Debris to Delta-V: Leveraging Man-Made Space Resources for Mobility

Authors: L. Steinke, A. O'Leary, J. Pawelski, E. Richter, T. Mould, J. W. Schroeder

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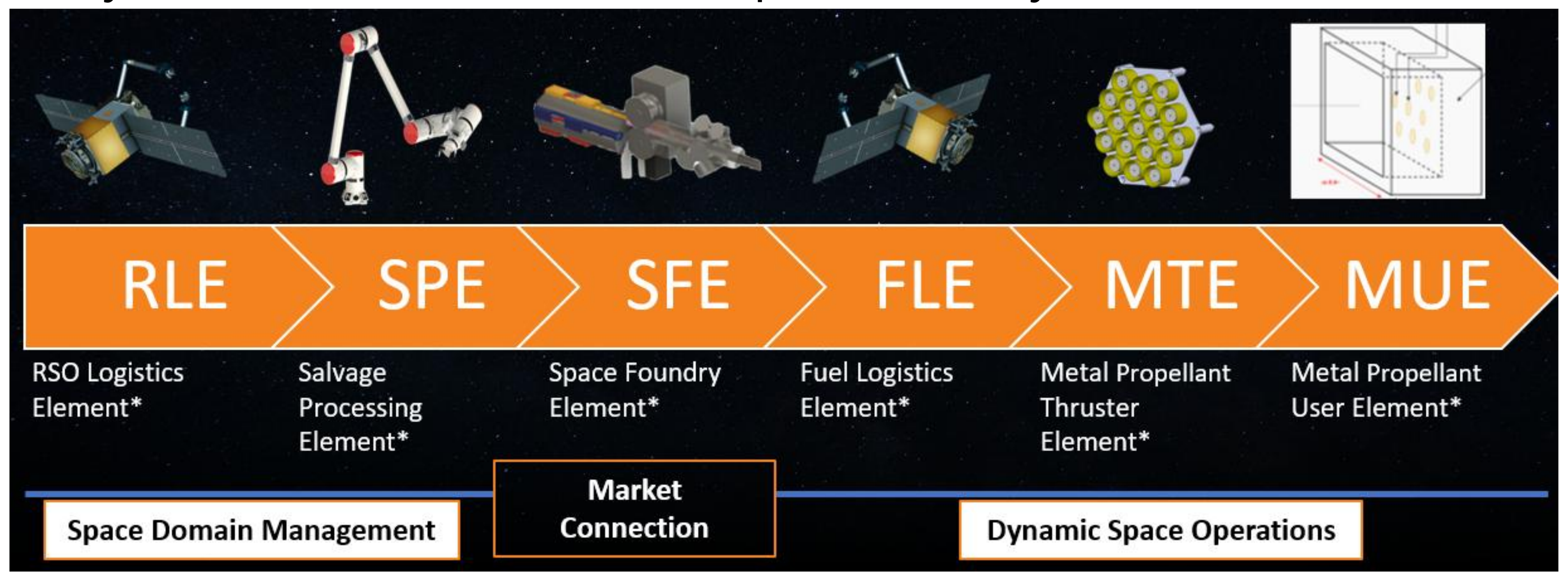
Analysis of Data on the Metal Propellant Ecosystem, Debris to Delta-V



Key Learnings

- It would cost a hydrazine provider 250 times what it would cost an MPE provider to deliver the same amount of delta-v to GEO.
- Just two recycled GEO spacecraft could meet the station-keeping propulsion needs of the entire GEO market
- The slightly poorer performance of aluminum is dramatically offset by its significantly lower cost in space
- A space station's waste metal, if recycled into metal propellant, could meet over half of its own station-keeping delta-v needs

Compounding Cost Savings of MPE
Cheaper Substance
Elimination of Launch Cost
Less Mass for Same Delta-V

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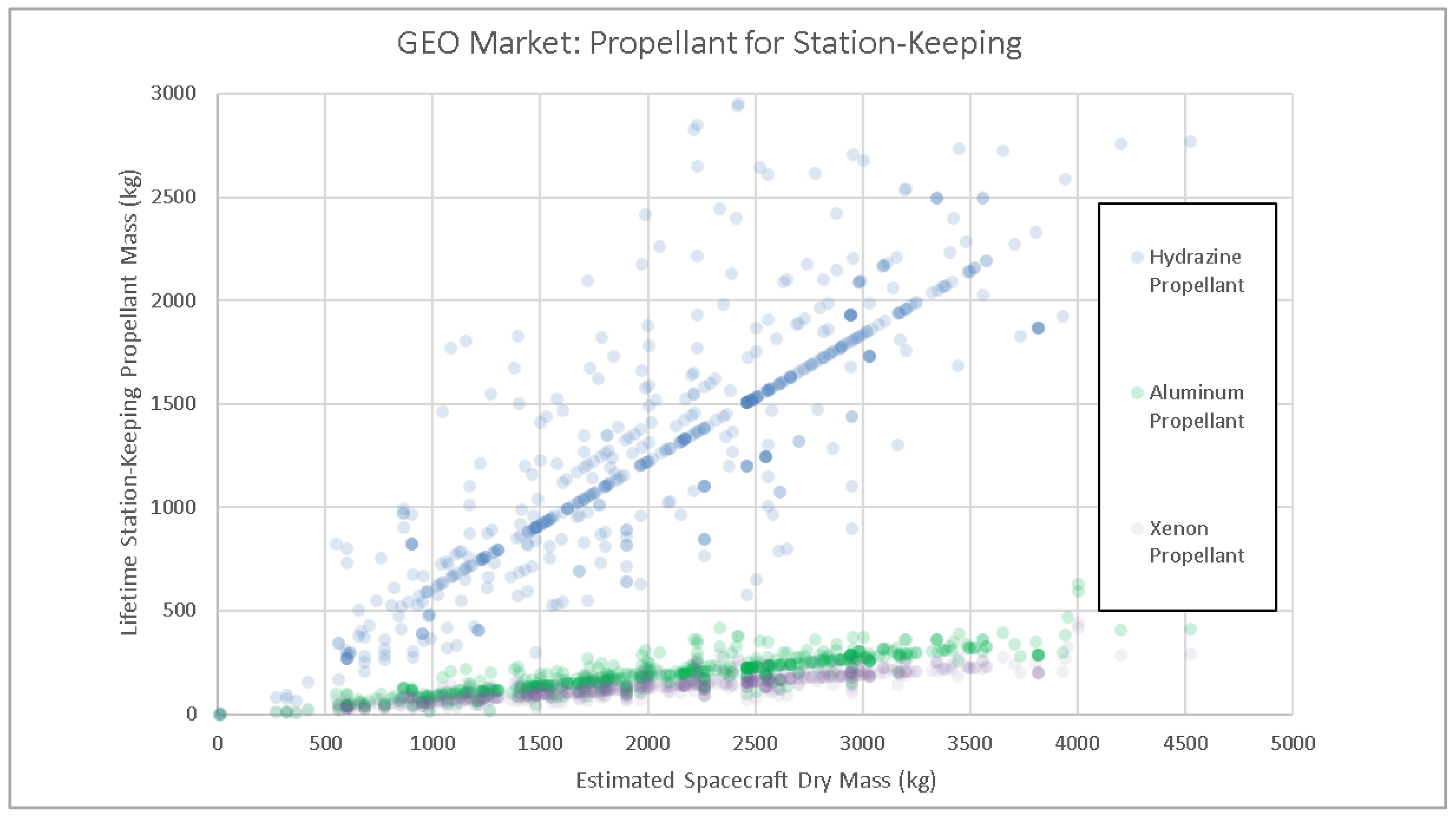


PROPELLANT	ALUMINUM	XENON (S/C Grade)	HYDRAZINE (S/C Grade)
TYPE	EP	EP	CP
$/KG TO PURCHASE ON EARTH *	$1.20 to $3.50	$1,000 to $3,000	$68.81
POSSIBLE STATES DURING OPS	Solid	Gas Liquid Super-critical	Liquid Gas
PERFORMANCE	Low thrust	Low thrust	High immediate thrust
POWER DRAW	500-3000 watts	500-3000 watts	<100 watts
STORAGE	Inert solid rods	Safe to store and handle, but requires high-pressure storage tanks	Toxic, corrosive, careful handling and storage
IN-SPACE TRANSFER	Low Risk	High Risk	Medium Risk
APPLICATION SUITABILITY	Long-duration mission, high efficiency	Long-duration mission, high efficiency	Agility, precise 6 degrees of freedom attitude & translation control
SPECIFIC IMPULSE	High	High	Low
THRUST SOURCE	Ablation	Ionization	Chemical reaction
PROPELLANT CONDITIONING REQUIRED	No	Yes	Yes
ADVANTAGE	Easy to handle, cheap, high efficiency	Extremely efficient	High thrust
DISADVANTAGE	Low thrust, low TRL	Lower thrust, phase management	Toxic, corrosive

	Relative Cost per Unit of Delta-V to Providers of Xenon Architecture	Profit Margin on Aluminum Pricing Set by Discounting Xenon Architecture Cost by 50%	Relative Cost per Unit of Delta-V to Providers of Hydrazine Architecture	Profit Margin on Aluminum Pricing Set by Discounting Hydrazine Architecture Cost by 50%
LEO-Sourced Aluminum in LEO	1:8	298% or ~3X	1:17	~8X
GEO-Sourced Aluminum in GTO	1:15	~6X	1:111	~57X
GEO-Sourced Aluminum in GEO	1:29	~12X	1:250	~111X

Other Space Resources Related Accomplishments from CisLunar Industries

Lunar Extruder

Introduction

- Challenge: NASA needs in-situ manufacturing to reduce lunar supply chain costs.
- Goal: Enable 3D printing and repair capabilities using lunar resources (e.g. recycled metals or by-products of oxygen production)
- Solution: Lunar Extruder produces aluminum wire from molten metal in a vacuum—simulating lunar conditions.

Methods

- Designed and built a bench-scale extrusion machine capable of forming small diameter wire for additive manufacturing
- Develop a casting system capable of producing billets for extrusion
- Operate casting and extrusion system in vacuum chamber with automated transfer of billets from casting to extrusion

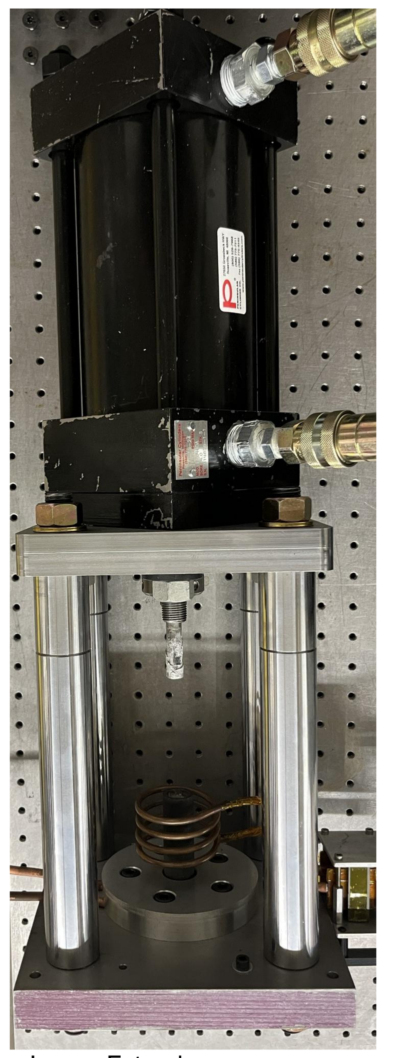
Results

- Successfully extruded continuous lengths of 1.2mm and 2.5mm diameter aluminum wire from multiple billets.
- Demonstrated casting of aluminum billets in vacuum chamber at 10^{-6} Torr
- Bench tests verified system operation; billet transfer mechanism functional, with reloading system integration underway.

Discussion

- Demonstrated the feasibility of wire production from molten aluminum in vacuum.
- Remaining work: Complete cast to extrusion integration with billet transfer system. Full system vacuum test.
- Future development: Improve process instrumentation and automation. Optimize structure to reduce mass. Change actuator to self-contained system.

Extruded Samples



Lunar Extruder

Modular Space Foundry (MSF) Integrated System: Microgravity Testing Through Parabolic Flight

Technological Need

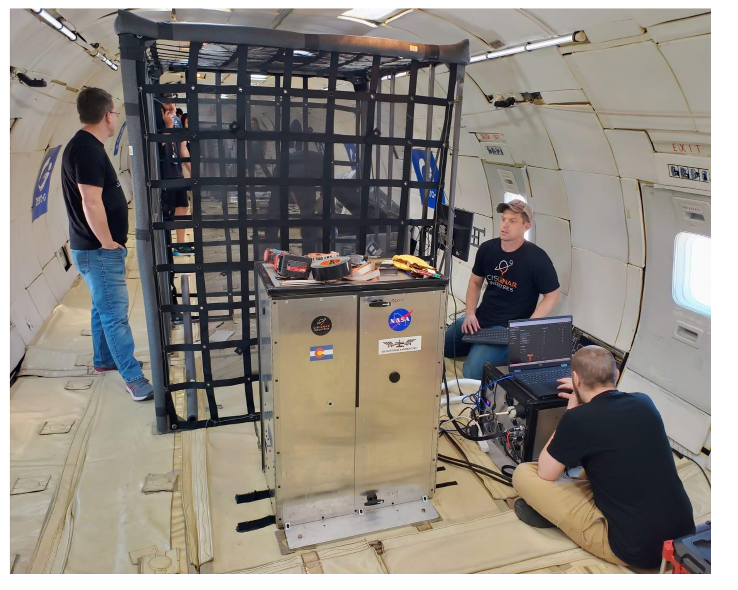
- **Permanent lunar habitat:** Processing metal in-space and on celestial bodies is an important technological keystone with the planned return and habitation of the Moon within the decade.
- **Commercial technological infancy:** Off-earth commercial metal processing has only a limited number of companies working on it; especially so when focused on metal melting, manipulation, and casting technology.
- **Current technology is unscalable:** The materials science foundry (EML-MSL) on the ISS is a scientific payload limited to very small size samples with no processing capabilities.
- **ISAM requires power levels not flight qualified yet:** Not only do metal processing technologies need to be developed, but an entirely new approach to space power systems needs to be developed for this new scale of power demands.

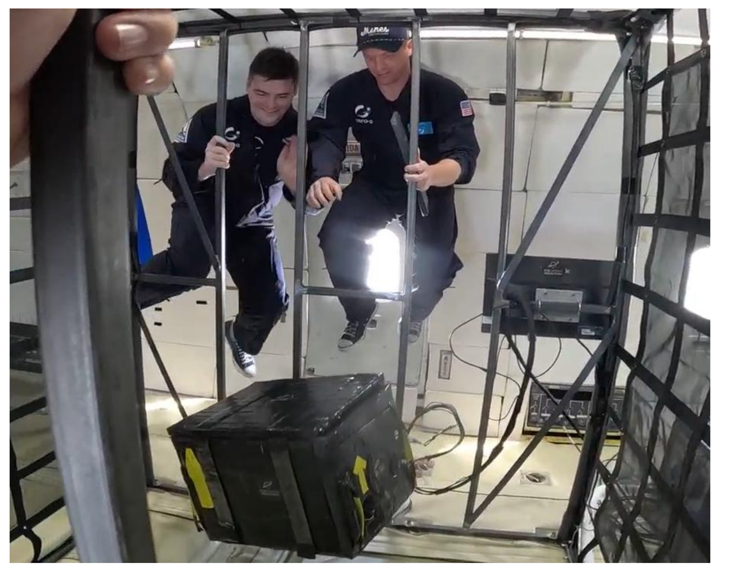
Technology Concept -MSF was developed as discrete modules:

- **MSF-Cast:** melt and cast process portion - An induction heater, cooling, and a modular sample-mould assembly for rapid sample switchout to test casting parameters in µg.
- **MSF-Steer:** contactless maneuver process portion - A battery of induction coils with fine software control to assess magnetic metal control parameters in µg.

Innovation

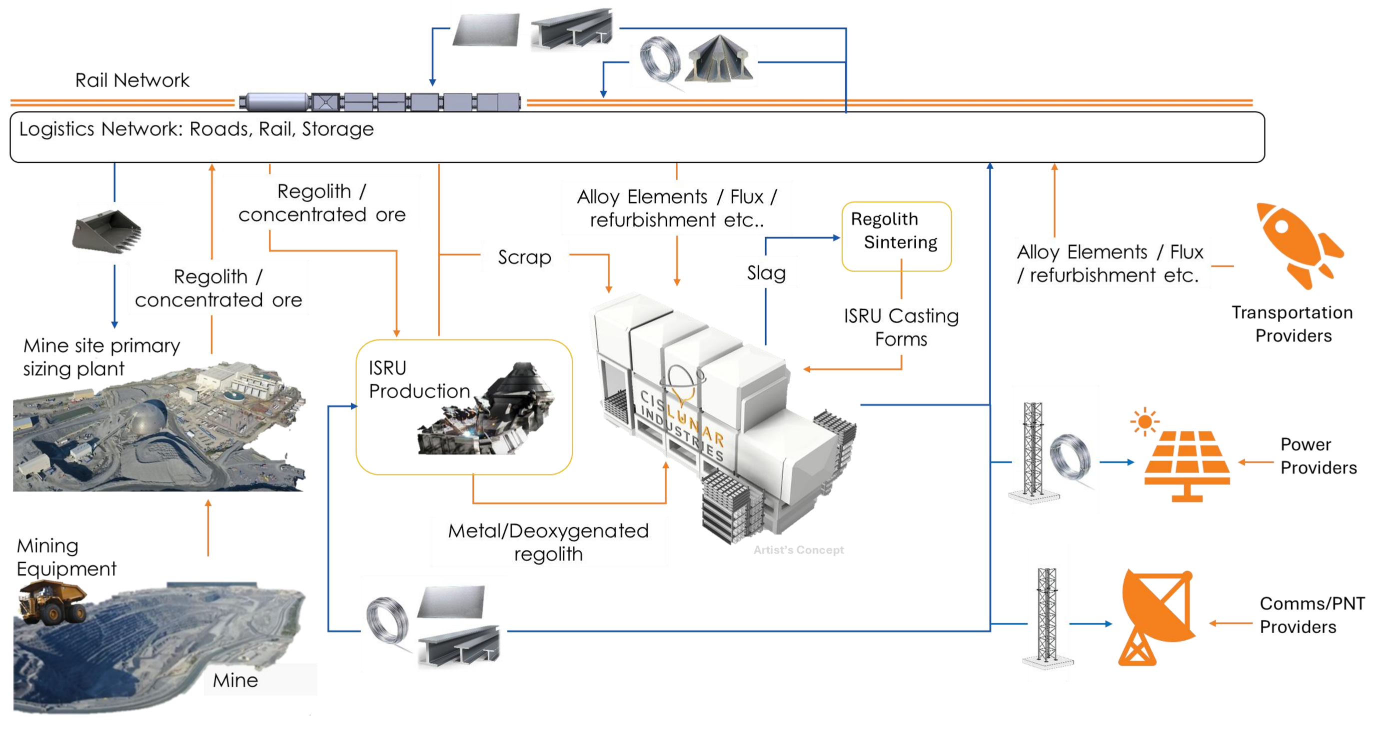
- **Increased keystone technologies TRL:** larger scale of µg metal melting, forming, and movement. Progression toward permanent off-world usage.
- **Created paradigm-shifting power system:** created new, efficient power system to meet high-power challenges which has wide applicability and has been spun out as an independent product line.
- **Precision control over metal position:** using magnetic fields opens spin-out opportunities.





METAL – Material Extraction, Treatment, Assembly & Logistics

ISRU Value Chain Overview



CisLunar Industries Lunar Space Foundry (LSF)

Building infrastructure and enabling sustainable mining operations