

METAL PROCESSING. IN SPACE. FOR SPACE.



Building the First Modular Space Foundry Prototype
A Path to Transforming Space Debris into a Resource

Space Resources Roundtable 2022

June 8, 2022

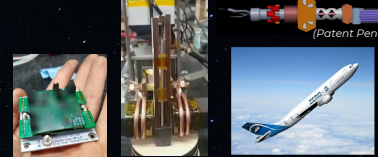
Joe Pawelski
Co-Founder and CTO

cislunarindustries.com

The Moment Has Arrived ...



(Patent Pending)



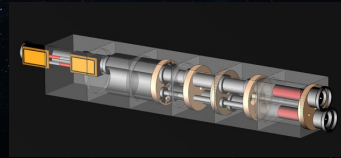
2022 – Liftoff !

NASA Phase 2 SBIR
CO Advanced Industries
Grant
More Outside Investment
Seraphim Space Camp
Parabolic flight test of
Micro-g Continuous
Casting
Specific Customer Use
Cases



2021 – Ignition

Win and Execute
Successful NASA Ph 1
SBIR
1st Outside Investment
Concept to Working
Prototype
Live Demo Debris
Recycling Value Chain



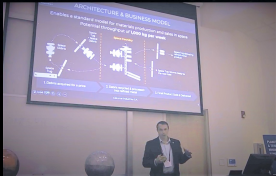
2020 – Inflection Point & Key Innovation

Invented Modular
Space Foundry (MSF)
NASA SBIR subtopic
perfect for CisLunar
Joe joins team



2019 – Concept Iteration

Presented
Space Foundry
Lab Module
at SRR



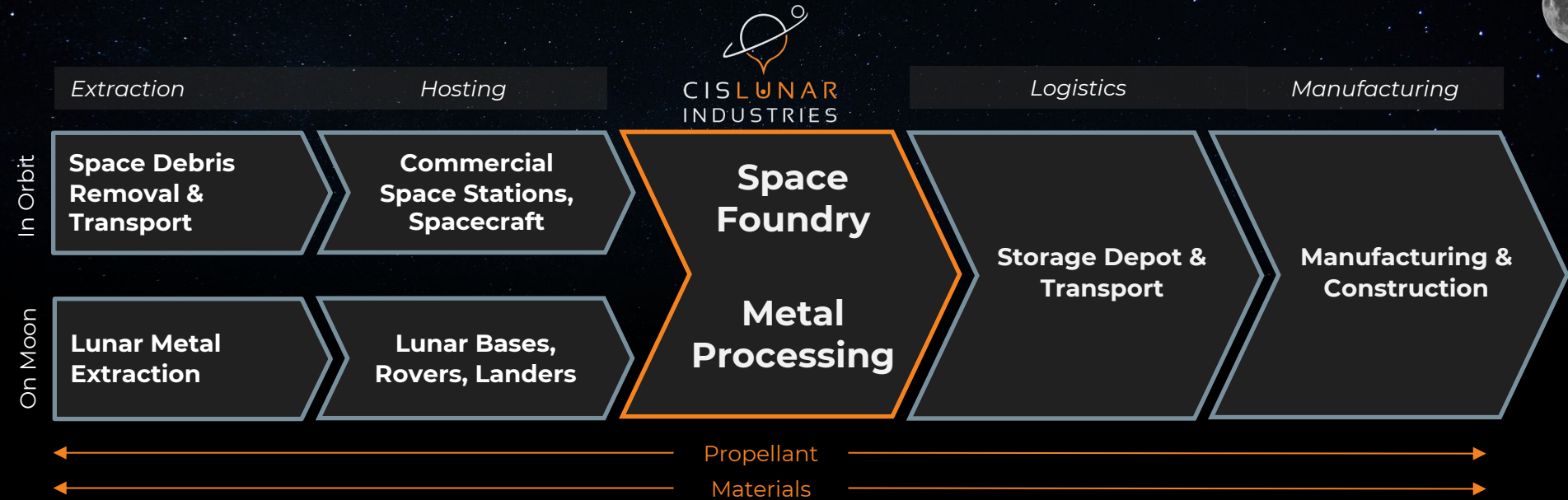
2018 - Concept

Presented
Space Foundry
at SRR

Metal processing. Foundation for the modern economy.



Metal Processing Is Critical To the Next Industrial Revolution



Enables Use of Space Debris as a Space Resource

Upper stages in LEO & GEO

\$5B to \$12B of potential material value

LEO (Low Earth Orbit)

>1,300,000 kg

>900 stages

Assume **\$1k/kg to \$5k/kg**

Near-GEO (Geosynchronous Earth Orbit)

>480,000 kg

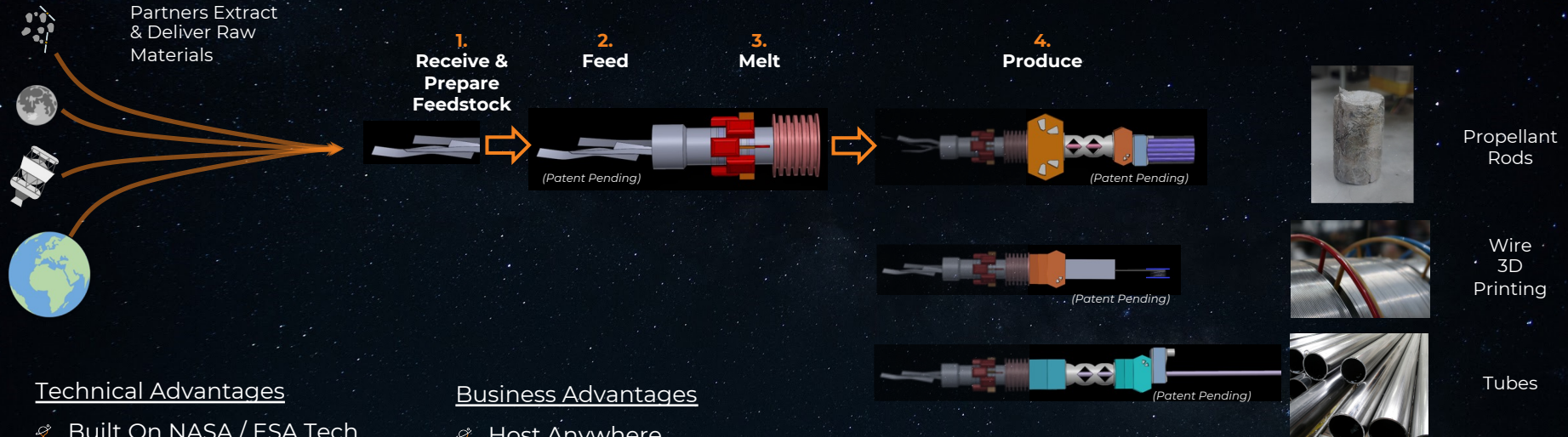
>250 stages

Assume **\$10k/kg to \$15k/kg**



Modular Space Foundry (MSF)

How It Works



Technical Advantages

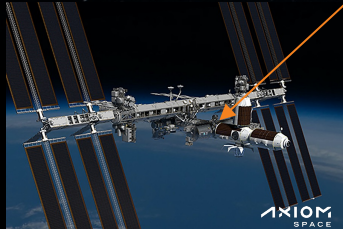
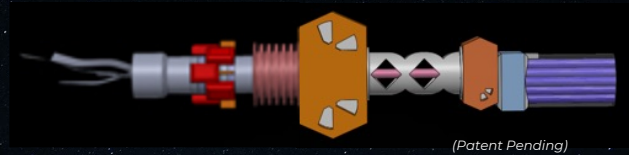
- 🚀 Built On NASA / ESA Tech
- 🚀 Multiple Feedstock Sources
- 🚀 Low Power / Low Mass

Business Advantages

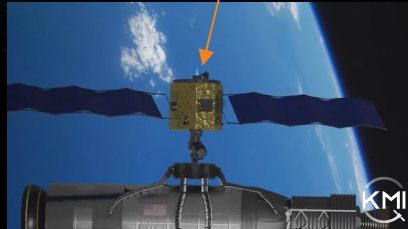
- 🚀 Host Anywhere
- 🚀 Modular
- 🚀 Scalable

Modular Space Foundry (MSF)

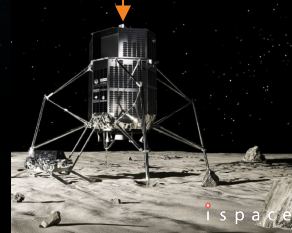
Host Anywhere



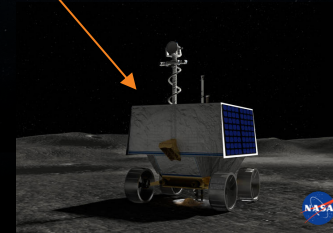
Space Stations



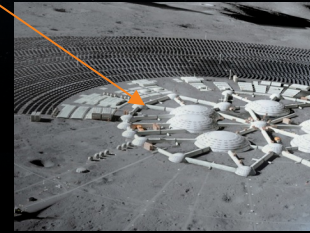
Debris Removal Spacecraft



Lunar Landers



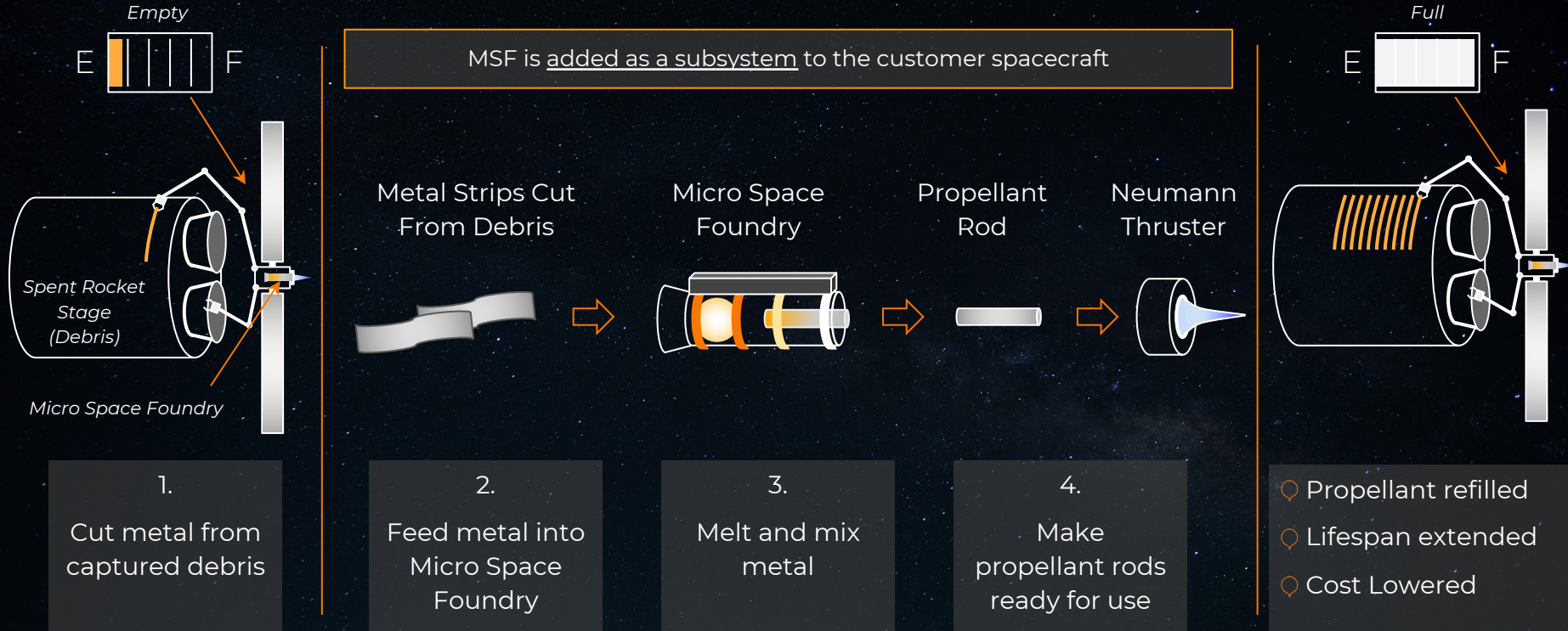
Lunar Rovers



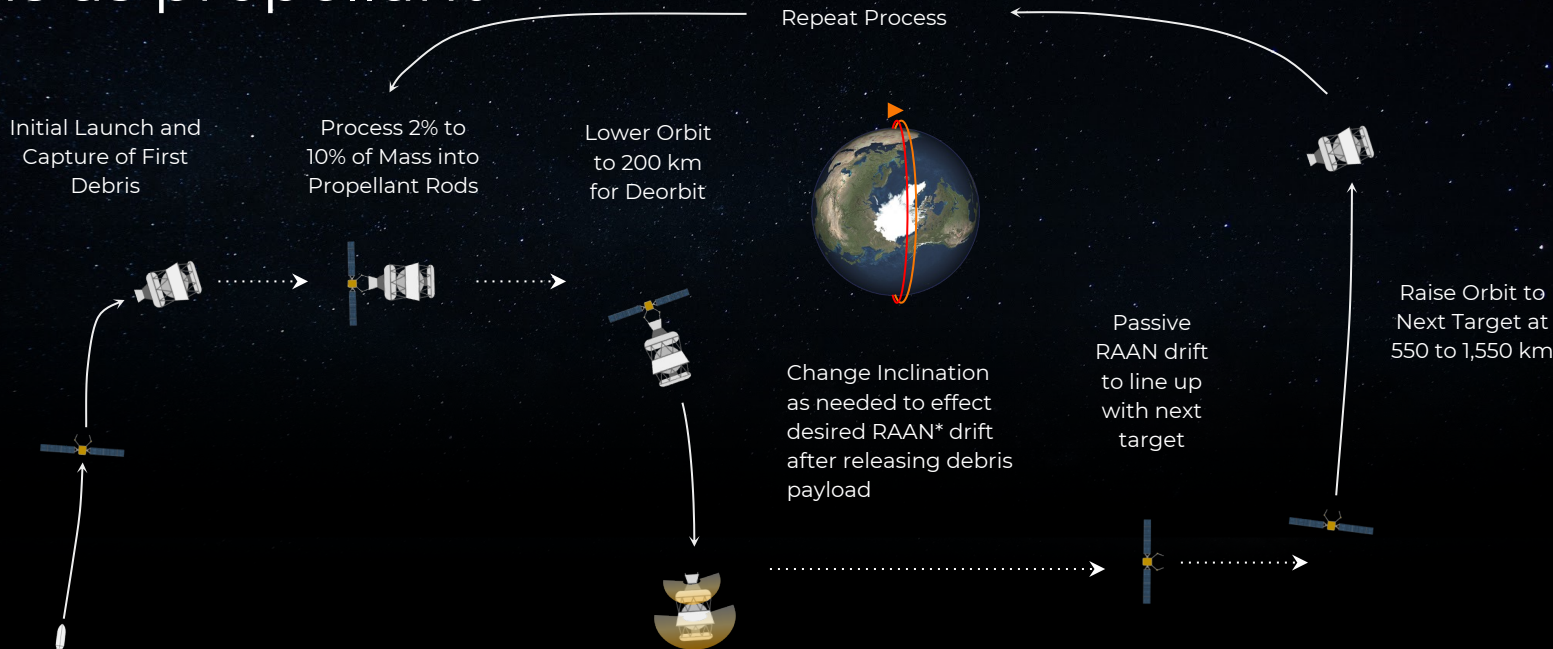
Lunar Bases

Debris to Delta-v

An onboard MSF transforms metal from captured debris into propellant allowing a customer spacecraft to **refuel itself** for the next mission



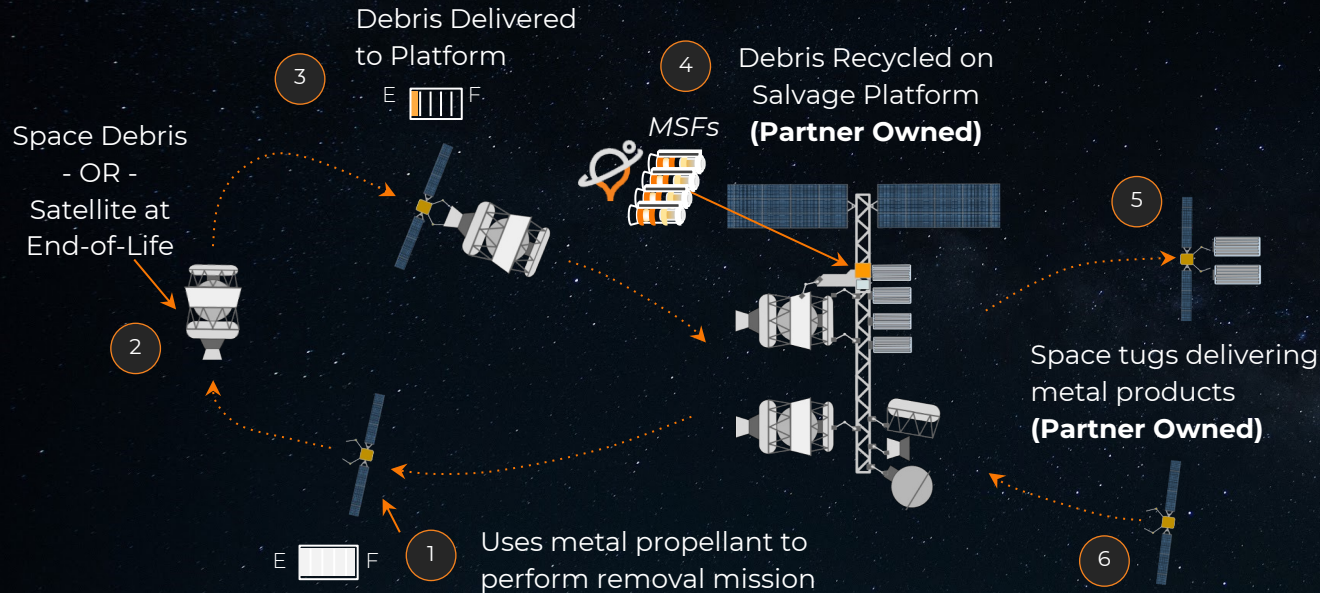
Debris to Delta-V Mission Profile: MSF + Neumann Thruster for LEO active debris removal w/ recycled debris as propellant



*RAAN is Right Ascension of the Ascending Node, meaning the equatorial longitude where orbit changes are made

Debris Recycling

Debris removal becomes a profitable commodities business:
Recycle space debris at space stations to produce key materials for sale to the emerging In-space Servicing, Assembly, and Manufacturing (ISAM) industry

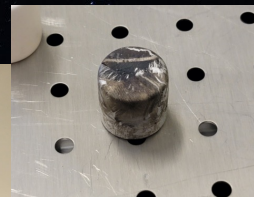
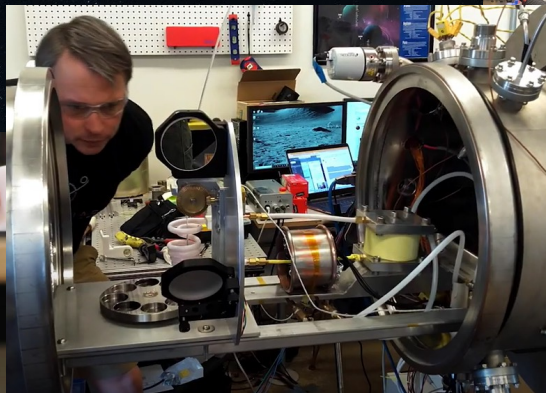
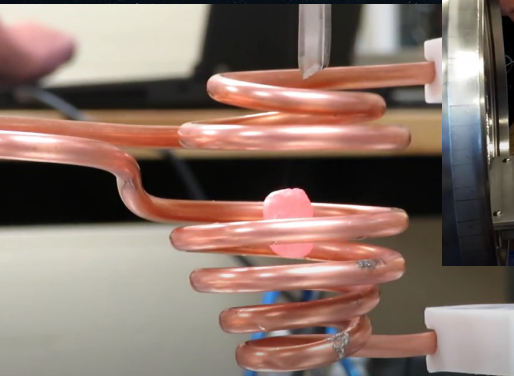
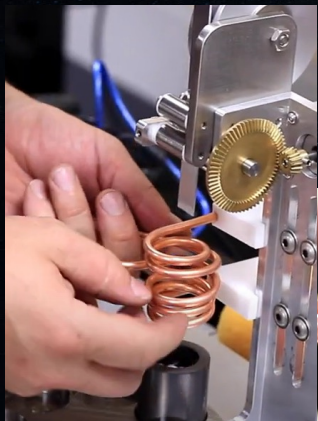


🚀 **CisLunar is focused on metal processing**

🚀 Partners provide space “real estate” and utilities

🚀 Partners provide space “trucking”

Building the First Prototype

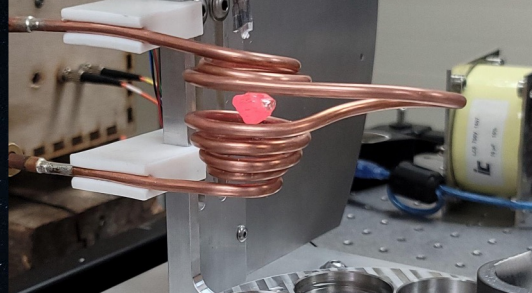


6 Months - Concept to Prototype



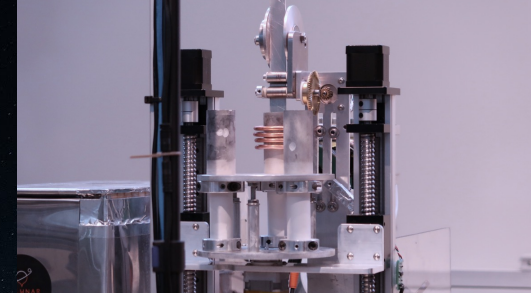
May 2021
Maker's Garage

June 2021
Garage Lab



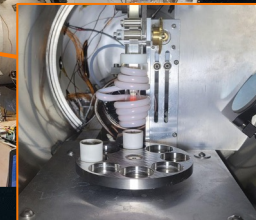
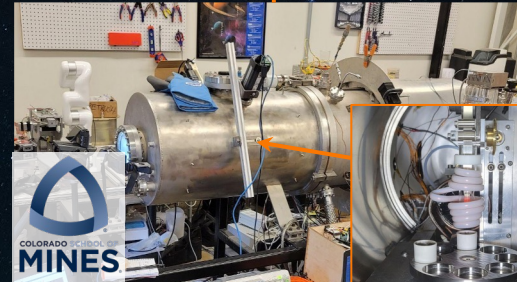
July 2021
Levitation Melting

August 2021
Vacuum Testing



October 2021
MSF Prototype

Ph1 SBIR Team



Key Findings – NASA P1 SBIR

Key Findings

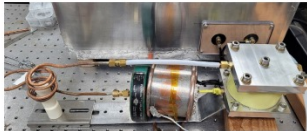
- 🚀 Lots of aluminum in older upper stages, Agena, Zenit, etc.
- 🚀 Strips not chips,
 - *energy requirements similar to terrestrial recycling
- 🚀 "Crappy Casts" Still work for VAT
- 🚀 Sample microstructure on par with typical casts



Induction Furnace Power Supply

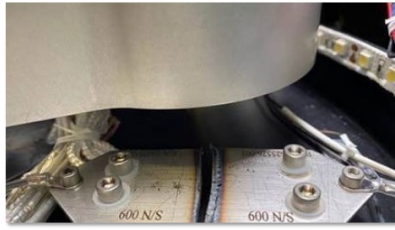


Primary Induction Circuit



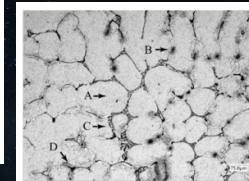
Induction Furnace Power Supply Internal

Figure 4. Induction Furnace Components.



1. Aluminum propellant rod in pulsed plasma thruster test bed.

Sample	Environment	Form	Observations	Image	Micrograph (500x)
1	Air @ 1 atm	Ribbon	Control		
2	Air @ 1 atm	Rod	25mm diam		
3	He @ 200 Torr	Rod	25mm diam		
4	He @ 200 Torr	Rod	25mm diam		
5	He @ 200 Torr	Rod	25mm diam		
6	Air @ 1 atm	Rod	Pulse mix test - resulted in cracking		
7	He @ 18 mTorr	Blob	Sample corresponding to Mg deposit (9)		
8	He @ 60 mTorr	Blob	Observed Mg evaporation		
9	He @ 18 mTorr	Tube Coating	Mg deposition on quartz tube from Sample 7		
10	He @ 65 mTorr	Blob	Least pressure without Mg evaporation		
11	He @ 200 Torr	Puck	Control for 200 Torr rods		
12	Air @ 55 mTorr	Blob	Mg Evaporation		

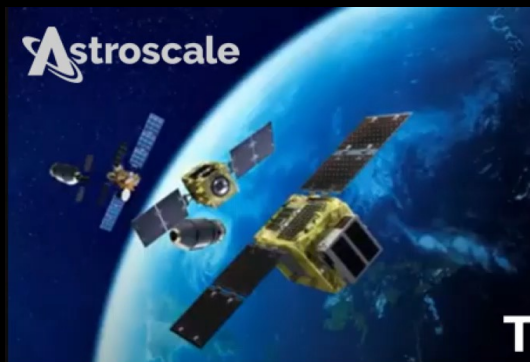


Sample #6 sidewall showing traditional cast appearance of 6061 alloy including primary alpha aluminum and interdendritic phases typically seen in the as-cast microstructure. Location A indicated primary alpha; location B indicates (Fe,C,Mn)3Si/Al12; location C indicates ternary eutectic; location D indicates Mg2Si.



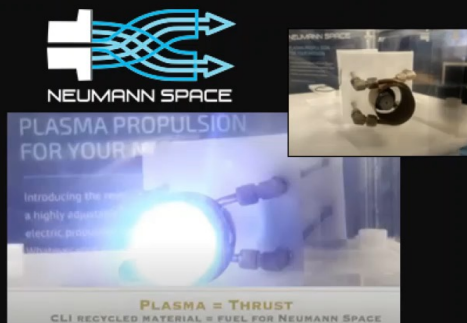
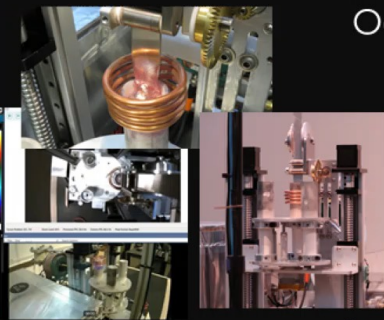
Micrograph of cast 6061 showing Mg₂Si, complex intermetallic, and ternary eutectic phase. From Skollanos et al., Materials Science and Engineering A231 (1997) 17-24

Demo Video

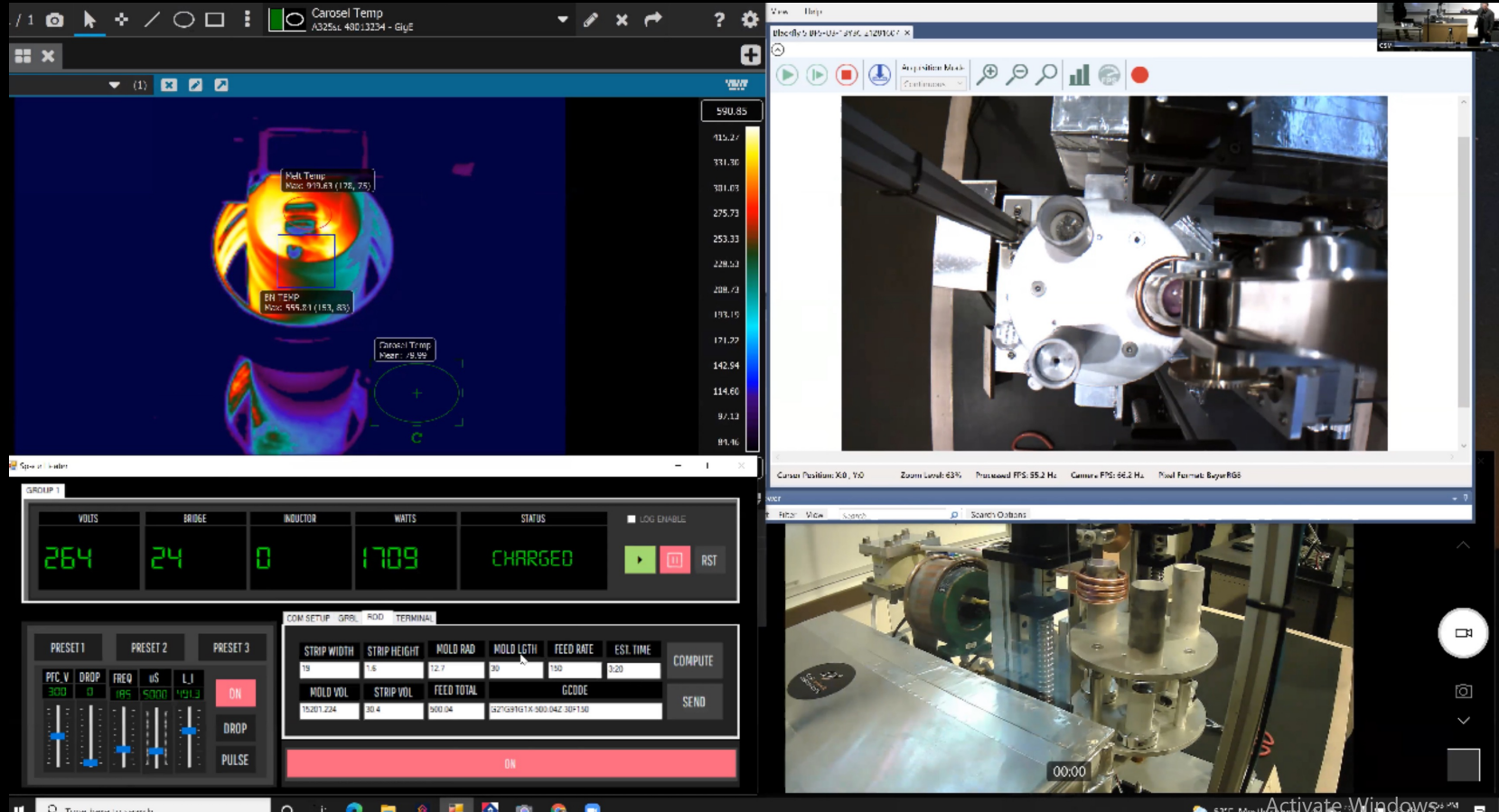


Trash to Treasure Space Debris Recycling Ecosystem

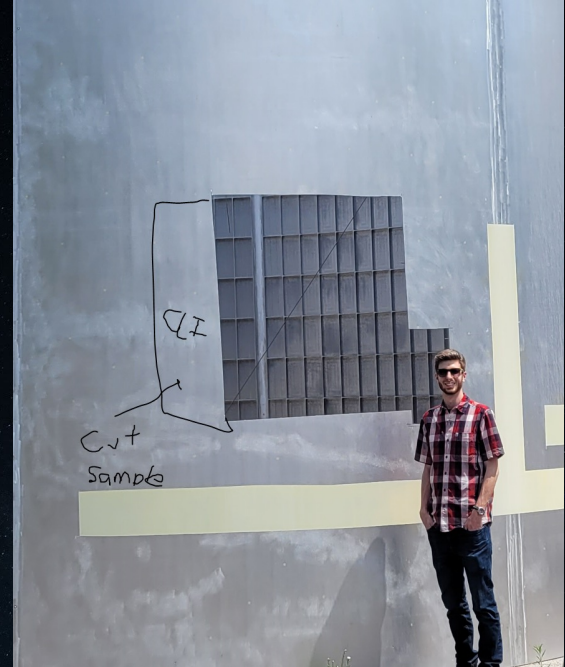
Live Demonstration
October 19, 2021



Demo Screen View



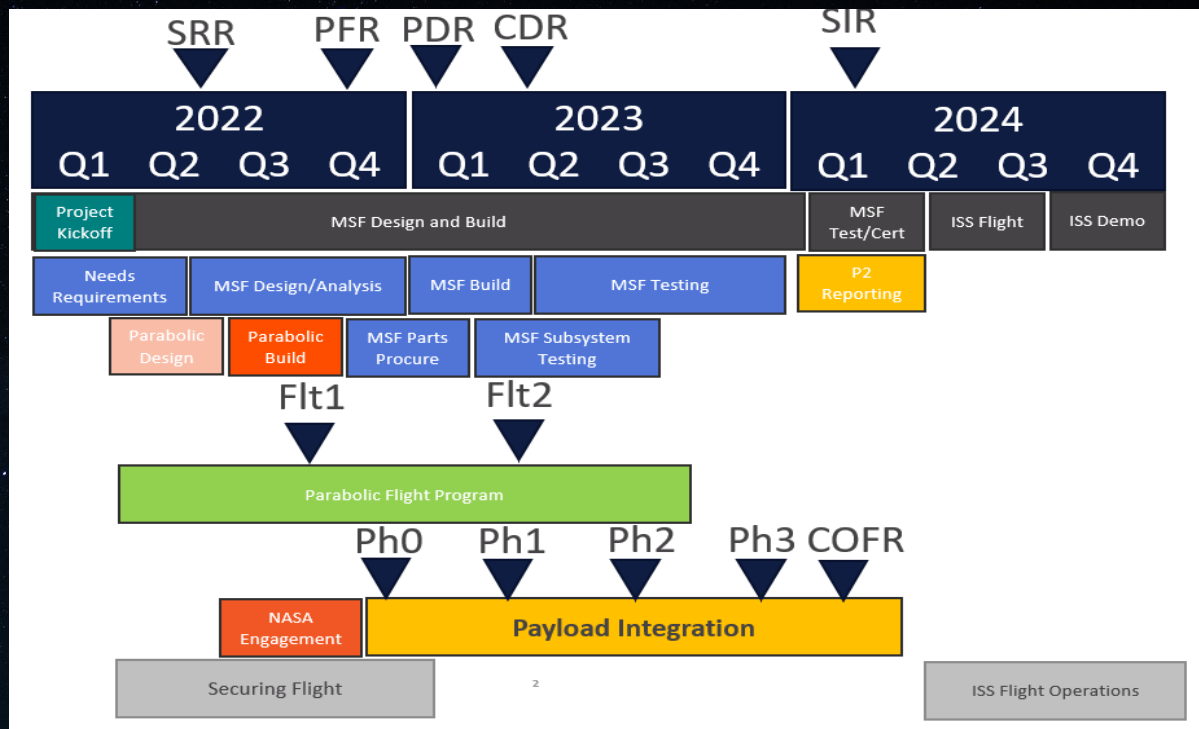
Path to Processing Metal In Space



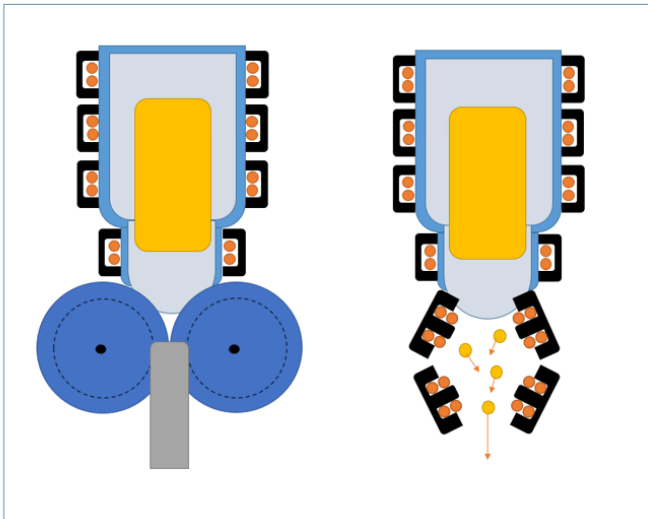
NASA Phase 2 SBIR



Ph 2 SBIR Team



Micro-G Continuous Casting Parabolic Flight Demo



Enclosed in inert gas environment EMI + Heat Shielding, ~ 3000 Watts x 2 units

Aluminum Enclosure/ Vacuum Chamber

Experiment 1:

- Furnace 1/3 kg Al Pre-Melted
- Sustain Melt Temp
- Control Discharge with Coil

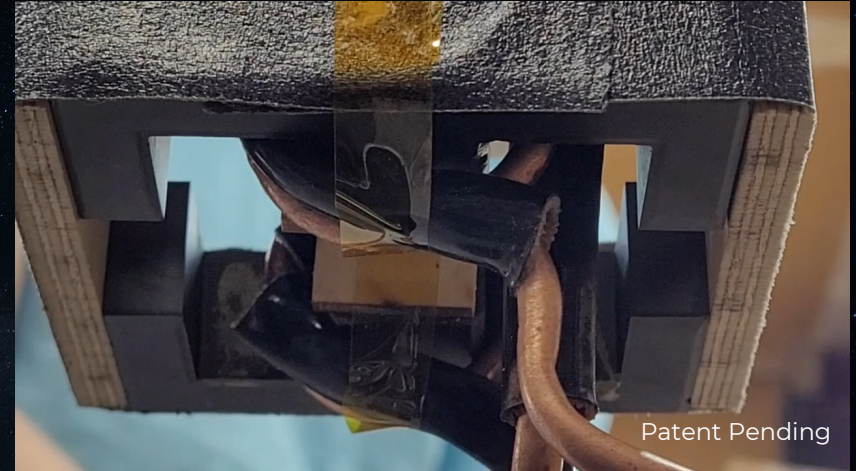
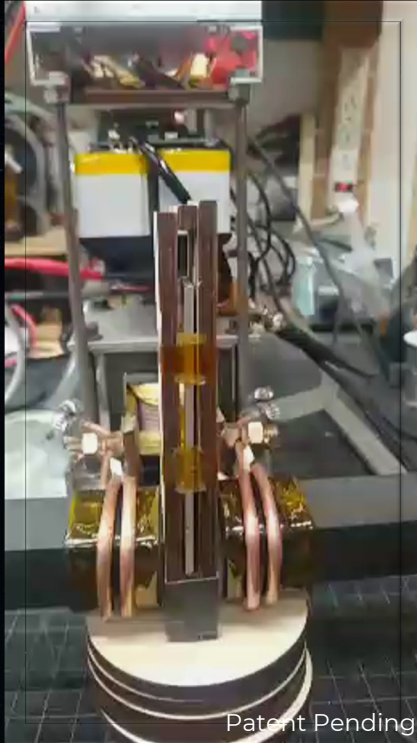
Experiment 2:

- Continuous Cast 25mm rod

Experiment 3:

- Feed and Steer

P2 Tech Updates

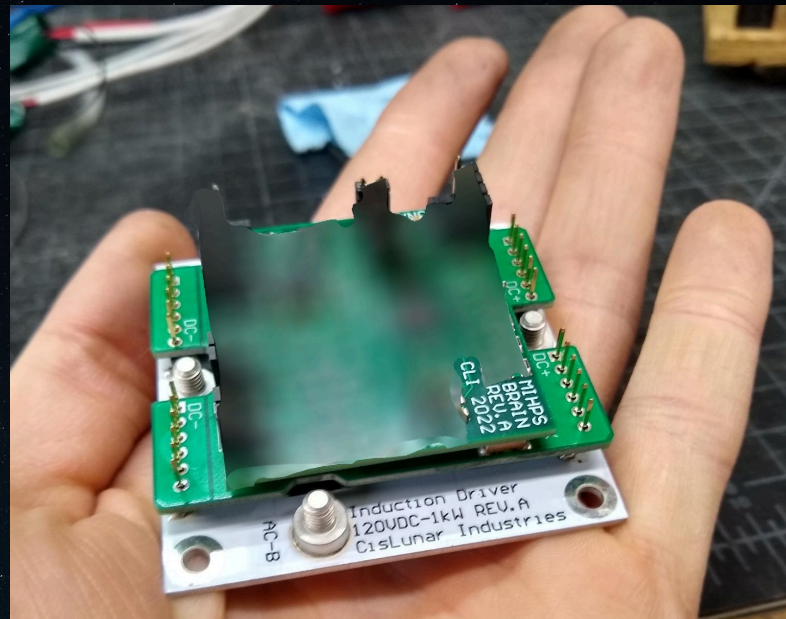
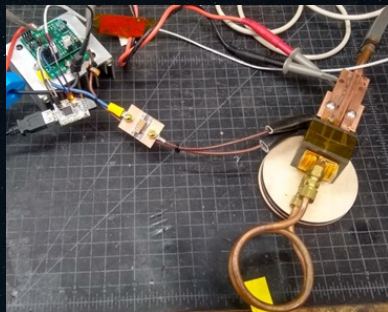


Cutting Edge Power Supply

Built for Space Foundry, Available for Other Applications

- 🔊 **Dimensions:** ~ 60mm x 60mm x 60mm, ~0.25 kg
- 🔊 **Input:** 120VDC, 8.33A, 1kW
- 🔊 **Output:**
 - 1-120 VAC
 - 15 Apk
 - 1-500 khz

Potential Applications ?





Questions

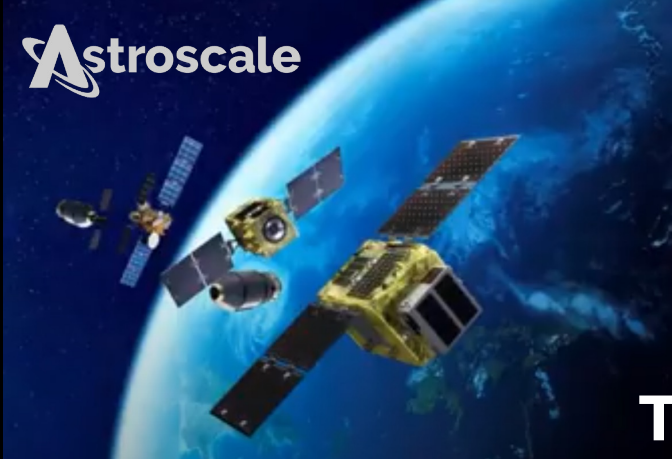
For More Info:

cislunarindustries.com

Contact:

Joe Pawelski,
CTO and Co-Founder
303-995-0733
joe@cislunarindustries.com





Trash to Treasure

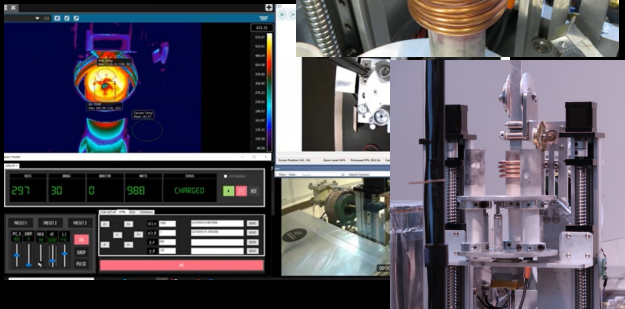
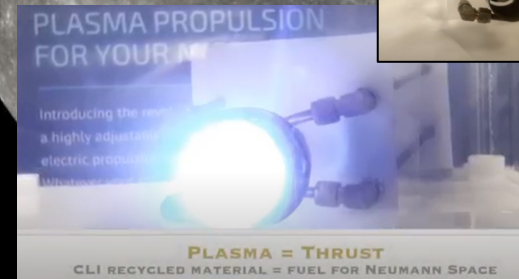
Space Debris Recycling Ecosystem

Live Demonstration
October 19, 2021

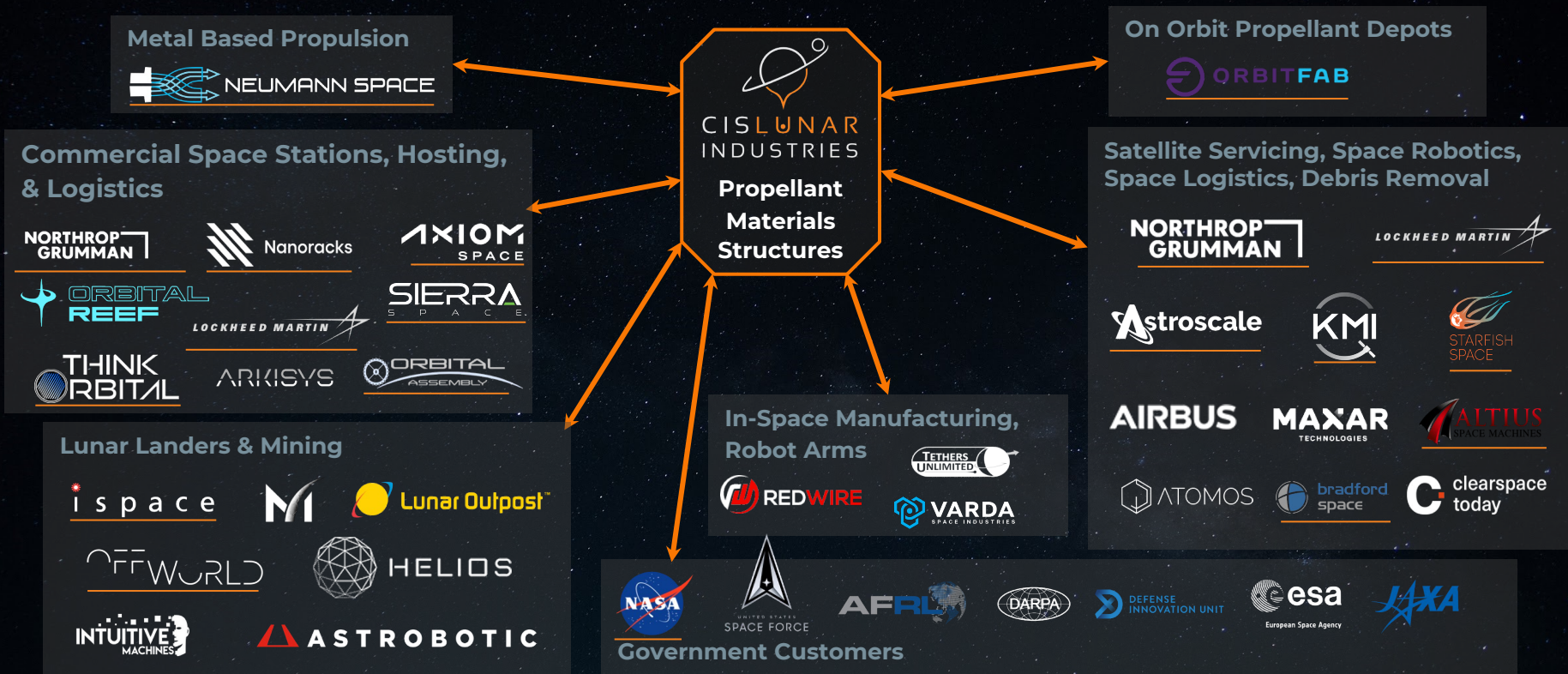


[Link to Abbreviated 2 Min Version
\(CisLunar + Neumann Space\)](#)

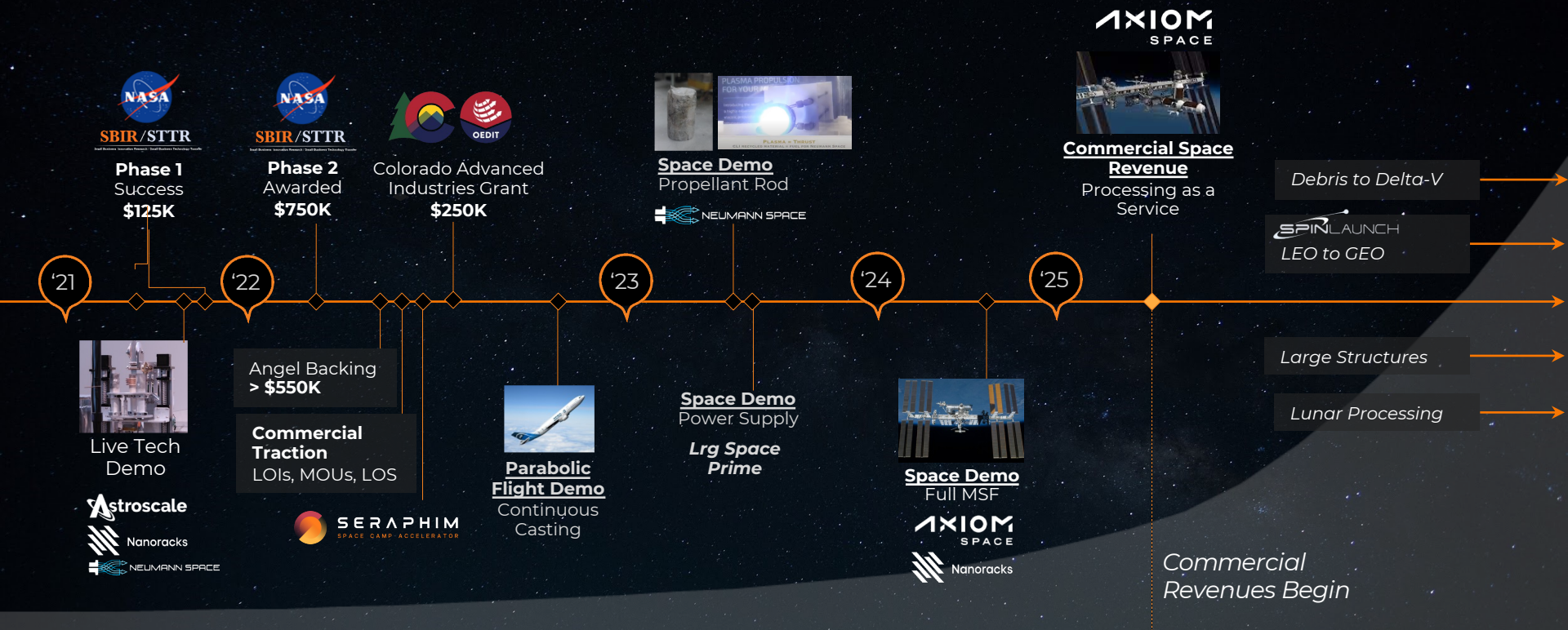
[Link to Full Replay
CisLunar Demo](#)
Starts 30:34



Partnering Across The Ecosystem



Roadmap



Space Debris

Accelerating Growth Demands Sustainable Solutions

Since the dawn of the space age in 1957 (as of Sept 20, 2021):

- 🚀 **12,000** Satellites Launched
- 🚀 **7,500** Still in Space
- 🚀 **4,700** Still Functioning
- 🚀 **29,600** Objects Tracked
- 🚀 **9,600,000 kg** (21M lbs)
Total mass
- 🚀 **>10x growth** of sat population
planned in next decade

ESA – Space Environment Statistics
(<https://sdup.esoc.esa.int/discosweb/statistics/>)

ESA - Visualization of Space Debris