the plasma torch and a machined surface facing the plasma torch.

MIMPACT

PTTF Images

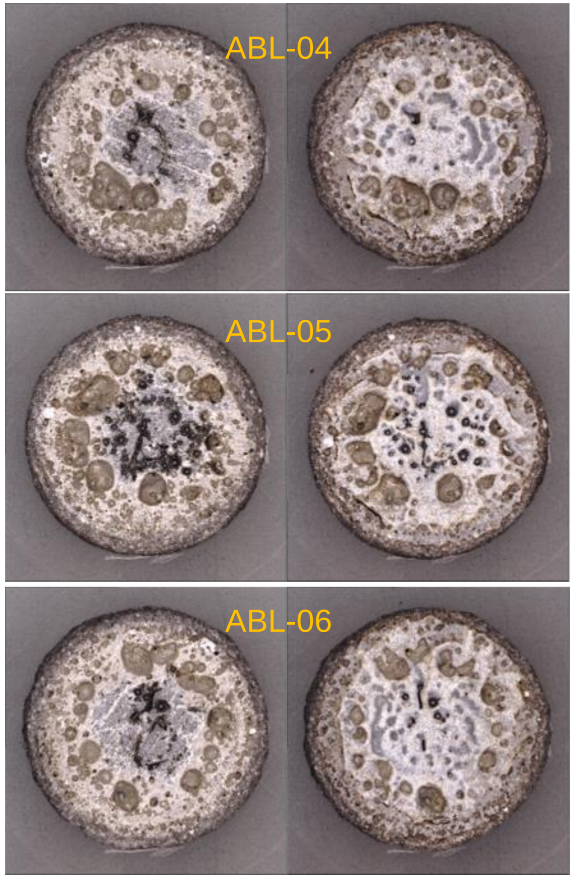
Machined

Pre-test Post-test



As-fabricated

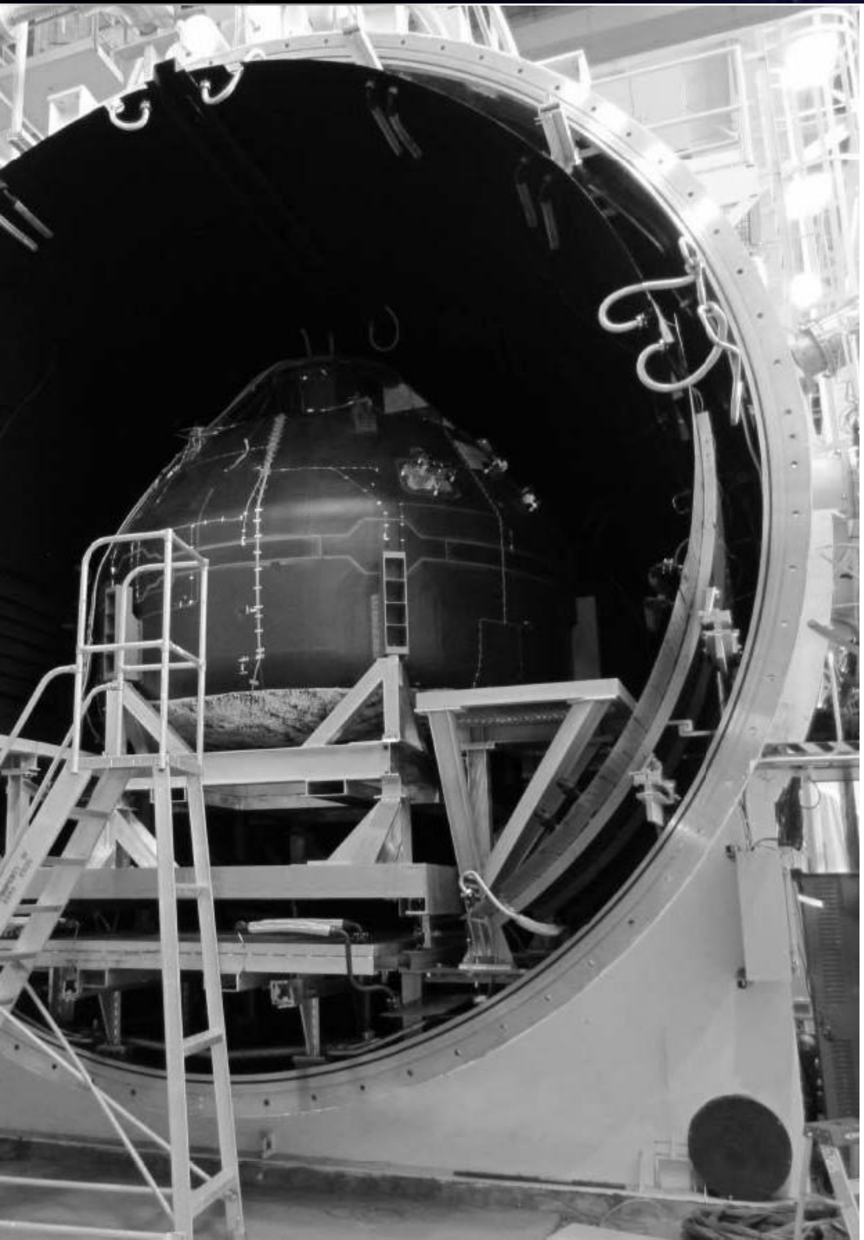
Pre-test Post-test



Candidate Materials and Processes

Material	Deposition Method	MMPACT Development & Test Responsibility
Laser Vitreous Material Transformation (VMX)	Thermal	ICON
Molten Regolith Extrusion	Extrusion	ICON
Microwave Multi-Mode Sintered Regolith	Thermal	NASA/MSFC
Calcium Sulfo-Aluminate (CSA) Binder/Lunar Regolith Concrete	Extrusion	NASA/MSFC
Sodium Silicate/Sodium Hydroxide (Geopolymer) Binder/Lunar Regolith Concrete	Extrusion	NASA/MSFC/PSU
Sulfur Binder / Lunar Regolith Concrete	Extrusion	NASA/MSFC/LSU
AT2LAS Polymer Binder / Lunar Regolith Composite	Extrusion	NASA/MSFC/AAT
Molten Regolith Tile Formation	Extrusion	NASA/MSFC/Astroport
Microwave Near Field Coupler Sintered Regolith	Thermal	NASA/MSFC/Radiance
Magnesium Oxysulfate (MgO) Binder/Lunar Regolith Concrete	Extrusion	NASA/MSFC
Sulfur / Nickel (S/NI) Binder / Lunar Regolith Concrete	Extrusion	NASA/MSFC
Aluminum/Graphite (Low Thermal Expansion)	Extrusion	NASA/MSFC

Next Steps Towards a Demonstration Mission
Testing in a Simulated Lunar Environment



- MSFC has a large (20 ft. diameter by 28 ft. depth) Thermal Vacuum Chamber (TVAC) called V20.
- It is being outfitted with a regolith bed for "dirty" operations
- V20 dirty vacuum chamber at MSFC is an excellent lunar environment analog
- V20 testing still differs from the actual lunar surface in many ways:
  - Simulant vs. Regolith
  - Earth vs. Lunar Gravity
  - Soft vs. Hard Vacuum
- Development system tests are planned
  - Thermal and kinematic testing of terrestrial robot arm (Fall 2023)
  - Development system – simulation of proof of concept mission (Summer 2024)
    - System functionality
    - Material test articles
    - Demonstration article
    - Instrumentation
    - Site preparation
    - Process model anchor data

Current Mission Partnerships

NASA Centers
- MSFC
- LaRC
- KSC
- JPL

OGA Leveraging
- AF Civil Engineering Center
- Defense Innovation Unit (In Discussions)

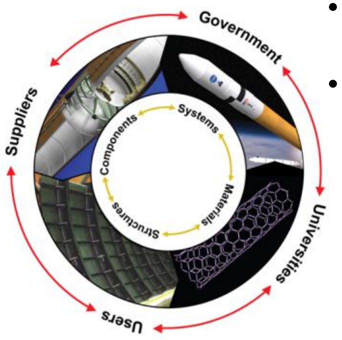
Initial STRATFI ICON Phase 2 SBIR Partners:
- AF Civil Engineering Center
- AF Special Operations Command (AFWERX)
- USAF
- Defense Innovation Unit
- Texas Air National Guard

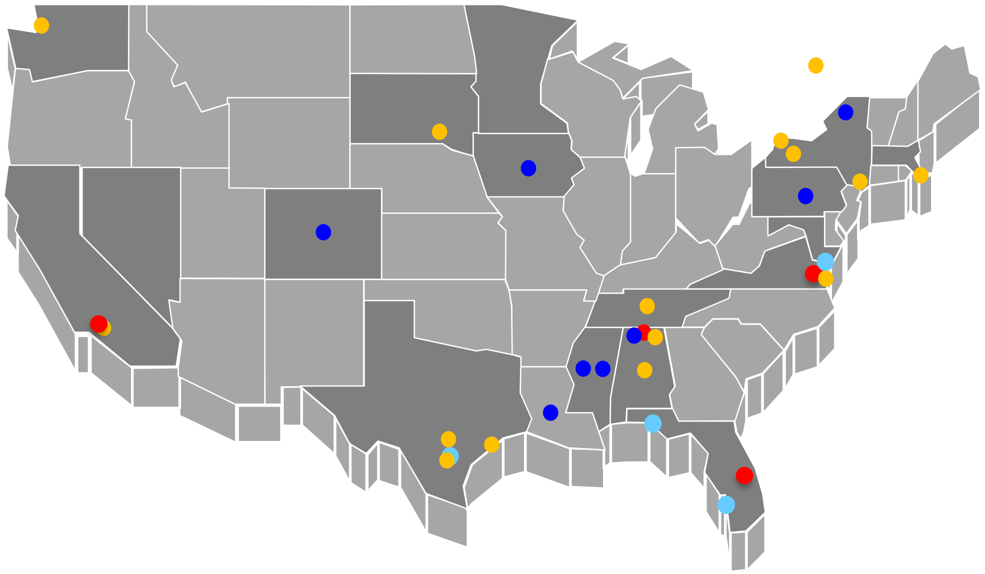
Public/Private Partnerships/Contract
- ICON Build
- Dr. Holly Shulman
- Radiance Technologies
- RW Bruce Associates, LLC
- Blue Origin
- Jacobs Space Exploration Group
- JP Gerling
- Microwave Properties North
- Southeastern Universities Research Association
- Southern Research Engineering/Kratos
- Bjarke Ingels Group (BIG)
- Cislune
- Washington Mills
- Texas Research Institute (Austin)
- Astroport

Technology Providers/ Contributing Partners: Academia
- Colorado School of Mines
- University of Texas in San Antonio
- Mississippi State University
- Pennsylvania State University
- University of Mississippi
- University of Alabama in Huntsville
- Clarkson University
- Iowa State University
- Louisiana State University
- Alfred University
- Sinte Gleska University
- Drake State

SBIR/STTR
- Construction Scale Additive Manufacturing Solution
- Millimeter Wave Camera
- High Efficiency Sintering via Beneficiation of the Building Material

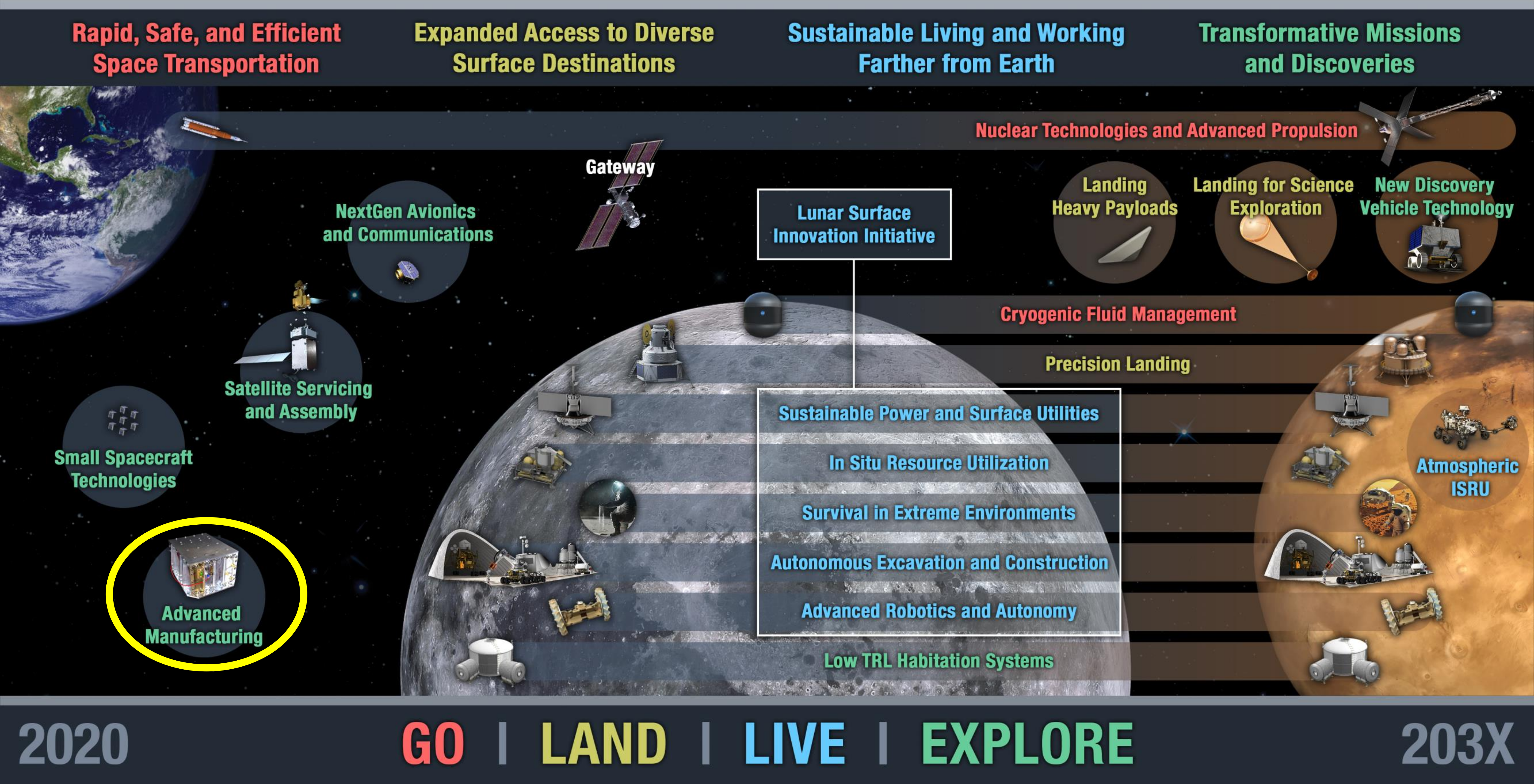
Potential Customer
- Artemis
- Commercial





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

TECHNOLOGY DRIVES EXPLORATION



EXPLORE: Develop technologies supporting emerging space industries

Priorities - Targeted advanced manufacturing outcomes aligned with space industry trends that will shape the course of research and development over many years

In-Space Manufacturing and Space Infrastructure

> 50% Mass reduction, > 99% 3D printer readiness. A catalyst for space infrastructure and economic opportunities

1

3D Printing / Additive Manufacturing

>50% Cost reduction, 12 months instead of five years,
Parts reduction >100 to 1

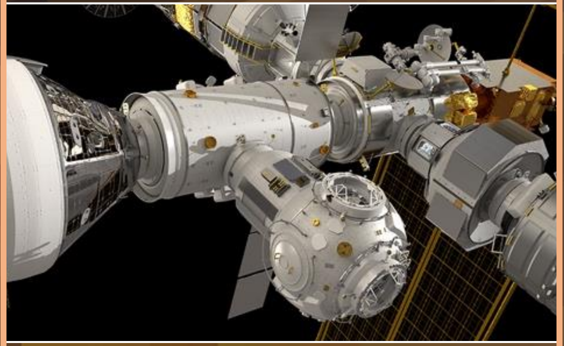
2

Digital Transformation Digital Twins and Artificial Intelligence

>50% of physical resources replaced with virtual
More intelligent and more accurate predictions and capabilities

3

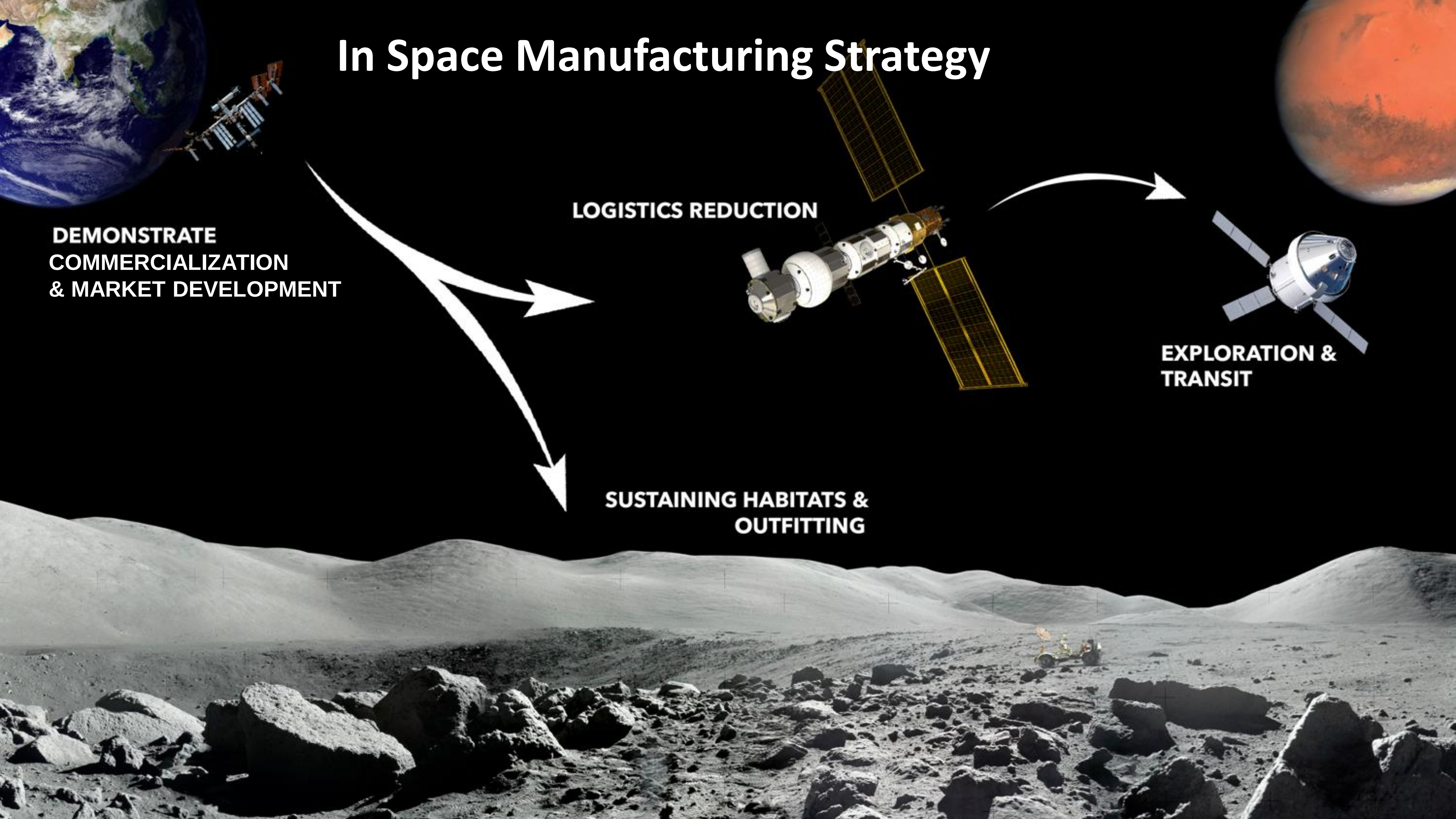
Lightweight Composite Spacecraft



30% - 50% Mass reduction, More payload, equipment, and experiments

4

In Space Manufacturing Strategy



Phase I for ISM - Develop a Space Economy

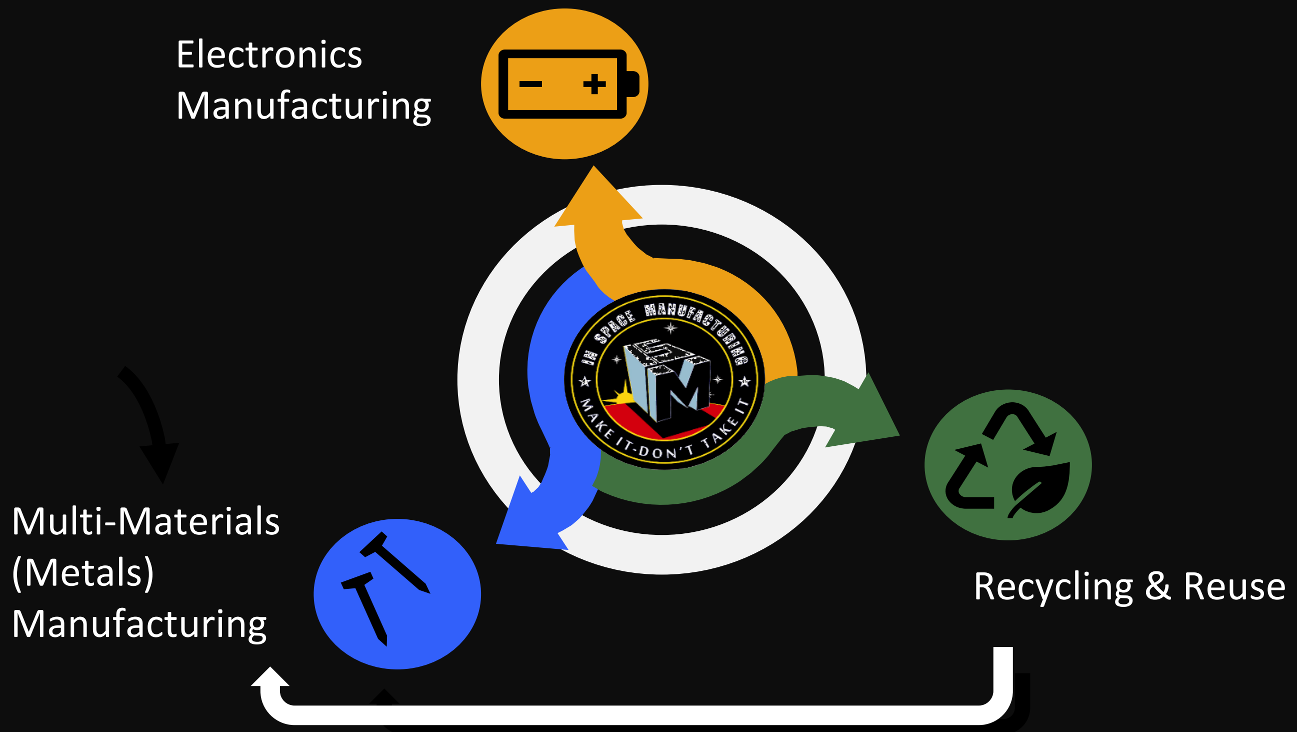
In Space Manufacturing Vs In Space Construction:

Construction is focused on the process of building facilities and infrastructure.

Manufacturing is focused on creating goods (e.g. textiles, tools, furniture, etc)

Use microgravity environment to manufacture goods for Government and Commercial Uses

- ISS, Commercial Space Stations, Lunar gateway
- Technology Focus on printing Metals, Electronics, and Logistics Reduction (e.g. Recycling)

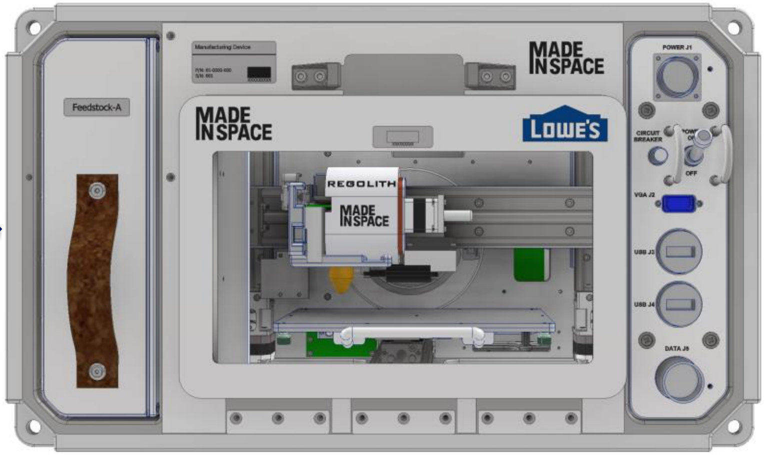


On Demand Manufacturing Of Multi-materials

Goal: Demonstrate metals additive manufacturing in microgravity and characterize the impact of microgravity.

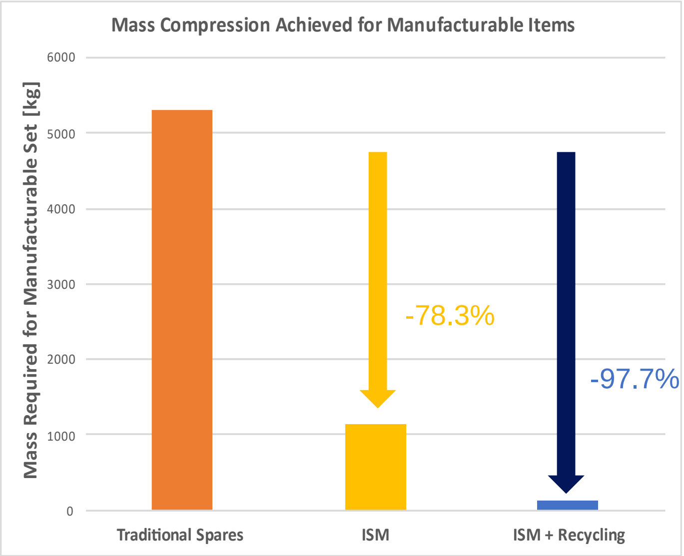
Sub Projects:

1. **Outfitting:** Develop the capability to manufacture on-demand utilities, furnishings, tools, etc. for off-earth habitation including the use of In-Situ Resources.
2. **Recycling and Reuse:** Develop the capability to recycle and reuse materials into useable feedstocks for in-space, on-demand manufacturing.



Recycling and Reuse

Fundamental Assumption: Payloads are designed to be maintainable/manufacturable with ISM systems



Andrew Owens and Olivier De Weck. "Systems Analysis of In-Space Manufacturing Applications for the International Space Station and the Evolvable Mars Campaign", AIAA SPACE 2016, AIAA SPACE Forum, (AIAA 2016-5394)

Outfitting

Image Credit: ICON

CHAPEA

Provided 3D printer and scanner for crew analogue

Goal: Understand crew interaction with manufacturing systems.

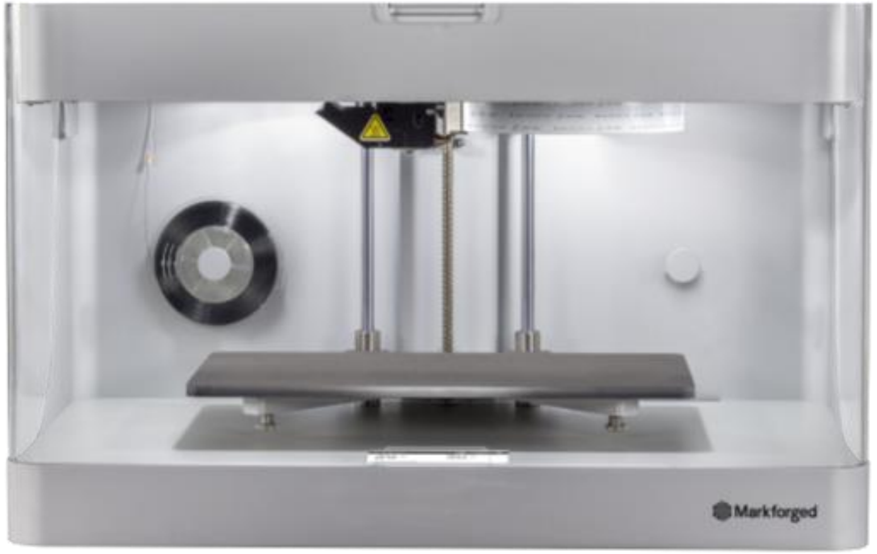
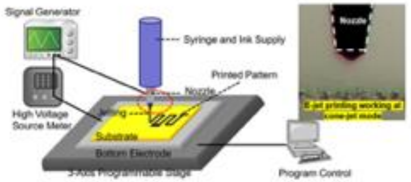


Image Credit: Markforged

On Demand Manufacturing Of Electronics

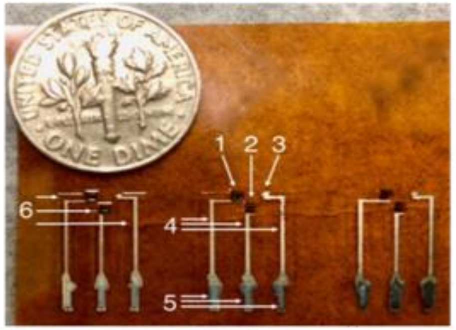
Goal: Develop and demonstrate on demand printing of electronics in microgravity and characterize the impact of microgravity.

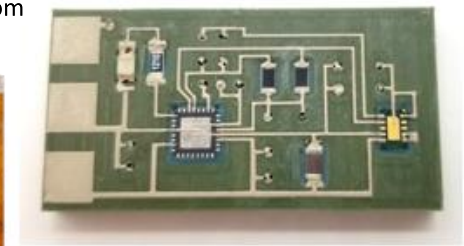
Faraday Electrodeposition of Covetic Copper



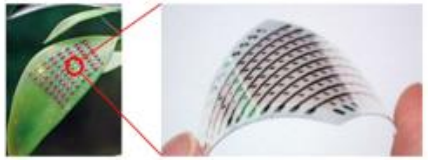
Electrohydrodynamic Ink Jet Printer

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



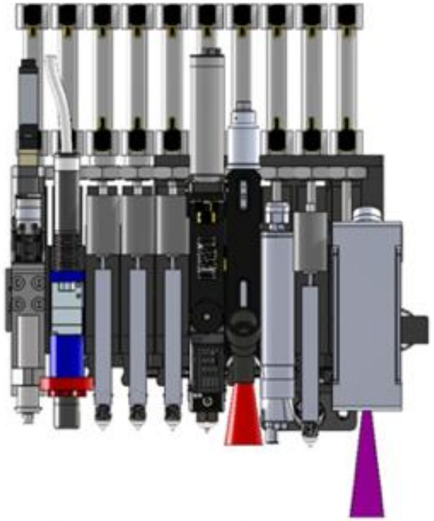


Printed CO2 Sensor (ODME ISS Demo)



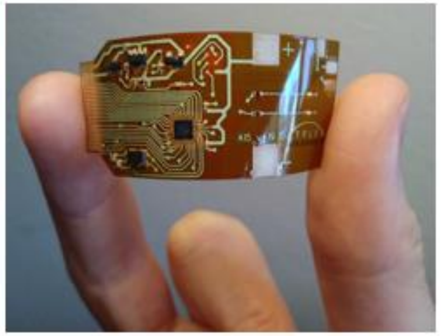
University of Illinois Plant Growth Sensor

TechShot FabLab Multi-material 3D Printer for ISS Demo



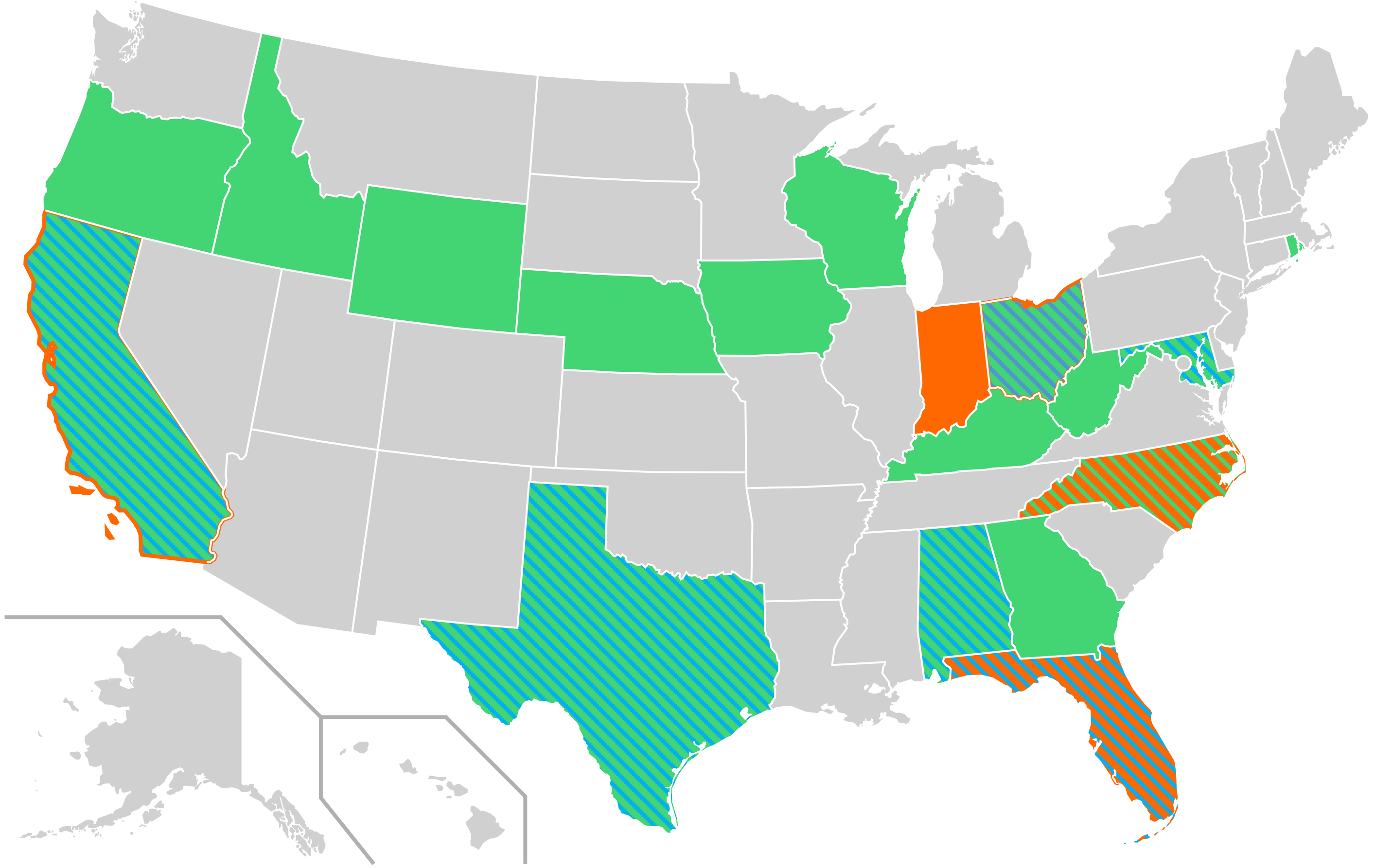
FabLab Advanced Toolplate with Newly Developed Deposition Tech

RF Power Harvesting Antennas- UAH



NextFlex Wireless Flexible Sensor Board

Partnerships'/Collaborators



Academic

- University of Louisville
- University of California Berkley
- University of Nebraska
- University of Alabama Huntsville
- Appalachian State
- Auburn University
- Boise State
- Georgia Tech
- California Tech
- Iowa State University
- University of Miami
- Florida A&M University
- Oregon State
- West Virginia University
- Youngstown University
- University of El Paso
- University of Wisconsin
- University of Wyoming
- University of Delaware

NASA Centers

- Marshall Space Flight Center
- Ames Research Center
- Johnson Space Center
- Kennedy Space Center
- Goddard Space Flight Center
- Air Force Research Center
- Jet Propulsion Laboratory
- Glenn Research Center

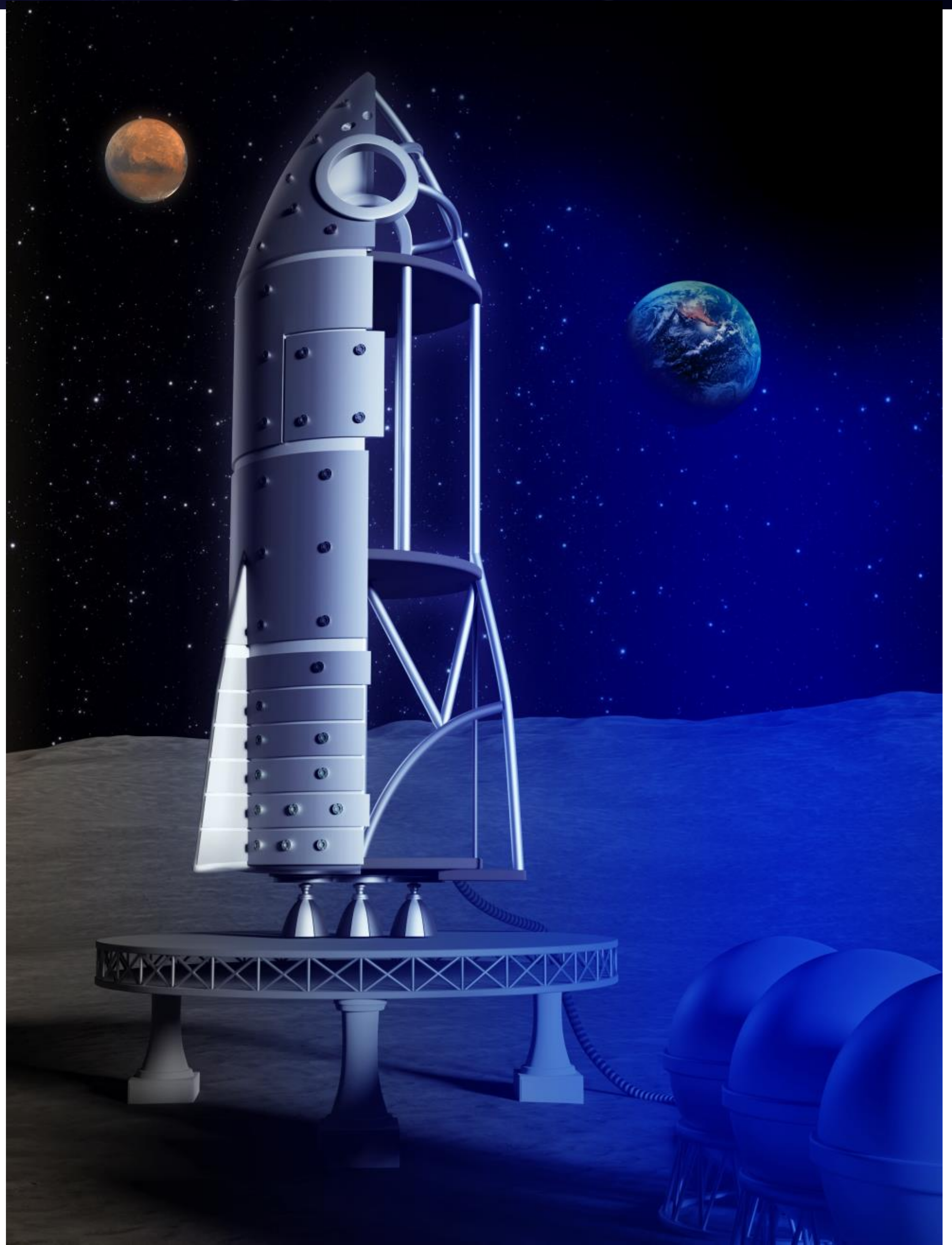
Industry

- Techshot
- Redwire Space
- Cornerstone Research Group
- NextFlex
- nScrypt
- Multi3D
- LambdaVision
- Faraday Incorporated

Extraterrestrial Construction and In Space Manufacturing Summary

- NASA has developed its Moon to Mars Strategy and Objectives
- Multiple resources are available to provide additional information on the background and development of the strategy:
  - https://go.nasa.gov/3zzSNhp
  - https://www.nasa.gov/feature/nasa-details-strategy-behind-blueprint-for-moon-to-mars-exploration
  - https://www.nasa.gov/sites/default/files/atoms/files/acr22-wp-why_nrho-the-artemis-orbit.pdf
- Advanced manufacturing and autonomous surface construction are specified as key objectives for demonstration:
  - LI-4L: Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.
  - LI-8L: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, needed for continuous human/robotic presence.
- **We have a lot of work to do to demonstrate and to institutionalize these capabilities.**

DON'T LEAVE HOME (EARTH) WITHOUT THEM



www.nasa.gov/spacetech

QUESTIONS

Overview of FabLab

Print Module

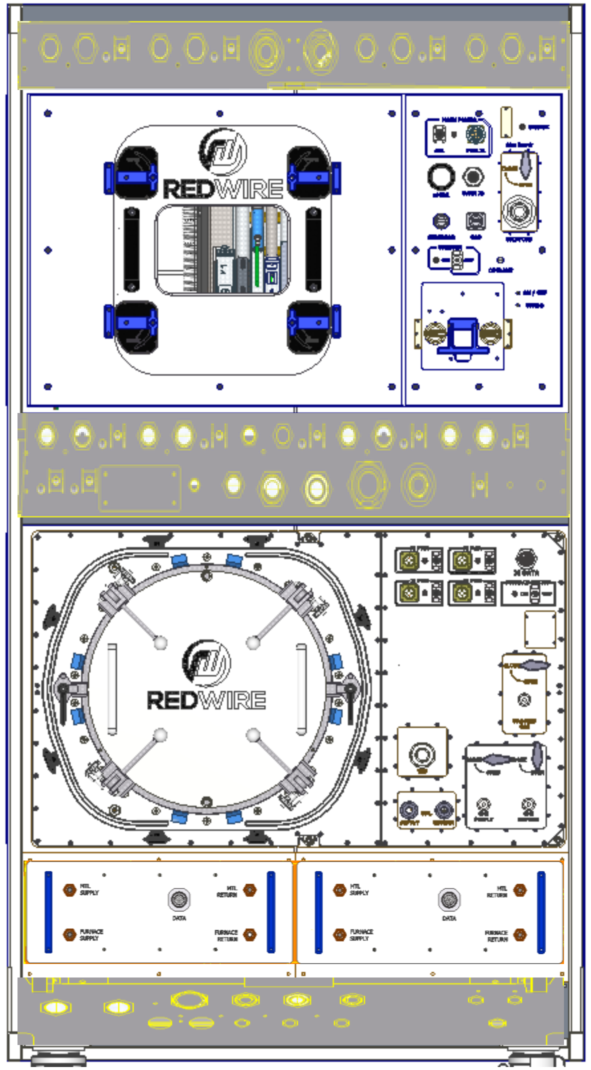
- Advanced Toolplate:
  - Printing of Metal and Polymer Parts
  - Finish Milling
- Inspection Subsystem
  - Defect Detection and Remediation
- Environmental Control
  - FOD capture system
- Electronics Manufacturing
  - Smart Pumps, Directed Energy, Pick and Place, etc.
- Avionics and Control

Furnace Module

- Sintering of Metal Parts
- Brazing of Assemblies
- Avionics and Controls

Process Gas Drawer

- Provides Argon to Furnace Module



Full Payload

- Glovebag concept for FOD control
- Part Transfer Box for transport between modules
- Remote Commanding for limited crew interaction

Surface Construction

Capability Description, Outcomes, State of the Art, and Technology Gaps (Class III)

Capability Description:

- *<u>Class II</u>*: Assembly of components into built-up structures (e.g., Earth-sourced or ISRU-based truss, panel, paver, bricks); deployment of human-rated preassembled or inflatable structures
- *<u>Class III</u>*: In-situ additive construction (e.g., 3D printed regolith-based construction)
- In-situ testing and inspection techniques for certification (material and structural)
- Structural enhancement and repair
- Construction Systems: design for lunar survivability, reliability, and maintenance

Outcomes

- Towers (50+ m tall for Power and Communication)
- 10s km of roads
- 100-m-diameter launch/landing pads (LLPs)
- Blast containment shield (BCS)– 7m-tall, 100s m long
- Shelters & habitats (1000s m^3 volume) to provide asset and crew protection (thermal, radiation, etc.)

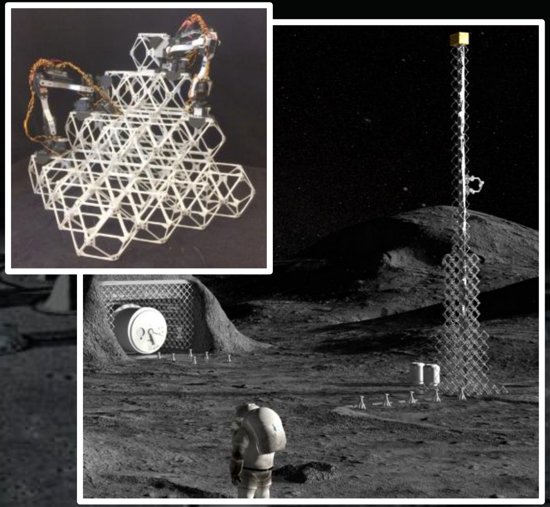
SoA: Extraterrestrial surface construction has never been attempted. Terrestrial prototypes at low TRL.

Technology Gaps (Class III)

- Deposition of print material in low-pressure environment while controlling porosity
- High-temperature materials for LLPs
- LLP Paver joining
- Surface stabilization, Foundations, and Anchors
- Repair technologies
- Process inspection and control
- In-situ V&V of construction materials

Terrestrial printing of cementitious material

Class II: Assembly & Deployables



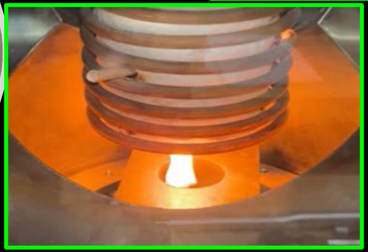
Class III: In-situ Construction

Process Development

Laser melting in vacuum

Microwave sintering in vacuum

Molten extrusion in vacuum



WHY- The Case for Lunar Surface Construction: PROTECTION

Lunar ISRU-based infrastructure provides protection from a variety of environmental hazards.

RADIATION

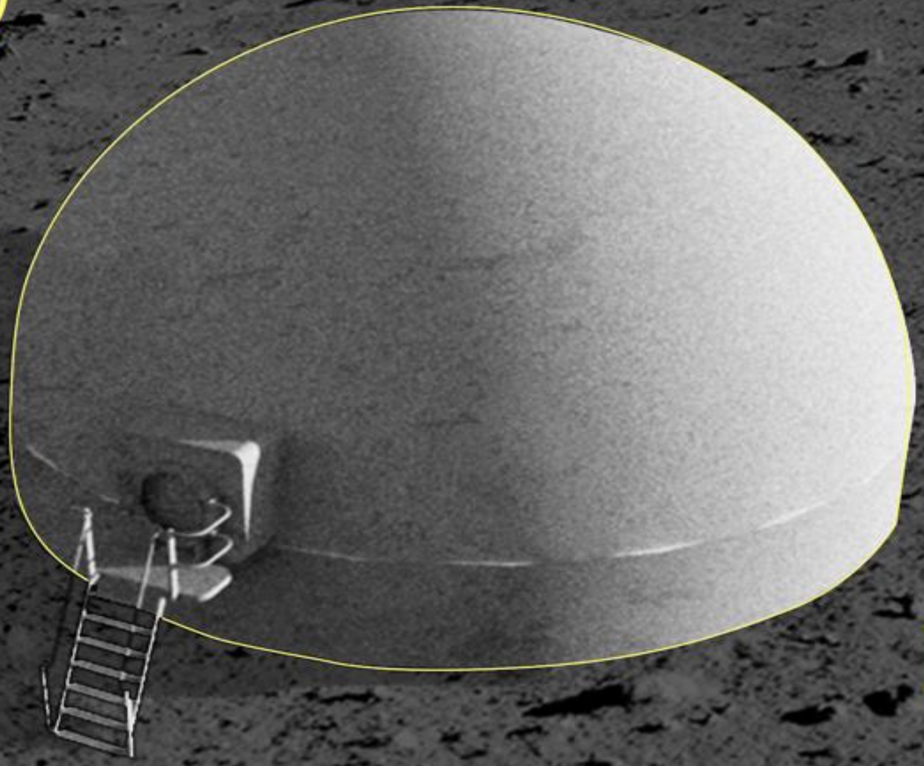
- Galactic Cosmic Rays (GCRs)
- Solar Particle Events (SPEs)
- Secondary Particles
- Albedo

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



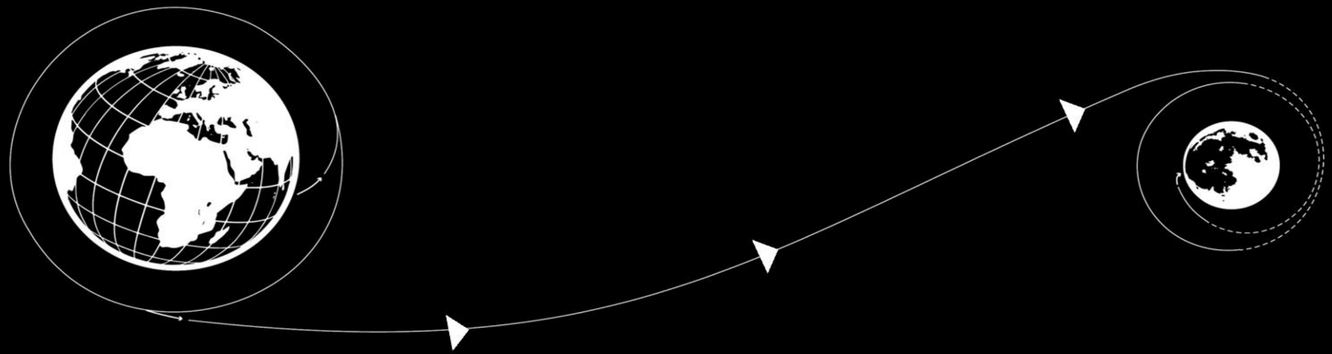
EXTREME TEMPERATURES

- Extreme Material Stresses
- Structural & Material Fatigue

Image courtesy of SEArch+

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

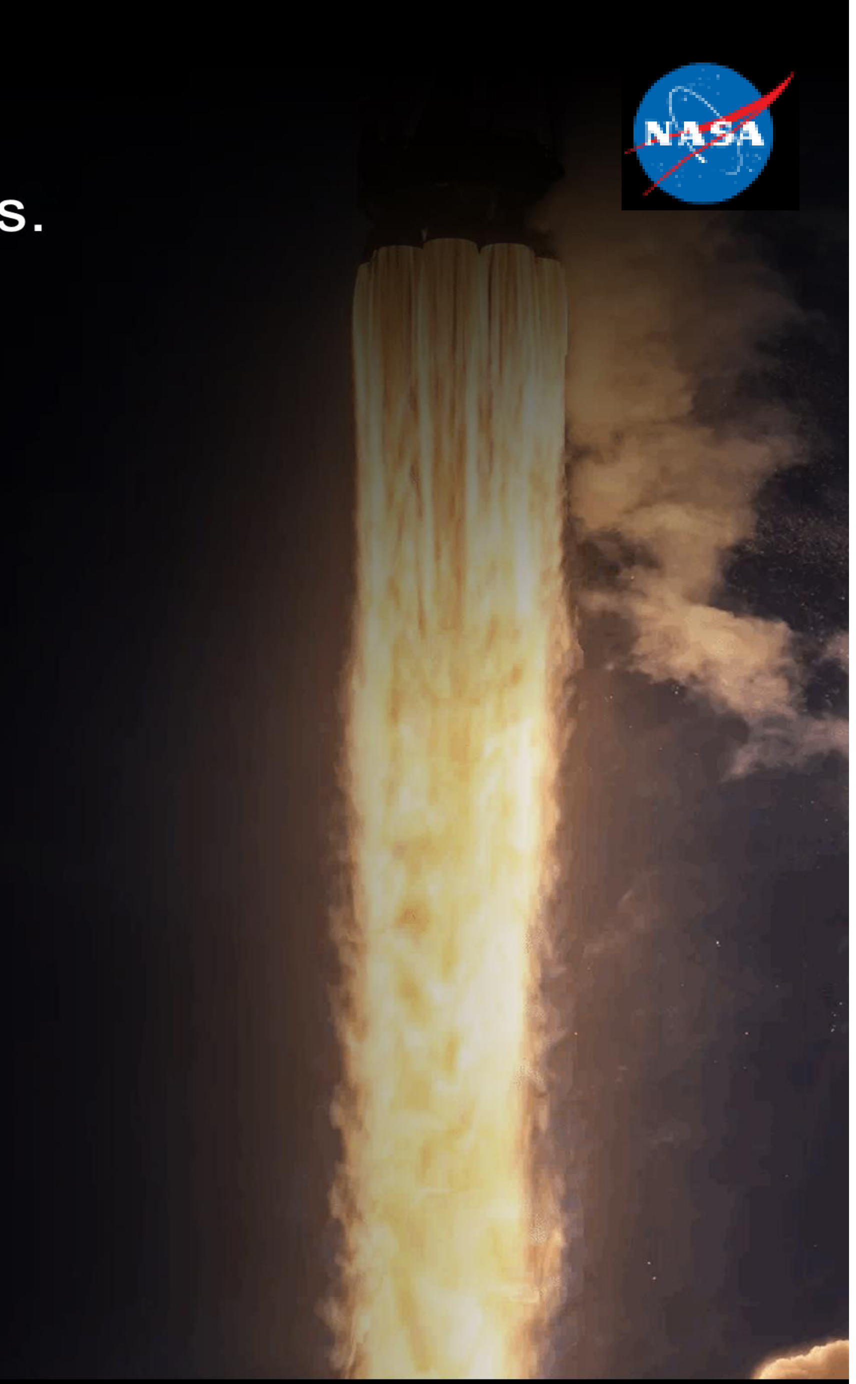
Even with commercial space flight dramatically dropping the launch costs to all-time historic lows, flying pre-built structures doesn't make financial sense. Even flying building materials from Earth to the Moon is costs prohibitive.



$ 0.11 per Kg
Costs of dry concrete on Earth

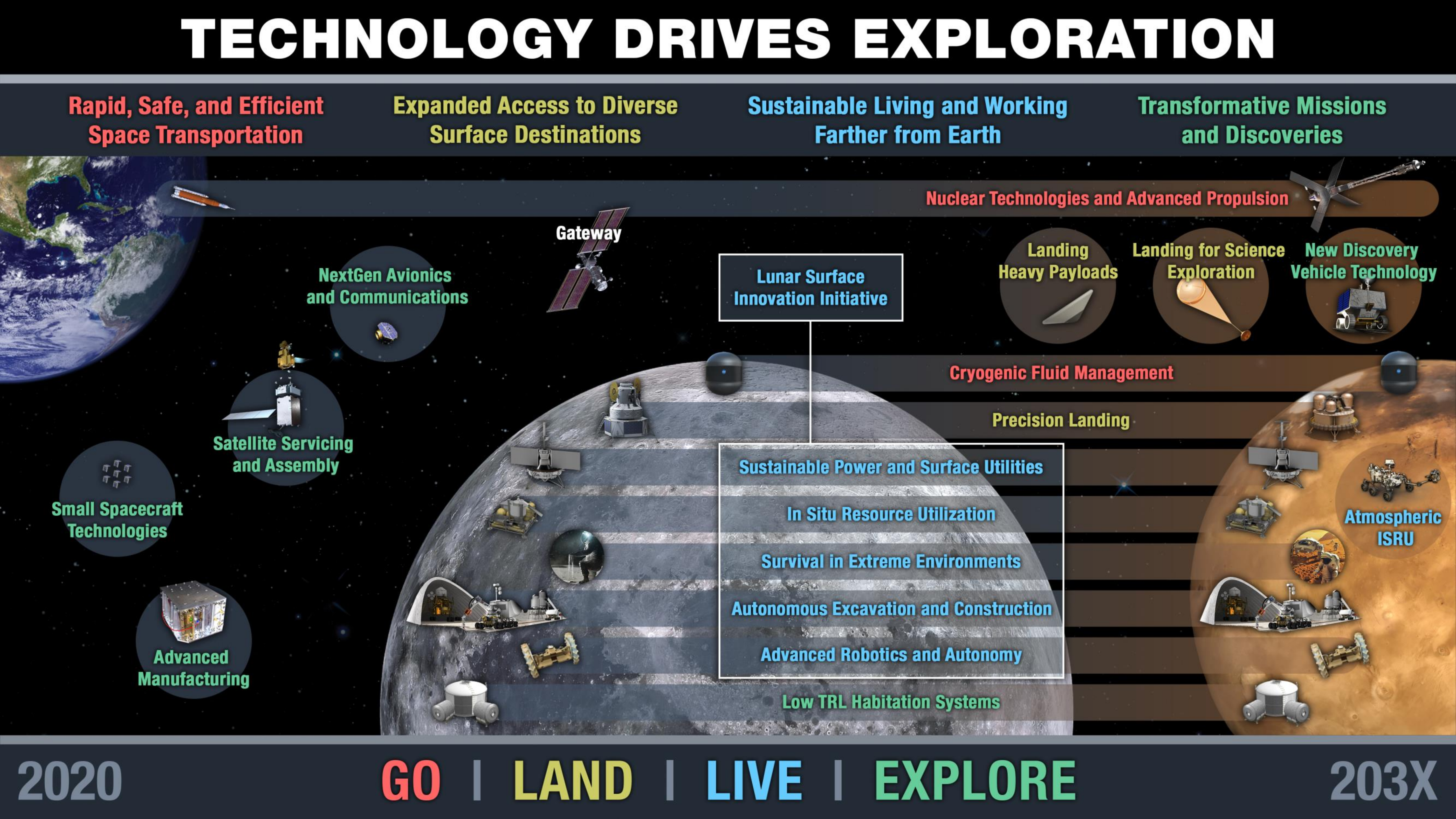
$ 1,200,000 per Kg
Cost to transport concrete to the Moon

$ 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

In Situ Fabrication and Repair Program Element– circa 2004


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
Satellite Servicing and Assembly
Small Spacecraft Technologies
Advanced Manufacturing
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
2020
GO | LAND | LIVE | EXPLORE
203X

Process/Material Baseline Selection

- **Laser Vitreous Material Transformation (VMX) selected as baseline for early lunar construction demonstration**
  - Capability for both horizontal and vertical construction – process versatility
  - Most mature among the candidate processes/materials – process maturity
  - No construction materials required to be launched – process efficiency/launch mass and cost reduction
  - Sample size to date limited by the size of the vacuum chamber
  - Large scale capability demonstrated in atmosphere
  - Early physics models correlated well with empirical observations of glass ceramic material production
  - Demonstration at scale in simulated lunar environment (temperature and vacuum) to be conducted in V20 to validate performance/properties
  - Process is extensible to structures at scale on the lunar surface

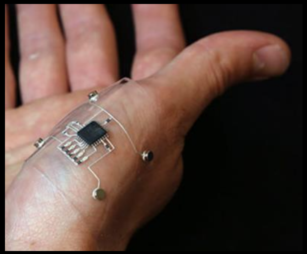
Laser VMX enables true on-demand infrastructure capability

Phase II for ISM: On-Surface sustainable Habitats

Focus on making living and working in space **sustainable,** reducing Operations cost.

- Metal Manufacturing for Life Support Systems
- Outfitting for Habitats
- Environmental and health sensors
- Energy Storage
- Medical devices
- Food and Pharma
- Modular Excursion Devices
- Textiles

Heat Exchangers



Wearable Disposable Flexible Sensors

Modular Excursion Devices

On Demand Farming Tools

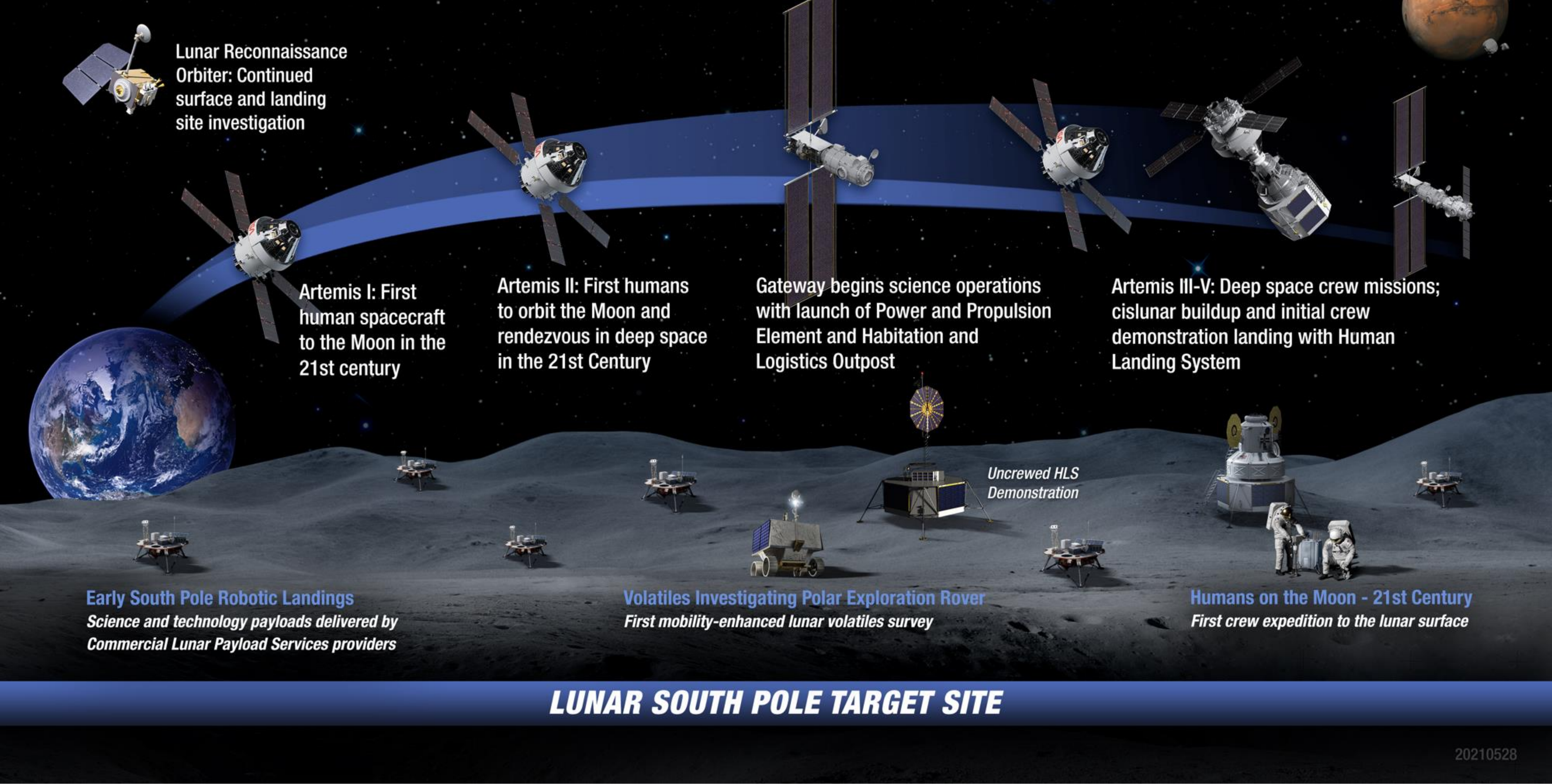
On Demand Shoes

On Demand Cast

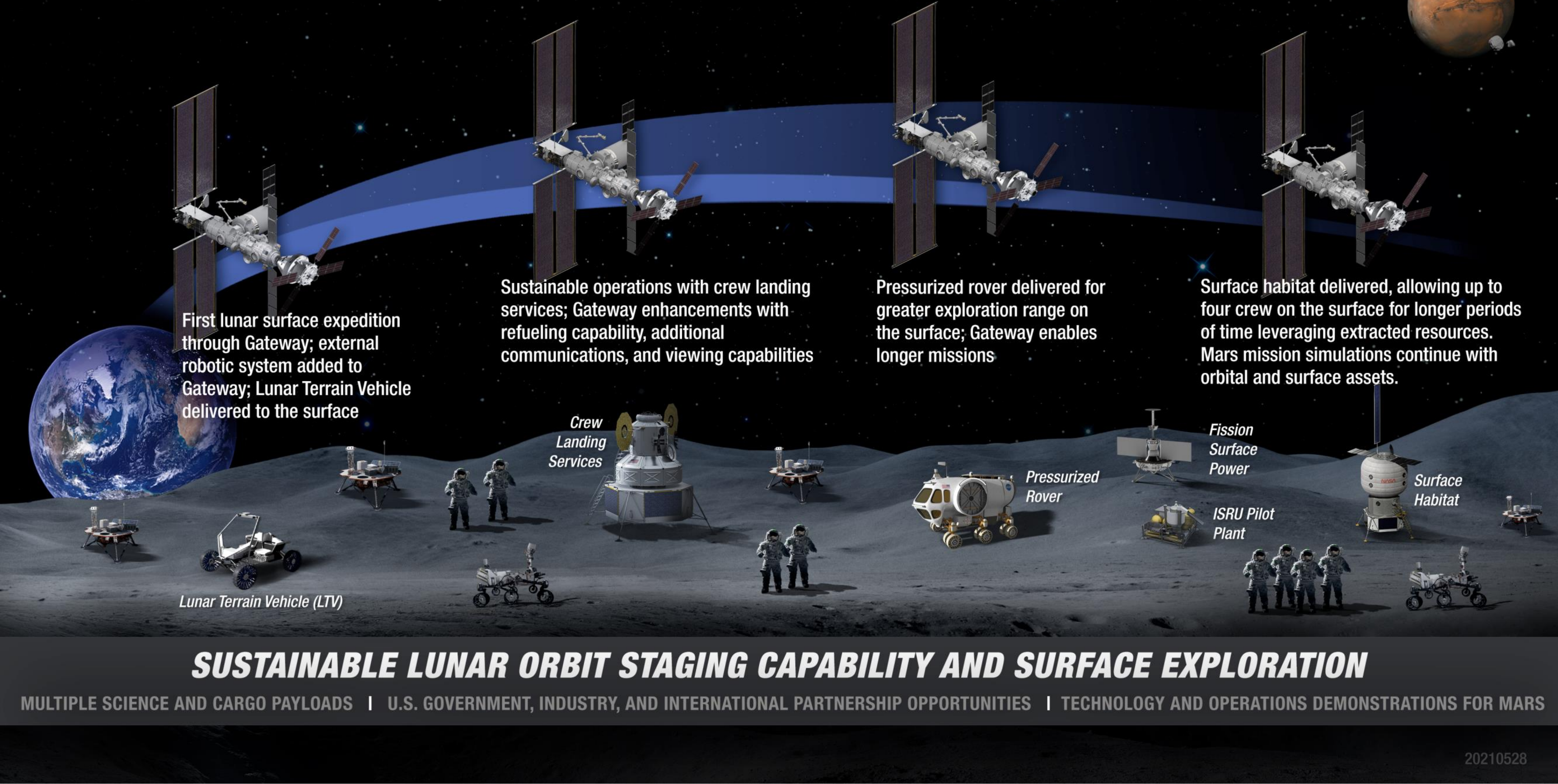
Fasteners and Tools

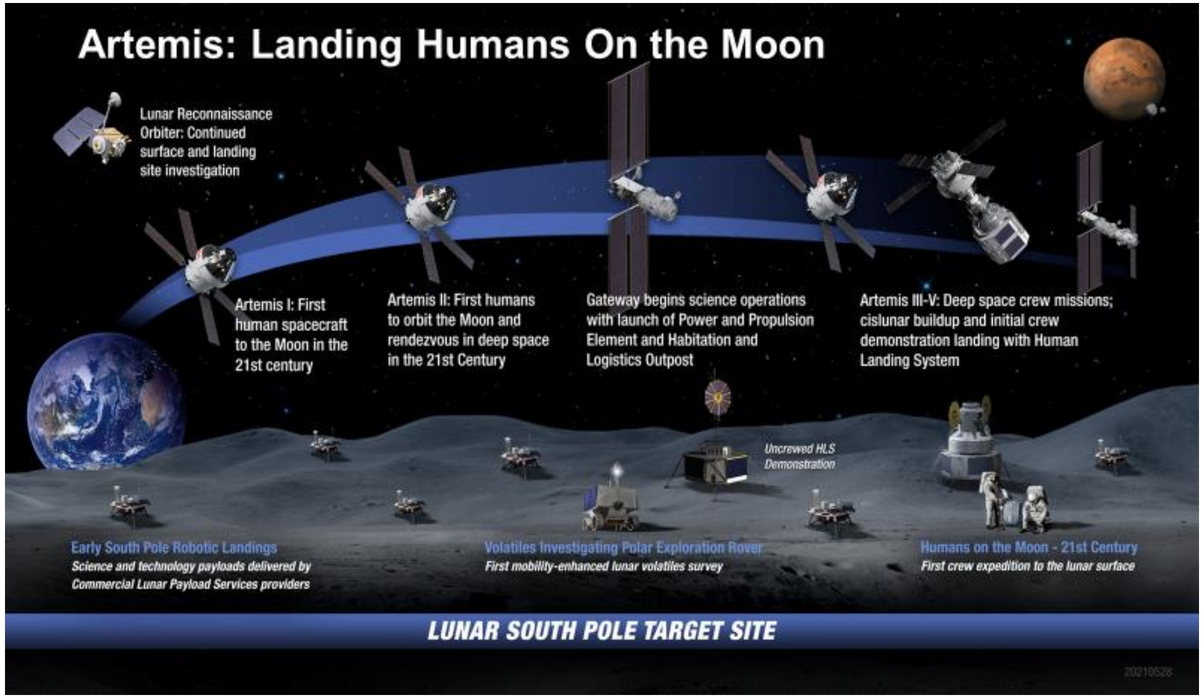
Food for Space

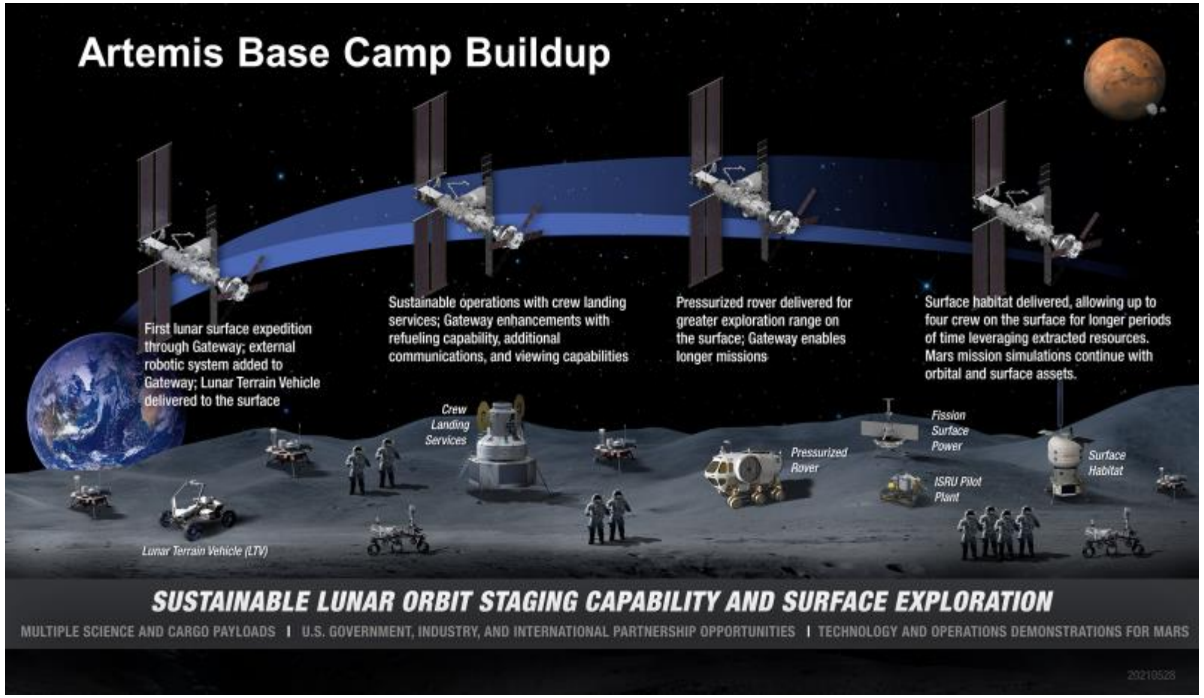
Artemis: Landing Humans On the Moon



Artemis Base Camp Buildup




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


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.
Crew Landing Services
Pressurized Rover
Fission Surface Power
ISRU Pilot Plant
Surface Habitat
Lunar Terrain Vehicle (LTV)
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

CHAPEA / Mars Dune Alpha

To prepare for long-duration missions to Mars, ICON constructed a Martian analog habitat designed by BIG at Johnson Space Center. The 1,700 ft^2 structure will be home to four crew members in year-long missions as part of the Crew Health and performance Exploration Analog (CHAPEA) program beginning in 2022.