EMBRY-RIDDLE
Aeronautical University

FORGE

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URI
UNDERGRADUATE
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COSMIC Capstone Challenge Final Briefing

Facility For On Surface Refining Gathering and Extraction

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Advisor: Dr. Siwei Fan, Matthew Haslam

Mentor: Dr. Jeffery Burton

April 14th, 2026

Presentation Outline

- Introduction
- Project Background
- Design Overview
  - Trade Studies
  - Design Process
  - Digital Design
- Prototype
- Conclusion

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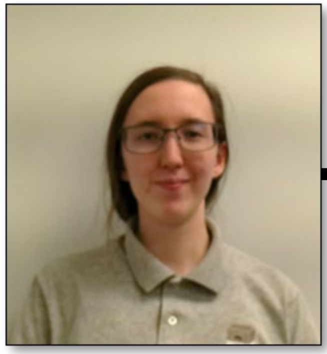
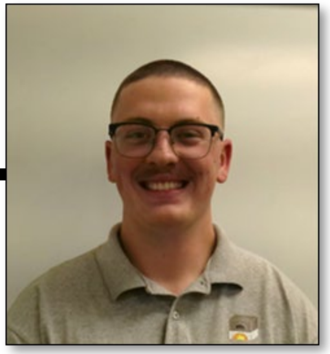
Team Overview



Jessica Martineau
FORGE Co-Lead



Jacob Hart
FORGE Co-Lead

Luka Arozqueta

Ethan Cerniglia

Garrett Greve

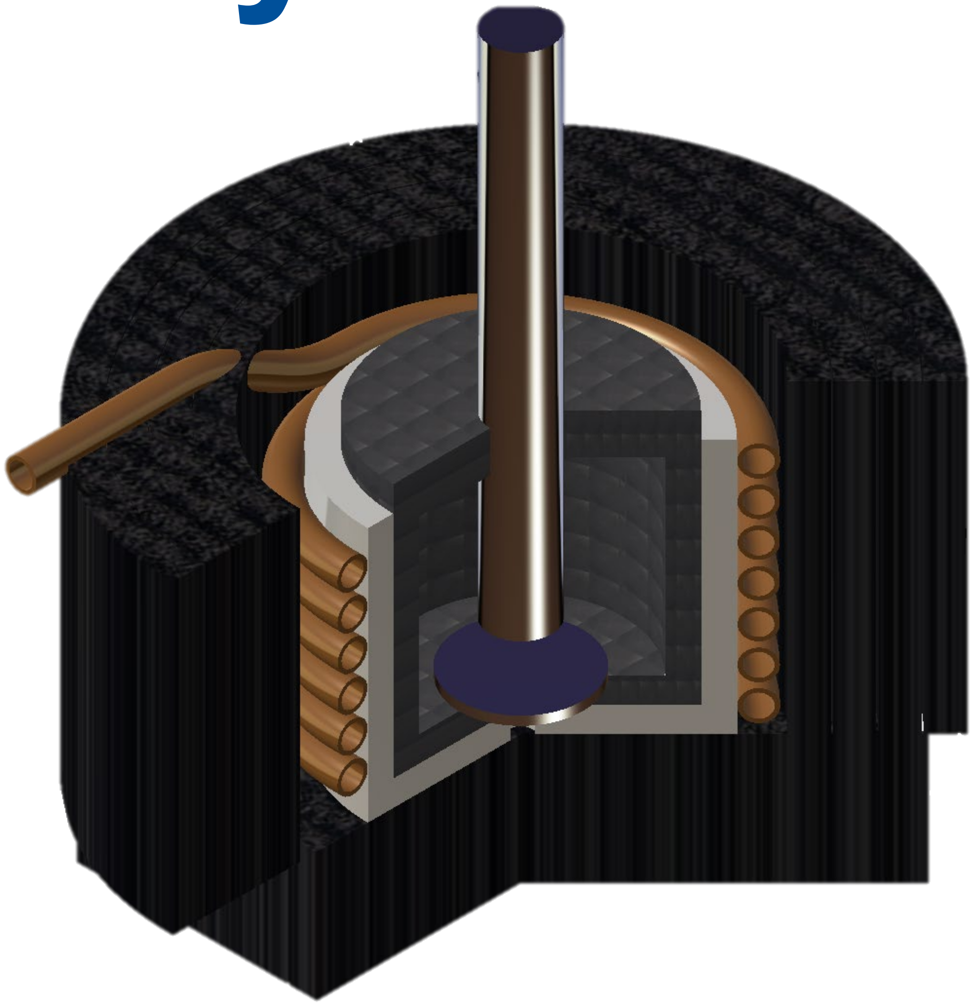
Ryan Raglin

Nicholia Moody

Executive Summary

FORGE is a Research Project

- **Research** elemental separation using molten regolith electrolysis (MRE) for in-situ resource utilization (ISRU)
- **Expand** on NASAs MRE research by employing a stepped temperature decrease cooling scheme
- **Solve** the issue of hard to extract metal byproducts
- The project is currently in prototyping and testing phase for the **FORGE Technology Demonstrator (FTD)**



FORGE Technology Demonstrator

2.4 Program Management Milestones

Aug. 2025

Jessica M. and Jacob H. selected as team leads

Sept. 2025

Selected Lunar metal refining as goal of FORGE

Oct. 2025

Defined system objectives and requirements

Dec. 2025

Completed four main Trade Studies

Feb. 2025

Finalized conceptual design of FORGE

Mar. 2025

Developed path to Preliminary Design Review

Impact

Reduce launches to the moon

- FORGE aims to reduce the cost of lunar base construction
- Improve ISRU on lunar and mars missions
- FORGE saves money on fuel, material, and

Feasibility

Proven tech, small gaps

- Extensive research on the topic of MRE
- NASA plans to use MRE for Lunar oxygen production
- Very similar to many materials refining processes used on Earth

Innovation

Pure Elemental separation

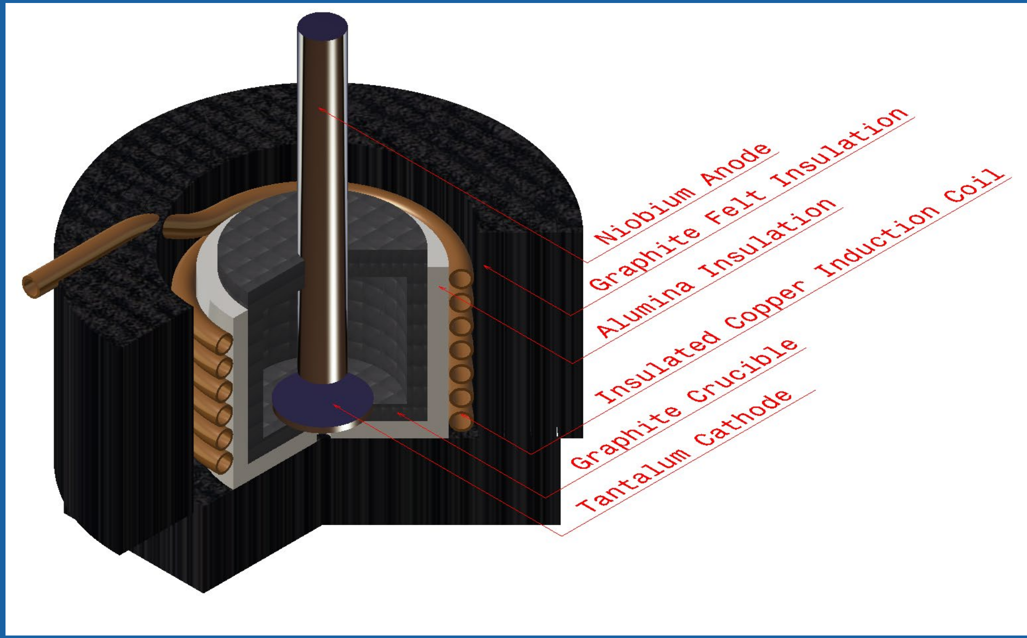
- Few systems separate materials from regolith
- No project combines melting and separation in one process
- Induction enables contactless and more efficient heating

Required Elements

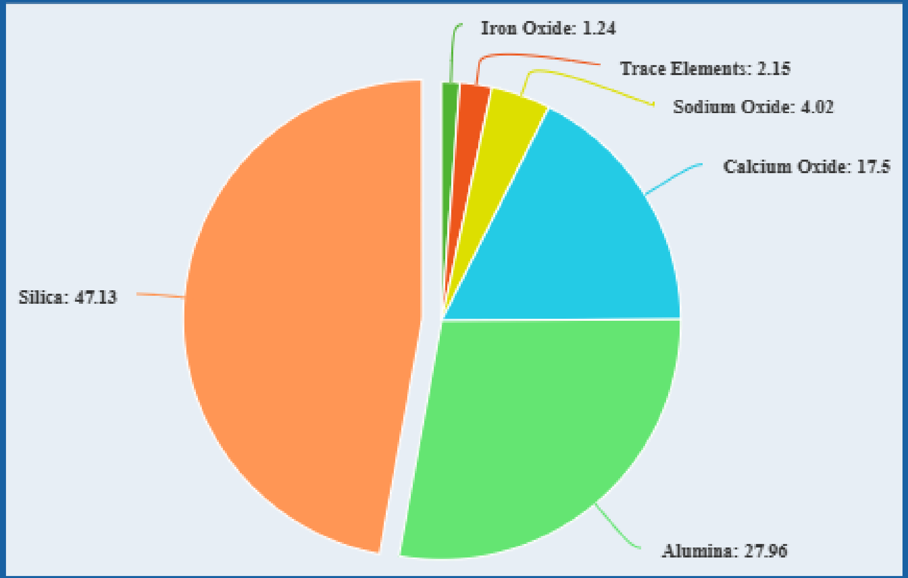
Design and Chemical Elements

- **Efficient** Heating Method
- **High Performing** Electrodes
- **Reliable** Thermal Insulation
- **Resilient** Sensors
- Lunar South Pole Regolith Simulant 2 (LSP-2)

Components of the FTD

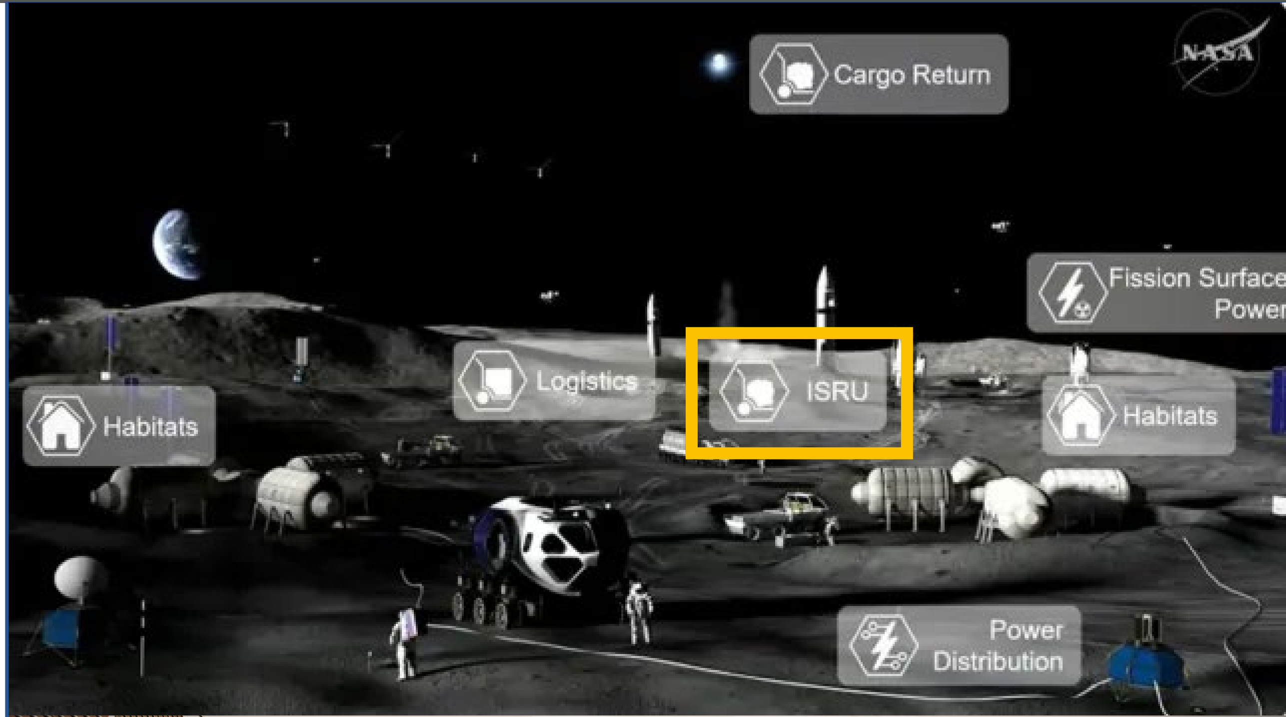


Makeup of LSP-2



1.4 Advancing High Value Missions

- FORGE support missions on the Lunar and Martian surface by improving **ISRU**
- Aids in production of fuel and oxidizer from regolith
- Produces usable construction material to support base development



Images retrieved from wordlesstech.com and nasa.gov

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Trade Studies

Parts Selection

Furnace Subsystem

Heating Method Options

Induction Furnace

~~Plasma Arc Furnace~~

~~Joule Heating~~

~~Gas Torch~~

Separation Subsystem

Electrode Options

Tantalum Cathode

Niobium Anode

~~Molybdenum Anode~~

~~Platinum Cathode~~

~~Tungsten~~

Insulation Subsystem

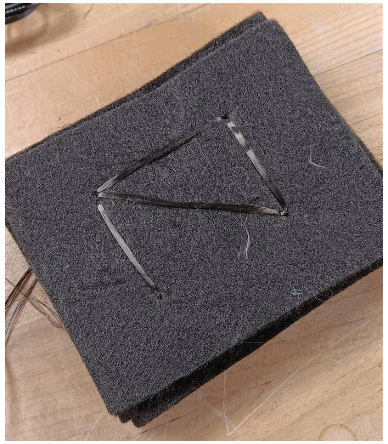
Insulator Options

Graphite Felt

~~Graphite Foam~~

~~Mullite foam~~

~~Alumina foam~~



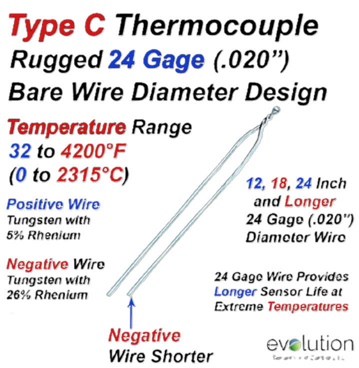
Measurement Subsystem

Thermal Sensor Options

Infrared Sensor

Type C thermocouple

~~Pyrometer~~



FTD Design Iterations

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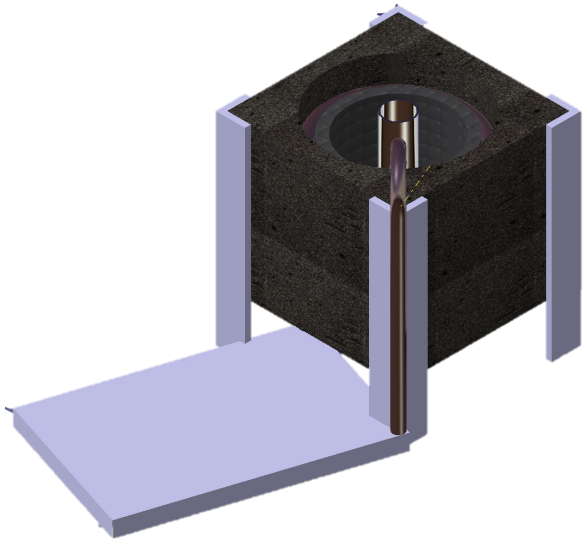
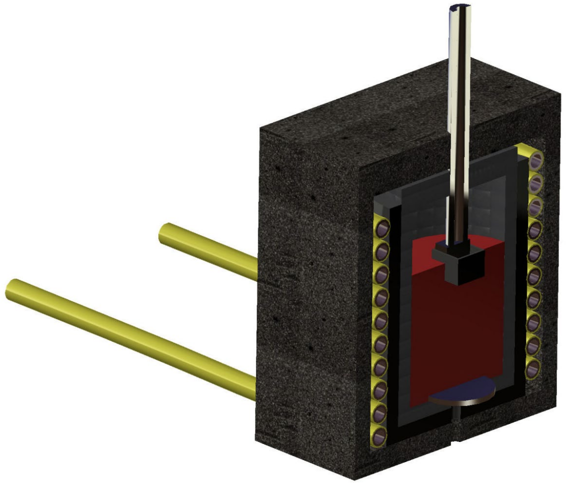
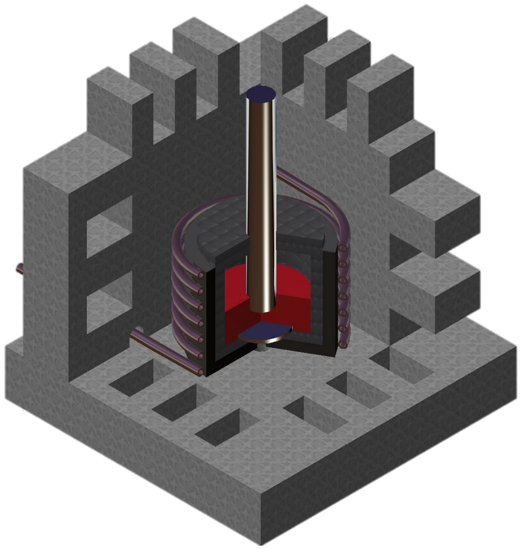
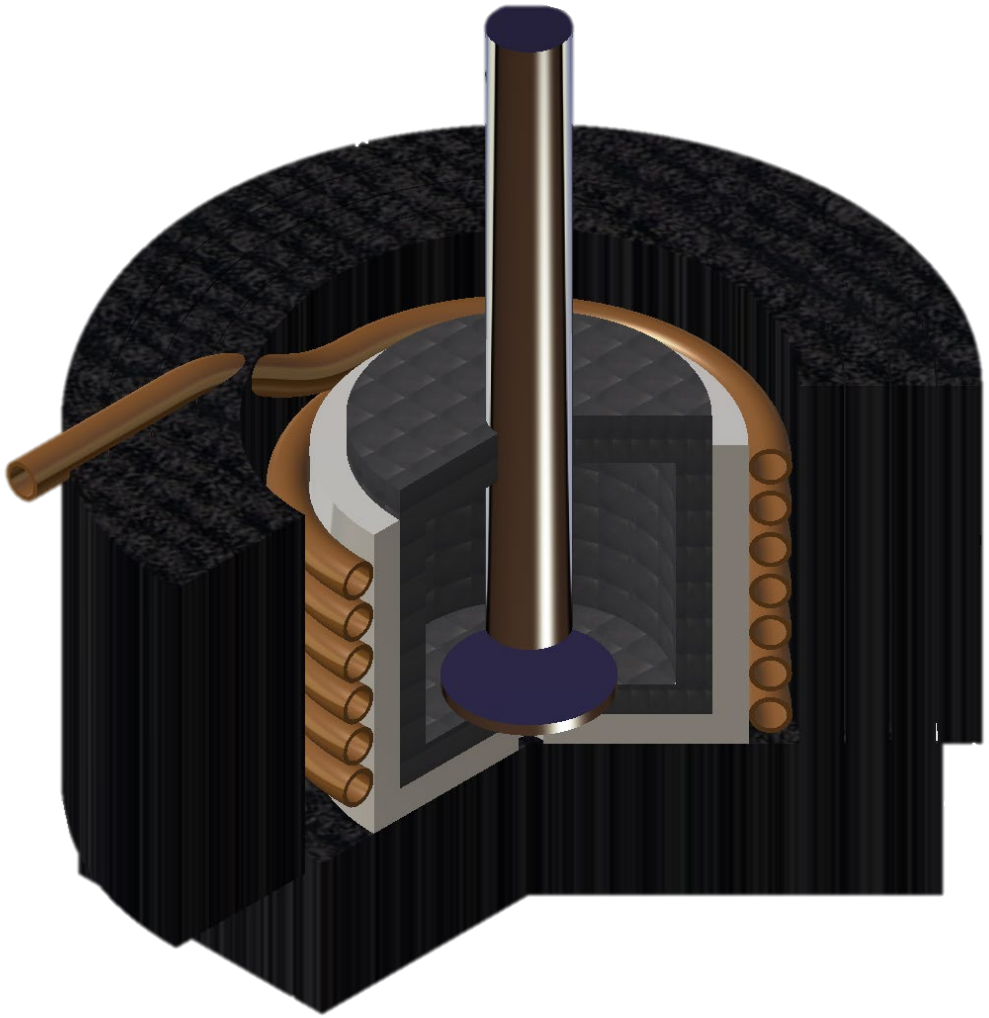


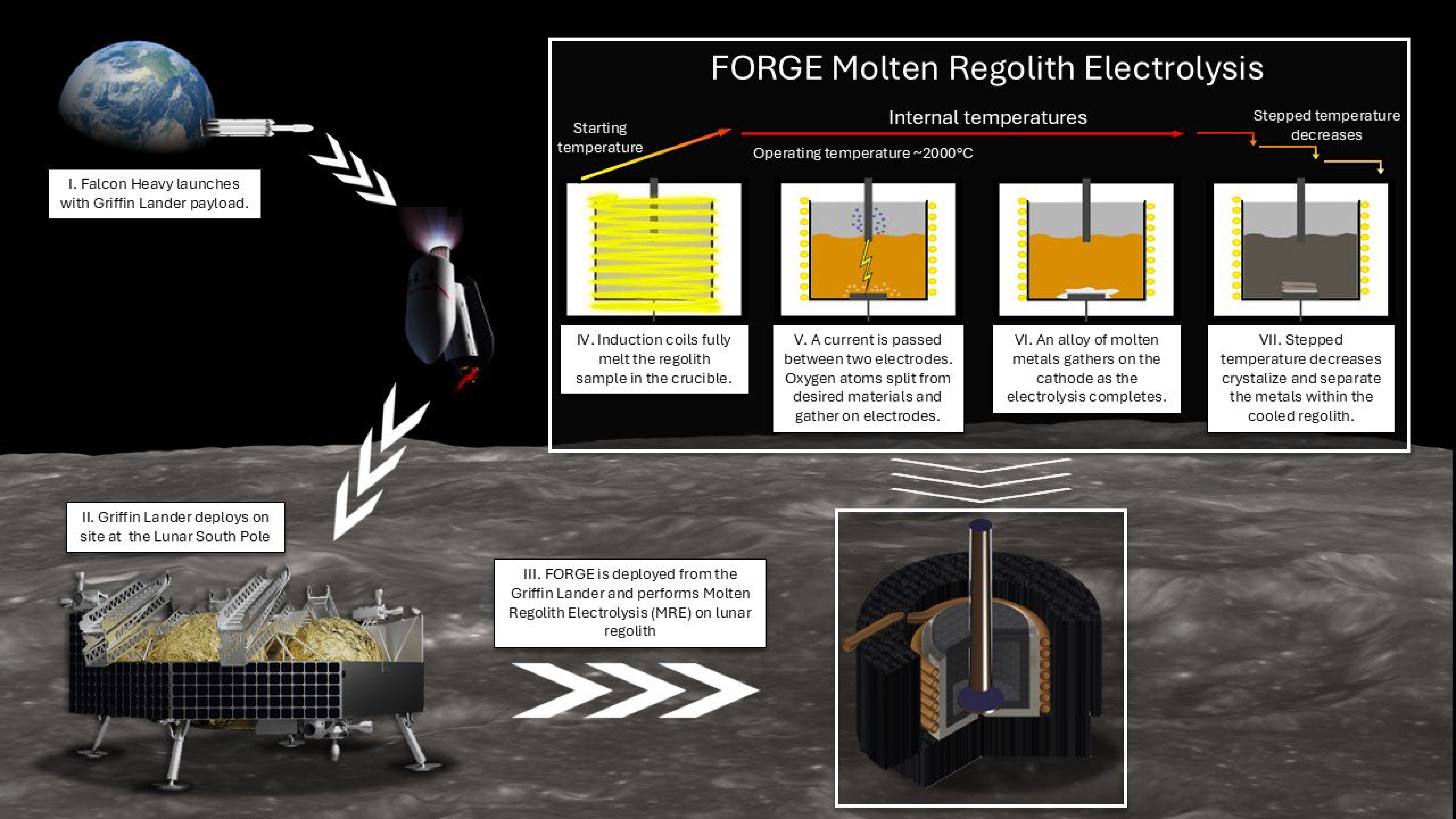




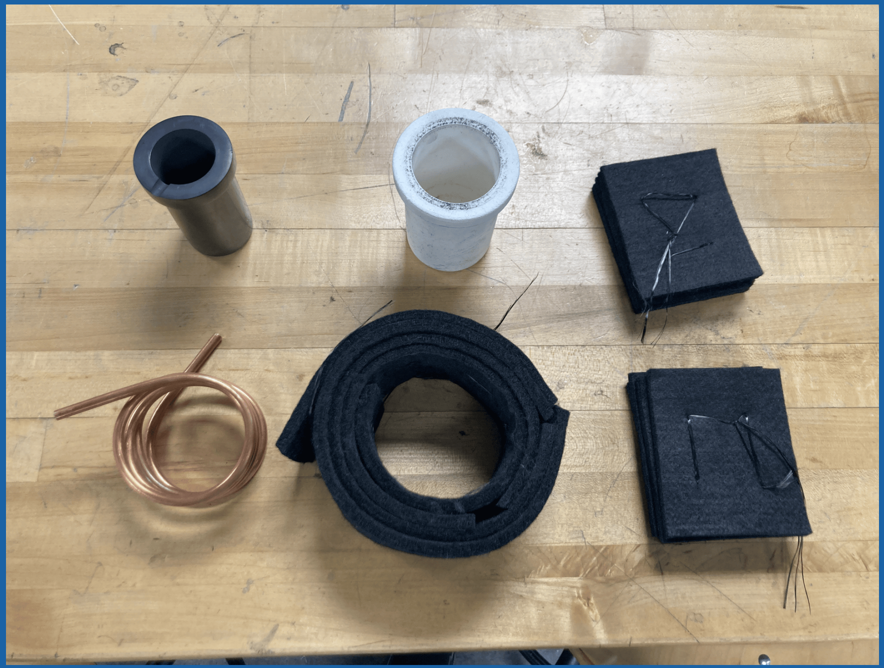


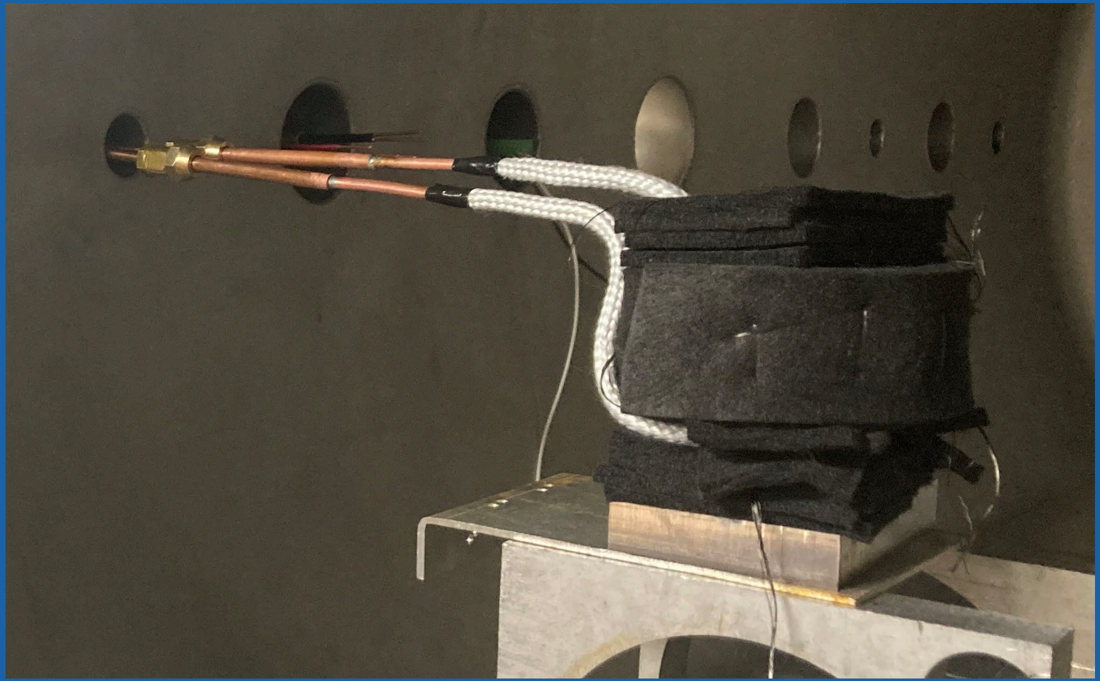
2.1 FTD Assembly Video

2.2 FORGE Concept of Operations


FORGE Molten Regolith Electrolysis
Starting temperature
Internal temperatures
Stepped temperature decreases
Operating temperature ~2000°C
IV. Induction coils fully melt the regolith sample in the crucible.
V. A current is passed between two electrodes. Oxygen atoms split from desired materials and gather on electrodes.
VI. An alloy of molten metals gathers on the cathode as the electrolysis completes.
VII. Stepped temperature decreases crystalize and separate the metals within the cooled regolith.
I. Falcon Heavy launches with Griffin Lander payload.
II. Griffin Lander deploys on site at the Lunar South Pole
III. FORGE is deployed from the Griffin Lander and performs Molten Regolith Electrolysis (MRE) on lunar regolith

Current Iteration of FTD





- Expected to melt 26.4g of LSP-2 in seven minutes
- Induction coils not expected to reach over 100°C
- Graphite insulation not expected to reach over 100°C
- Anode expected to survive 5 hours of MRE

3.2 Risks

- High temperatures required for MRE
- High current required for MRE
- Shorting power through structures or insulation
- Oxidization of crucible and electrodes
- Boiling of LSP-2
- Possibility of poor separation

Debris on Graphite Insulation

Damaged Crucible Insulation and LSP-2 Boil Over

3.3 Data Handling and Comms

- Full Moon Operation
  - Full Autonomous – No required inputs from any user.
  - Required Collaborative Assistance – Feed Lunar Regolith for processing.
  - Bluetooth - Feed Data directly to the Griffin Lander to send back to earth.

- Lab Testing
  - Wire Fed Data - Data collected through wired sensors into a DAQ system to confirm temperature and time operated.
  - In Person interaction – Hand inputs to start, stop, feed, reset the FTD.

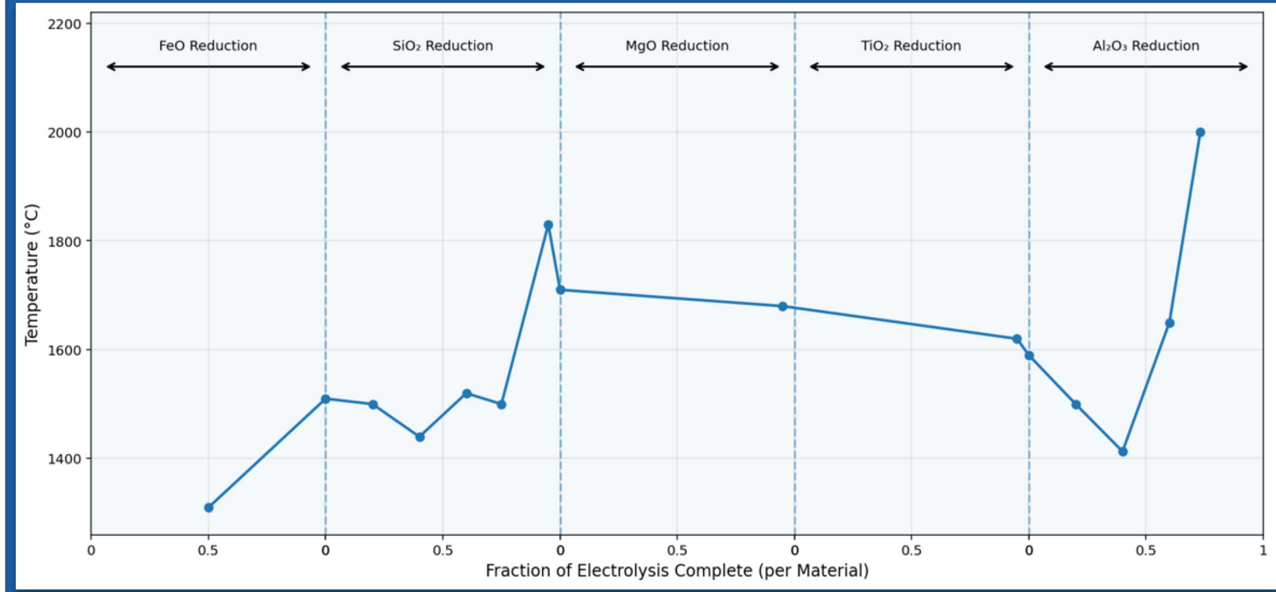
4.1 Most Innovative Concepts

•Stepped Cooling for Metal Separation

•Vacuum-Based High-Temperature Processing

•Integrated MRE + Material Processing System

•Induction Introduces Precise Temperature Control

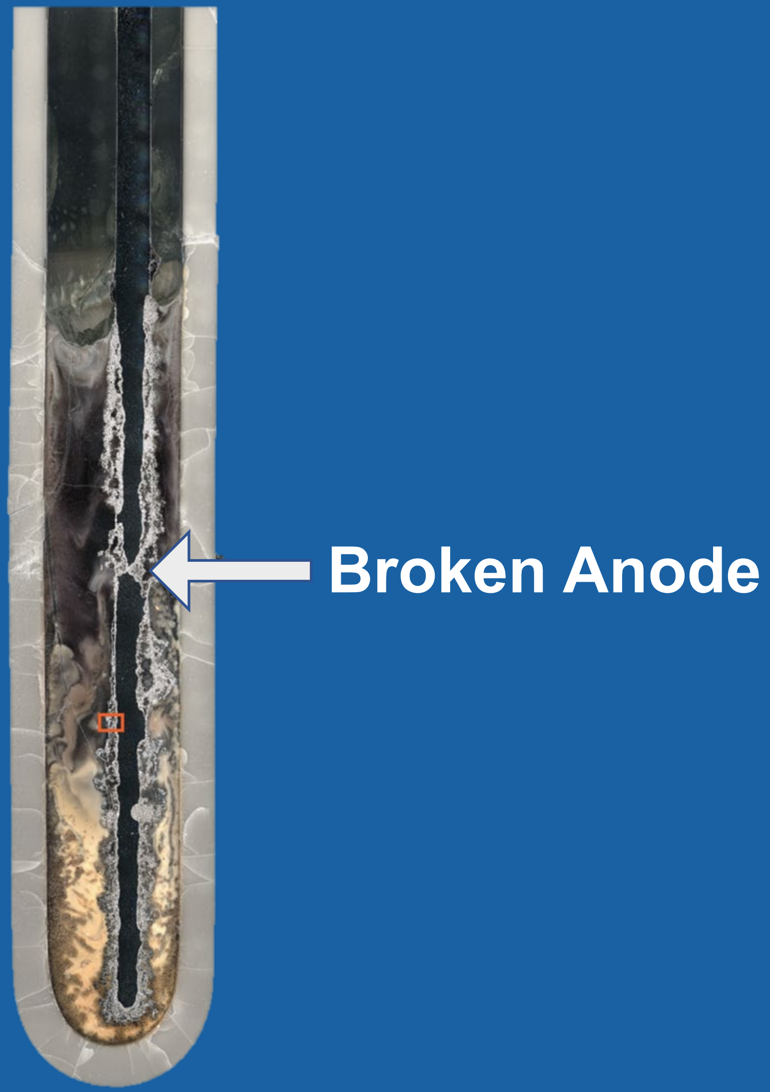


4.2 Most Important Technology Gaps

- Highly Survivable Anodes: Anodes degrade rapidly from oxidation, reusable or longer lasting anodes increase efficiency and confidence
- Autonomous operation: MRE is a heavily monitored process, autonomous operation would make the mission much more feasible
- True Elemental Separation: Full elemental separation makes the mission more viable for manufacturing

Heavily Oxidized MRE Cell

Retrieved from K. Yu Et al. 2025



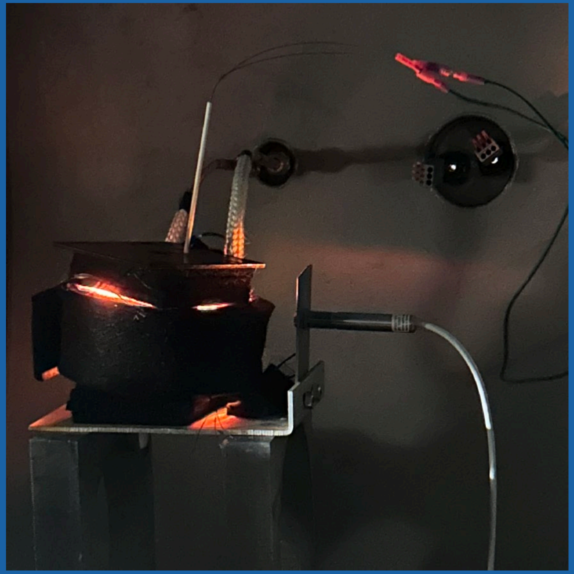
Prototype

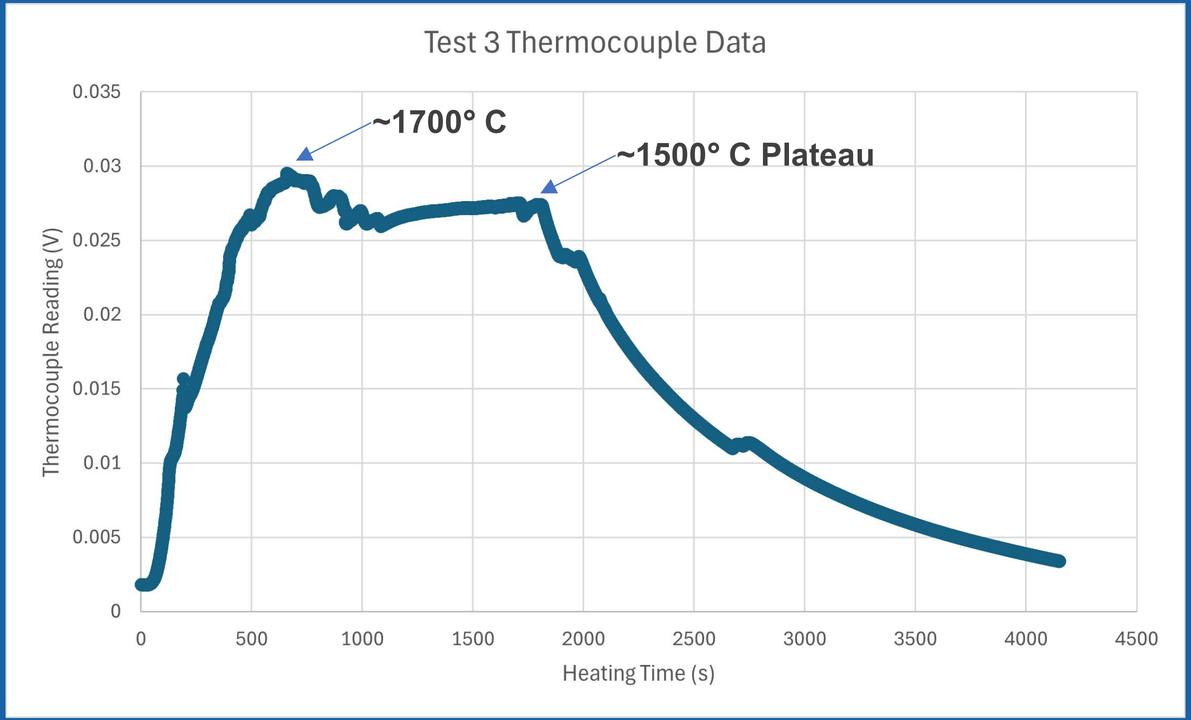
FTD shows promise

- U.S. Solid 15 kW induction heater (4kW operation)
- Vacuum chamber to simulate Lunar environment
- Promising results for tests 1-3
- Quick heating time
- Likely capable of 2000° C

4.3 Biggest Challenges Encountered

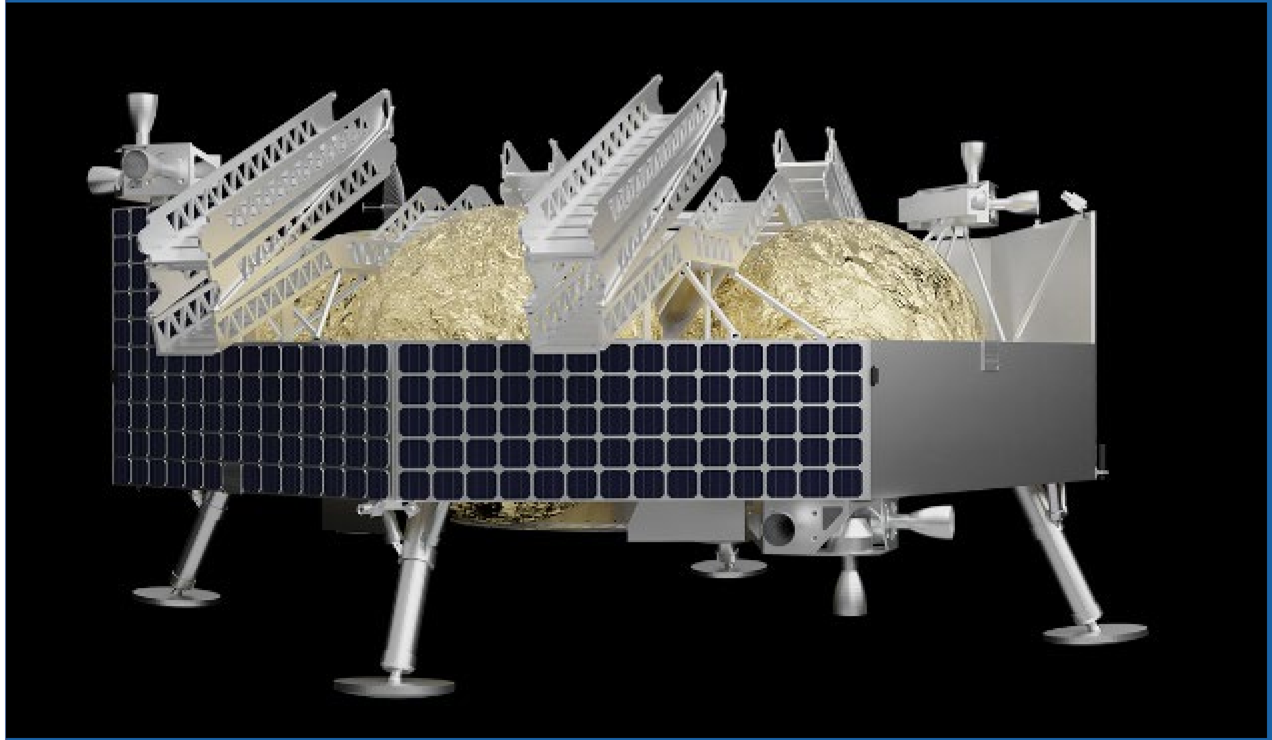
- Temperature Extremes
- Induction Capability
- High electrical current
- Large Power Requirement
- LSP-2 Boiling out of crucibles
- Instrumentation Errors





2.3 Path to PDR

- Upscale FTD
- Integrate all components into a fixed assembly
- Automate Induction and MRE processes
- Design closed loop cooling for use on the Moon
- Design an attachment plate that can affix to and deploy FORGE from the deck of the Griffin Lander



Conclusion and Highlights

FTD is plausible

Conclusion

FORGE has partial prototype constructed, with 3 pieces remaining

FTD has a TRL of 4.71875

FORGE on track to prove viability of ISRU on lunar surface on April 10th, 2026

FORGE will provide a cost reduction option for lunar missions

Highlights

FORGE has completed 3 prototype tests

1. Systems and Electronics Test
2. Temperature Control Test
3. Regolith Simulant Melting Test

Fourth Test (Full Systems Test) scheduled to analyze MRE process in entirety

QUESTIONS?

EMBRY-RIDDLE Aeronautical University FORGE

THANK YOU

Team Forge

Aeronautical Engineering Astro Track

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