

National Aeronautics and
Space Administration



Moon to Mars Planetary Autonomous Construction Technology (MMPACT)

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

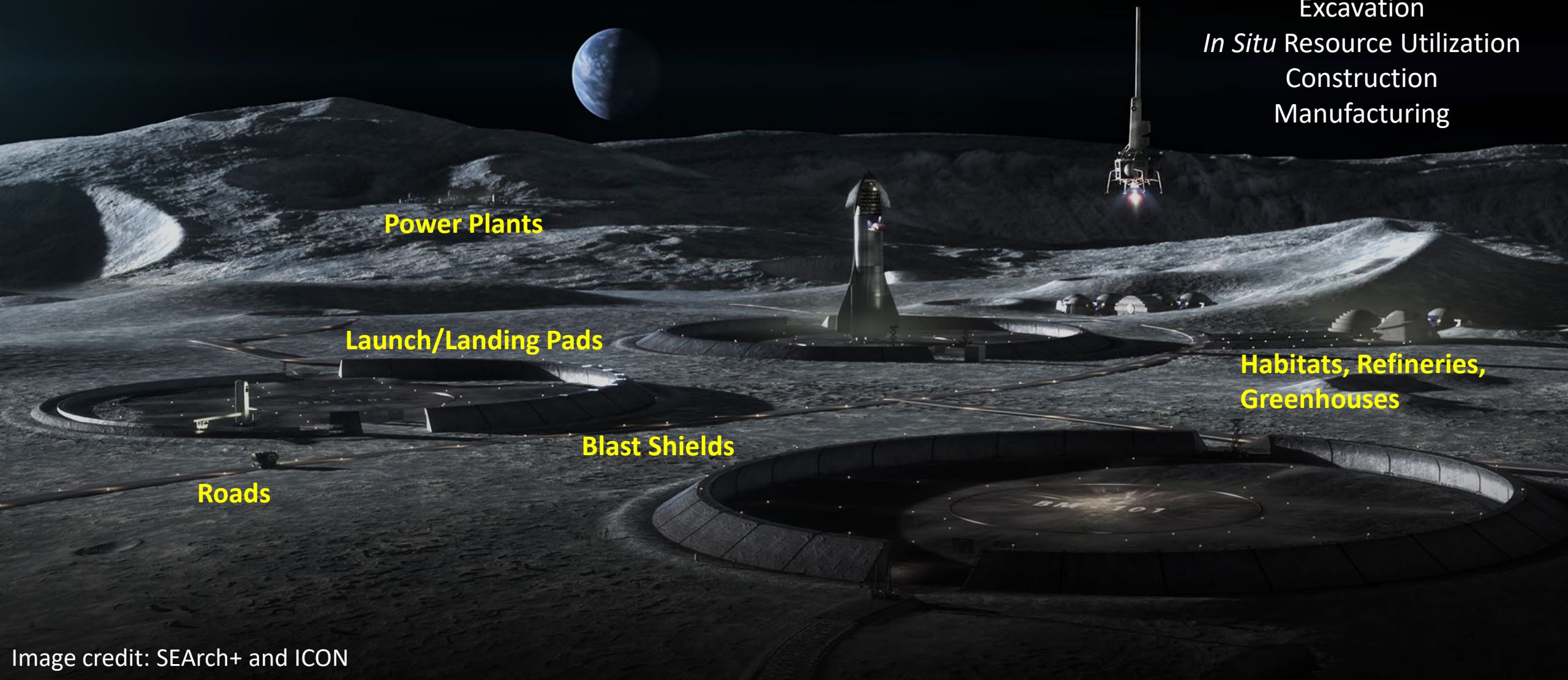
Critical Technology Needs:

Excavation

In Situ Resource Utilization

Construction

Manufacturing



Power Plants

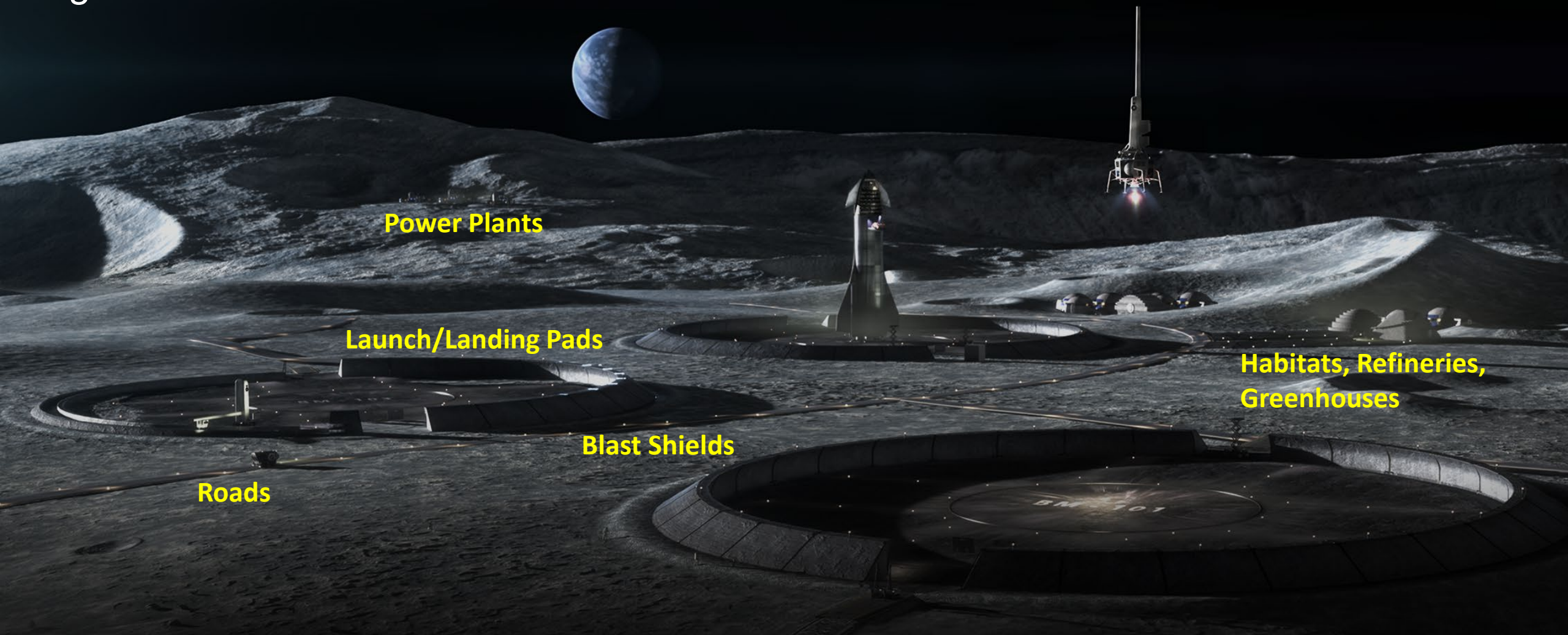
Launch/Landing Pads

Habitats, Refineries,
Greenhouses

Blast Shields

Roads

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



Power Plants

Launch/Landing Pads

Habitats, Refineries,
Greenhouses

Blast Shields

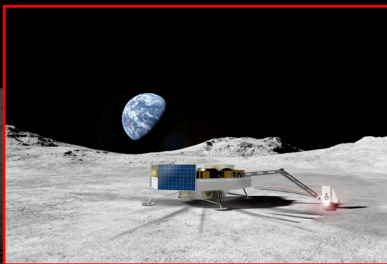
Roads

MMPACT Objectives

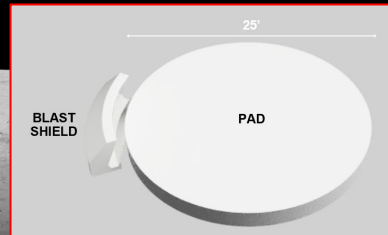
- Develop and demonstrate additive construction capabilities for various structures as materials evolve from Earth-based to exclusively *In Situ* Resource Utilization (ISRU)-based
- Develop and demonstrate approaches for integrated sensors and process monitoring in support of *in situ* verification & 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)

2026

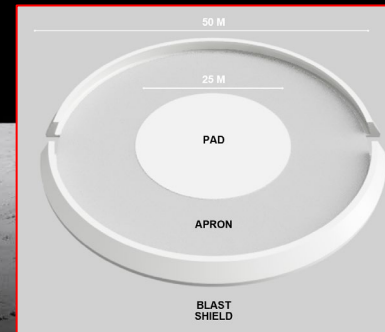


Demonstration
Mission 2 (DM-2)



Qualification
Mission 1 (QM-1)

2030's



Qualification
Mission 2 (QM-2)



MMPACT Requirements and Assumptions

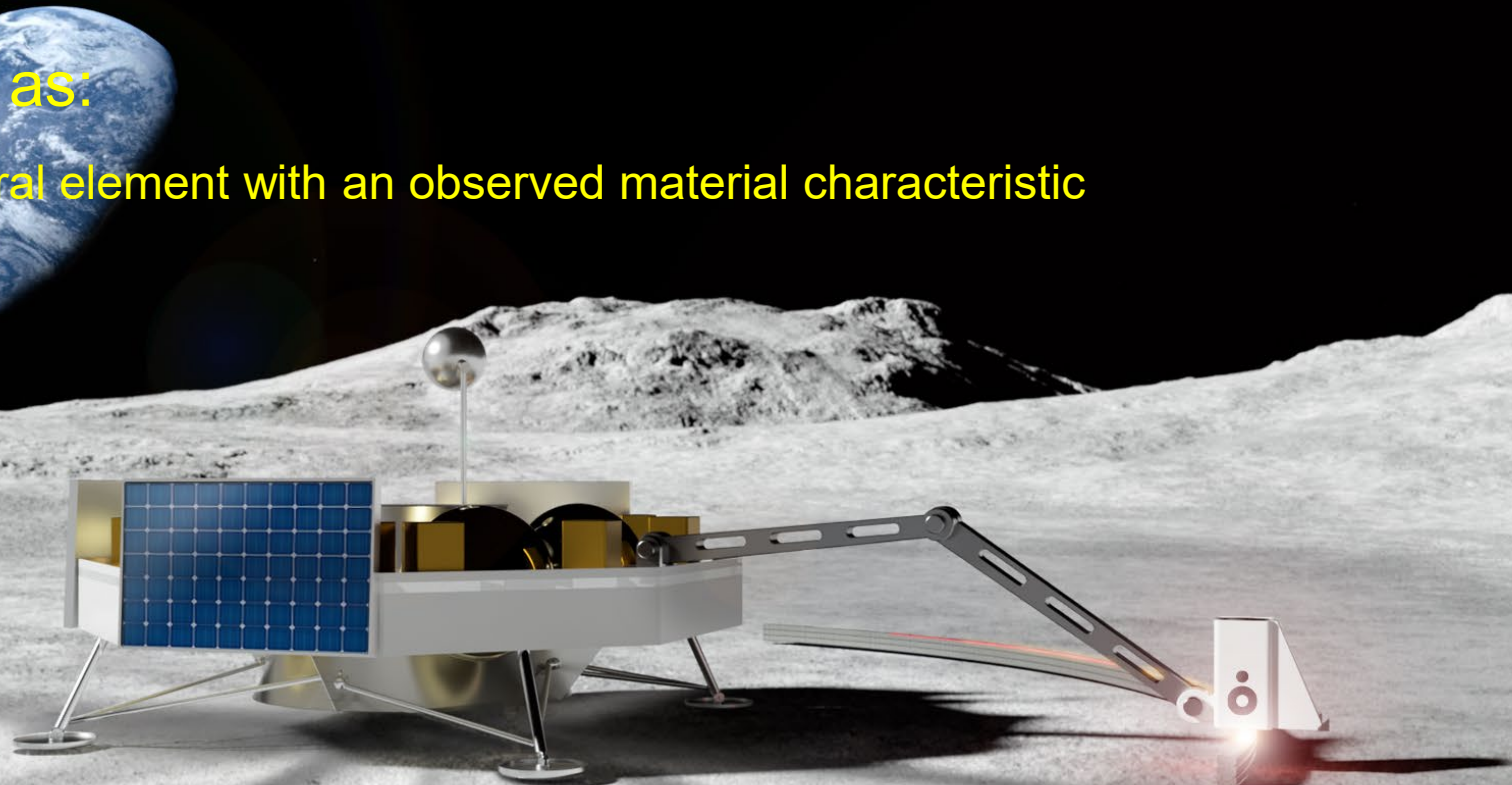
- Level 1 requirements:
 - The system shall demonstrate lunar construction for future missions
 - The system shall additively construct structures using in-situ resources on the lunar surface
 - The system shall implement both autonomy and remote operations to carry out its tasks

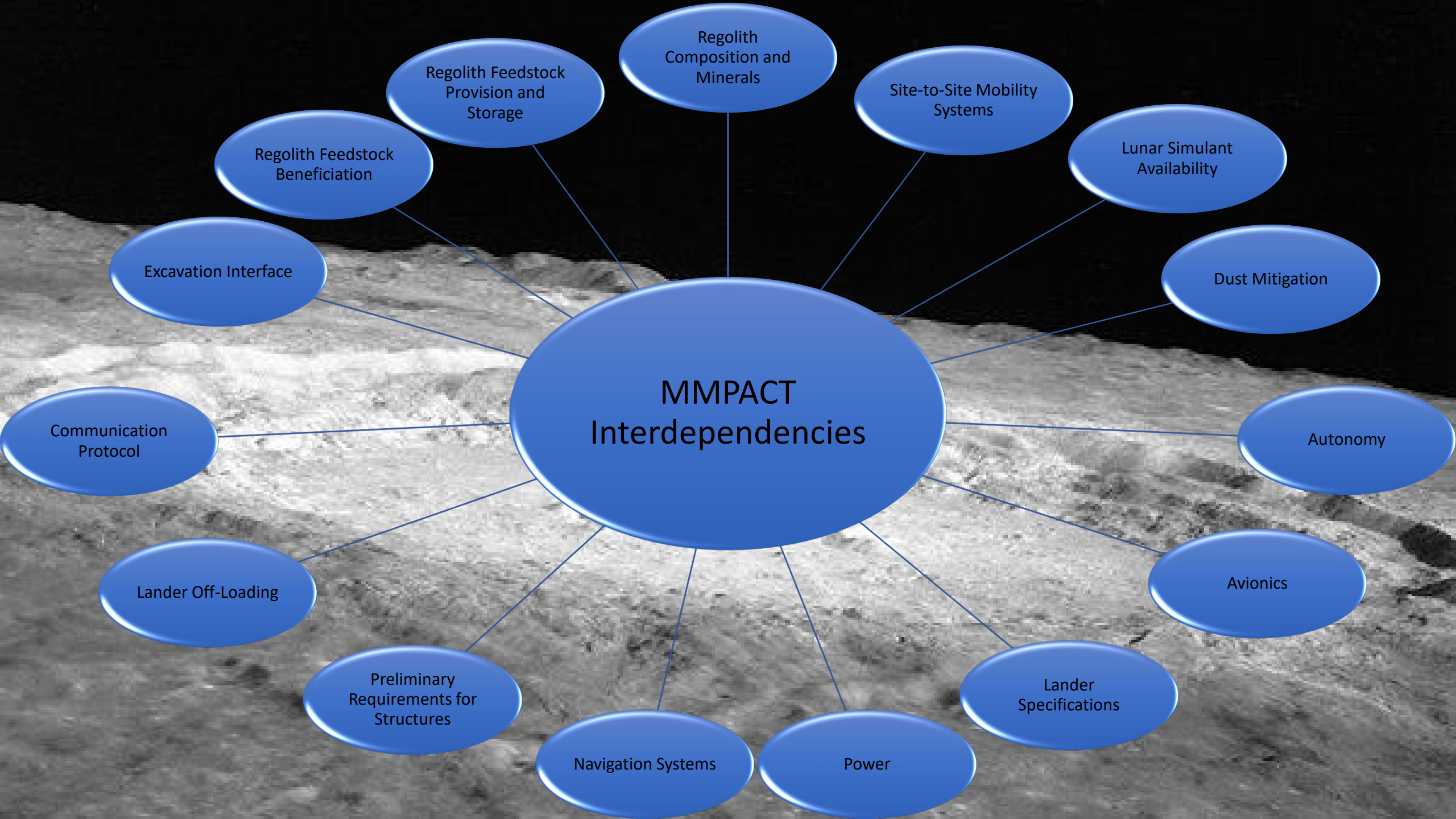
- Mission success is defined as:

- The ability to emplace a structural element with an observed material characteristic

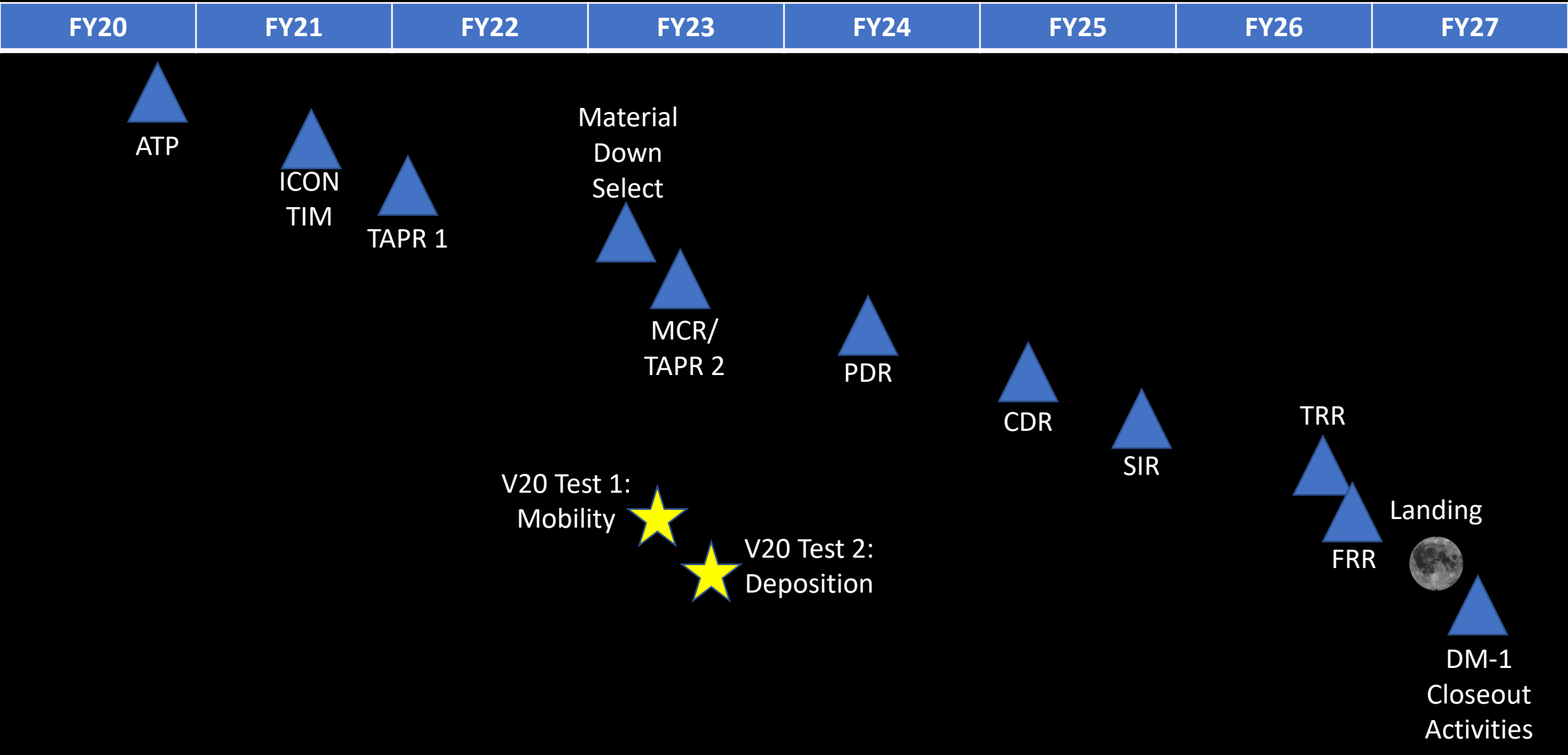
- Assumptions:

- South polar region regolith
 - South polar region lighting





High Level Schedule



Accomplishment Highlights

- Olympus/MSFC:
 - Successful build and test of LunarPAD
 - Successful upgrade of ACME gantry printer
 - Characterization of lunar ISRU-based cementitious materials (calcium sulfoaluminate and magnesium oxysulfate binders) including low pressure cure tests and early-set performance testing
 - Completed fabrication of prototype environmental enclosure in support of cementitious materials processing at reduced pressure
 - Completed static and dynamic Electrical Impedance tests, demonstrating the capability to detect voids as small as 0.07% of the measured volume



Accomplishment Highlights

- Olympus/ICON:
 - Successful build and test of LunarPAD
 - <https://www.youtube.com/watch?v=cN7v2v27kmU>
“World’s First 3D-Printed Rocket Pad”
 - Successful laser melting and fabrication of 100% regolith (simulant) samples in vacuum
 - Process baselined for material down select
 - Successful extrusion of molten 100% regolith (simulant) samples in vacuum
 - Thermal profile established to achieve the same microstructure as the laser deposition system
 - Successful completion of mobility system trade studies for Demonstration Mission 1
 - Outside of MMPACT – successful construction of the Crew Health and Performance Exploration Analog (Mars Dune Alpha) at JSC

Sample of laser melted CSM-LHT-1 simulant, 1.3kg (size of a soda can)



Accomplishment Highlights

- MSCC:

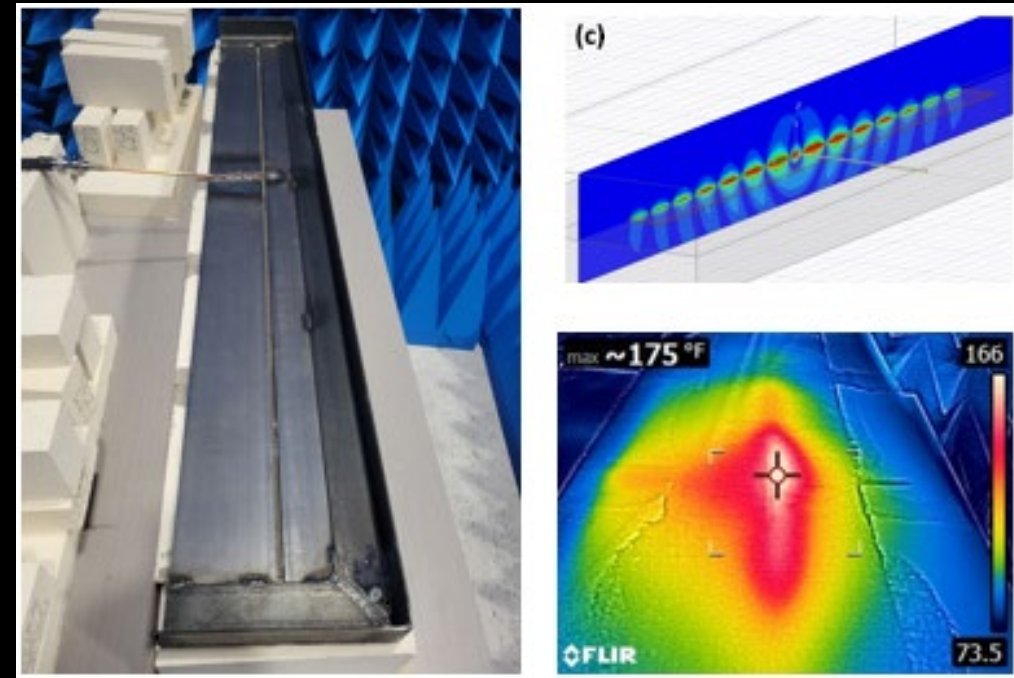
- Successful NU-LHT-4M, JSC-1A, and CSM-LHT-1G simulant brick sintering in inert atmosphere
- Establishment of simulant bakeout procedure for three simulants
- Successful development and benchtop demonstration of multimode (vacuum) and near field coupler (benchtop air) applicators
- Successful development of cryogenic and broad frequency range dielectric testing
- Successful development and benchtop demonstration of a site preparation tool
- Successful development of NU-LHT-5M simulant



CSM-LHT-1G
post-sintering
Diameter: ~5.01cm
Height: ~2.10cm



Left: Prototype steel Near Field Coupler (NFC). Right top: NFC electromagnetic field map model. Right bottom: proof-of-concept of NFC predictable heating pattern.



FY2022 Milestone Summary

- Formulated and secured CSM-LHT-1G simulant, determined heat treatment procedure, and began production of down select samples
- Working toward Material Down Select 11/28/22
- Current Activities
 - V20 TVAC/DTVAC Conversion Team
 - Test Summary, V20 Test Objectives
 - Integrated Master Schedule Baseline
 - Project Plan Baseline
 - Technology Maturation Plan
 - Simulant and Sample Characterization
 - Numerous Procurements



MMPACT Issues

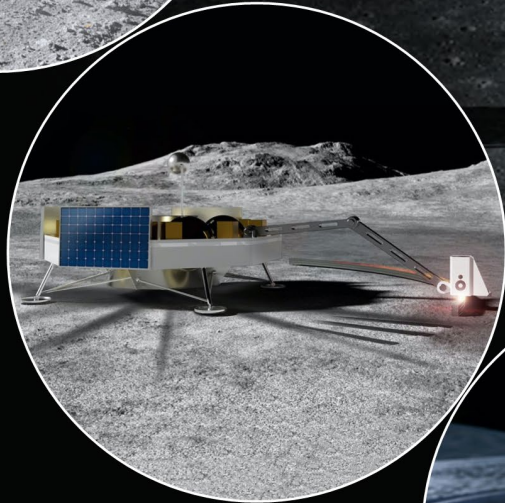
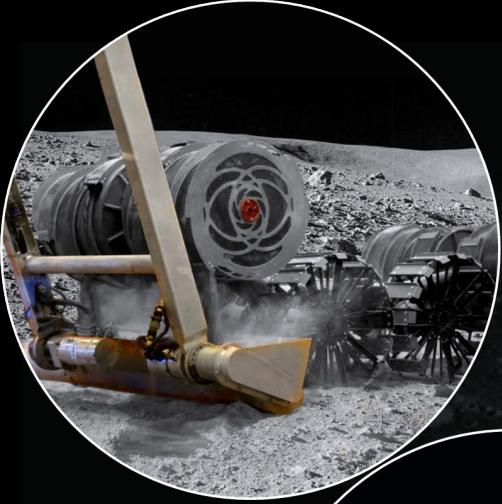
Issue Title	Description/Status	Proposed Mitigations
Simulant Quantity	There is a lack of large quantities of simulants	Use lower fidelity simulants to develop engineering units, then refine processes as appropriate simulants become available
Simulant Quality	There is a lack of representative simulants with sufficient fidelity to replicate the majority of lunar regolith	Design a system to operate within a range to account for variation in geochemistry, particle size, particle shape, density, etc.
Vacuum-Compatible Components	COTS hardware is not generally vacuum-compatible	Identify system components that are not vacuum-compatible and purchase compatible components / develop components in-house

Forward Plans (if Project IS NOT Completed)

- Continue materials development as able
- Continue technology development as able
- Continue large-scale simulant prospecting
- Continue to support partners and garner new partnerships as able
 - SBIR/STTR
 - Cooperative Agreement Notices (CANs)
- Continue to identify technology gaps
- Continue to participate in roadmap activities
- Continue to publish results
- Continue to advocate for ISRU and Excavation, Construction, and Outfitting areas

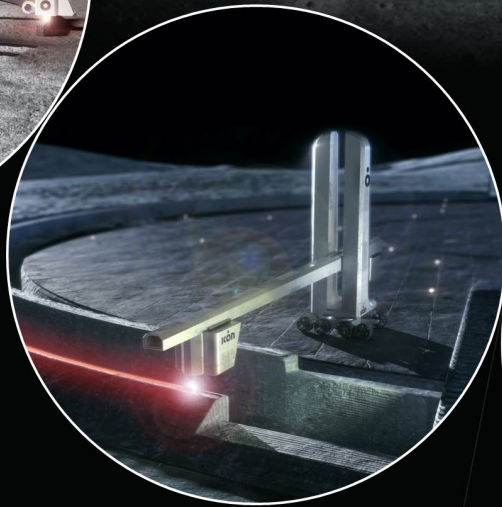


Forward Plans (if Project IS Continued)



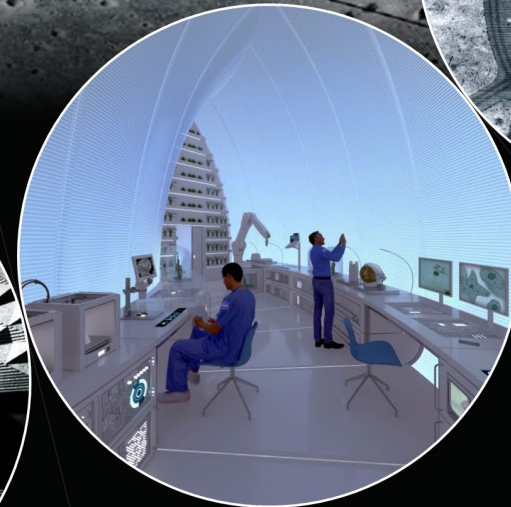
Phase 1:

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



Phase 3:

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



Technology Gaps



Primary source -

<https://www.globalspaceexploration.org/wordpress/wp-content/uploads/2021/04/ISCG-ISRU-Technology-Gap-Assessment-Report-Apr-2021.pdf>

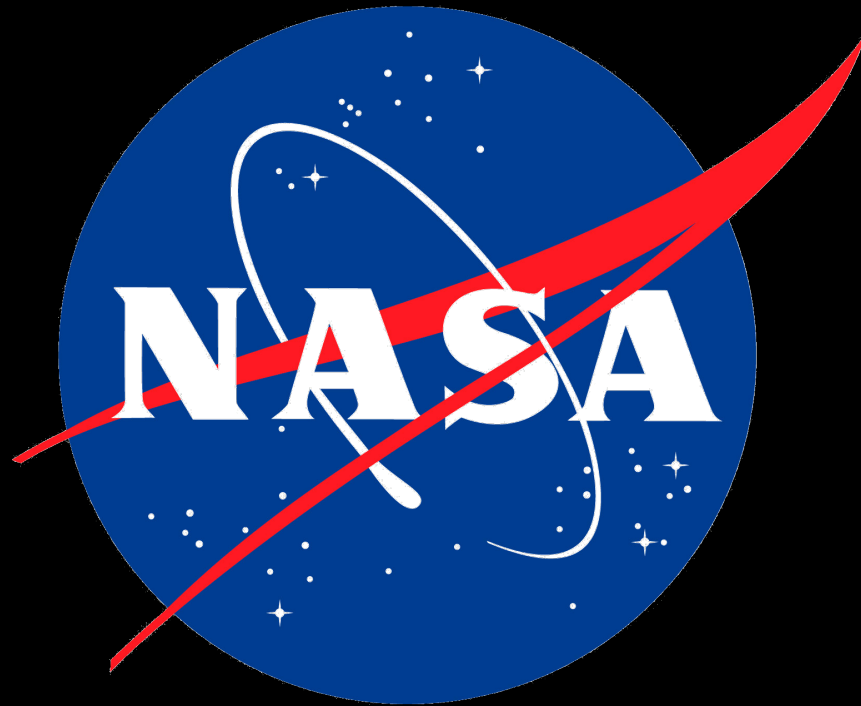
(International Space
Exploration Coordination
Group ISRU Gaps)

- 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 parts from ISRU-based materials
- Joining and assembly
- Process monitoring and part verification

Contributors and Acknowledgements



- Moon to Mars Planetary Autonomous Construction Technology (MMPACT) and In-Space Manufacturing (ISM) Teams
- Dr. R. G. “Corky” Clinton, Jr. – MMPACT Principal Investigator
- Mike Effinger – MMPACT Microwave Structure Construction Capability Project Manager
- Mike Fiske – MMPACT Olympus Autonomous Construction Technology Project Manager
- Dr. Frank Ledbetter – Senior Technical Advisor for MMPACT and ISM
- John Vickers – Principal Technologist (PT) in Advanced Manufacturing
- Jerry Sanders – *In Situ* Resource Utilization System Capability Leadership Team Lead
- Dr. Mark Hilburger – PT in Excavation, Construction, and Outfitting
- Jason Ballard, Evan Jensen, Eamon Carrig, and the ICON Technologies, Inc. Olympus Team
- Michael Morris – Space Exploration Architecture
- MMPACT’s Numerous Partners



www.nasa.gov/spacetech