The NASA MMPACT Project – Autonomous Construction of Infrastructure on the Lunar Surface

R. G. Clinton, Jr., PI, Jennifer Edmunson, Mike Fiske, Mike Effinger, Jason Ballard, Evan Jensen

LSIC Excavation and Construction Working Group Monthly

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Agenda
Moon-To-Mars Planetary Autonomous Construction Technology (MMPACT) Overview

- In Space – Extraterrestrial Construction
  - Lunar Contour Crafting within the In Situ Fabrication and Repair Element
  - ACES/ACME – Destination Mars
  - Artemis and the Lunar Surface Innovation Initiative (LSII)
  - Moon-to Mars Planetary Autonomous Construction Technologies (MMPACT)
- Questions

In Situ Fabrication and Repair

(In Situ Fabrication & Repair)

O
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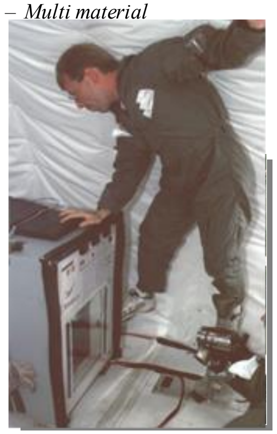
S

FABRICATION

OF TOOLS AND PARTS WITH THE FOLLOWING EMPHASIS:

- *Feedstock flexibility (In Situ, provisioned, recycled)*
- *Miniaturization*
- *Speed*
- *Part accuracy ad surface finish*
- *Multi material*



First Microgravity Flight

REPAIR

CAPABILITIES WITH THE FOLLOWING EMPHASIS:

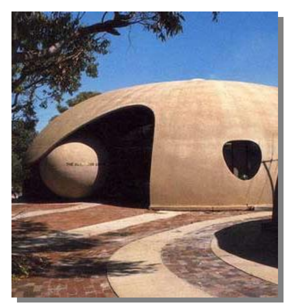
- *Unique material properties*
- *Environmental performance*
- *In Situ processes*

Welding

HABITAT STRUCTURES

CAPABILITIES WITH THE FOLLOWING EMPHASIS:

- *Radiation shielding features*
- *Use of In Situ resources*
- *Autonomous construction*



Inflatable Concrete Structure

NON DESTRUCTIVE EVALUATION

CAPABILITIES WITH THE FOLLOWING EMPHASIS:

- *Independent quality assurance of In Situ processes*
- *Integrated closed loop control of In situ process*
- *Failure analysis and routine inspection applicability*

Measuring Machine/Laser Scan

RECYCLING

CAPABILITIES WITH THE FOLLOWING EMPHASIS:

- *Reuse of failed parts & waste materials*
- *Limitation of waste stream variety*
- *Simplification*

Reactor

SYSTEM OF SYSTEMS / APPLICABILITY AND CONSIDERATION:

- *Mobile Army Parts Hospital*
- *Interoperability between ISFR, FAB, REPAIR NDE, RECYCLING, and, HAB concepts*

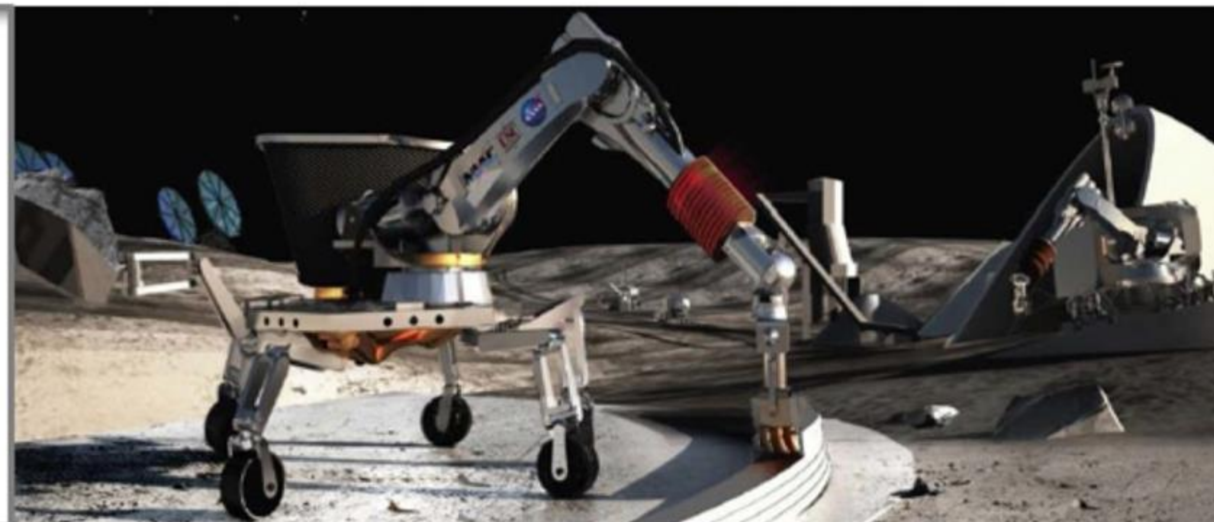
ISFR BRIEFING 7373004

ACME and ACES Systems

Additive Construction Projects Leveraging Common Technologies

US Army Corps of Engineers. Engineer Research and Development Center

Additive Construction with Mobile Emplacement (ACME)
NASA



Shared Vision: Capability to print custom-designed expeditionary structures on-demand, in the field, using locally available materials.

Automated Construction of Expeditionary Structures (ACES)
Construction Engineering Research Laboratory - Engineer Research and Development Center (CERL – ERDC)

B-hut
(guard shack)
16′ x 32′ x 10′

ACME → ACES

- Partnership between NASA (MSFC, KSC), USACE, and Contour Crafting Corporation (NR-SAA with Caterpillar)
- Funded by NASA/STMD-GCDP and USACE-ERDC
- Based on an earlier collaboration between NASA/MSFC and USC (Dr. Behrokh Khoshnevis) from 2004 to 2007

ACME-1 System

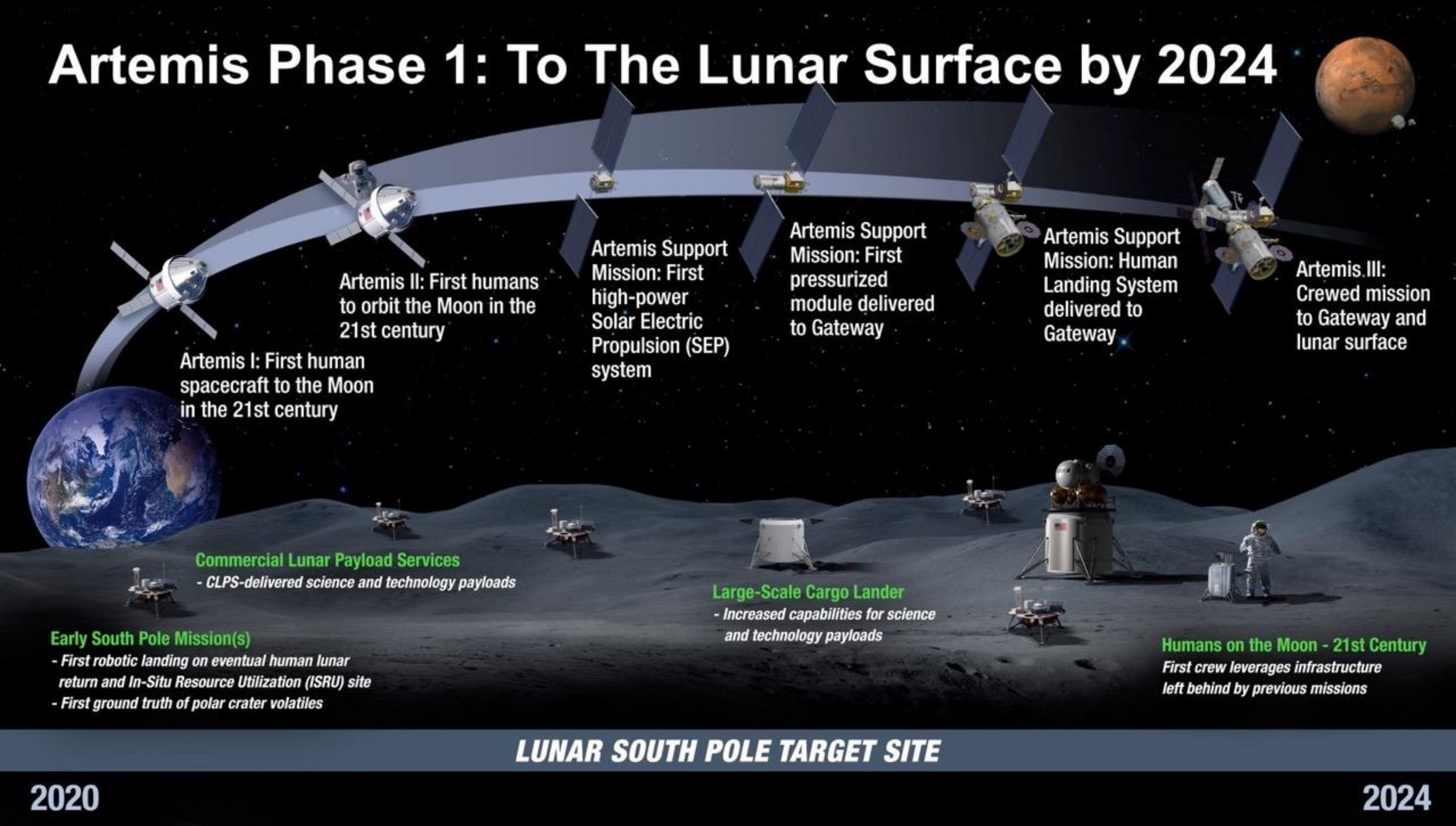
- **Completed conversion to "3-D" system, resolved composition issues, and began programming and printing various simple geometries.**
- **Experimented with translation rate vs concrete cure time and strength to optimize overall process.**

ACME-1 to ACME-2 System

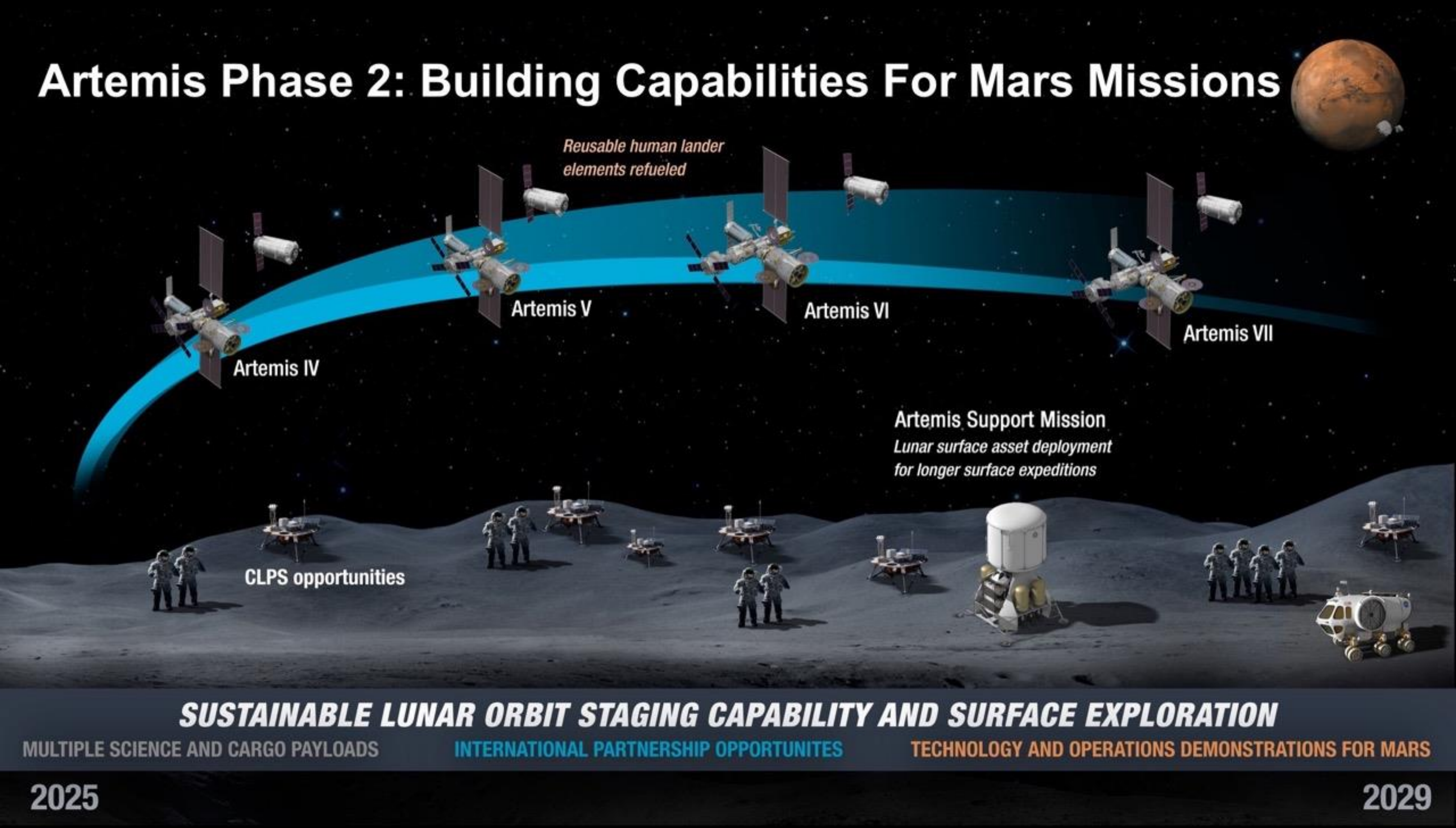
- **Focus was on converting from a "batch" system to a "continuous feed" system.**
- **Removed extrusion chamber and plunger hardware, replaced with large mixer, continuous pump, accumulator, hoses, fittings, etc.**

ACME-2 to ACES-3

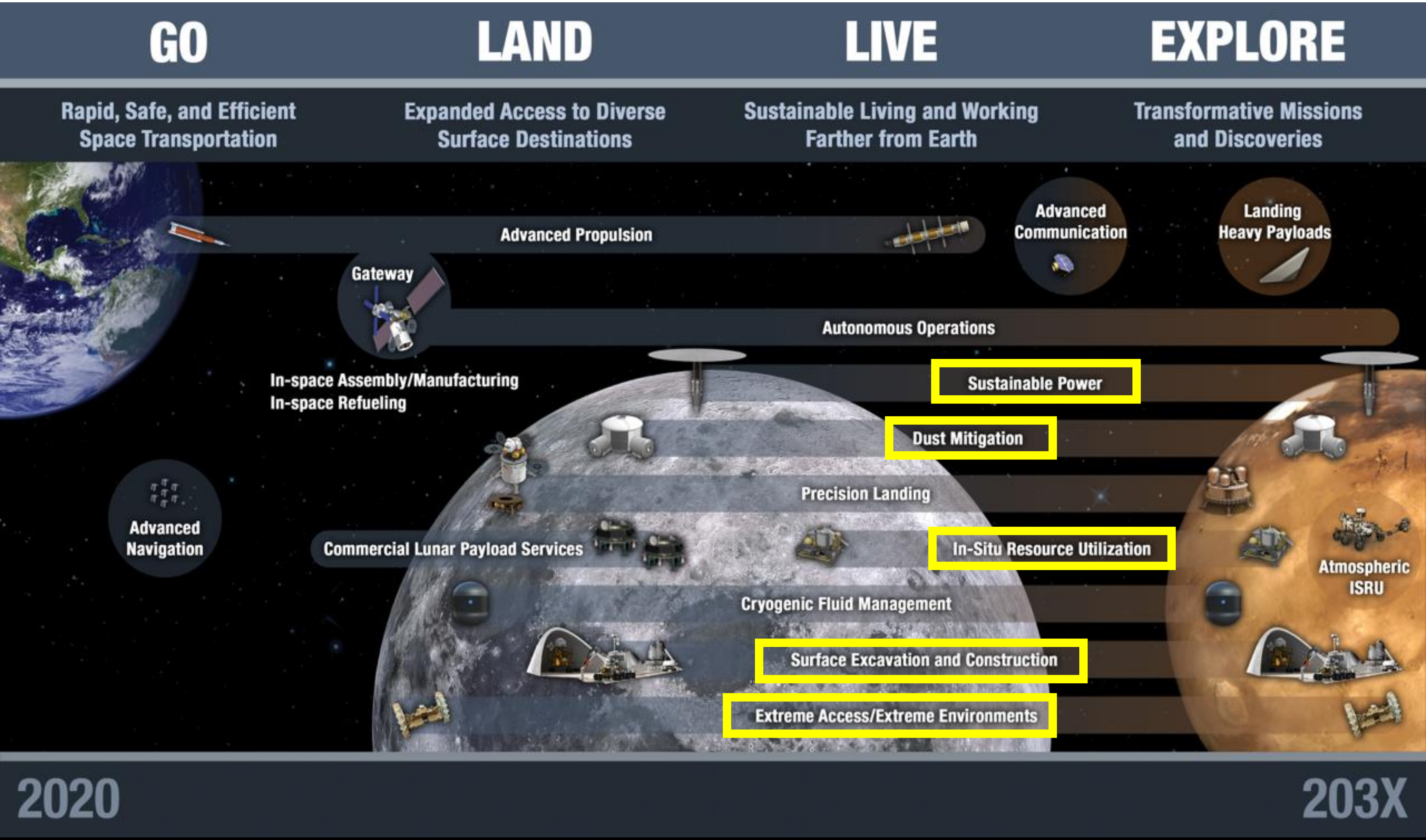
- **Focus on transition from sub-scale to full-scale**
- **Issues included:**
  - **Optimum mobility system (gantry vs truck/boom arm vs robotic arm, etc)**
  - **Hose management**
  - **Cleaning**
  - **Positional accuracy**
  - **Mobility**
  - **Assembly/disassembly**
  - **Print speed/volumetric flow rate**



Artemis Phase 1: To The Lunar Surface by 2024
Artemis I: First human spacecraft to the Moon in the 21st century
Artemis II: First humans to orbit the Moon in the 21st century
Artemis Support Mission: First high-power Solar Electric Propulsion (SEP) system
Artemis Support Mission: First pressurized module delivered to Gateway
Artemis Support Mission: Human Landing System delivered to Gateway
Artemis III: Crewed mission to Gateway and lunar surface
Commercial Lunar Payload Services
- CLPS-delivered science and technology payloads
Early South Pole Mission(s)
- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
- First ground truth of polar crater volatiles
Large-Scale Cargo Lander
- Increased capabilities for science and technology payloads
Humans on the Moon - 21st Century
First crew leverages infrastructure left behind by previous missions
LUNAR SOUTH POLE TARGET SITE
2020
2024


Artemis Phase 2: Building Capabilities For Mars Missions
Reusable human lander elements refueled
Artemis IV
Artemis V
Artemis VI
Artemis VII
Artemis Support Mission
Lunar surface asset deployment for longer surface expeditions
CLPS opportunities
SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION
MULTIPLE SCIENCE AND CARGO PAYLOADS
INTERNATIONAL PARTNERSHIP OPPORTUNITES
TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS
2025
2029

Lunar Surface Innovation Initiative (LSII) Strategic Technology Investments



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, berms and blast shields using lunar regolith-based materials.

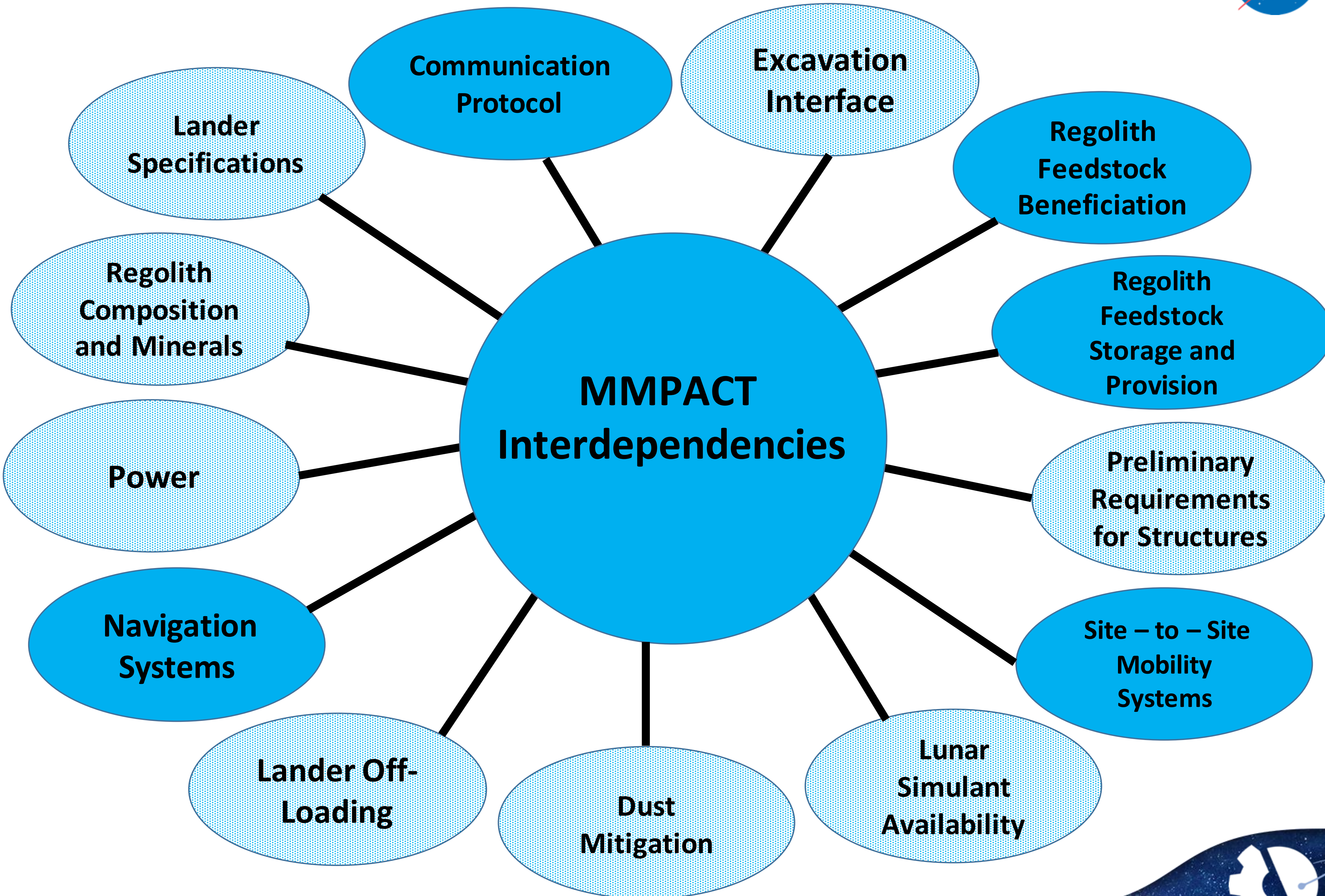
APPROACH

- 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

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

MMPACT Interdependencies



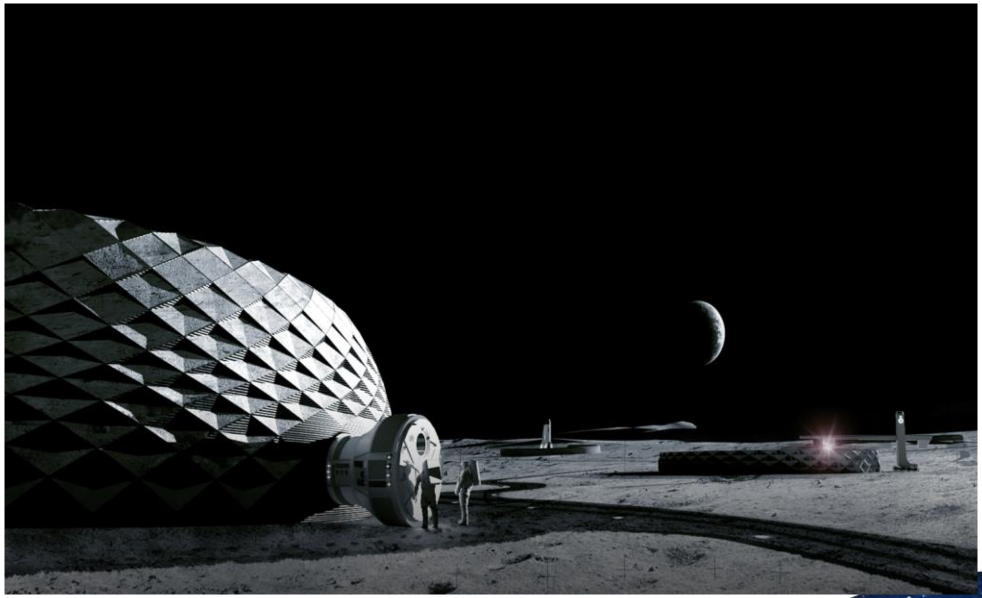
Architectural Concept Designs for Lunar Landing Pads and Habitats

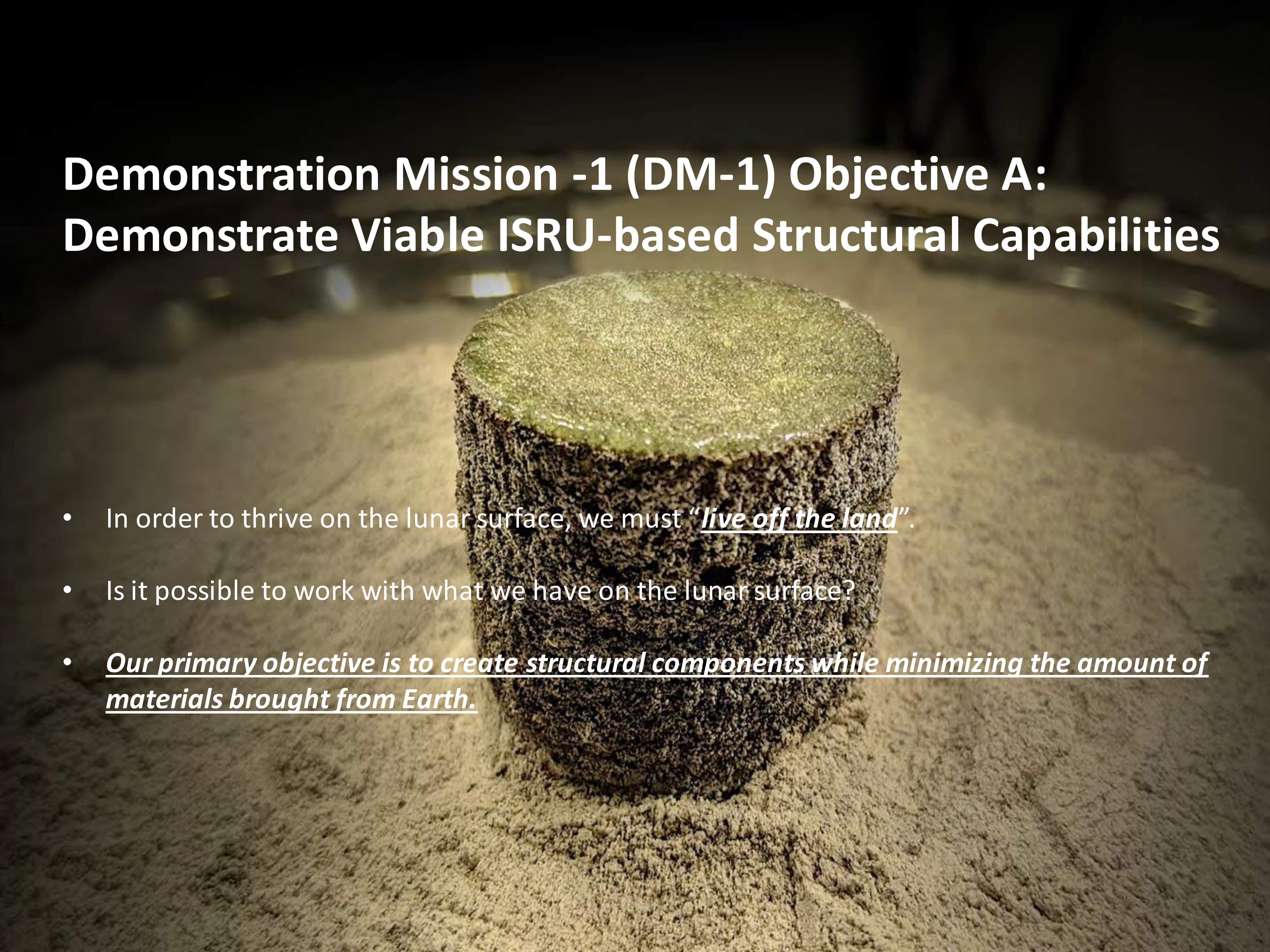
- **ICON engaged leading architectural firms to develop preliminary concepts for both Landing Pads and Habitats to inform engineering decisions for Olympus construction hardware design and development**

- Space Exploration Architecture (SEArch+)
  - Landing Pad Concepts (primarily)
  - Design winners in two phases of NASA's Centennial Challenge for a 3D-Printed Habitat.
- Design Concept 100% Complete

- Bjarke Ingels Group (BIG)
  - Habitat Concepts (primarily)
  - UAE Mars Science City Design, Google Headquarters, 2 World Trade Center, Lego House…
- Design Concept 100% Complete

- **Concept design summaries were presented to NASA Space Technology Mission Directorate Leadership, and Principal Technologists in early December**



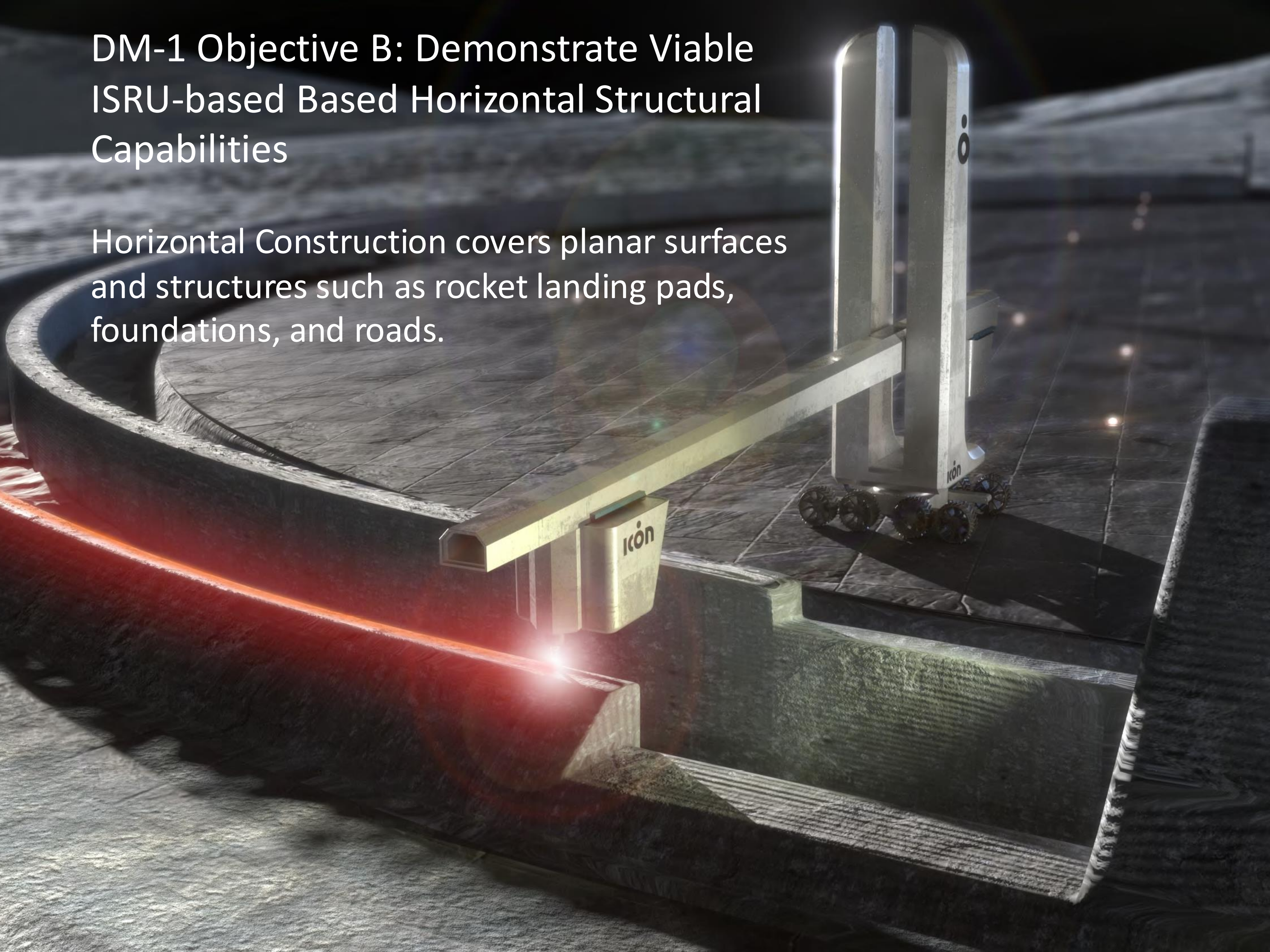


Demonstration Mission -1 (DM-1) Objective A: Demonstrate Viable ISRU-based Structural Capabilities

- 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.***

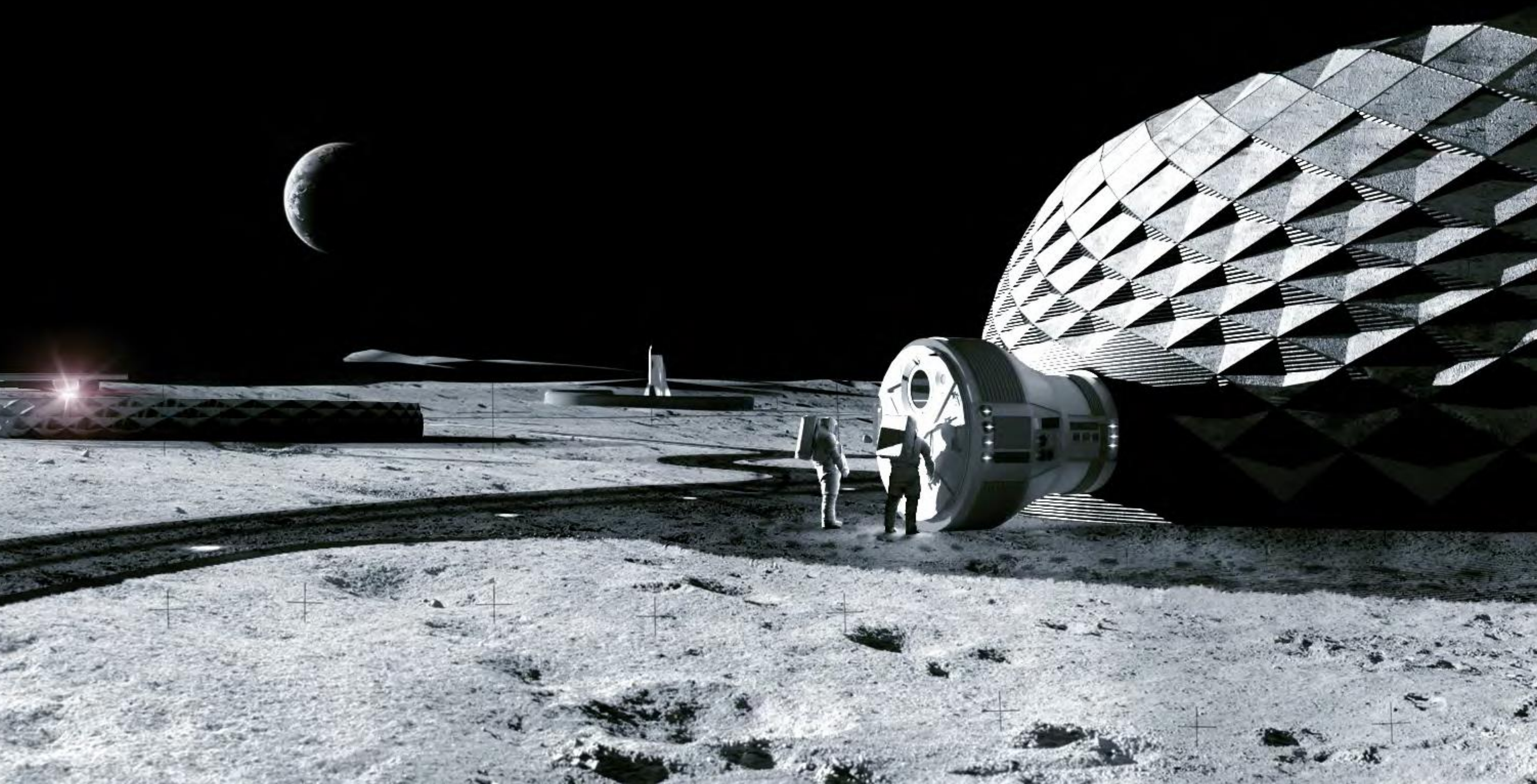
DM-1 Objective B: Demonstrate Viable ISRU-based Based Horizontal Structural Capabilities

Horizontal Construction covers planar surfaces and structures such as rocket landing pads, foundations, and roads.



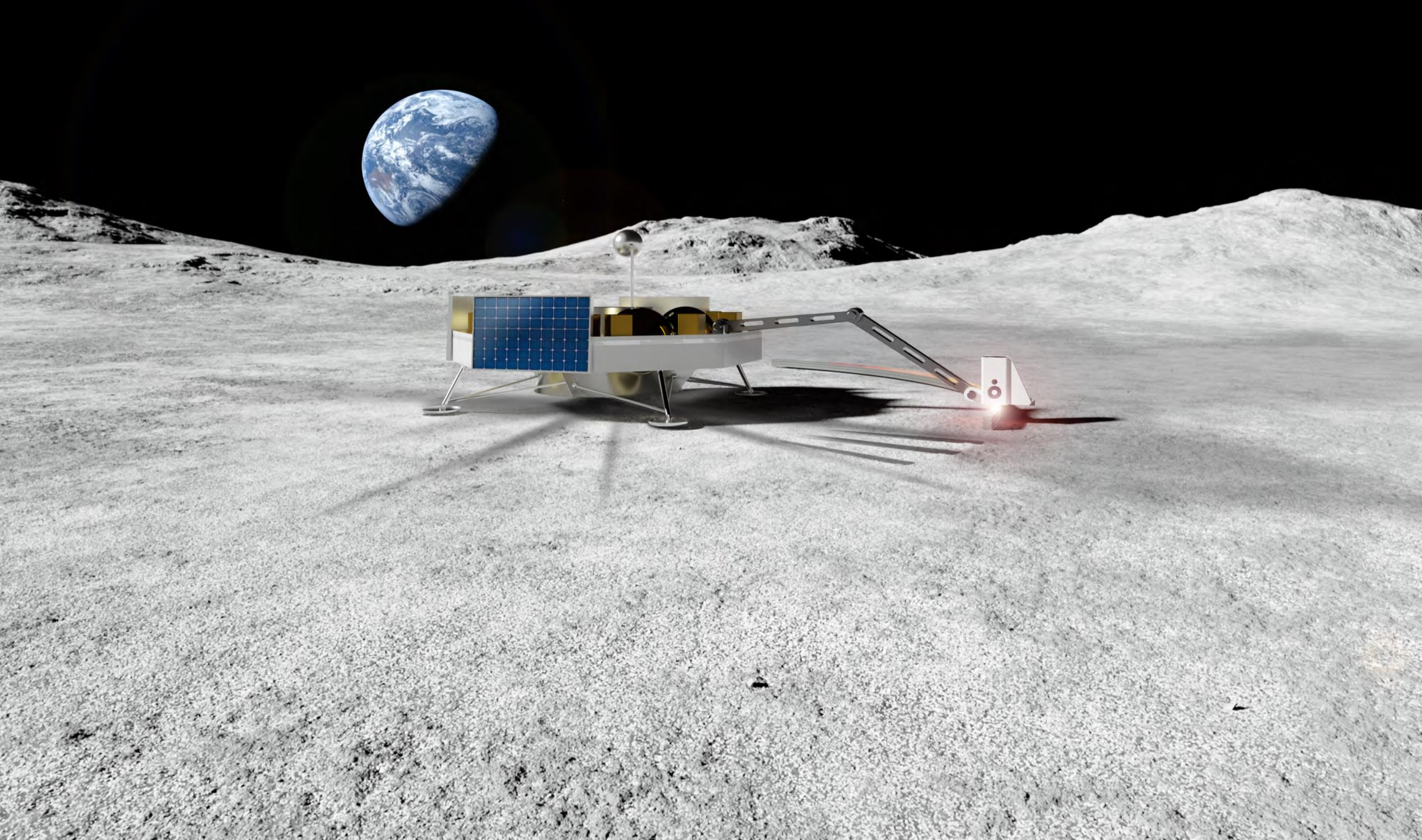
DM-1 Objective C: Demonstrate Viable ISRU-based Based Vertical Structural Capabilities

Vertical Construction covers volumetric structures such as habitats, garages, and protective berms.

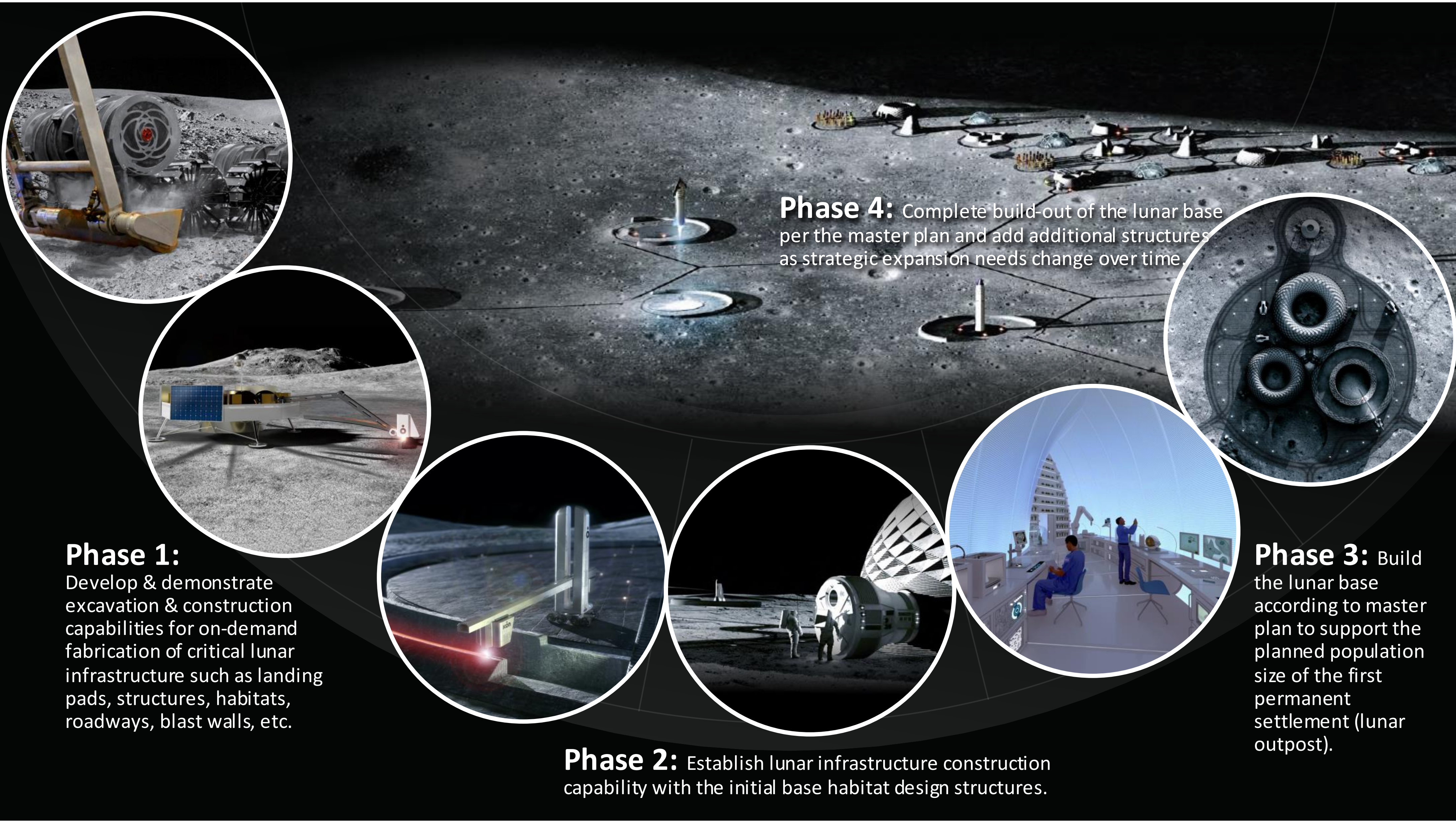


MMPACT Preliminary Concept DM-1

A demonstration mission that serves as a proof of concept for newly developed ISRU additive construction technology.



Lunar Construction Capability Development Roadmap




NASA
Technology Drives Exploration