Beneficiation of Lunar Regolith Simulants through Electrostatic and Magnetic Separation: Concept of Operations

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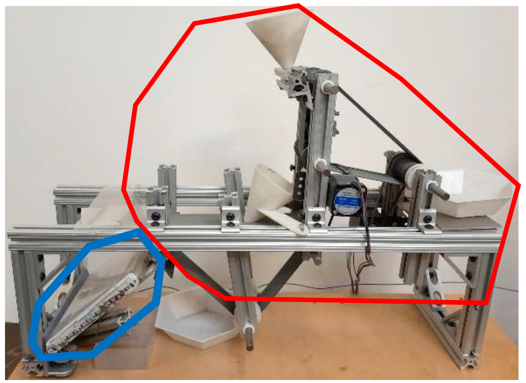

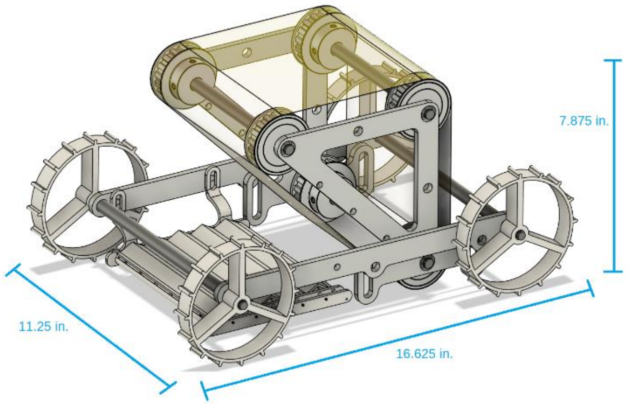

NASA LuSTR21 Missouri S&T Project
Regolith Beneficiation System for Production of Lunar Calcium and Aluminum
PM: Harri Vanhala (HQ) | NASA RC: Michael Zanetti (MSFC)

Regolith Beneficiation System for Production of Lunar Calcium and Aluminum

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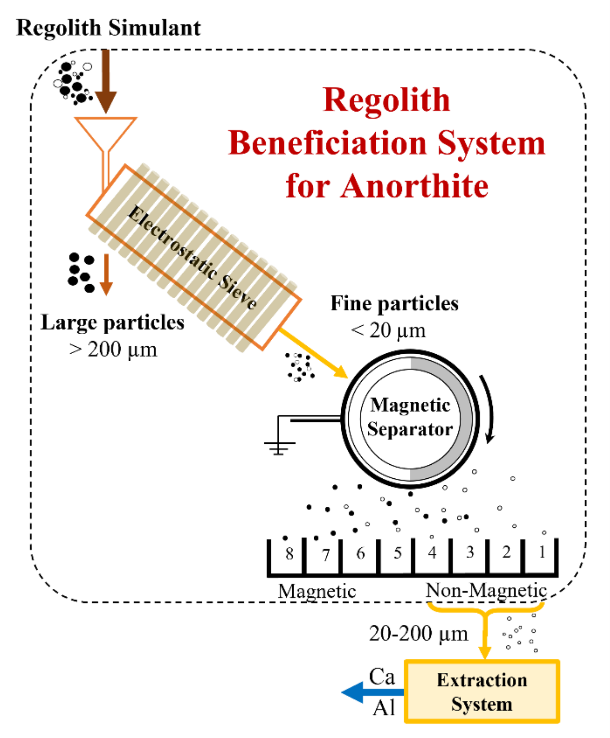
D. Bergman, Honeybee Robotics
M. Roth, Off Planet Research, LLC

Development Objectives

- Build and demonstrate integrated system for particle size classification and enrichment of anorthite from lunar mare and highland simulants with varying agglutinate fractions.
  - TRL4 → TRL5
  - Output >70 wt% anorthite, particles 20-200 µm
  - Final system <0.51 m^3, 35 kg, 300 watts
  - System throughput ≥3 kg/hr



Approach

- Develop and test sub-systems:
  - electrostatic sieve
  - magnetic drum separator
- Under operational conditions:
  - -196°C to 120°C
  - ambient & vacuum pressure
  - representative test materials
- Integrate into complete system, validate vacuum performance
- Optimize size, mass, and power needs of integrated system.

Impact and Infusion

- Enables efficient processing to extract calcium and aluminum from lunar regolith
- Direct application to ISRU and construction materials anywhere on lunar surface
- TRL 6 achievable within 2 years
- TRL 8 achievable within 5 years

Project Goal

- Build and demonstrate integrated system for particle size classification and enrichment of anorthite from lunar mare and highland simulants with varying agglutinate fractions.
- Specific sub-goals:
    1. Develop an electrostatic particle size separation subsystem for a range of simulants under both ambient atmospheric and vacuum (hot and cold) conditions.
    2. Develop a magnetic separation subsystem for enrichment of anorthite mineral particles under both ambient atmospheric and vacuum (hot and cold) conditions.
    3. Integrate the subsystems into a beneficiation system capable of increasing the anorthite concentration and optimizing the particle size distribution of feedstock, for subsequent extraction of calcium and aluminum.

Project Deliverables

- As specified in solicitation:
  - System produces particles of 20-200 µm size
  - System product consists of ≥ 70 wt% anorthite
- As stated in proposal:
  - System volume ≤0.51 m^3
  - System mass ≤ 35 kg
  - System power requirement ≤300 watts
  - System throughput ≥3 kg/hr

Top-level Schedule

- Expected task completion dates:

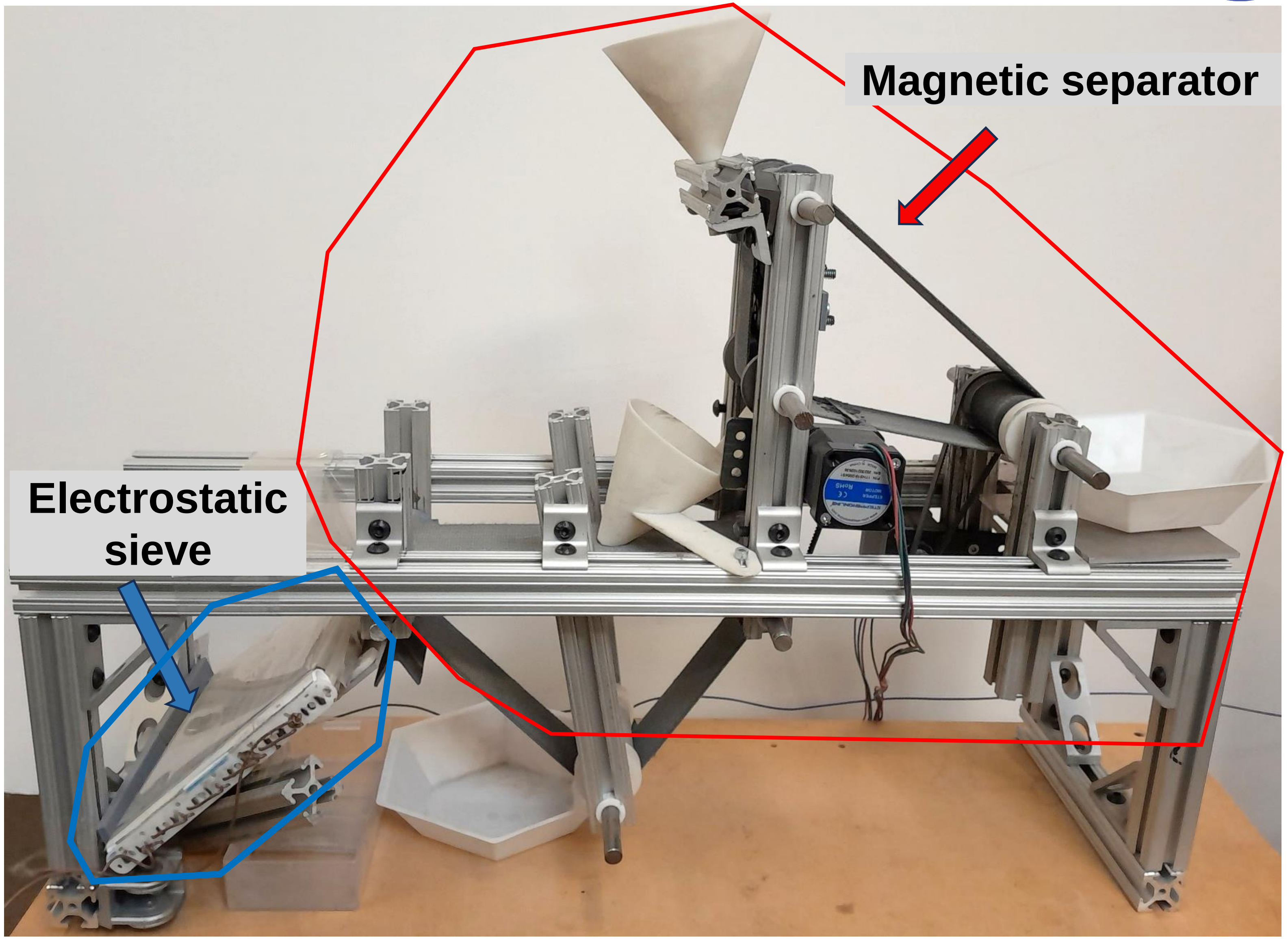
1. Prepare simulants and test equipment	Done
2. Fabricate particle size classifier	Done
3. Test and model particle size classifier	Done
4. Fabricate magnetic separator	Done
5. Anorthite separation testing and analysis	Done/iterating
6. Integrate subsystems, develop ConOps	Done/iterating
7. Optimize total system and ConOps	Ongoing

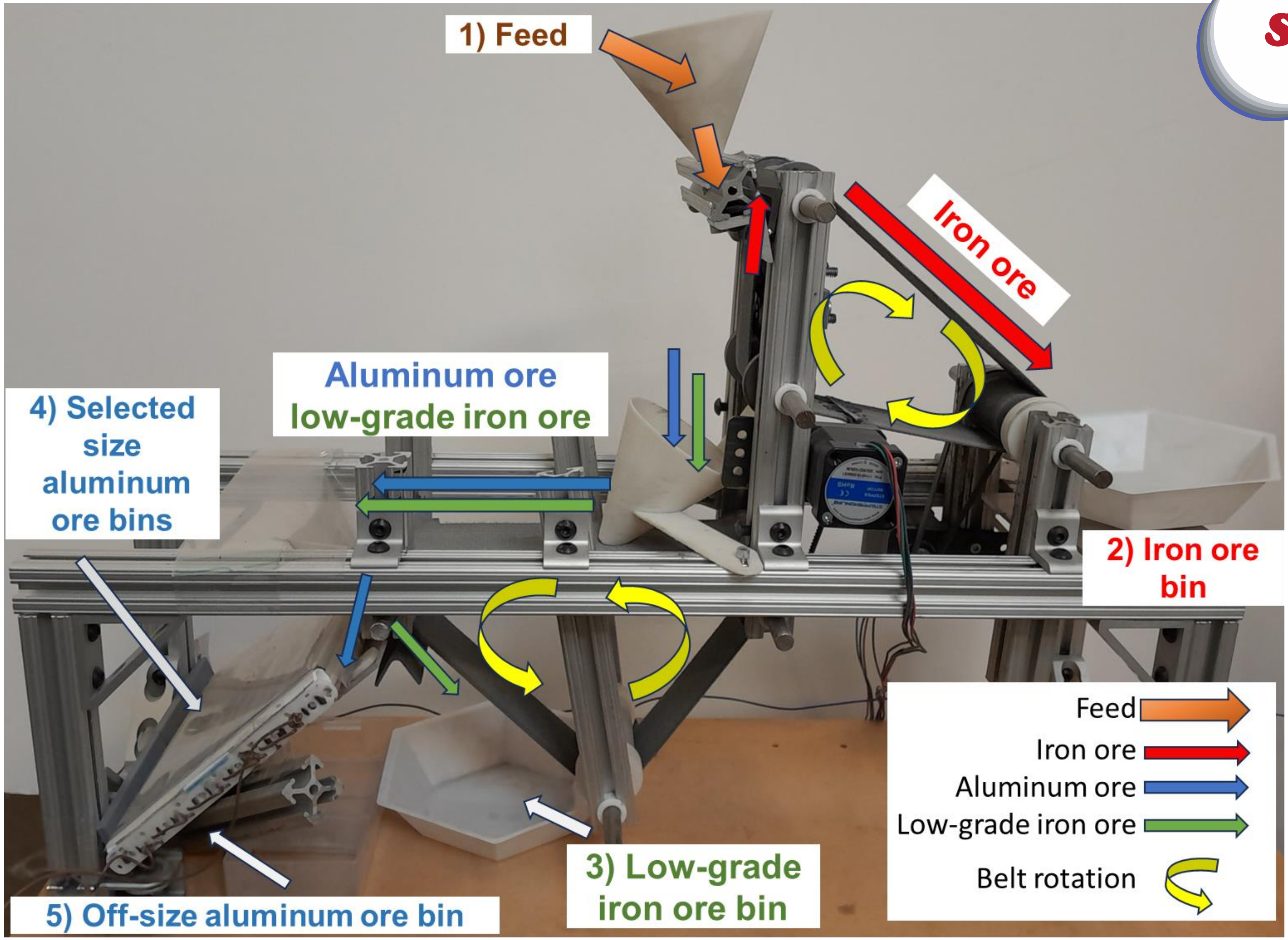
- Completion of Task 6 will satisfy TRL 5 exit criteria

Year 2 Status

- Developed 2 ConOps
  - Stationary – pilot plant on the Moon
  - Mobile – integrated with a rover

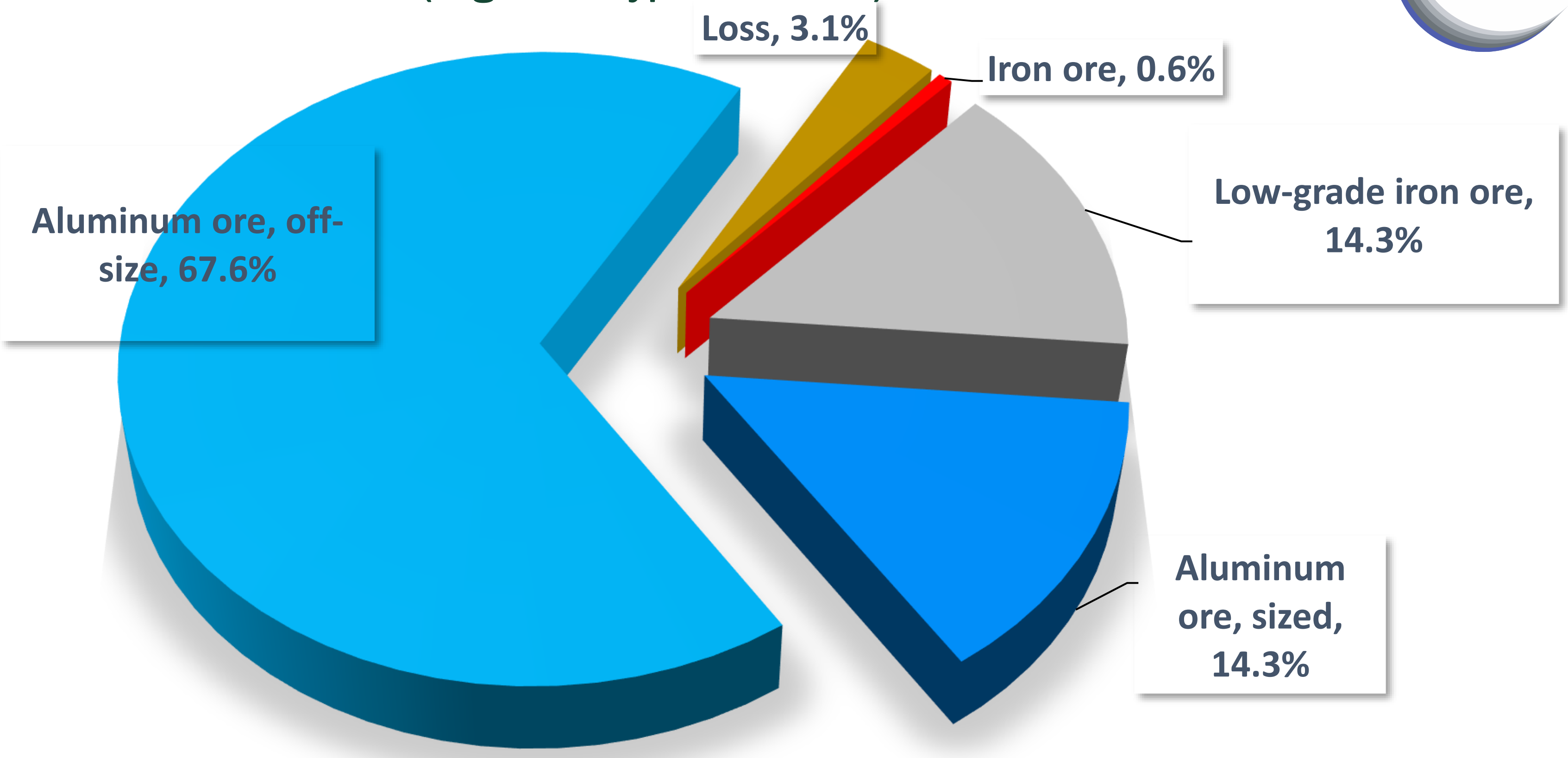
Stationary Mk I




1) Feed
Iron ore
Aluminum ore
low-grade iron ore
4) Selected size aluminum ore bins
2) Iron ore bin
3) Low-grade iron ore bin
5) Off-size aluminum ore bin
Feed
Iron ore
Aluminum ore
Low-grade iron ore
Belt rotation

Video: Approx. 3.6 kg/hr throughput rate

Mass Percent (Highland-Type Simulant)

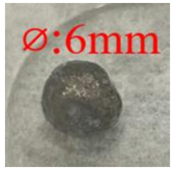


Signal Frequency 20 Hz	Station #1	Station #2	Station #3	Station #4	Station #5	Loss
Simulant Name	Mass In (g)	Iron ore (g)	Low-grade iron ore (g)	Aluminum ore, sized (g)	Aluminum ore, off-size (g)	(g)
H4W10g814	32.1	0.2	4.6	4.6	21.7	1.0

Initial Performance of Stationary Mk I

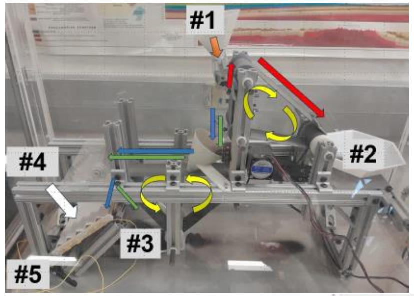
(20 Hz, with big uncertainty, to be verified with more tests)

- Feed: 1 kg of regolith simulant (highland type)
- After magnetic separation: ~ 800 g
- After electrostatic sieve: ~ 140 g
  - 95% by wt. is Anorthite: that's about 133 g $CaAl_2Si_2O_8$
  - Contains ~26 g of Aluminum
    - LISAP Molten Salt Electrolysis (NASA BIG Idea Challenge 2023 project)
    - Got a few grams of Aluminum (manuscript in preparation)



- Tech Demo for the Stationary Mk I prototype
- Poster for BIG Idea Challenge 2023 project

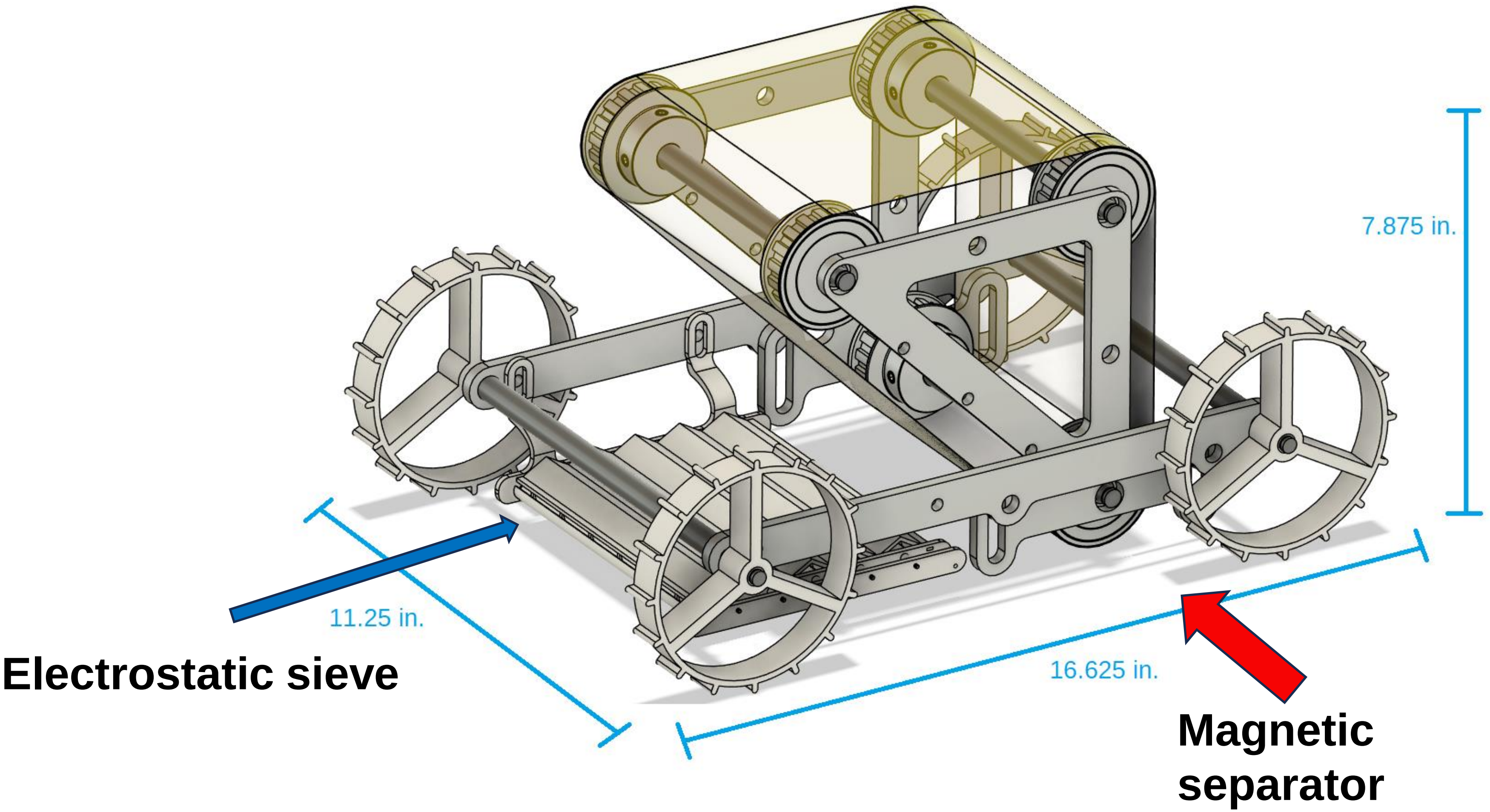
(…more tests at 30 Hz)



Grams output per one kg input

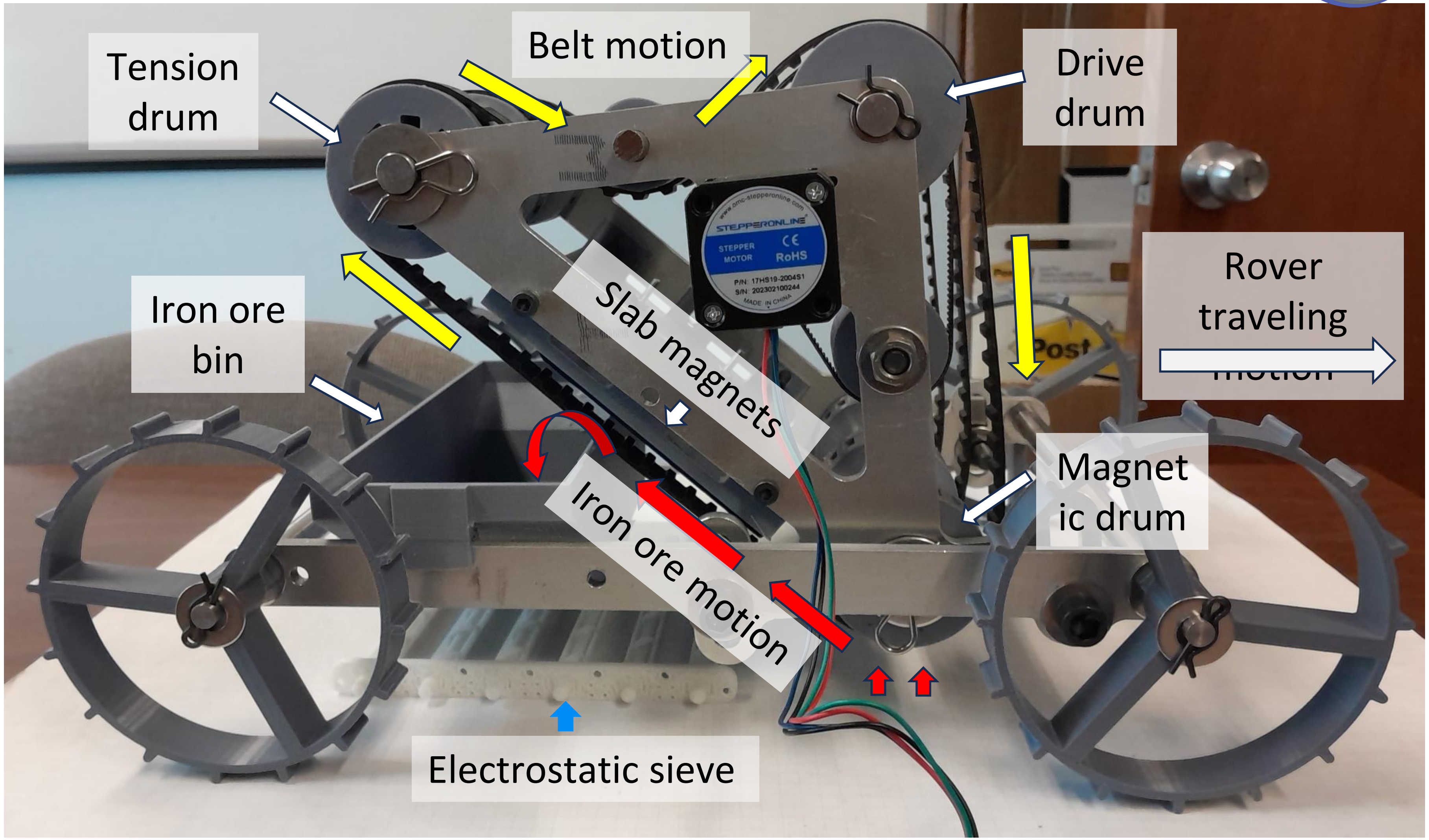
Signal Frequency (30 Hz)	Station #2	Station #3	Station #4	Station #5	
Label Name	Iron Ore (g/kg)	Magnesium/Iron /KREEP (g/kg)	Aluminum Ore Selected Size (g/kg)	Aluminum Ore Non-selected Size (g/kg)	Loss (g/kg)
L2W10g6	35	530	25	355	55
L2W60g6	95	627	25	184	70
H4W10g6	20	125	30	710	115
H4W60g6	5	160	35	745	55
L2W10g814	95	530	20	320	35
L2W60g814	70	560	20	305	45
H4W10g814	20	150	30	715	85
H4W60g814	15	140	10	785	50

Mobile Mk I

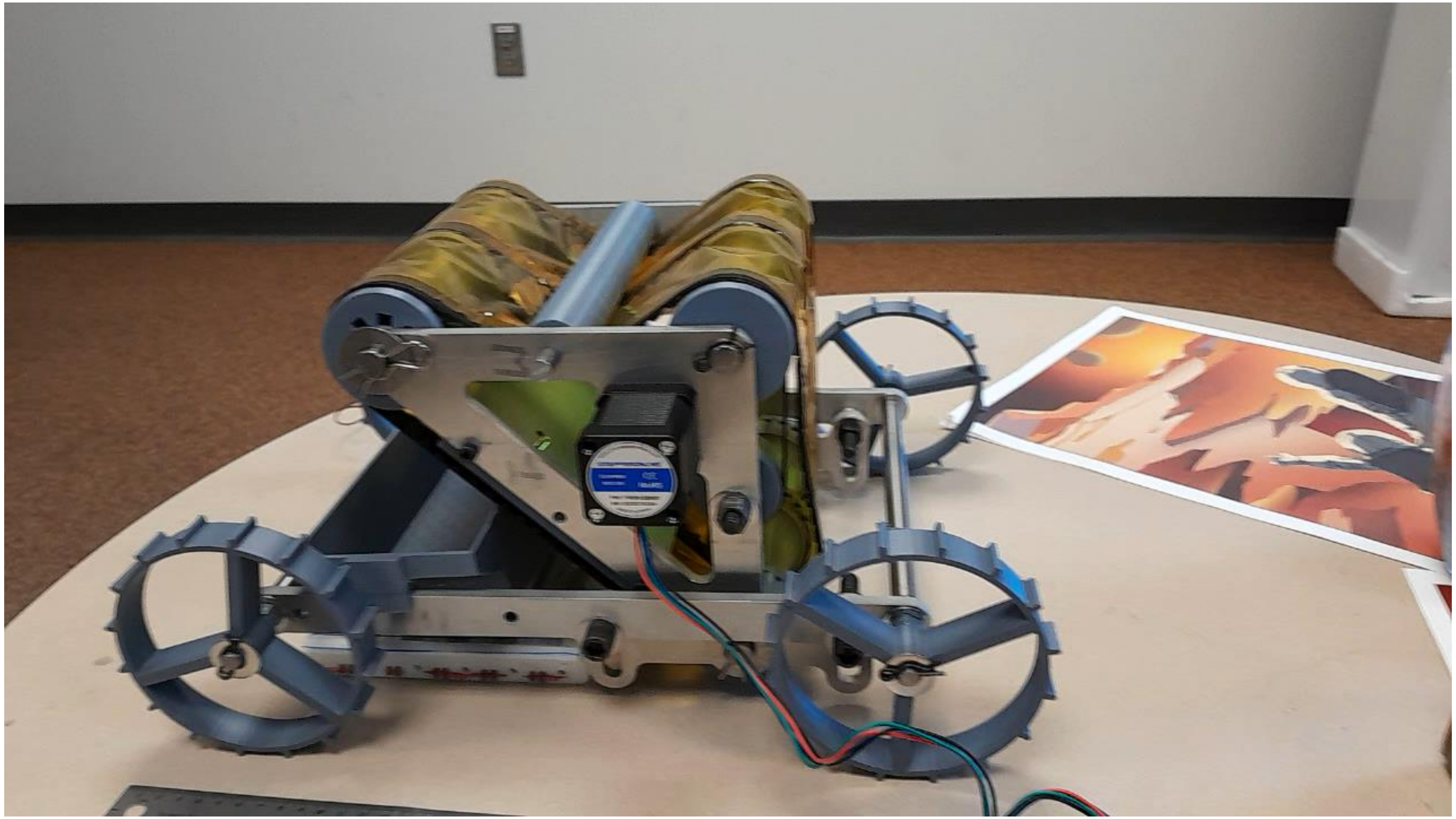


7.875 in.
11.25 in.
16.625 in.
Electrostatic sieve
Magnetic separator

ConOps II: Mobile Mk I



Video: Mobile Mk I



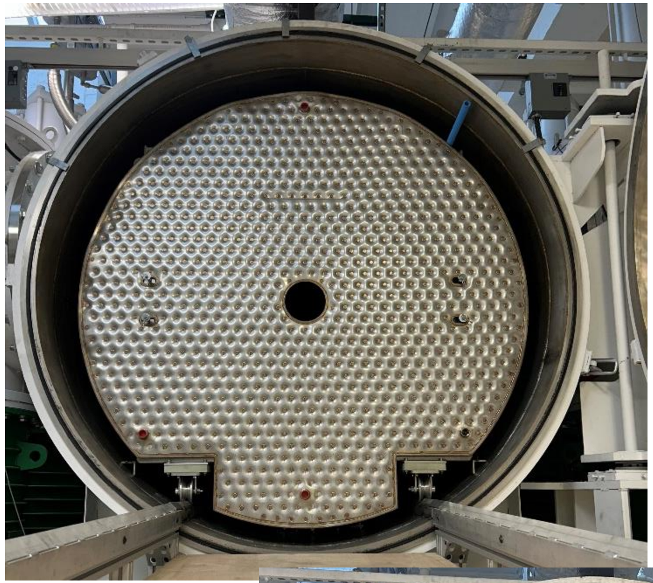
Summer 2024

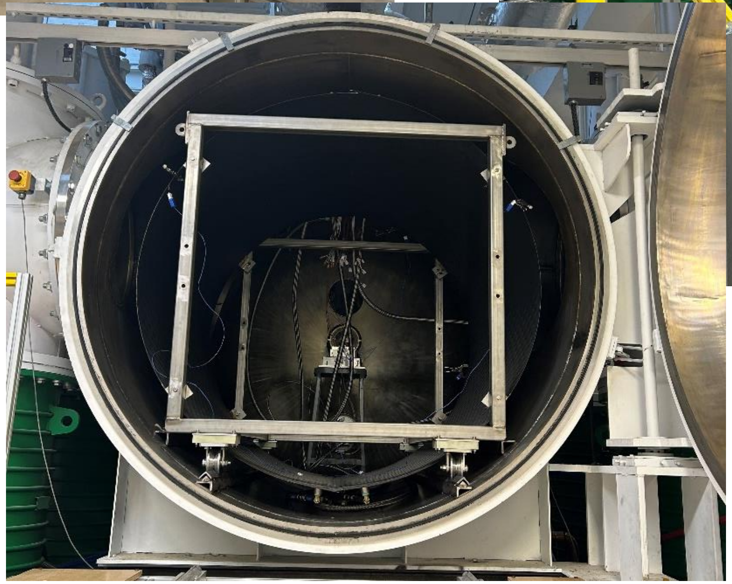
“horse tank” / “water tank”

Summer 2024 - TVAC

Space Resources Roundtable

MISSOURI S&T





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HONEYBEE ROBOTICS
D. Bergman *et al.*

BECHTEL
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OFF PLANET RESEARCH
M. Roth

BACK UP SLIDES