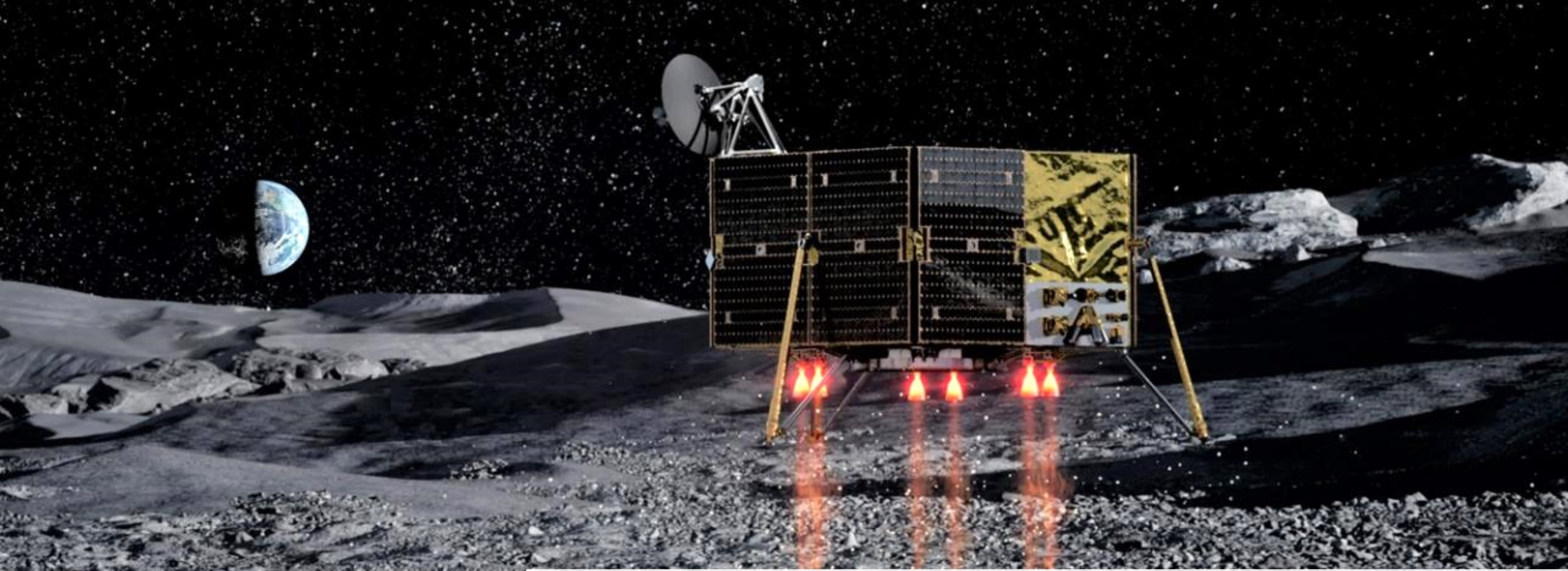


MASTEN

Low-Energy Additive Construction for the Moon and Mars

Travis Vazansky | Project Manager
Space Resources Roundtable 2022

MASTEN OVERVIEW

THE SPACE INFRASTRUCTURE COMPANY

In 2004, Masten pioneered the development of reusable VTVL technology with the ultimate goal of unlocking the value of space.

We're enabling a future where…

- **Lunar landings are commonplace**
- **Space ecosystems are thriving with commercial leadership**
- **Humankind is benefiting from resources extracted across the solar system**

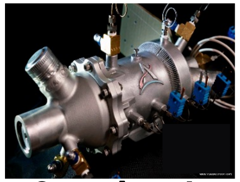
MASTEN

1st	One of the first commercial company to deploy reusable vertical takeoff and vertical landing (VTVL) rockets
600+	Successful rocket-powered landings across 5 rockets, leading the industry in number of flights
1 of 4	Companies selected by NASA to deliver payloads to the Moon
1st	Independent rocket testbed, which validated the landing technology for the successful 2020 mission to Mars
18	Years' experience building & flying rockets to prepare for lunar and Martian missions
1st	To develop new additive manufacturing methods for rockets & liquid propulsion

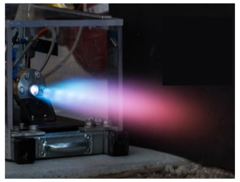
ACCELERATING SPACE ECOSYSTEMS ON THE MOON, MARS & BEYOND

Tech Development

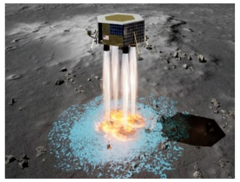
Developing mission-enabling technologies to solve the most pressing space challenges.



3D-printed rocket parts

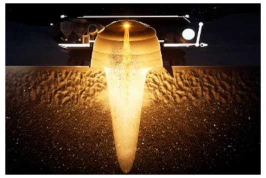


Propulsion technologies

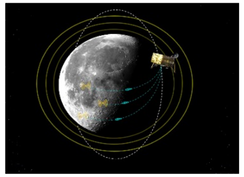


Landing pad technologies

Heat & power systems



Rocket mining system



Lunar "GPS" network

Rocket Testbed

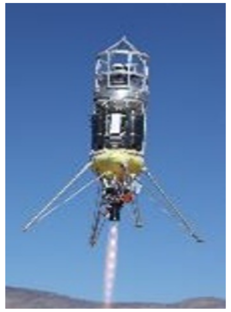
Testing technologies aboard our reusable VTVL vehicles & engine stands to advance readiness for space.

Xombie

Xoie

Xaero-A

Xaero-B

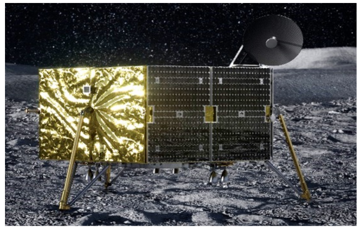


Xodiac

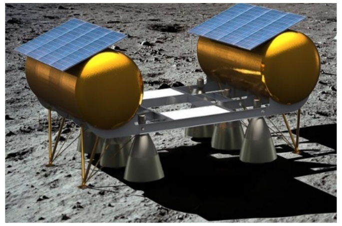
Xogdor

Lunar Delivery

Providing end-to-end mission solutions to safely deliver and operate payloads aboard our lunar landers.



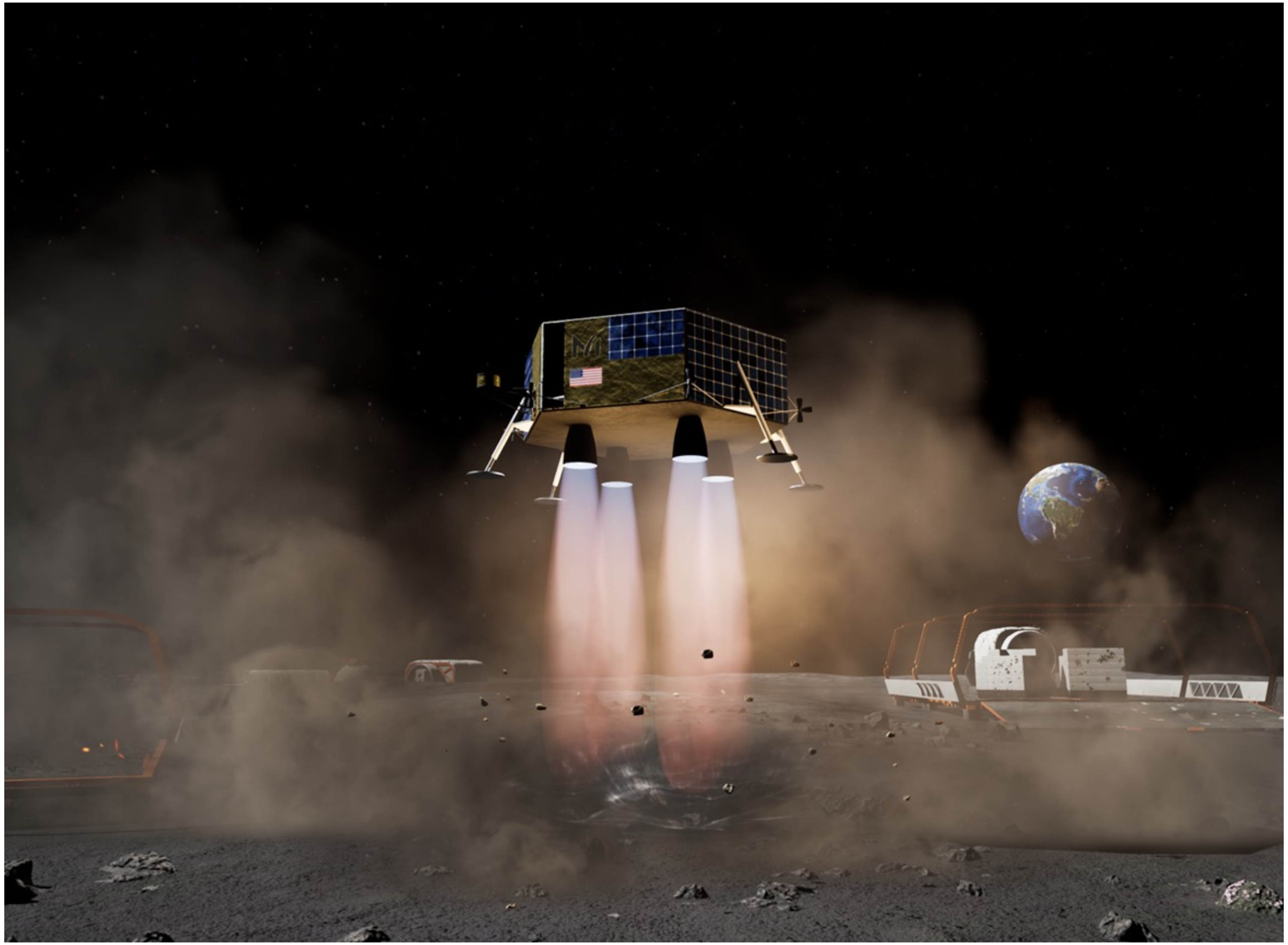
Xelene



XL-2

Xeus

MASTEN



SUSTAINABLE LANDING OPERATIONS

- Challenges Ahead
- Potential Solutions

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CHALLENGES AHEAD

Outpost Buildup

Establishing a permanent presence on the Moon and Mars will require multiple landings at the same location.

Dust Mitigation

Dust ejecta from plume surface interactions during landing pose a risk to personnel and assets.

Energy Requirements

Early surface operations will have limited power availability for construction operations.

Sustainable Infrastructure

Costs to transport materials from Earth are high, so infrastructure that can be constructed, maintained, and repaired using in-situ material are desirable.

POTENTIAL SOLUTIONS

Method	Description	Energy Expended* (MWh)	Mass from Earth* (tons)	Time to Construct* (days)
Microwave Sintering	• Can produce mechanically strong surfaces with single pass • Relatively uncomplicated deployment method • Deep penetration into Lunar soil • High energy	87.5	9.4	18.2
Baking Pavers	• Bake paver in over and then deploy • Complex automation required to fill molds and distribute pavers • Grouting joints also required after paver deployment • High energy	97.2	3.6	61.3
Polymer Infusion	• Quick deployment • Unknown if feasible to use as central landing pad material • Large mass transported from earth • Low energy	0.011 (Inner Pad Only)	7.6 (Inner Pad Only)	0.56 (Inner Pad Only)

*Note: Assumes construction of 27m radius landing pad consisting of inner and outer zones

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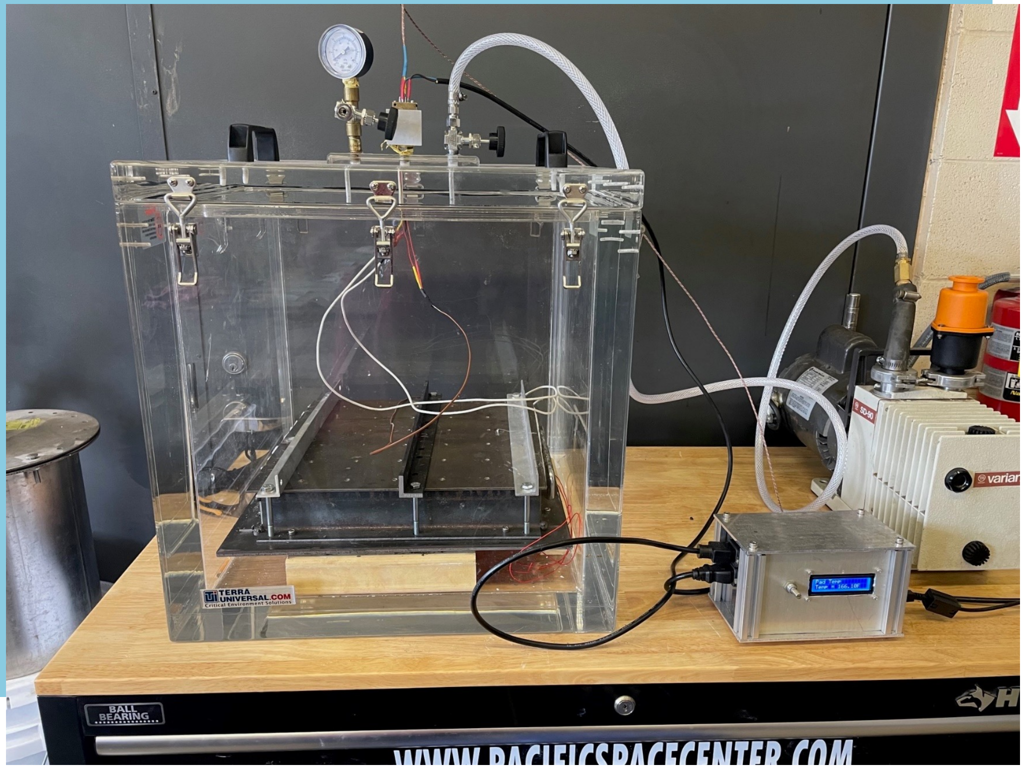
Source: P.T. Metzger and G.W. Autry. "The Cost of Lunar Landing Pads with a Trade Study of Construction Methods," *arXiv*, 2022. [Online]. Available: https://arxiv.org/abs/2205.00378. [Accessed Jun. 8, 2022].

LOW-ENERGY ADDITIVE CONSTRUCTION

- Technology Overview
- Key Benefits
- Test Program
- Conclusions
- Program Status and Next Steps

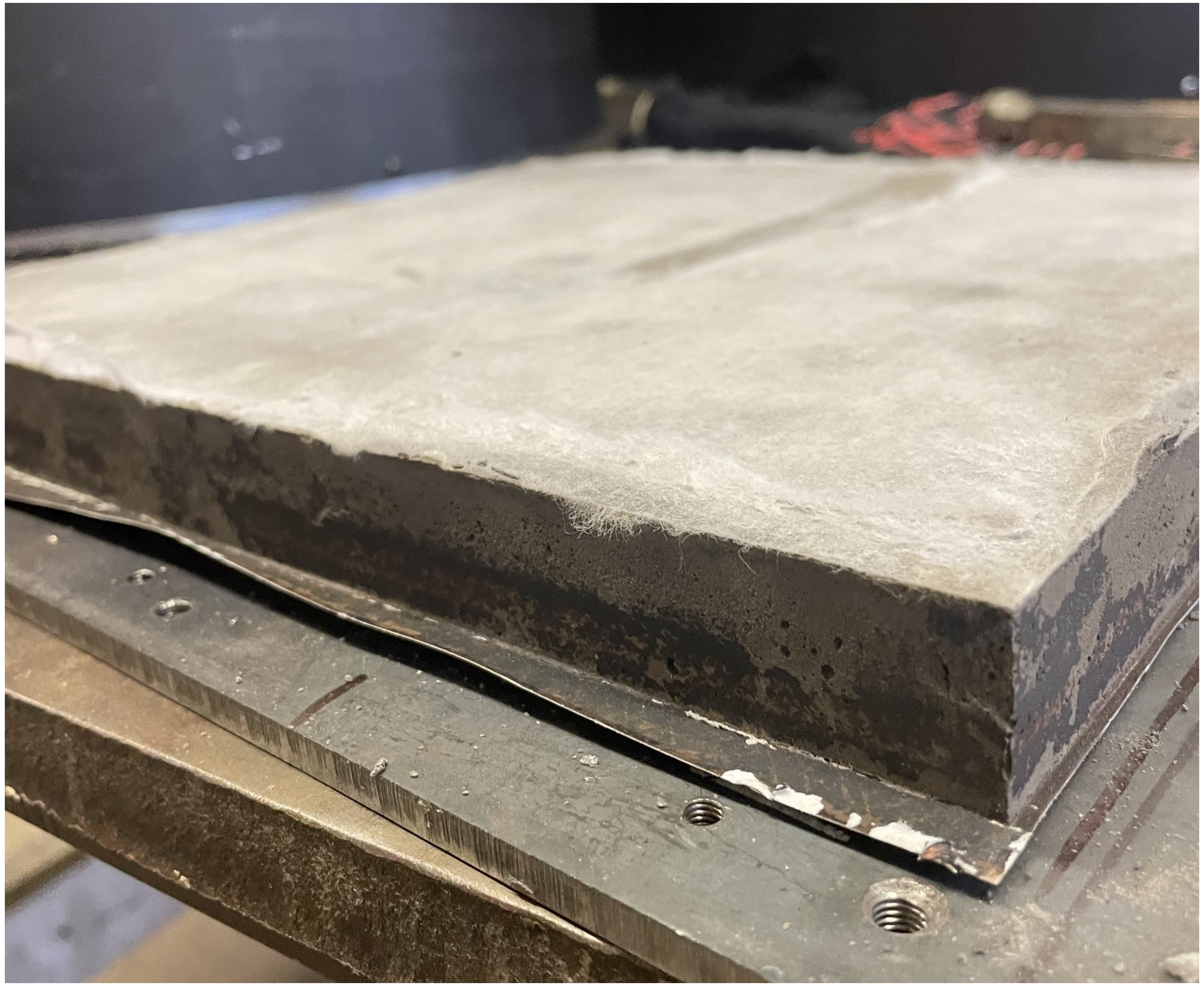
TECHNOLOGY OVERVIEW

- **Structural Binder:** Fabrication method is based on a novel application of an existing binder in aqueous solution that has potential for extraction from in-situ resources.
- **In-Situ Materials:** To form the composite, binder is mixed with basalts similar to those found on the Moon and Mars.
- **Curing Process:** Pavers are formed in a mold and cure in 24-hours from desiccation in vacuum or CO_2 environment.
- **Deployment:** For real-world applications, the mixture would be extruded directly onto the surface or extrude bricks that can be placed later.
- **Grouting and Repairs:** The same binder-regolith composite that is used for paver fabrication is also used for grouting and repairs.

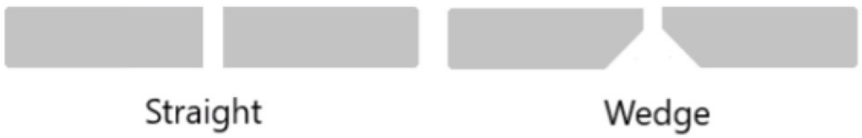


Paver Curing in Vacuum at PISCES Lab in Hawaii

TECHNOLOGY OVERVIEW



TECHNOLOGY OVERVIEW



Types of Joints for Grouted Pavers

KEY BENEFITS

MITIGATE DUST & CRATERING HAZARDS

Address effects of plume surface interactions during landing/launch events

ENALBE MULTIPLE MISSIONS

Enables multiple missions to land at a common location for outpost operations. Repairability extends landing pad lifetime.

LOW-ENERGY USE

Mixing and extruding material are low-energy processes. Curing does not require energy input.

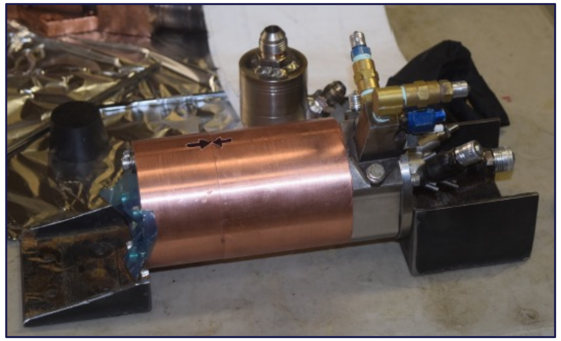
COST EFFECTIVE

Launch costs reduced through utilization of in-situ resources for binder and regolith

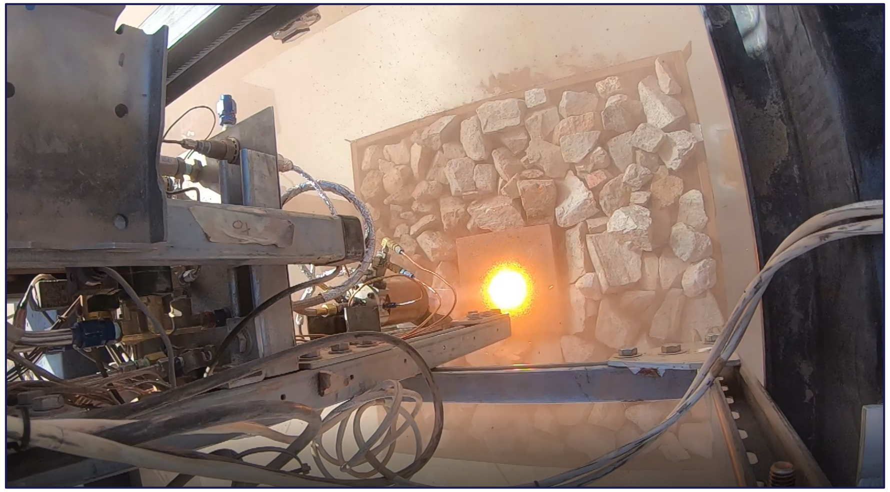
FLEXIBLE DEPLOYMENT

The extrudable binder can be deployed directly to the Lunar/Martian surface or as brick pavers in centralized production area.

TEST PROGRAM - SETUP



- 100lbf Heat Sink Engine
- 2 second test fires @ 0.2m
- 2500K temperature at stagnation point
- Sieved regolith base with surround gabion rocks to reduce dust
- Repair and refire
- Structural testing

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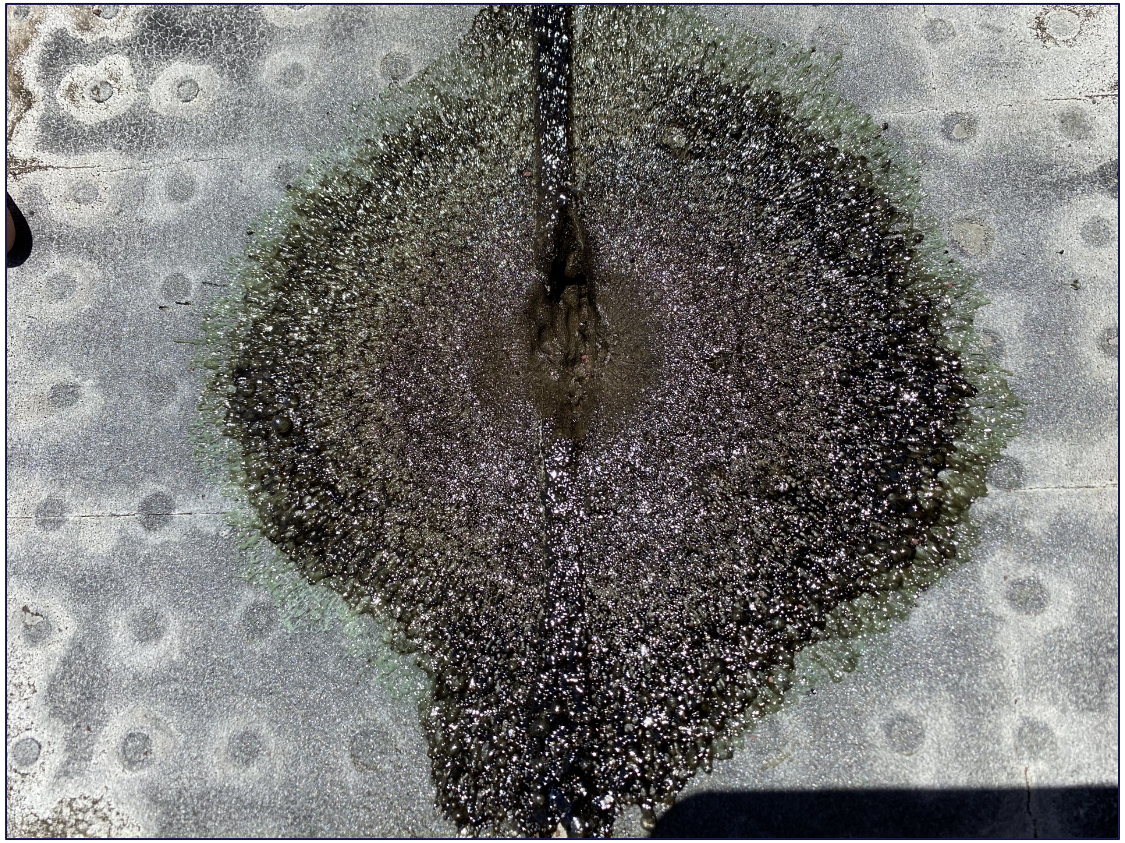
TEST PROGRAM – INITIAL TEST FIRES

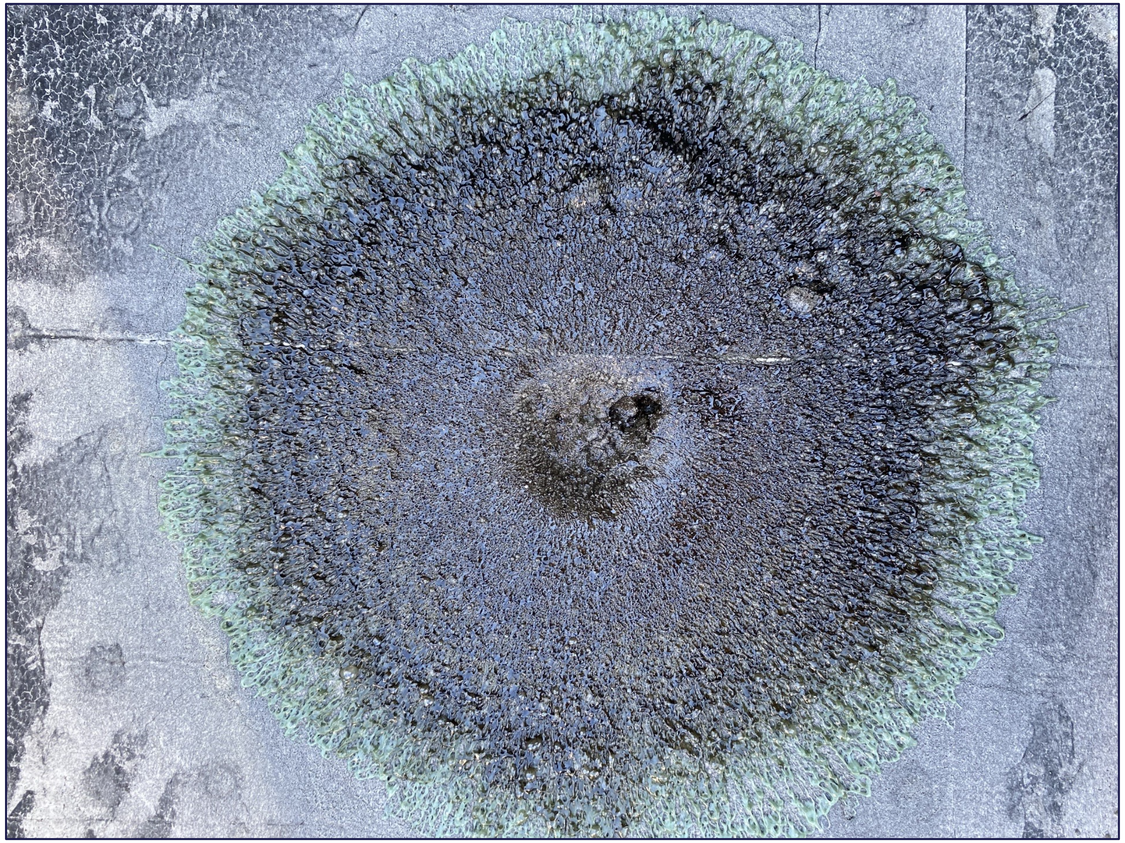
Grouted Lunar Paver (GL1)

Single Lunar Paver (SL1)

TEST PROGRAM – INITIAL TEST FIRES



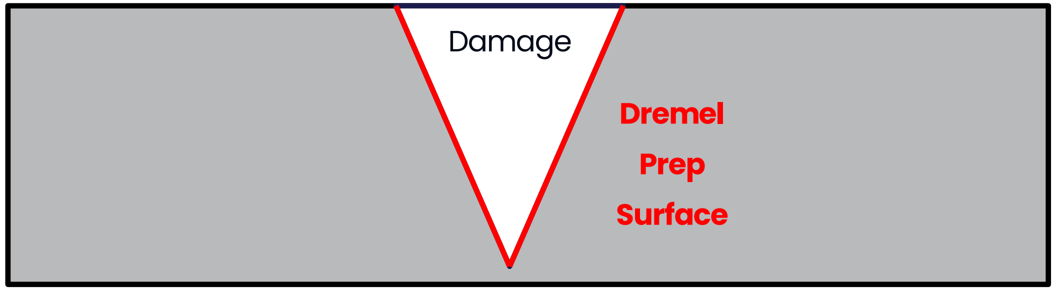
Grouted Martian Paver (GM1)

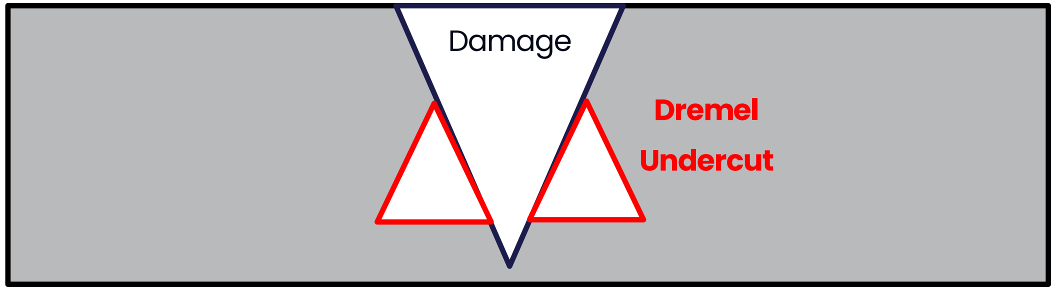


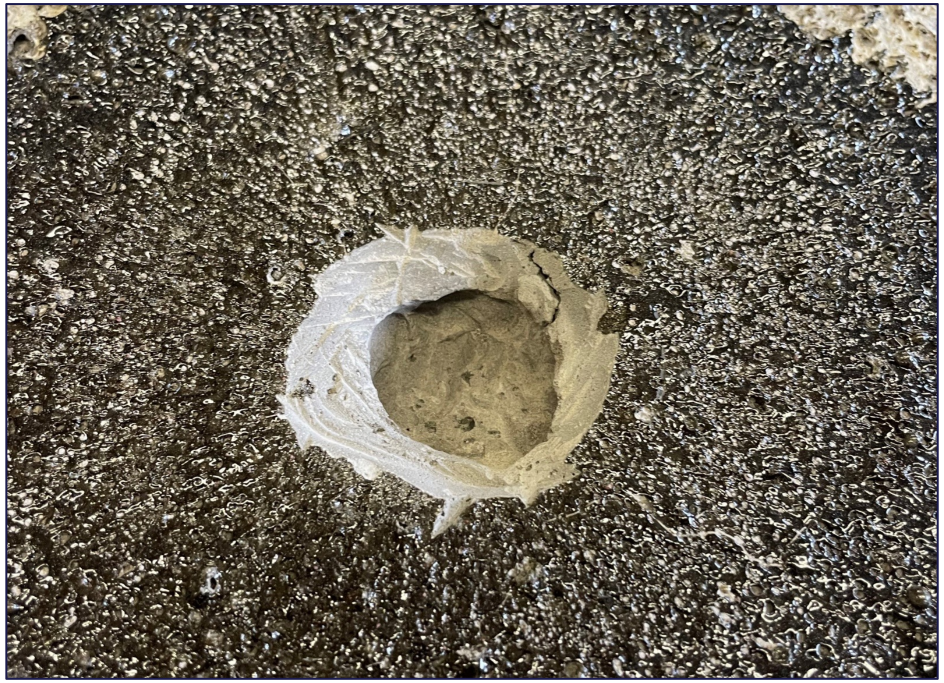
Single Martian Paver (SM2)

TEST PROGRAM – REPAIRS

- **Repaired Test Articles:**
  - 2 single Lunar pavers
  - 2 single Martian pavers
- **Repaired Types:**
  - V-Repair
  - Hourglass repair
- **Execution Method:**
  - Dremel out appropriate repair type
  - Apply binder
  - Cure in relevant Lunar or Martian environment







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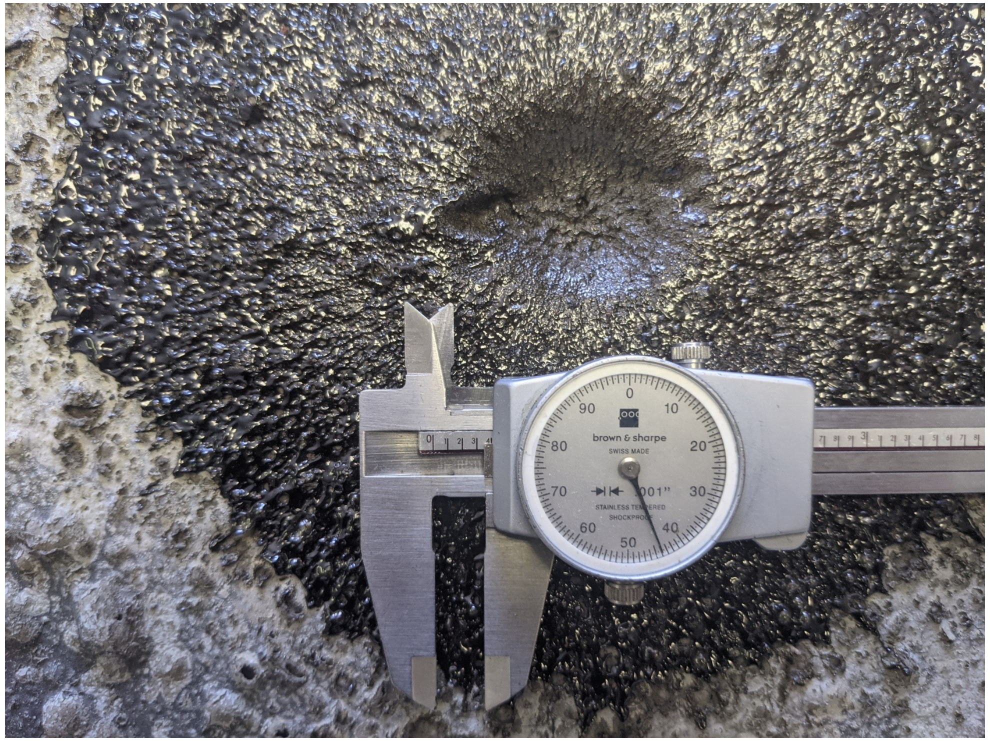
TEST PROGRAM – REPAIR AND RE-FIRE



Single Martian Paver (SM1)

Initial Test

Repair & Re-Fire

Single Martian Paver (SM1)

Re-Fired

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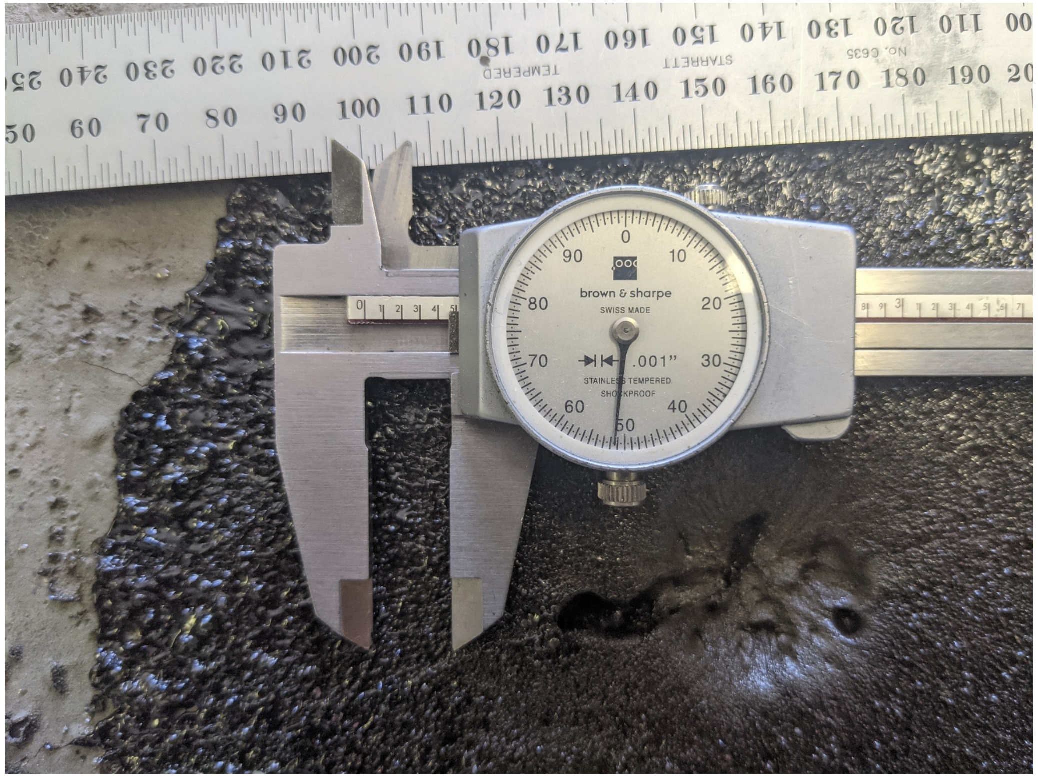
TEST PROGRAM – NO-REPAIR AND RE-FIRE



Single Lunar Paver (SL1)

Initial Test

Re-Fire

Single Lunar Paver (SL1)

Re-Fired

and...

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TEST PROGRAM – NO-REPAIR & RE-FIRE

LN2 Soak

Single Lunar Paver (SL1)

10-min LN2 Soak

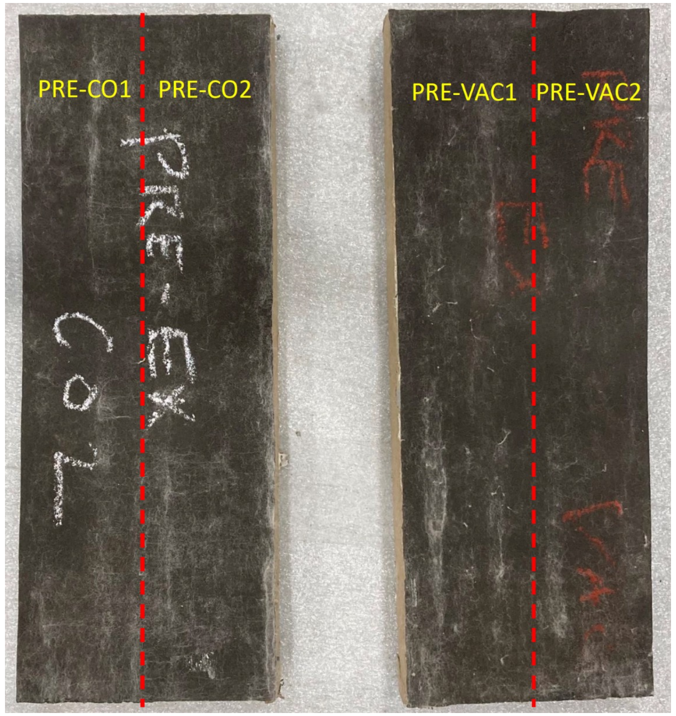
Re-Fire

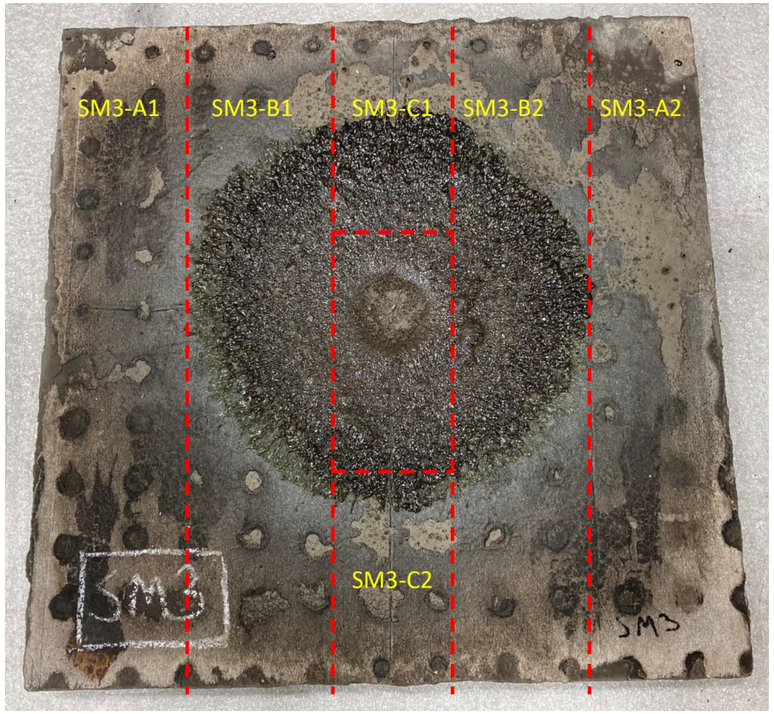
Single Lunar Paver (SL1)

Re-Re-Fired

TEST PROGRAM – STRUCTURAL TESTING

- Includes compressive and flexural testing
- Testing completed on "fresh" pavers that were not subjected to hot fires
- Different segments of each paver selected for structural test types





CONCLUSIONS

- Pavers acted as an effective barrier to isolate the regolith surface from the plume environment
  - Dust ejecta only produced as plume propagated off the edge of the pad
- Re-fires and repairs demonstrated capability to support multiple landing/launch events
- Curing method demonstrated the low-energy process for fabrication in Lunar and Martian environments
  - Better quantification of total power requirements for deployment would be useful
- Current level of development would require binder brought from Earth, but there is potential for in-situ resource utilization that will reduce launch costs
  - This project would benefit from a more in-depth analysis of total deployment time and mass requirements
- Extrusion deployment mechanism is being further developed to prove out flexible deployment capability

MITIGATE DUST & CRATERING HAZARDS

ENABLE MULTIPLE MISSIONS

LOW-ENERGY USE

COST EFFECTIVE

FLEXIBLE DEPLOYMENT

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PROGRAM STATUS & NEXT STEPS

- **NASA STTR Phase I**
  - Program demonstrated fabrication techniques and tested feasibility of material for landing pad use
  - Develop PDR-level extruder design
  - Completion scheduled June 2022
  - Will reach TRL 3

- **NASA STTR Phase II**
  - Submitting proposal June 2022
  - Focus on extruder development
  - Will reach TRL 5

Future Development
Lunar Demonstration

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