The Inaugural Over the Dusty Moon Challenge

Kevin M. Cannon, Angel Abbud-Madrid, Chris Dreyer, George Sowers

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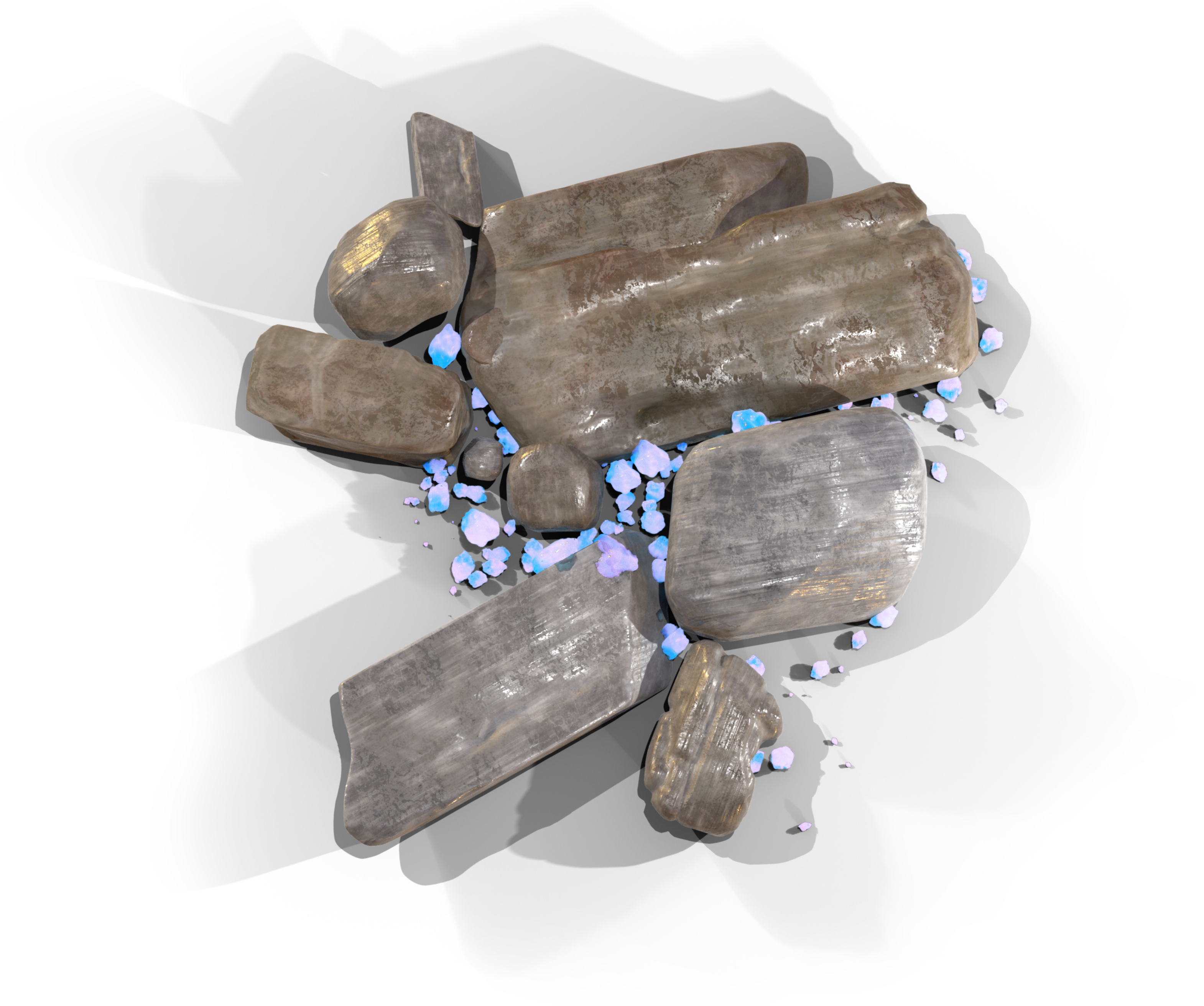
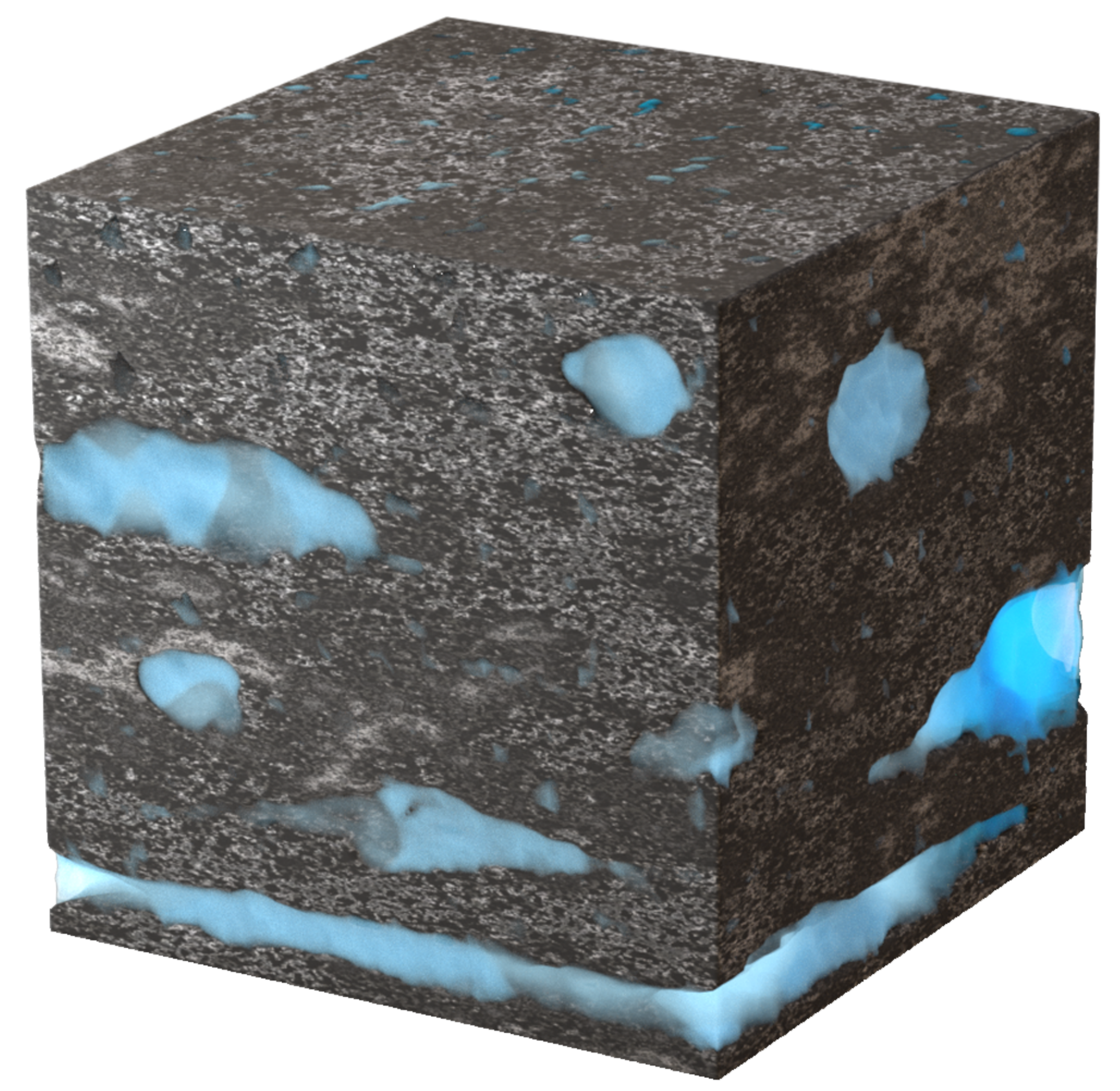
Regolith is fundamental to space resources:

Resources *in the regolith*



Resources *under the regolith*



Regolith *as the resource*

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Working with lunar surface materials: Review and analysis of dust mitigation and regolith conveyance technologies

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ABSTRACT

The Moon's dusty surface environment threatens any equipment that operates there, especially for long-duration infrastructure needed for a sustained lunar presence. This is doubly true for systems that convey regolith, which by agitating the soil are certain to generate dust. Here, we provide a comprehensive review of technologies that have been proposed to convey regolith on the lunar surface, and to mitigate against dust hazards that are generated by such transport systems. We define functional taxonomies for both regolith conveyance and dust mitigation, then carry out quantitative trade studies in several categories for each. Examples include passive and active dust mitigation, and horizontal and near vertical conveyance. Conveyance technologies that scored particularly high include wheeled haulers, conveyor belts, and auger/hopper transfer points. High scoring dust mitigation technologies include the lotus leaf passive coating, Electrodynamic Dust Shield, and boots or bellow made of fiberglass fabric. We also explore novel or unconventional concepts and describe how dust mitigation and regolith conveyance can be combined using a systems approach with multiple technologies layered together. The results from the trade studies and the subsequent recommendations constitute a practical guide that can be used for designing and developing systems that must perform efficiently and reliably to carry out useful tasks on the Moon or Mars, such as resource extraction, construction, and additive manufacturing.

1. Introduction

Loose granular materials are ubiquitous on the Moon and every landing site is coated by regolith and its finest fraction, dust. With growing interest in a sustainable return and buildup of lunar infrastructure, there is a greater need to learn how to work with natural surface materials and mitigate against the hazards they present to astronauts and robotic systems. The issues of lunar dust are well documented dating back to the Apollo experience [1–4], and in the intervening years many technologies have proliferated to address these concerns (i.e., dust mitigation). However, it is not clear which of these have the most promise; rigorous comparisons have been lacking so far. A related set of issues come from the need to move regolith from one place to another (i.e., regolith conveyance), which is necessary to do almost any useful task in lunar development: excavating, constructing, or processing. The unique properties of lunar regolith include very poor flowability and high abrasivity. When combined with the lunar environment (strongly fluctuating temperatures, high vacuum, low gravity) this may require terrestrial and lunar conveyance approaches to differ. Previous studies have compiled excavation technologies to assess and compare them for lunar in-situ resource utilization (ISRU) [e.g., [5]], but no similar work has been done for conveyance technologies. Dust mitigation and regolith conveyance are coupled because any system that conveys lunar regolith will likely create a dust hazard in the surrounding environment, while at the same time these systems must be resilient to dust that threatens their mechanical components.

Lunar dust is defined by convention as the size fraction of the regolith with particle diameters <20 μm. The dust is part of the surficial regolith on the ground but is also present above the lunar surface as the dusty plasma that makes up the lunar exosphere [6]. Dust can be mobilized by

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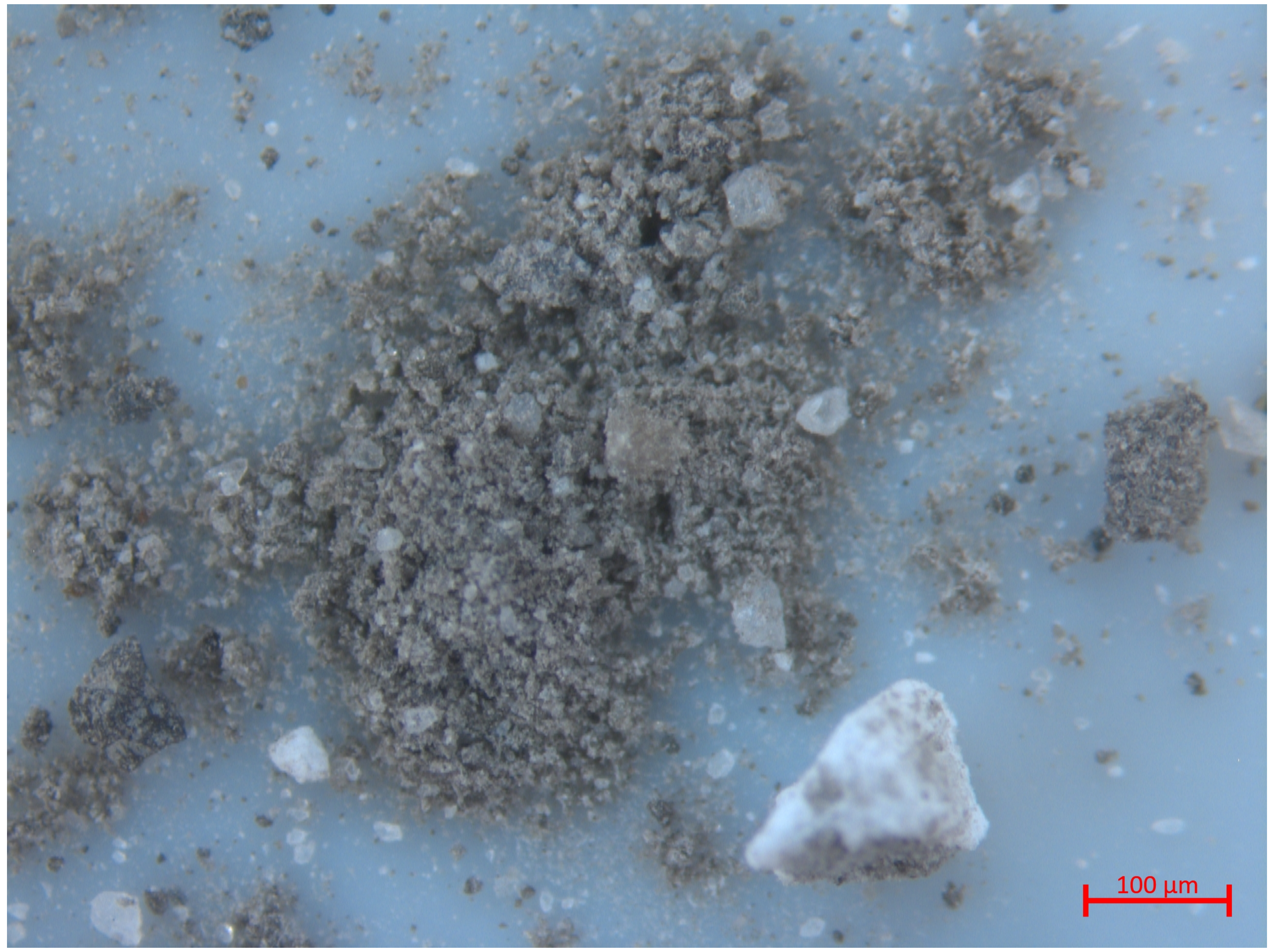
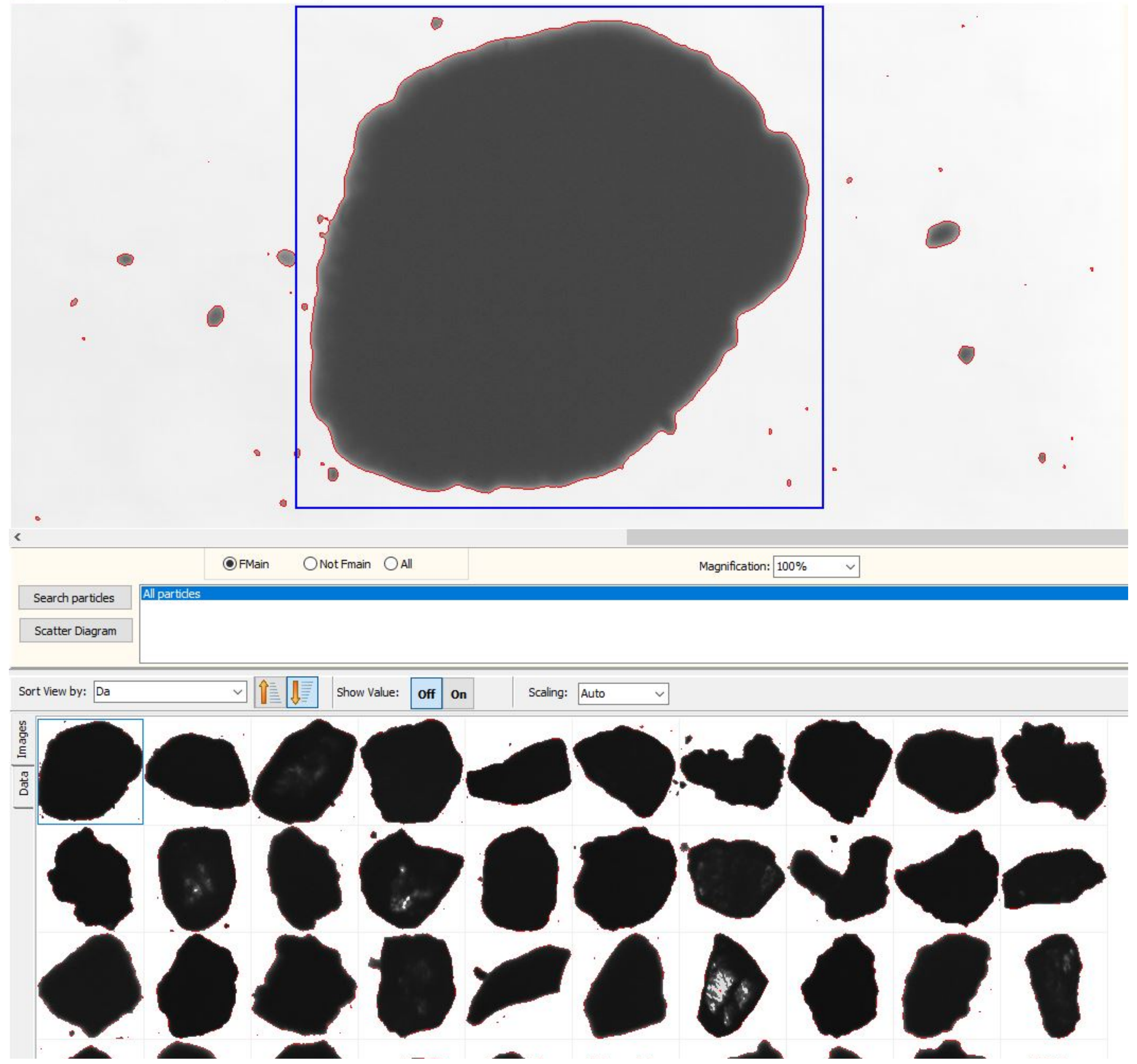
Simulants
at Mines

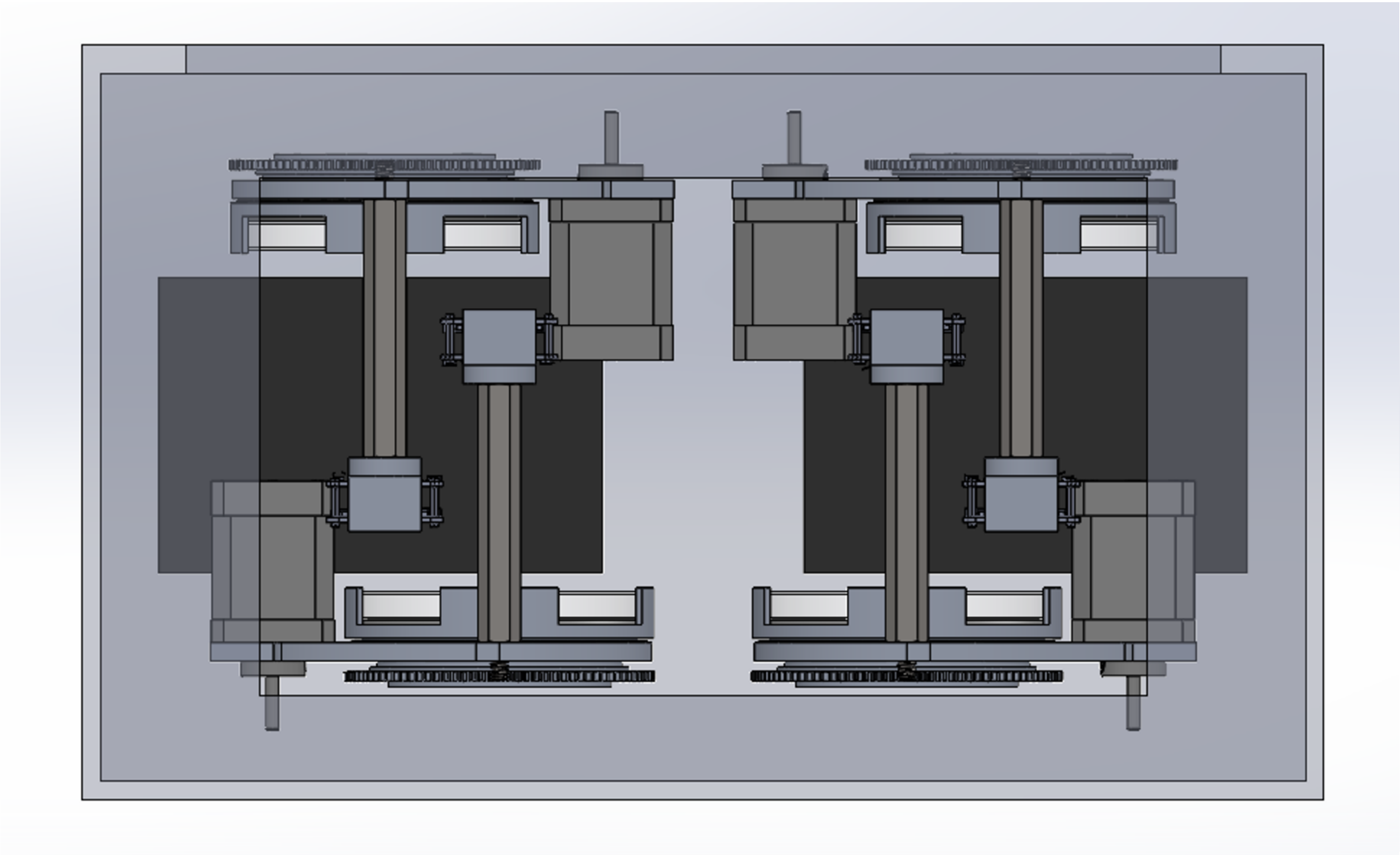

Simulants
at Mines
CSM-LMT-1 Mare Type
DANGER
Simulants
at Mines
CSM-LHT-1 Highlands Type
DANGER
May cause cancer by inhalation. Causes damage to lungs
through prolonged or repeated exposure by inhalation.
Obtain special instructions before use. Do not handle until all safety precautions
have been read and understood. Use personal protective equipment as required.
Do not breathe dust/fume/gas/mist/vapors/spray. Wash face, hands and any
exposed skin thoroughly after handling. Do not eat, drink or smoke when using this
product. Store locked up. If exposed or concerned: Get medical advice/attention.
Dispose of contents/container to an approved waste disposal plant.
Colorado School of Mines
Center for Space Resources
1310 Maple St., GRL 234
Golden, CO 80401 USA
Emergency Number: 1-800-535-5053
See SDS for further information

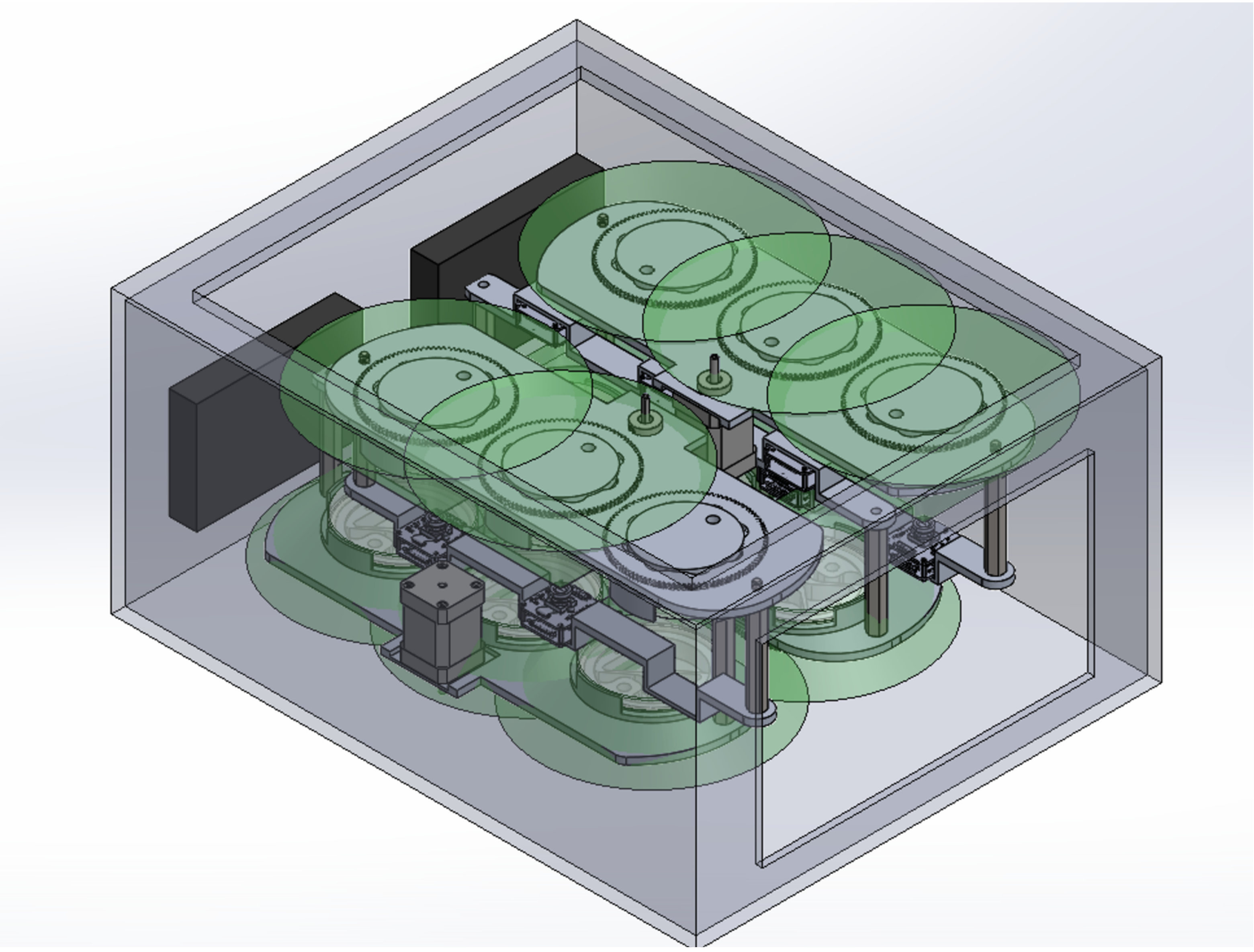


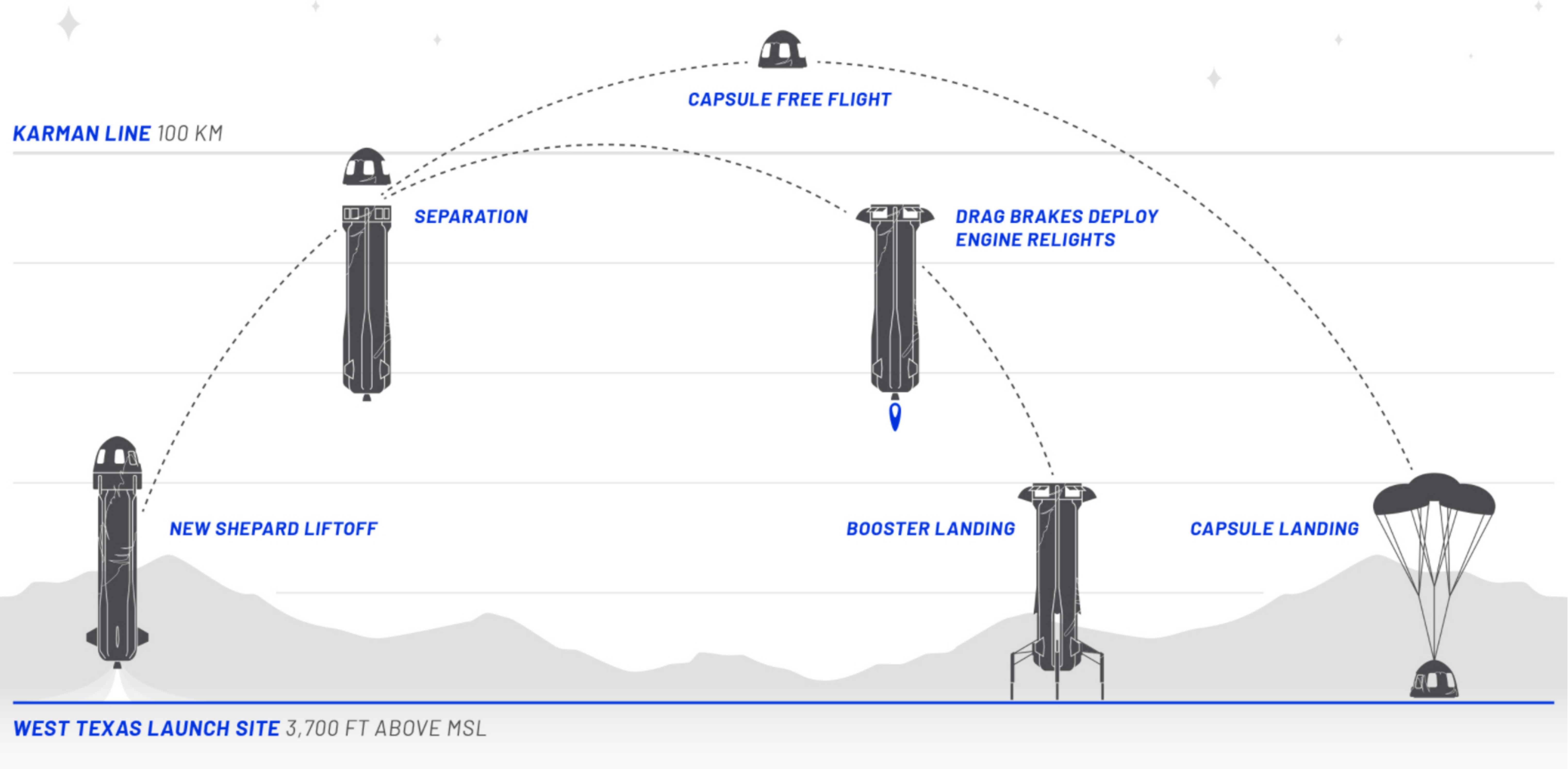


Apollo 16 sample 64501

Project *Duneflow*





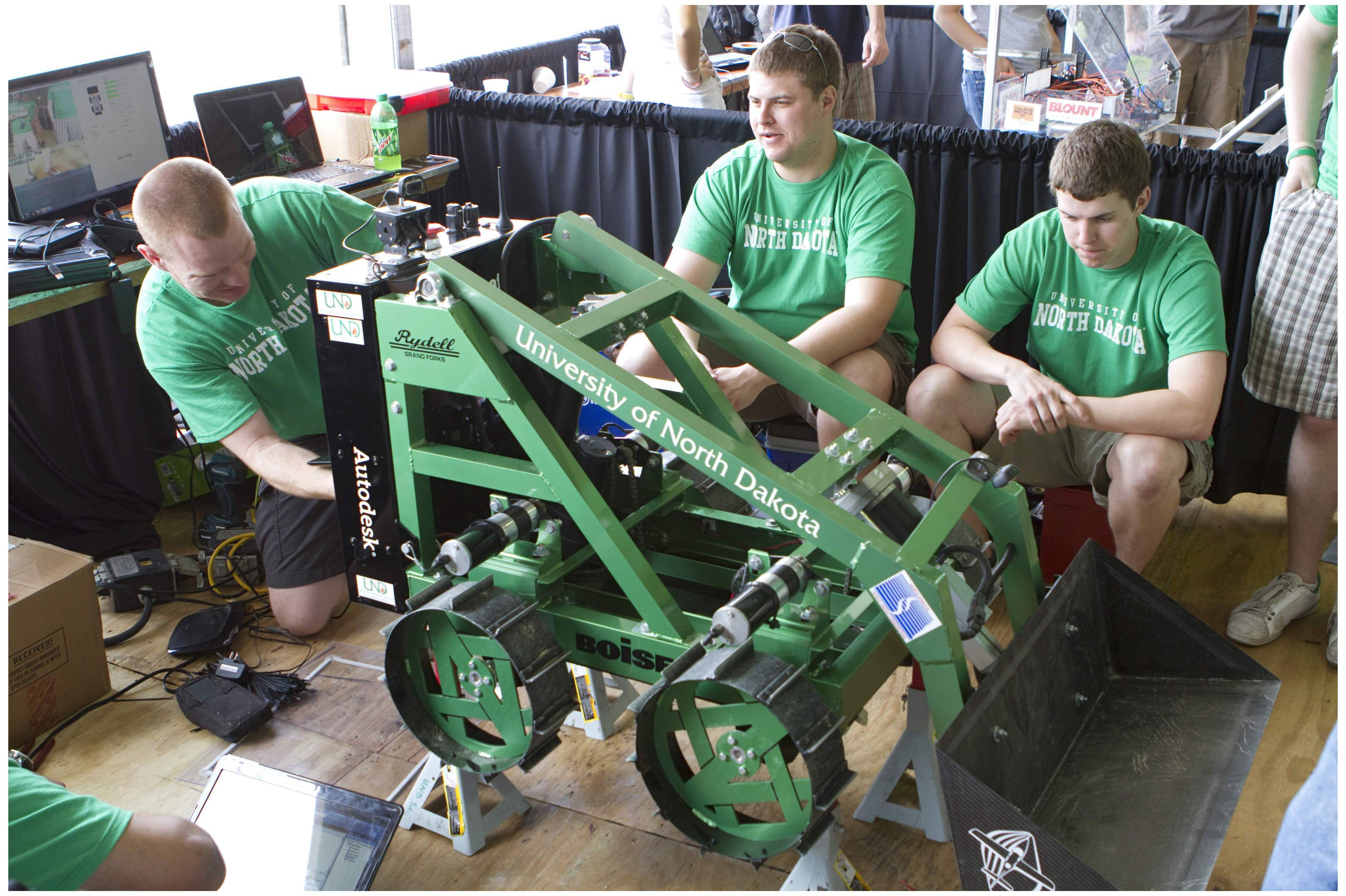


Initial ideas

1. Regolith conveyance
2. Airtight regolith structures
3. Habitat burial
4. Mechanically stabilized regolith
5. Basalt fiber machine
6. Dust mitigation
7. Internal dust mitigation
8. Design of Artemis basecamp

Initial excavation

NASA
EX LUNA, SCIENTIA
RMC: LUNABOTICS



Final use cases

3D-PRINTED HABITAT CHALLENGE
A NASA CENTENNIAL CHALLENGE

Initial excavation

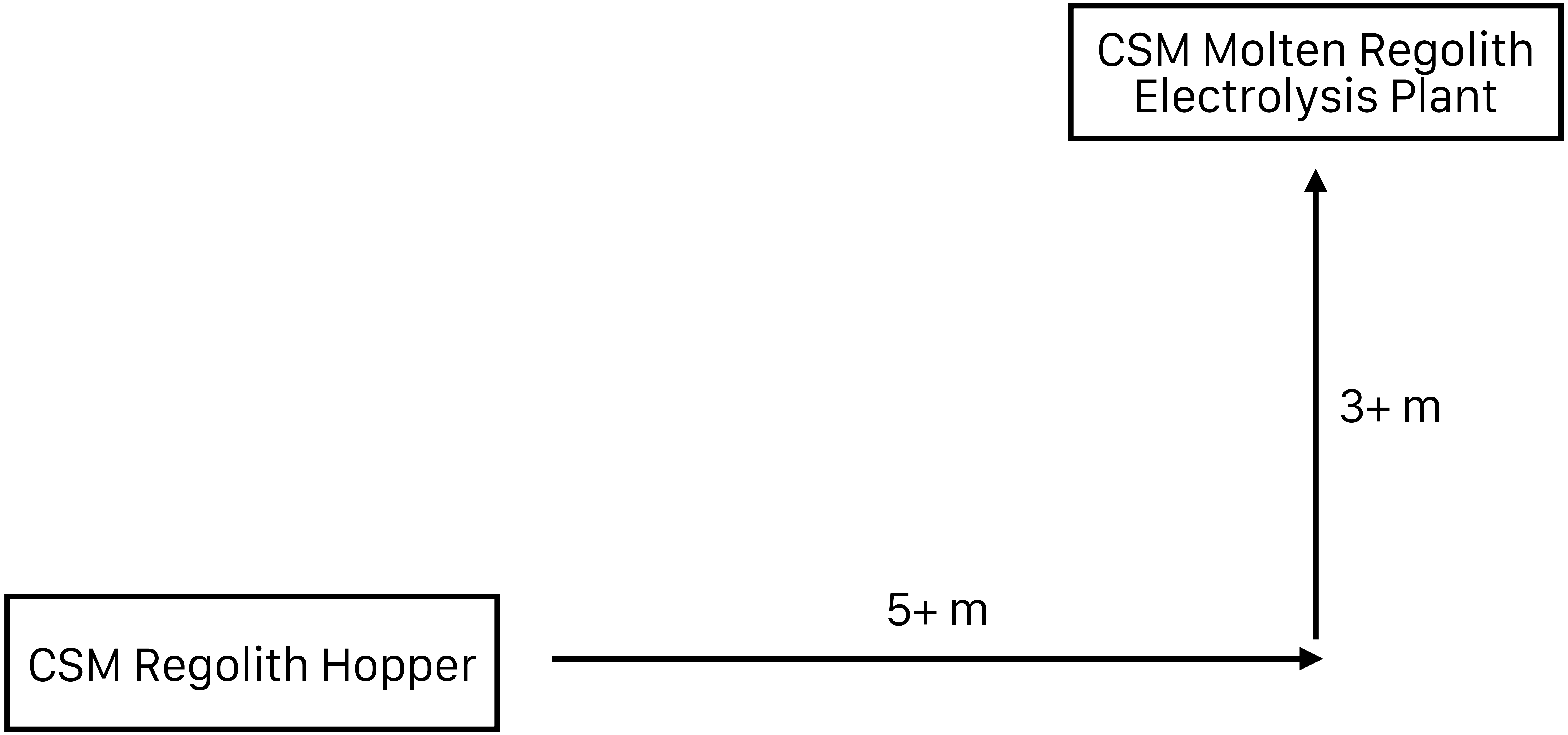
Conveyance

Beneficiation

Transfer points

Hopper design

Final use cases


CSM Molten Regolith Electrolysis Plant
3+ m
5+ m
CSM Regolith Hopper

Dust generation

Poor flowability

Timeline

Jan 2021: Initial ideation

Sept 2021: Phase 1 launched

Jan 2022: Phase 1 winners announced, Phase 2 initiated

Jun 2-3, 2022: In-person competition

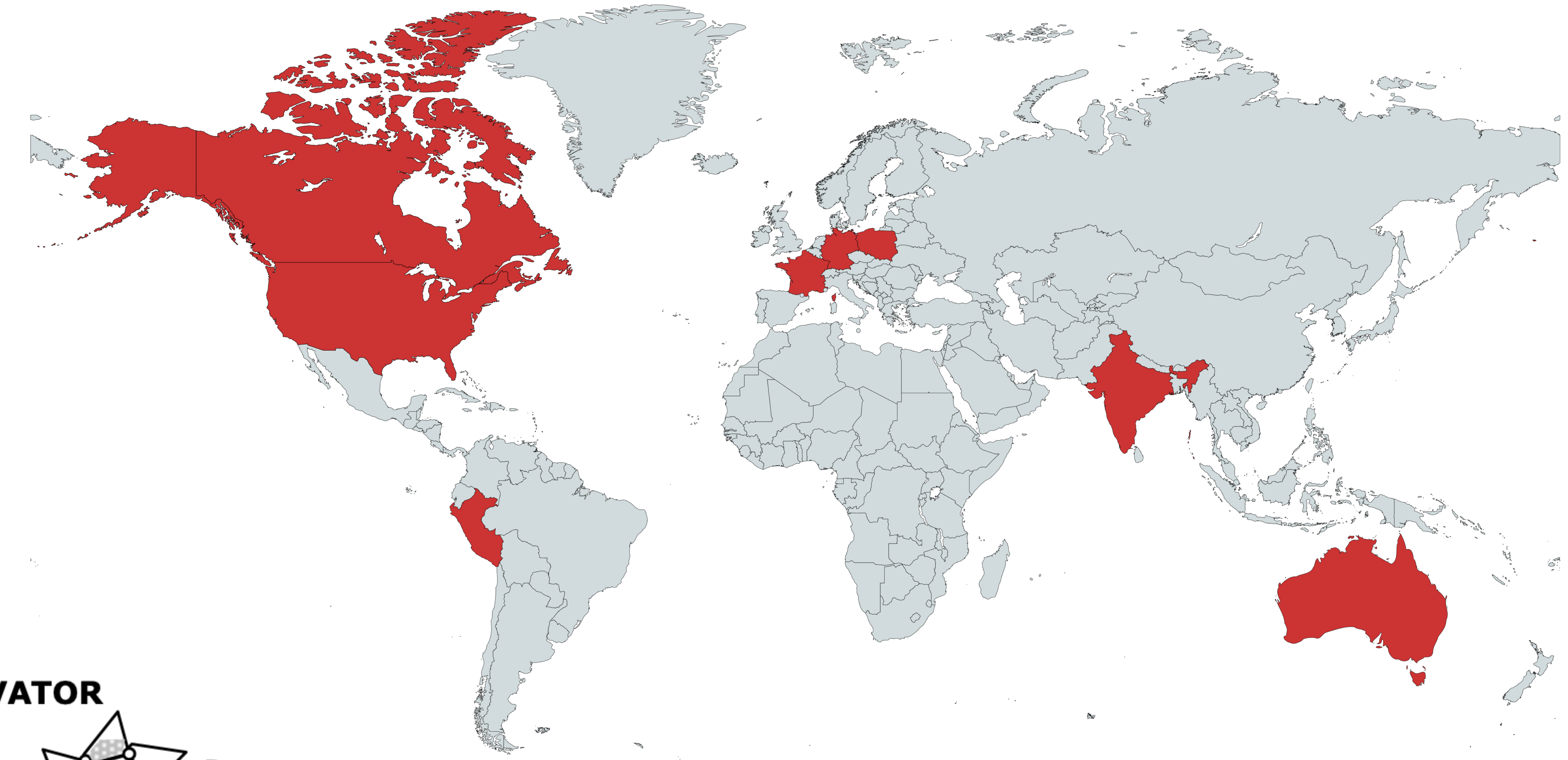
DESIGN AND BUILD A REGOLITH TRANSPORT SOLUTION FOR THE MOON

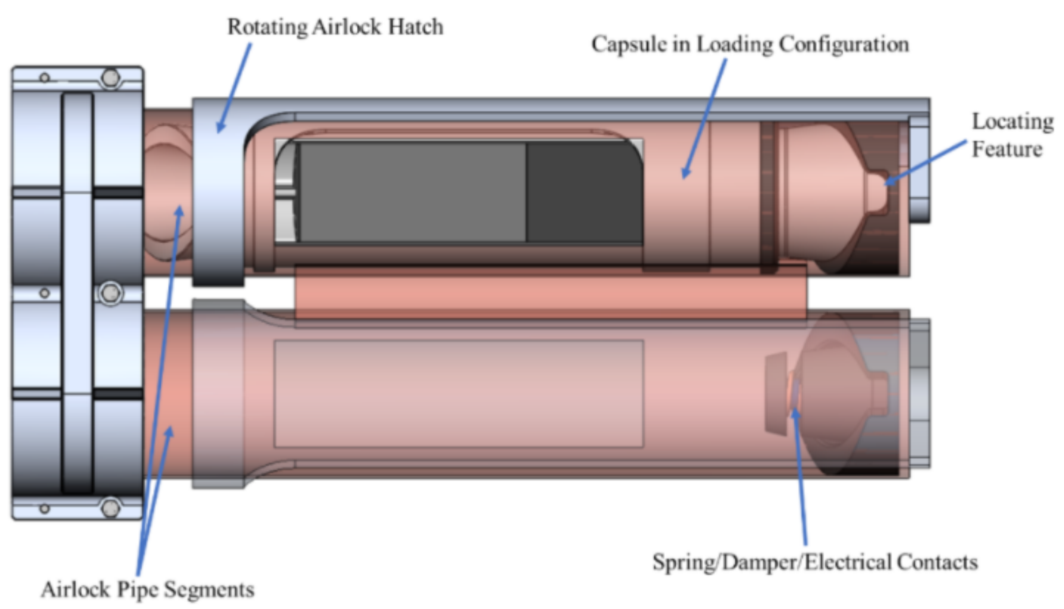
Lunar regolith is an important feedstock for construction, mineral processing, and other ISRU activities. To help us learn how to work with this difficult material in the harsh lunar environment, Colorado School of Mines and Lockheed Martin invite university teams from around the world to compete in the Over the Dusty Moon Challenge.

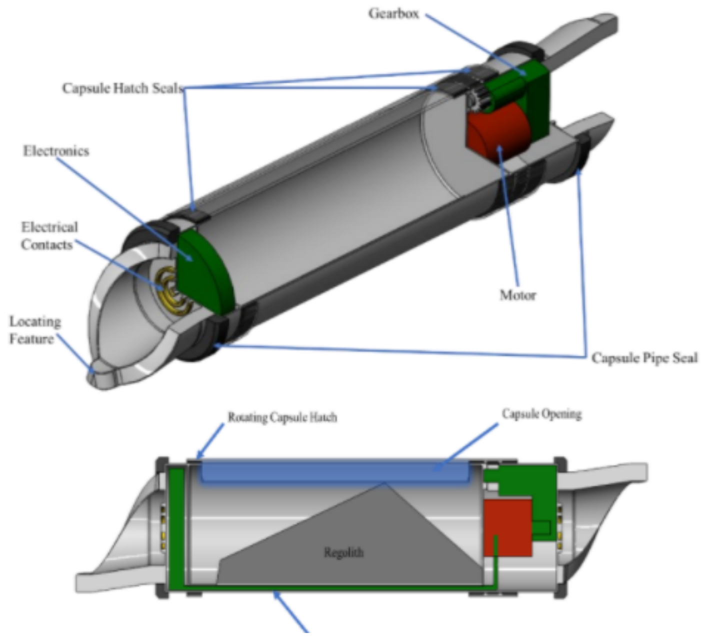
Explore the challenge. Enter your team. Win Prizes.

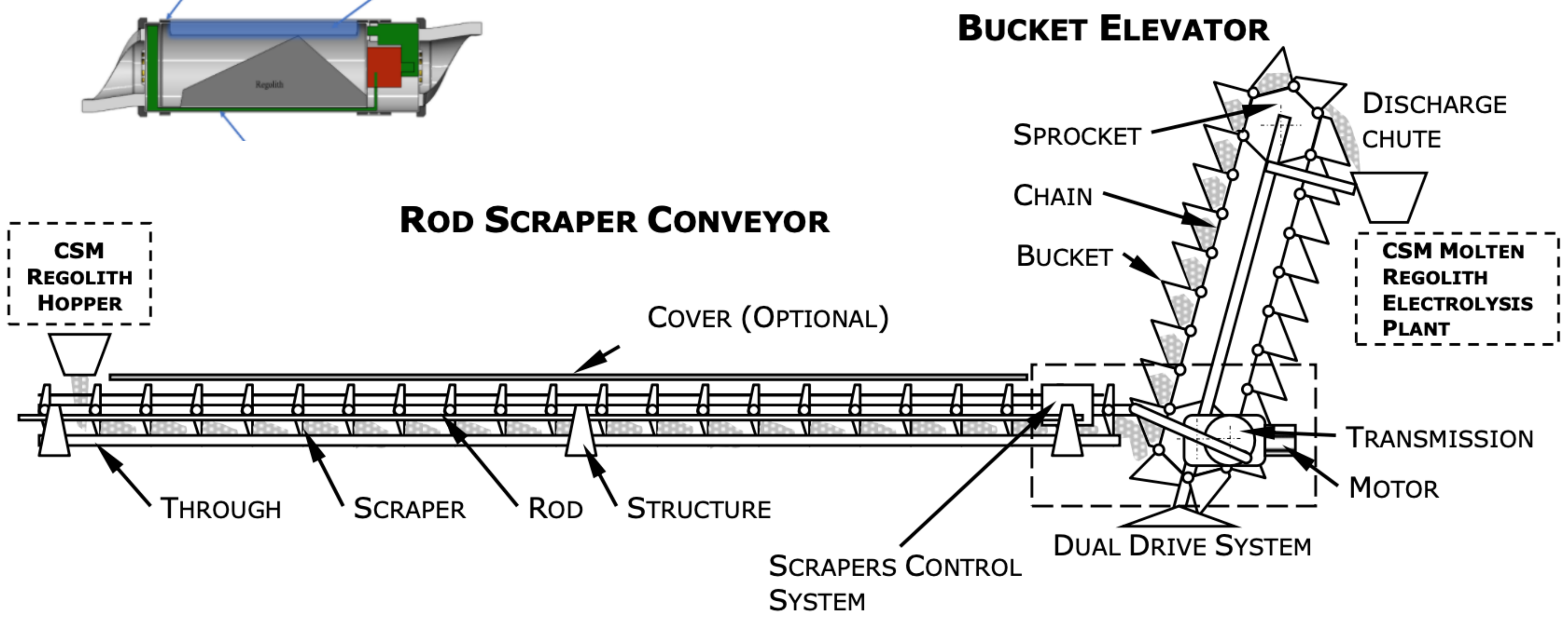
View the Phase 1 Winners

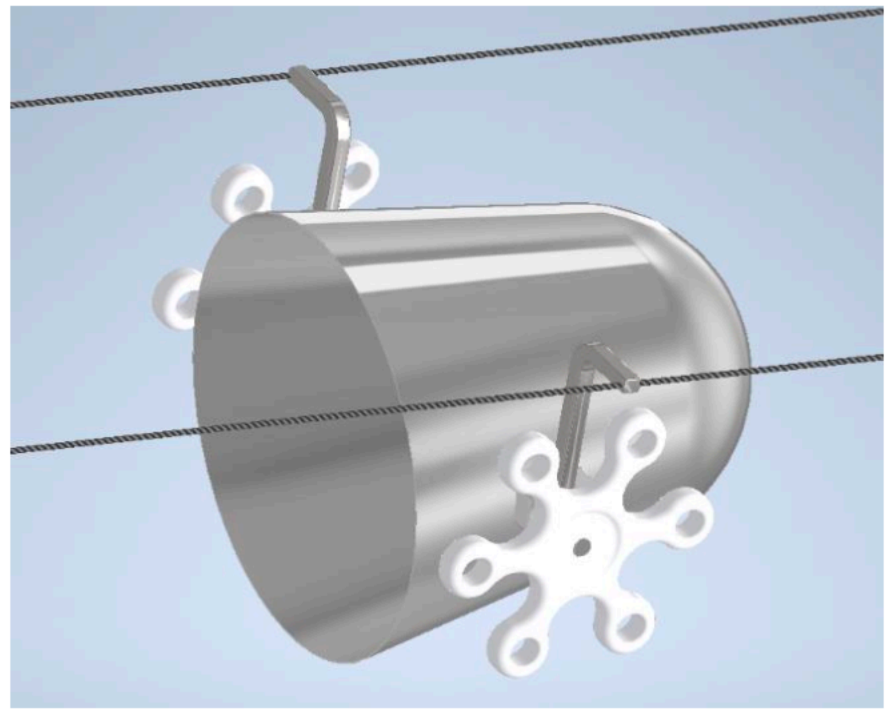
Phase 1 submissions

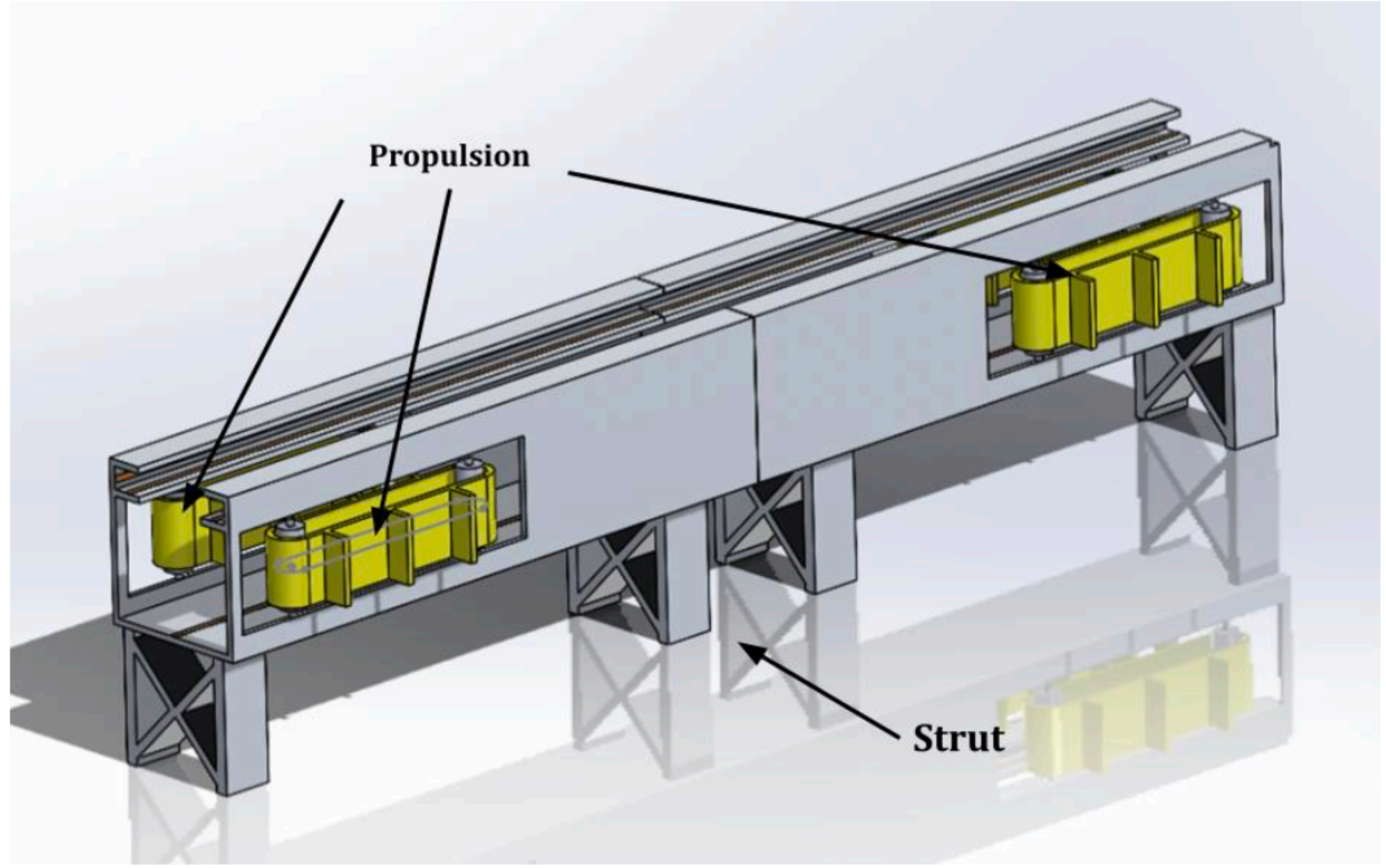


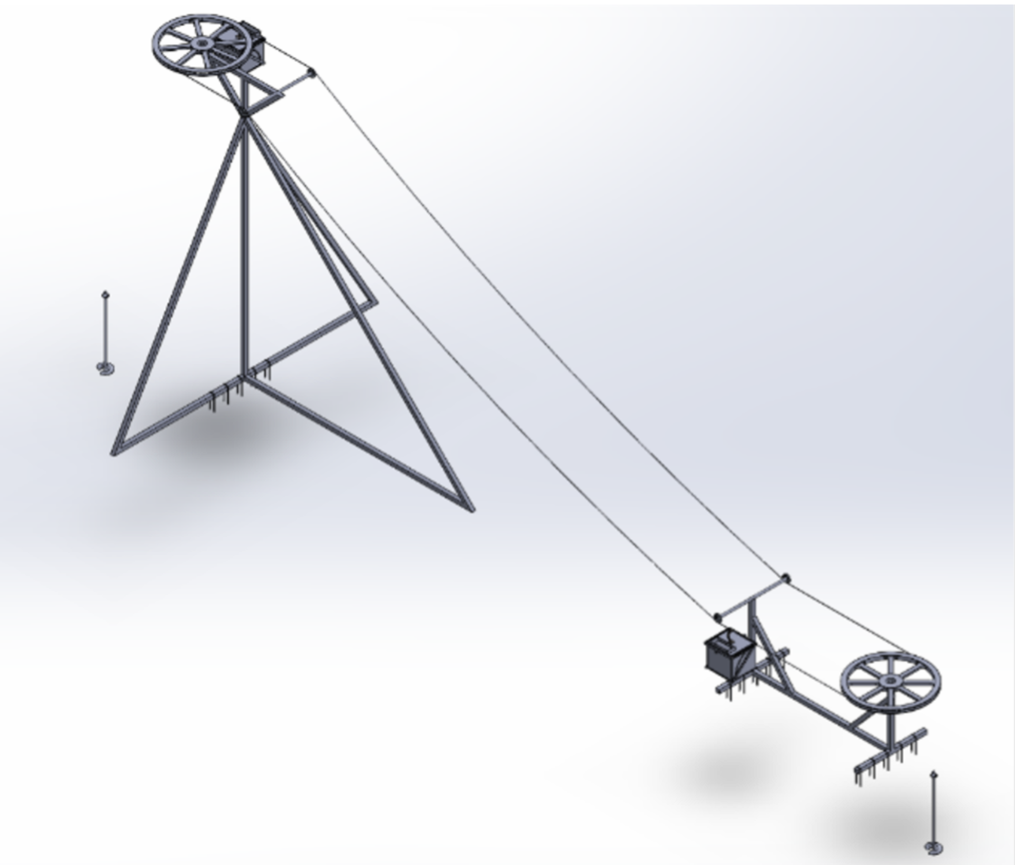


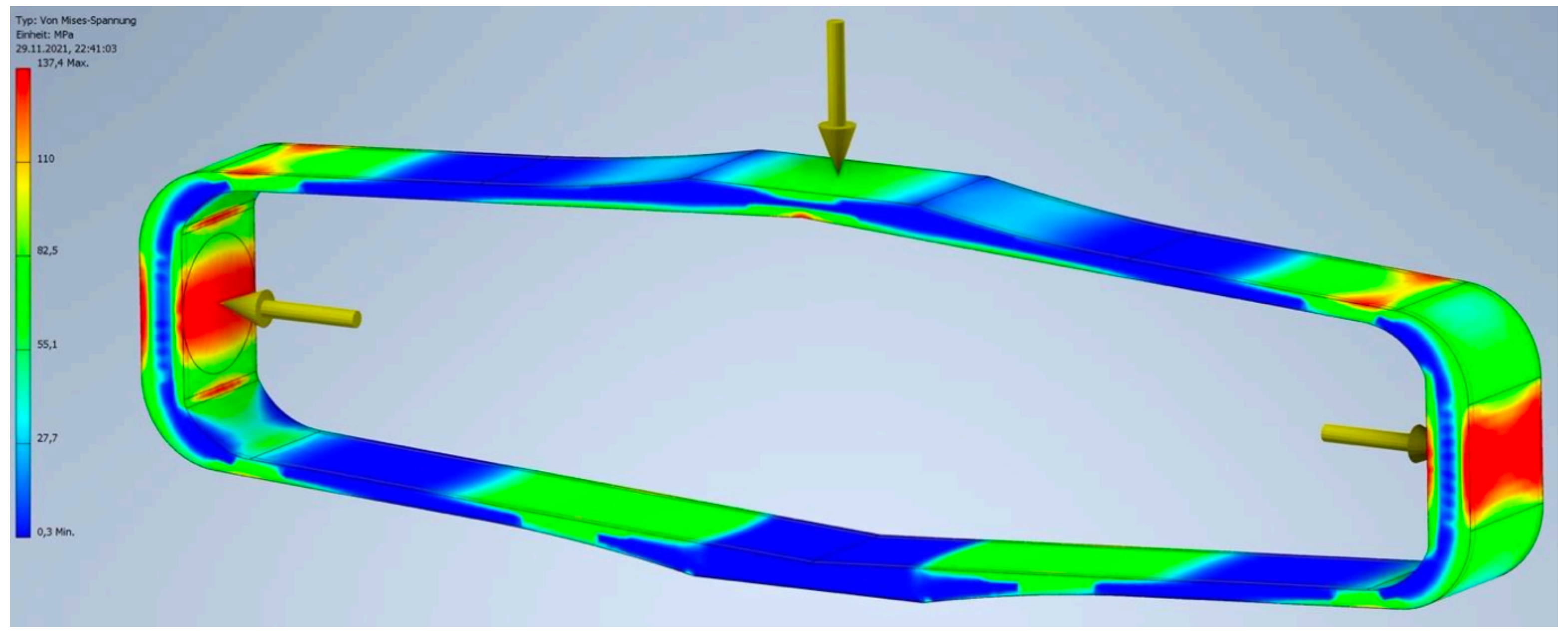






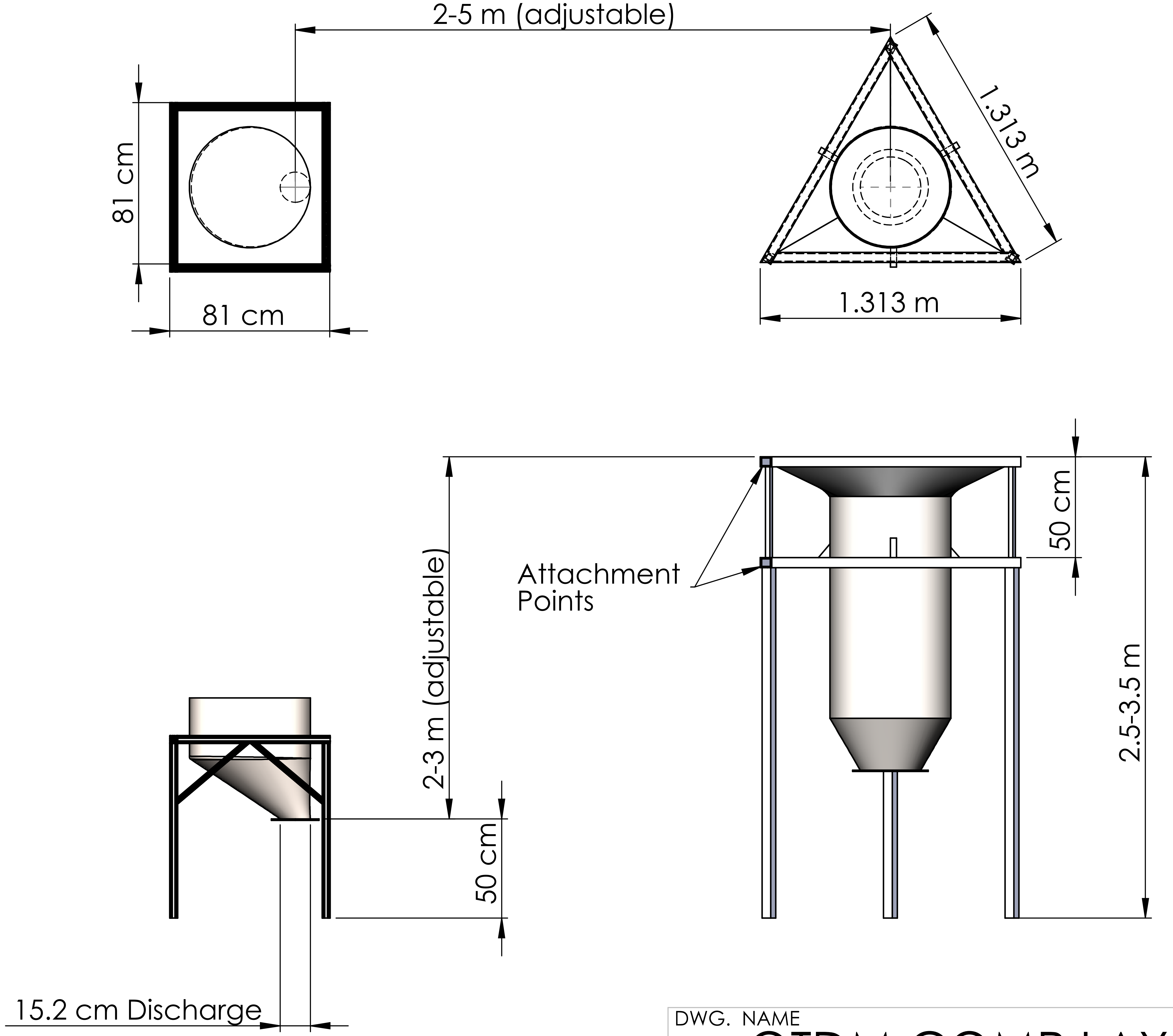






Phase 1 submissions

Other:
magnetic acceleration (1)
electrostatic (1)



DWG. NAME OTDM COMP LAYOUT		REV
	SCALE:1:30	SHEET 1 OF 1




1st place	🇨🇦 Laurentian Lunars 🍁	Laurentian University, Canada
2nd place	🇵🇱 SpaceTeam AGH 🥟	AGH University, Poland
3rd place	🇦🇺 Team UNSW 🦘	University of New South Wales, Australia

Participant	🇺🇸 Dustbusters 🦅	Colorado School of Mines, United States
Participant	🇩🇪 Moon Aixperts 🥨	RWTH Aachen University, Germany

Thank-you's:

LOCKHEED MARTIN

CSM team

Dewey Gazvoda

Joshua Gogolski

Evan Reynolds

John Schmit

Sarah Heckel

David Purcell

Cruz Strom

Judges

Rob Mueller (NASA)

Eamon Carrig (ICON)

Lisa D. May (Lockheed)

Ryan Dubisher (Lockheed)

Joe Minafra (NASA)

Stay tuned for next year

OVER THE DUSTY MOON CHALLENGE

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