



# Overview of NASA's Moon-to-Mars Planetary Autonomous Construction Technology

R. G. Clinton, Jr., PI, Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT)  
Lunar Surface Innovation Consortium Excavation and Construction Technical Interchange Meeting  
August 31 – September 1, 2021

A decorative background on the left side of the slide showing a red planet (Mars) and a large grey moon against a starry blue space background. The right side of the slide is white with a curved border separating it from the space image.

## Agenda

- Space Technology Mission Directorate: Technology Drives Exploration
  - Advanced Manufacturing
    - In Space Manufacturing (ISM) – Portfolio and Challenges
  - Lunar Surface Innovation Initiative (LSII)
    - Excavation, Construction, and Outfitting (ECO)
    - Related BPS Work: Penn State University Experiments with Geopolymers and Cement in Microgravity
    - In Situ Resource Utilization (ISRU)
- Summary
- Questions

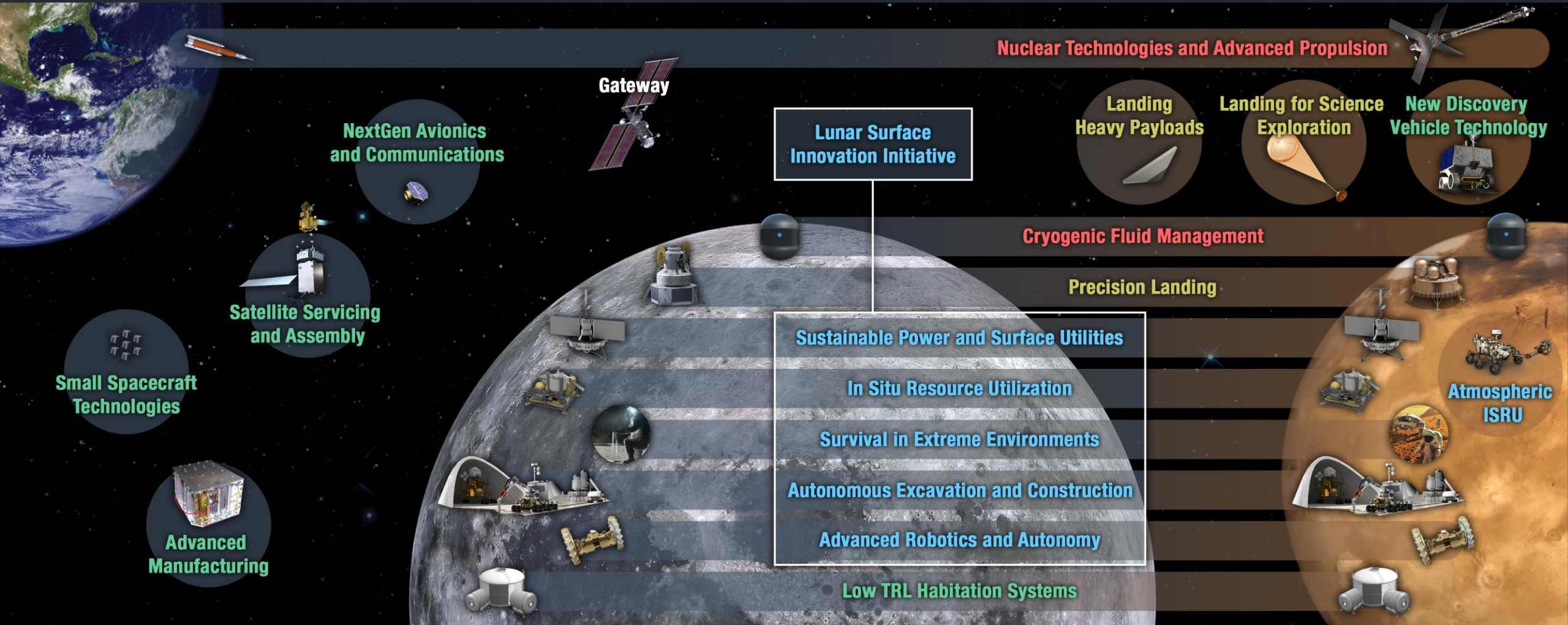
# TECHNOLOGY DRIVES EXPLORATION

Rapid, Safe, and Efficient  
Space Transportation

Expanded Access to Diverse  
Surface Destinations

Sustainable Living and Working  
Farther from Earth

Transformative Missions  
and Discoveries

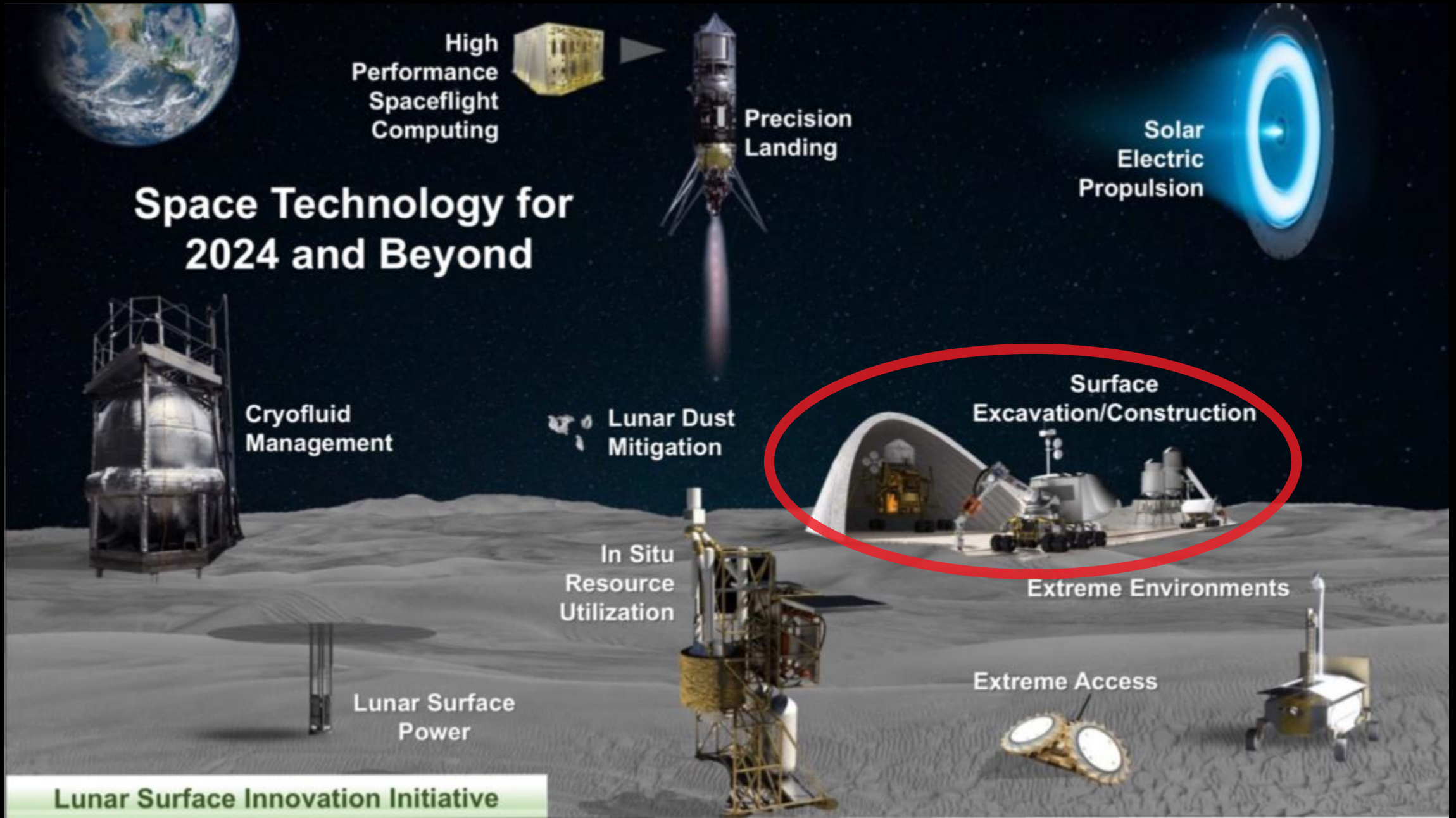


2020

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# NASA Lunar Surface Innovation Initiative (LSII)



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

A detailed illustration of a lunar base on the moon's surface. The base consists of several interconnected habitats, some with domed roofs, and various pieces of equipment. There are also several rovers or small landers scattered across the terrain. The moon's surface is covered in craters and rocks, and the lighting suggests a bright sun from the upper left, casting long shadows.

## 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 LSII 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 ELEMENTS, STRUCTURE, AND TEAM MEMBERS

**PI: Clinton**      **CE: Burlingame**  
**PM: Edmunson**    **LSE: Thompson**

**Resource Analyst: Clark**

## Construction Feedstock Materials Development

- MSFC CANs
  - Mississippi State University (2)
  - Branch Technologies
- MSFC CIFs (pending)
  - Mississippi State University
  - South Dakota School of Mines and Technology
- Penn State University (PSU) - NSTGRO

## Olympus – Autonomous Construction System

- AFWERX SBIR (W/AFCEC/TANG/DIU)
  - ICON Technologies
    - SEArch+
    - Bjarke Ingels Group
    - Blue Origin
    - Colorado School of Mines
- Jacobs
- LaRC
- MSFC CANs
  - Blue Origin
  - UAH (2)
  - Clarkson/PSU
  - University Of Mississippi (2)
  - Drake State (2)
  - Kappler
  - CANVAS
  - Sinte Gleska University
    - Sioux Tribes (Crow Creek; Yankton; Oglala)

## Microwave Structure Construction Capability

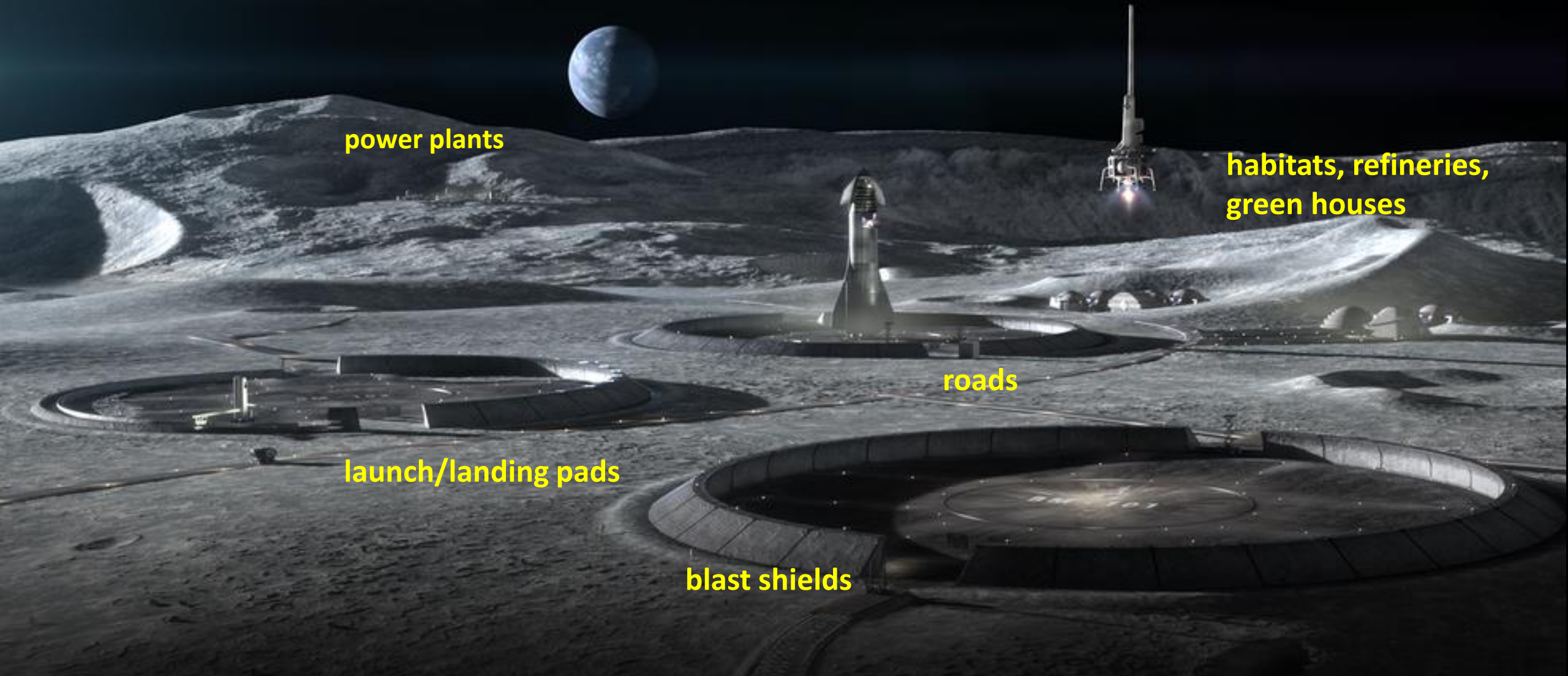
- JPL
- KSC
- Jacobs
- Dr. Holly Shulman
  - Microwave Properties North
- Radiance Technologies
- RW Bruce Assoc. LLC
  - JP Gerling Microwave Applications
  - Crown College
  - Space Resources Extraction Technologies
  - Microwave Materials Technologies
- Southern Research
- Colorado School of Mines
- SURA
- Aerie Aerospace
- MTS
- Logical Innovations

# Common Key Functional Requirements Development

- Developed individual requirements for Earth-based and Lunar construction with SEArch+
- Identified Common Technology Development Interests with SEArch for Earth-based and Lunar Construction Capabilities (Venn Diagram)
- Followed similar approach with ICON and DoD organizations for SBIR Proposal
- Results yielded shared set of key functional requirements that would benefit the goals of NASA, ICON, DoD, and SEArch+
  - Long-distance communication, monitoring, and control
  - Increased autonomy/automation of operations
  - Increased transportability / mass reduction
  - Expanded environmental range
  - Design for field reparability
  - Dust mitigation
  - Shielding / Ballistic Protection
  - Job-site Mobility
  - Off-foundation construction / foundation delivery
  - Multi-material printing & related control systems
  - Improved user experience/ease of operation (i.e. reduced training load)
  - Software Design Platform

# Building a Sustainable Presence on the Moon

- What infrastructure are we going to need?



power plants

habitats, refineries,  
green houses

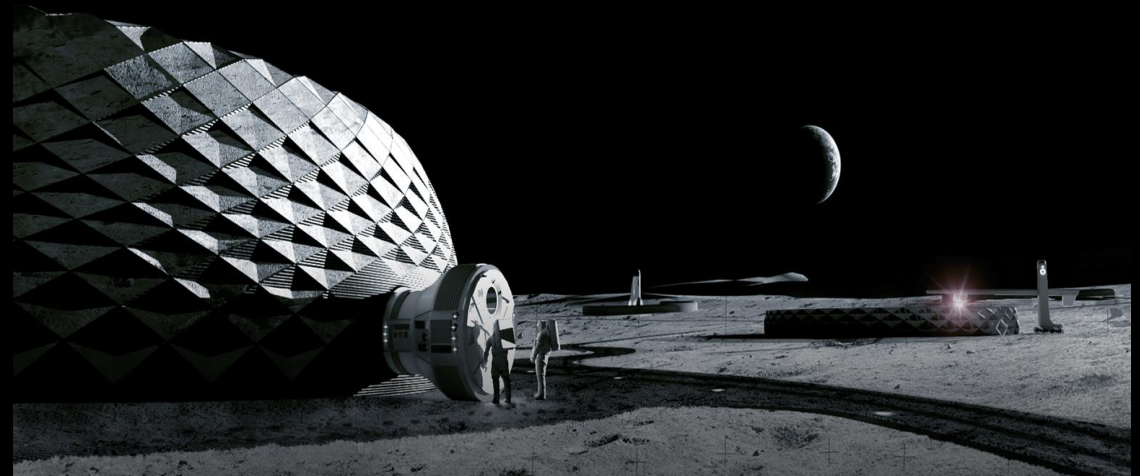
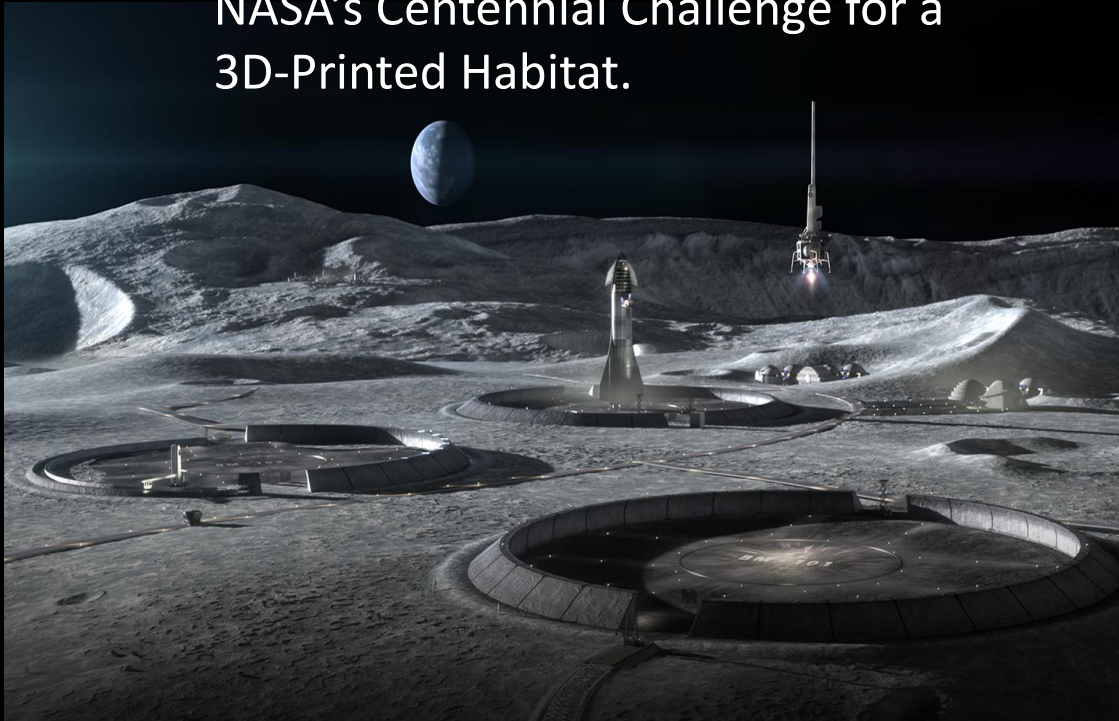
roads

launch/landing pads

blast shields

# Architectural Concept Designs for Lunar Landing Pads and Habitats

- ICON engaged leading architectural firms to develop preliminary concepts for both Landing Pads and Habitats to inform engineering decisions for Olympus construction hardware design and development
- Space Exploration Architecture (SEArch+)
  - Landing Pad Concepts (primarily)
  - Design winners in two phases of NASA's Centennial Challenge for a 3D-Printed Habitat.
- Bjarke Ingels Group (BIG)
  - Habitat Concepts (primarily)
  - UAE Mars Science City Design, Google Headquarters, 2 World Trade Center, Lego House...



# Autonomous Construction for the Lunar Outpost

## Regolith-based Materials and Processes:

- Cementitious
- Geopolymers
- Thermosetting materials, including melting
- Laser sintered
- Microwave sintered

## High Level Capability Gaps and Challenges

- Regolith excavation, beneficiation, transfer, and conveyance
- Deposition processes and associated materials
- Increased autonomy of operations
- Long-duration operation of mechanisms and parts under lunar environmental conditions (Reliability and Maintainability)
- Scale of construction activities
- Structural Health Monitoring and Repair
- Inspection and Certification of as-built structure
- Interdependencies on other infrastructure capabilities
- Material and construction requirements and standards

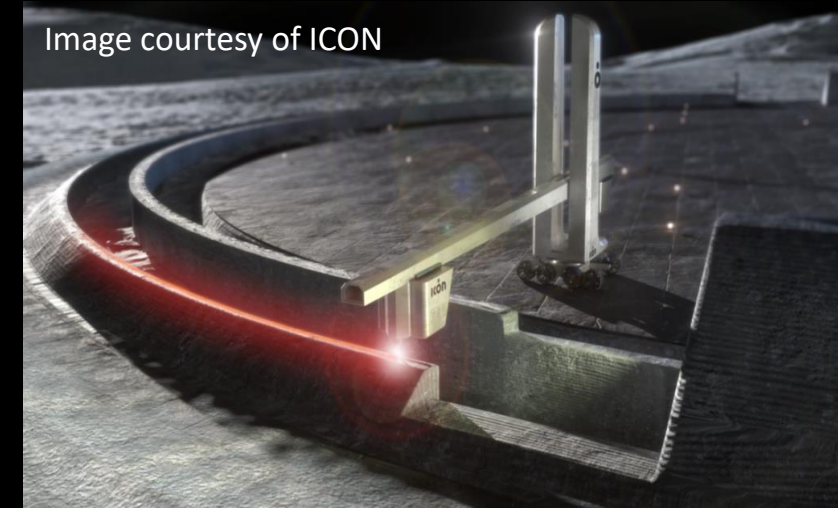


Image courtesy of Bjarke Ingels Group

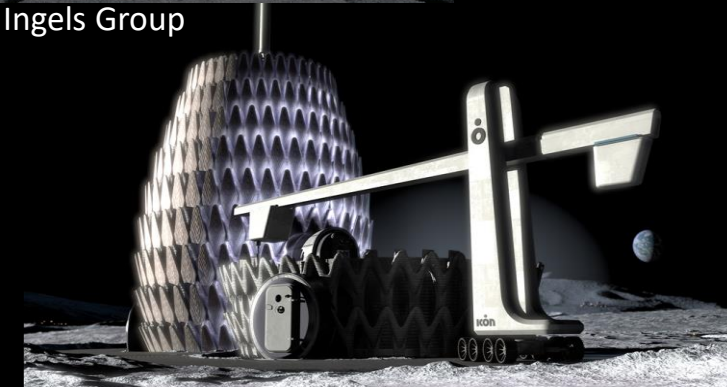
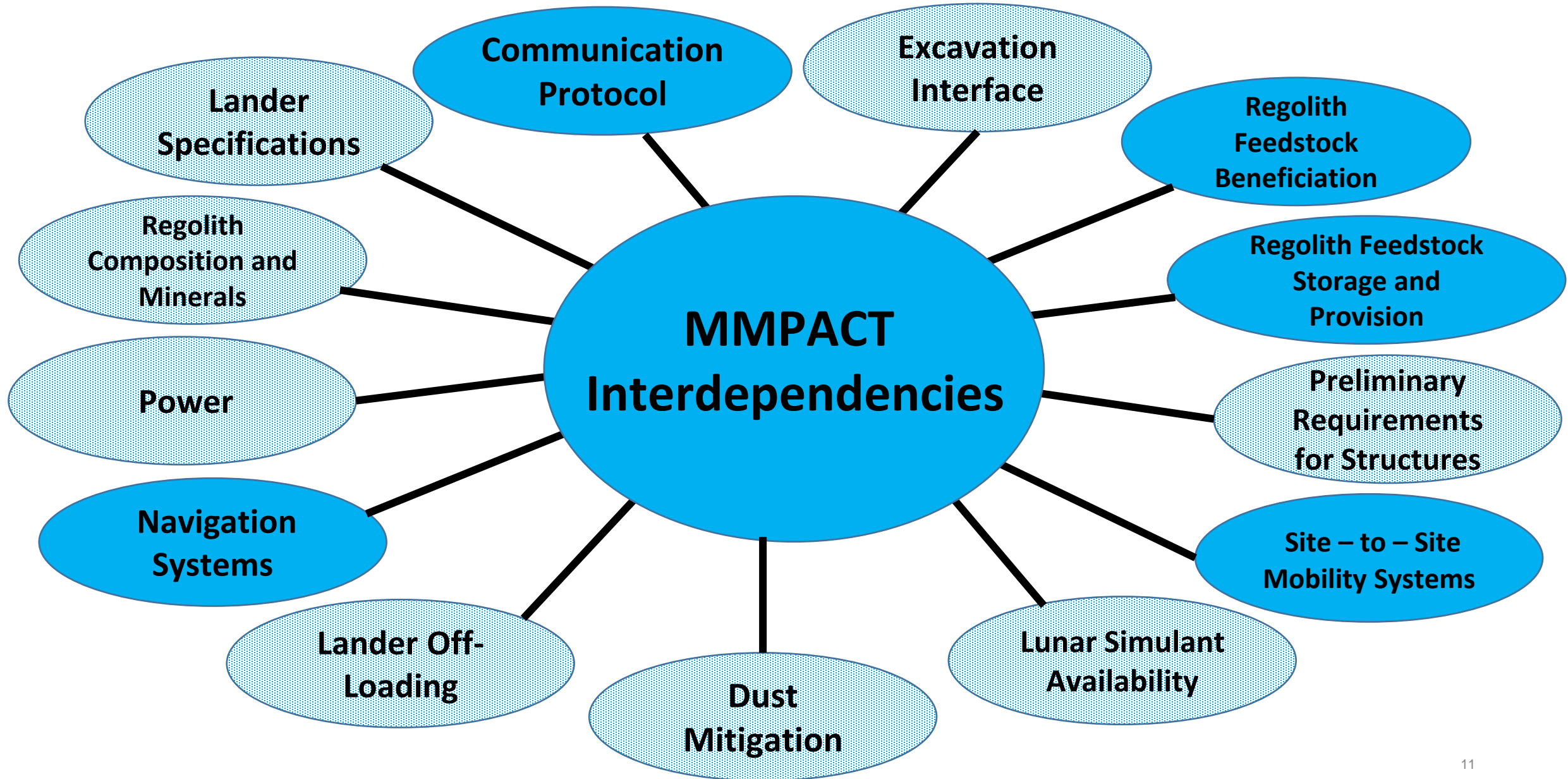


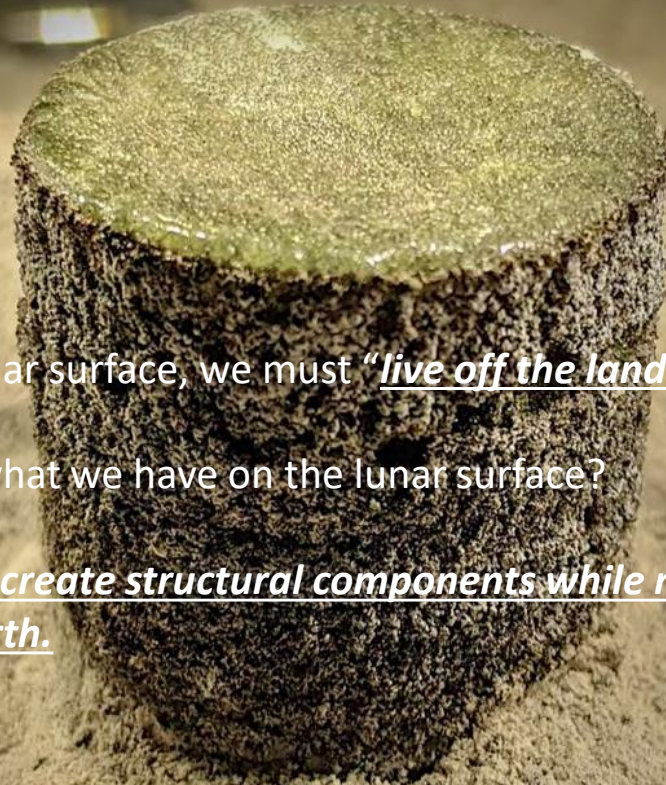
Image courtesy of SEArch+

# MMPACT Interdependencies



# Demonstration Mission -1 (DM-1) Objective A: Demonstrate Viable ISRU-based Structural Capabilities

- In order to thrive on the lunar surface, we must "live off the land".
- Is it possible to work with what we have on the lunar surface?
- Our primary objective is to create structural components while minimizing the amount of materials brought from Earth.



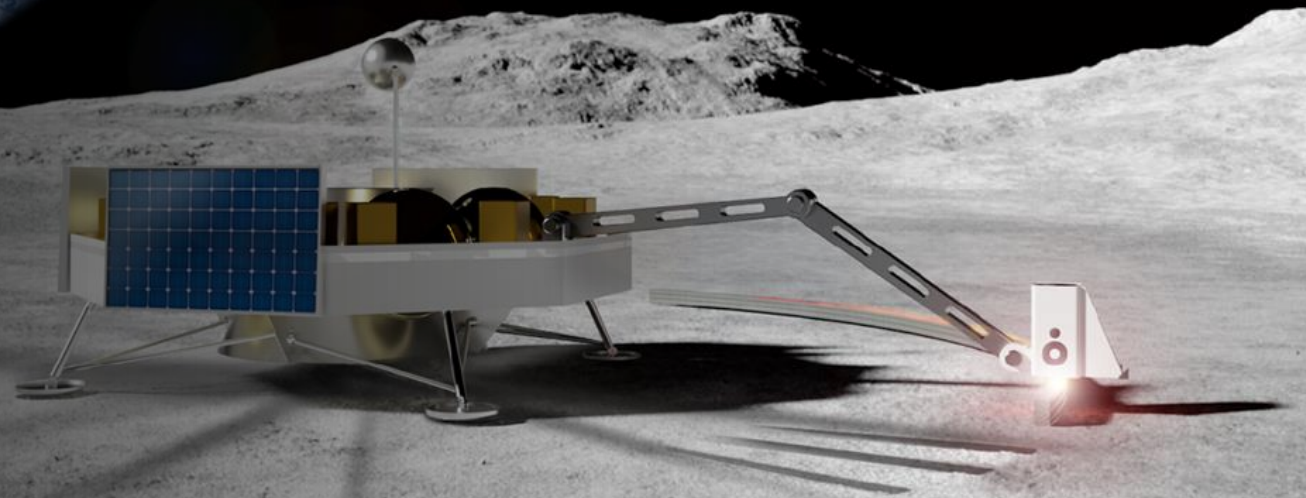
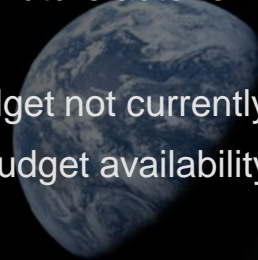
# Initial Construction Technology Demonstration Mission, DM-1 ( 2026 ) **IMPACT**

## 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
- Multiple systems development requires additional budget not currently available
- Multiple systems demonstration requires increased budget availability for increased lander size and P/L capability. STMD to address
- 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 relevant environments*

## 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



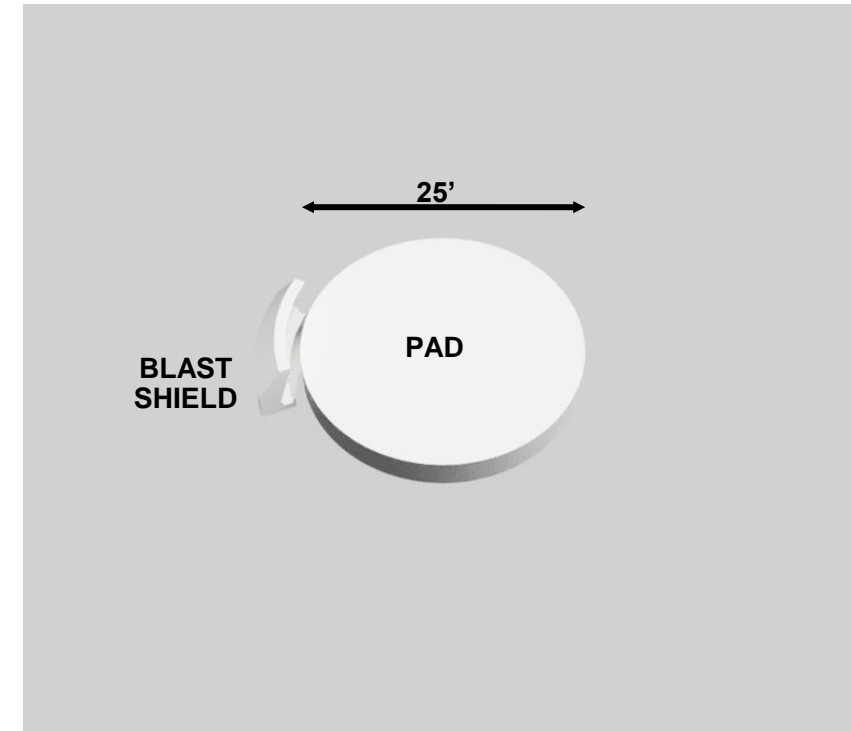
# Construction Technology Demonstration Mission, DM-2 ( Target: 2028 )

## Subscale Landing Pad Construction Demonstration



### Construction Roadmap

- Subscale ISRU-based LLP construction demonstration and vertical blast shield construction demonstration
  - ~25' diameter pad at least 6" thick
  - ~10' long, 3' tall blast shield on the perimeter
  - Resolve scale/dimensions with Mark and Excavation Team
- Mobile Autonomous Construction System
- Demonstrate interface with Excavation System (site prep, regolith feedstock provision) - Critical
- Test in-process monitoring and NDE capabilities on printed pad materials
- Requires key interdependencies to be functional (e.g. power, Comm and Nav, etc)
- Increased instrumentation for process and product characterization
- **Rationale:** Prove autonomous ISRU construction technology and mobility at reduced scale for horizontal and vertical structural elements prior to full scale



### Investigate in situ test methods for determining thermal performance and mechanical loading (landing loads) on subscale LLP

- **Rationale:** Need to verify construction roadmap pad performance under launch/landing conditions prior to building full scale pad

### Outcome

- **TRL 7** pad surface and vertical structure (blast shield) (if a hopper lands on the consolidated pad, then TRL 9 for CLPS-scale (hopper) landers)
- **TRL 9** for specific construction hardware and instrumentation

# Construction Technology Qualification Mission, QM-1 ( Target: 2030 )

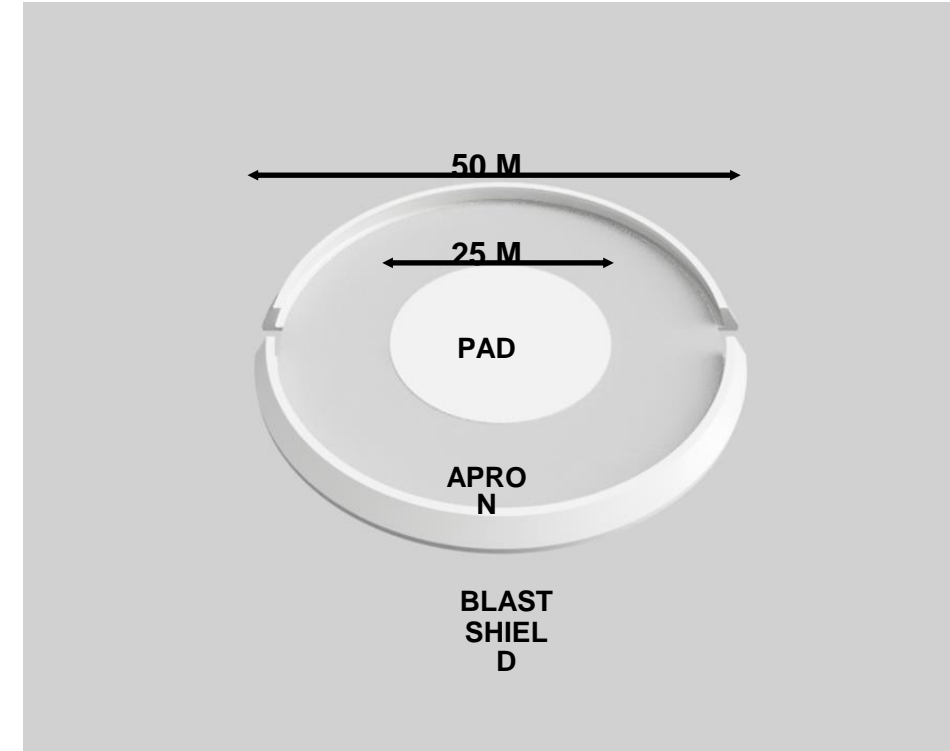
## Operational Pad Construction



### Construction Roadmap

Demonstrate autonomous construction of:

- 25 m radius autonomously constructed, consolidated lunar landing pad
- Additional 25 m radius (50 m total radius) autonomously constructed, consolidated apron with entry/exit ramp (resolve scale/dimensions TBD)
- Full-perimeter surface-hardened blast shield – for example, 2.6 m tall at 3 degree angle off horizontal for a 50M radius LLP - with opening for ingress-egress. (Pending updated PSI analyses of ejecta profile)
- Subscale unpressurized shelter (10' tall, 15' wide)
- **Rationale:**
  - Must prove berm building and pad site prep at medium scale prior to full scale
  - Must prove interface between construction and excavation system prior to full scale



### Outcome

- In 2030 we have an operational landing pad at Artemis base location suitable for landing of subsequent CLPS and HLS landers supporting sustained operations (pending resolution of scale/dimensions TBD)
- Construction Roadmap: TRL 9 construction system for full scale horizontal infrastructure elements
- Construction system ready for commercialization
- Formal excavation hardware may not be required but will be open for collaboration

# QM-2

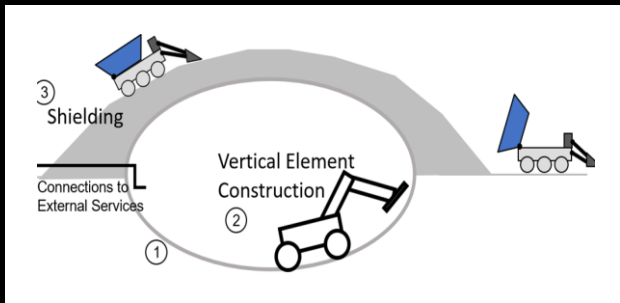
## Lunar Safe Haven

### Construction Roadmap

- Target safe haven type structure for previous vertical construction demos (DM-1, DM-2, QM-1)
- Full scale unpressurized shelter (20' tall, 30' wide) (resolve scale/dimensions with Mark and LSH Team)
- Demo LSH structure in QM-2

### 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



#### ▶ USMC Printed Vehicle Hide

3D-printed and assembled vehicle hide constructed by ICON for the USMC.

#### ◀ Mars Dune Alpha ( CHAPEA )

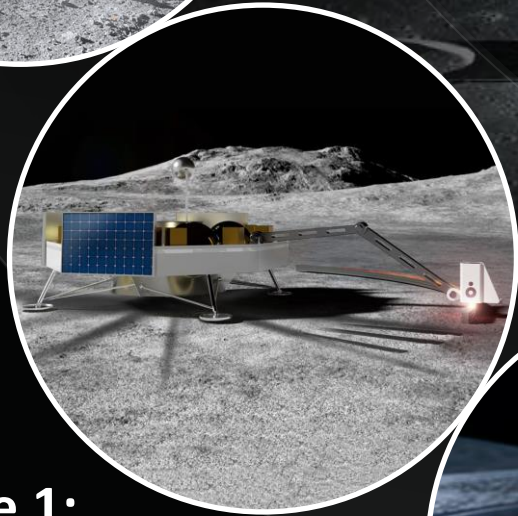
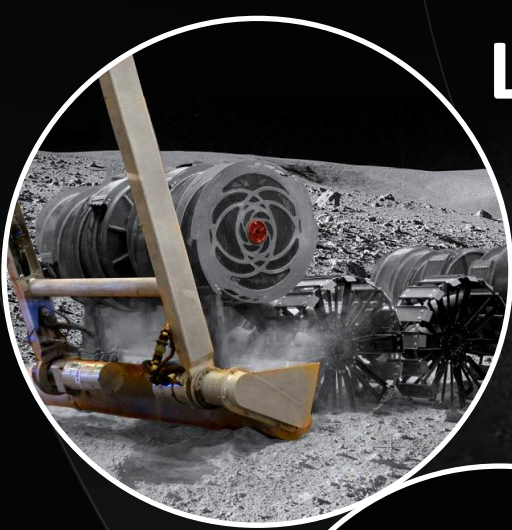
3D-printed Martian habitat analog under construction at JSC by MMPACT members ICON + BIG.

#### ◀ Excavation Roadmap

Vertical construction via the Excavation roadmap.

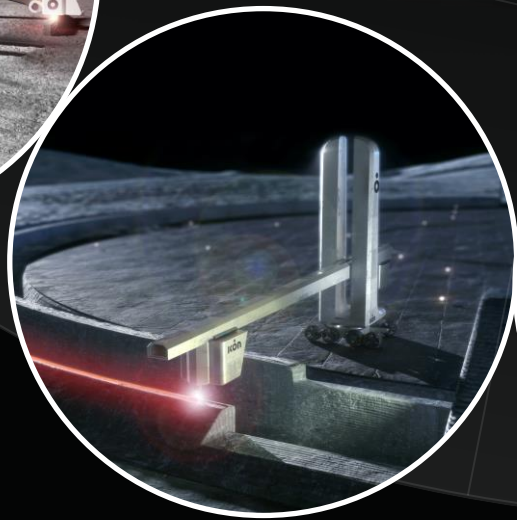


# Lunar Construction Capability Development Roadmap

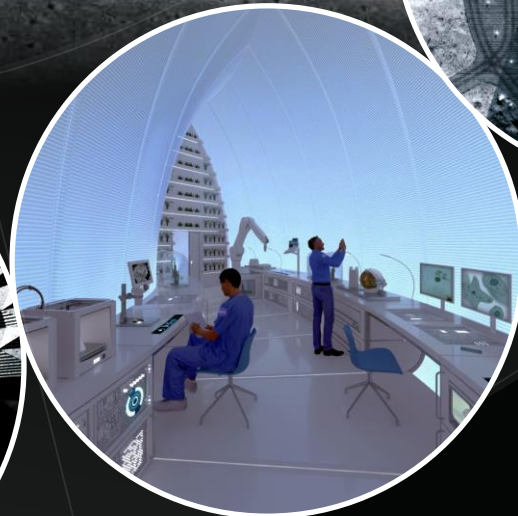


## Phase 1:

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.





[www.nasa.gov/spacetech](http://www.nasa.gov/spacetech)