COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

OVER THE DUSTY MOON CHALLENGE

Colorado School of Mines
Over the Dusty Moon Challenge
Phase 1 Competition Rules 8/15/2022

Revision Tracking Log

Status (Baseline/Revision)	**Document Revision**	**Effective Date**	**Description**
Baseline	V1	8/15/2022	Document Baseline
Revision	V2	8/28/2022	Revised receptacle height

1. Introduction

As we work to expand humanity's reach in space, a sustained presence on the Moon will allow for an in-space economy built around space resources, tourism, and other commercial activities. An important subset of space development technologies revolves around In-Situ Resource Utilization (ISRU), the use of local materials to mitigate the amount of material that needs to be transported from Earth.

One of the most abundant resources on the Moon is the lunar regolith. Every part of the Moon's surface is covered with loose unconsolidated soil and rocks. This material can be used in and of itself as a resource, for example 3D printing with regolith or casting. It can also be used as a feedstock from which to extract metals and oxygen using high-temperature processes.

For all these applications it will likely be necessary to excavate, transport, beneficiate, and process regolith. It will be important to learn how to perform these steps in a dusty environment while minimizing the dust hazard to nearby personnel and equipment.

Other challenges like the NASA Lunabotics competition have focused on the first steps in this processing chain: excavation and transport of raw regolith over short distances. In this year's Over the Dusty Moon Challenge, we focus on the next steps including high-volume horizontal and vertical regolith transport, transfer points, and rock removal, all with built-in dust mitigation strategies.

1.1. Technology Gaps

CSM has identified a number of key technology gaps related to transport of regolith and dust mitigation that could be addressed through a challenge, including:

- Transport of high volumes of regolith over medium to long horizontal distances
- Transfer points between one transport system and another
- Vertical transport to a receptacle high above the surface
- Mitigating dust during regolith transport
- Dealing with the extremely poor flowability of lunar regolith
- Removing rocks embedded in the finer regolith
- Hardware and equipment that operates well in extreme lunar environmental conditions, including: (1) Vacuum conditions, (2) Dust levels found on the lunar surface, and (3) Reduced gravity

The Over the Dusty Moon Challenge seeks to yield innovative approaches for transporting and delivering regolith in the dusty lunar environmental conditions. The challenge incentivizes creative solutions for maximizing delivery while minimizing power and the mass of equipment required to be transported to the lunar surface and minimizing dust generation during operations.

2. Challenge Description

2.1. Overview

The Over the Dusty Moon Challenge will have up to two phases, totaling no more than 12 months.

Phase 1 of the Over the Dusty Moon Challenge is focused on new ideas and approaches to a system architecture for horizontal and vertical transport of regolith over the lunar surface. The Challenge describes a hypothetical scenario and asks teams to design a system architecture addressing necessary hardware, concept of operations, lunar environmental conditions, and specific performance analyses, as well as the credibility and feasibility of the system architecture.

In Phase 1, Teams will have approximately four (4) months to register and submit a written report on their system architecture (see Phase 1 Submission below). Phase 1 will last a total of five (5) months, including approximately one (1) month of judging (see Competition Calendar below).

Following Phase 1, CSM expects to initiate Phase 2 of the Challenge, which will focus on designing and building prototype systems that would be tested with simulated lunar materials. Phase 2 will last approximately five (5) months with the in-person competition held at the end of this phase.

Based on the Phase 1 judging, up to 6 teams will be invited to participate in Phase 2 of the challenge. Prizes awarded during the Phase 2 are described in Table 1. In addition to the prizes, all teams invited to Phase 2 will receive room & board and a travel stipend during their stay in Colorado for the in-person trials, and free registration for the Space Resource Roundtable if they wish to stay for this conference the following week.

Table 1. Phase 2 Prizes (USD)

Phase 2 Prizes	
1st Place	$5,000
2nd Place	$4,000
3rd Place	$3,000

2.2. Challenge Scenario

The scenario described below is a hypothetical scenario similar to a real-world lunar case study, and will mimic the actual set-up for the in-person competition. Teams will design a system architecture to transport regolith based on the conditions, terrain, and regolith specifications, and hypothetical CSM assets described below.

The scenario takes place in a well-lit area near the lunar poles. The scenario includes two CSM assets: a CSM Regolith Hopper, and a CSM Molten Regolith Electrolysis (MRE) Plant. These assets are described further below. Teams' architectures must:

1. Take delivery of regolith from the bottom of the CSM Regolith Hopper
2. Transport the regolith horizontally over a distance of at least 5 meters
3. Optionally, transfer the regolith to the vertical transport system if this is separate from the horizontal system
4. Lift the regolith vertically to a height of at least 2.5 meters and deposit it in the receptacle of the CSM Molten Regolith Electrolysis Plant.
5. Embedded rocks (up to 3.5 cm diameter) must be removed from the regolith. Removing rocks can either be done using a separate system (placed before or after the Hopper) or integrated into one or more of the transport systems themselves.

There is no minimum mass of regolith that must be delivered, but we are interested in system architectures that can deliver at least 1,000 kilograms (kg) of regolith per 24-hour period.

System architectures must include:

- A description of all hardware needed to complete the regolith transport tasks
- A detailed concept of operations, addressing:
  - Deployment of the hardware from a lunar lander
  - Movement of regolith from the Regolith Hopper to the MRE plant
  - Lifting of regolith up into the MRE plant receptacle
  - Rock removal
  - Information on dust mitigation and any additional elements included
- An environmental analysis describing how equipment is expected to perform in extreme lunar environment conditions with regard to temperature, dust, reduced gravity, and vacuum
- Performance analyses, including:
  - Analysis of the landed mass of each piece of equipment that would need to land on the lunar surface to complete the task
  - Analysis of the mass of regolith delivered per unit time
  - Analysis of the power consumed by each piece of equipment, plus total power

In calculating mass, teams should not include mass associated with the CSM Regolith Hopper and CSM MRE Plant.

The total landed mass and volume of the system architecture is not limited in Phase 1 of the challenge. However, teams are encouraged to consider the constraints of delivering the hardware associated with their system architecture to the Moon.

2.2.1. Location

In this scenario, transport of regolith will take place in a well-lit, relatively flat region at one of the lunar poles.

2.2.2. Environmental Conditions

Teams must address the following environmental conditions in the system architecture. However, teams should keep in mind that the prototypes built in Phase 2 will be operating in terrestrial gravity and atmosphere.

- **Temperature Range:** Surface temperature ranges from 60 K to 230 K, with an average temperature of approximately 120 K.
- **Dust:** Fine lunar dust, defined as particles smaller than 20 microns in size, is present in the entire area. This dust is very abrasive to equipment and electrostatically charged; it can travel long distances when disturbed.
- **Reduced Gravity:** Gravity on the Moon is ~1/6 that of Earth's gravity.
- **Vacuum:** A hard vacuum is present at the lunar surface.

2.2.3. Terrain

Assume the terrain at the regolith transport site is relatively flat and free of large boulders, but contains some rocks up to 10 cm in diameter, small craters, and moderate small-scale surface roughness.

2.2.4. Regolith Information

Teams should assume the regolith is a lunar highlands composition (noritic to anorthositic), with a bulk density of approximately 1,500 kg/m^3. As reported by the Apollo astronauts, the lunar regolith is highly cohesive and exhibits poor flowability similar to the consistency of wet sand. Note that this property of regolith *is extremely poorly captured by terrestrial regolith simulants that flow freely*. High-precision measurements under controlled conditions have shown the angle of repose of Apollo regolith is up to 58° or higher, compared to values around 30-35° for lunar simulants. Teams should design for the poor flowability of actual lunar regolith.

2.2.5. CSM Assets

Teams should assume that CSM will provide the following assets, both for the Phase 1 design and for the Phase 2 in-person challenge. STEP files of both assets are available on the OTDM website.

Regolith Hopper

Deposits regolith out of a circular opening at the bottom of the hopper. Assume that flow rates are adjustable. The height of the hopper opening is 50 cm above the surface.

Molten Regolith Electrolysis Plant

This is the ultimate destination for the transported regolith. The MRE Plant is a large reactor, with a receptacle for the regolith located 2.5–3.5 m above the surface (adjustable).

2.3. Competition Calendar

Key dates for the challenge are listed in Table 2 below.

Table 2. Competition Calendar.

Expected Date	Description
Aug 15, 2022	Competition opens for applicants
Sept, 2022	Webinar(s) for Q&A
Dec 23, 2022	Deadline for registration and Phase 1 submissions
Dec 23, 2022-Jan 9, 2023	Judging of Phase 1 submissions
Jan 9, 2023	Notification to invitees, beginning of Phase 2
June, 2023	Phase 2 in-person competition in Colorado

3. Phase 1 Registration, Submission, and Judging

3.1. Registration

All teams must register for the challenge by the December 23, 2022 deadline (11:59 pm Mountain Time) and meet the eligibility requirements in order to participate in the challenge. Registration will take place through the official challenge website: https://www.overthedustymoon.com using the link to the Registration Form.

3.2. Phase 1 Submissions

All registered Teams must submit their system architectures by the December 23, 2022 deadline (11:59 pm Mountain Time). Teams will deliver their Phase 1 submission via email: contact@overthedustymoon.com. Phase 1 submissions should be in the form of a single PDF document will all required elements. If file sizes are large (>15 MB), upload the document somewhere and send a shared link in the submission email.

3.2.1. Submission Elements

- **Submission title**: This title will be displayed on the competition website post-submission for invited Phase 2 participants.
- **Team information**: Teams must submit a brief (one or two sentence) bio for each team member.
- **Technical abstract**: Teams must provide a brief summary description of the system architecture. The technical abstract should provide a concise and compelling overview of the team's submission.
- **Intellectual Property**: Teams must explain who owns the intellectual property of the proposed system architecture. If the architecture is built on existing or off-the-shelf technology, teams should detail the permissions (if applicable) they have to use that technology. The submission should indicate which team members own the intellectual property if applicable.
- **System Architecture Report:** A detailed narrative and supporting illustrations, computer models, data, or other materials describing the following elements:
    - All hardware needed to complete the mission, including:
        - Equipment that interfaces with the regolith
        - Any support or maintenance equipment
    - Concept of operations, addressing:
        - Deployment of the hardware on the surface
        - Horizontal transport of regolith over the surface (5 m distance)
        - Vertical transport of regolith to a height of 3 m
        - Optionally, transfer of the regolith from the horizontal system to the vertical system
        - Rock removal
        - Deposition of the regolith into the receptacle of the MRE Plant
        - Information on dust mitigation during transport of the regolith
    - Environmental Analysis: How equipment is expected to perform in the extreme lunar environment conditions with regard to temperature, reduced gravity, and vacuum
    - Performance Analysis addressing:
        - Analysis of the mass of each piece of equipment that would need to be landed on the lunar surface to complete the mission, plus total landed mass
        - Analysis of the mass of regolith delivered per unit time
        - Analysis of the power used by each piece of equipment during the mission, plus total power
        - Ratio of regolith delivered (per time) to total landed mass
        - Ratio of regolith delivered (per time) to total power

Table 2. Summary of Submission Elements & Limits

Phase 1 Submission Element	Word/Page Limit
Submission title	~10 words
Technical abstract	~250 words
Intellectual property	~50 words
Team bios	~100 words each
System architecture report	15 pages including figures & references

3.3. Phase 1 Judging

Following the Phase 1 submission deadline, the CSM judging panel made up of experts from academia will review the submissions and discuss, evaluate, and rank the Teams. Judges will assess submissions on the criteria described below.

Table 4. Submission Criteria, Description, and Maximum Points

Criteria	Description	Maximum Points
Scientific and technical merit	Does the system approach provide a detailed description of the design and all the subsystems? Is a full concept of operations included? Are sufficient technical details included to understand how the system operates? Does the system take into account the unique challenges of dealing with lunar regolith?	20
Feasibility of the design	Could the system be feasibly built and flown to the Moon in the near term? Does it represent a credible approach to achieving the goals in the scenario?	15
Creativity of the design	Does the system introduce new or creative approaches to solve the technology gaps identified by CSM?	10
Estimated mass of regolith transported	What is the estimated mass per unit time of regolith that the system can deliver to the MRE Plant?	10
Estimated power use	What is the estimated total power consumption of the system?	10
Estimated landed mass	What is the estimated total landed mass of the system?	10
Environmental concerns	Are all of the environmental concerns (temperature, dust, gravity, vacuum)	10

	addressed in the system design and described in the system architecture?	
Quality of writing and illustrations	Does the submission clearly communicate the system approach? Is the writing of a high quality and has been thoroughly proofread? Are the supporting illustrations legible and of high quality?	10
Completeness	Does the submission include all of the elements as described in Table 2?	5

4. Legal Requirements

4.1. In General

Teams are responsible for understanding and complying with all Challenge rules and eligibility requirements as stated below.

4.2. Eligibility

CSM welcomes applications from teams that meet the eligibility requirements provided below.

- All team members must be enrolled as students (undergraduate or graduate) at an accredited university.
- Teams may be mixtures of undergrads and grads, but there are no quotas for either.
- Multiple teams per university may compete.
- Each team must have a faculty advisor who is a faculty member employed at their university.
- Teams must be fully committed to building a prototype of their system and travelling to Colorado to participate in the in-person competition if invited.
- Companies and other organizations are not eligible to participate, but teams may establish partnerships with companies and other organizations for general advice and mentorship only (as well as sponsorship).
- Teams from countries determined by Department of State to be "State Sponsors of Terrorism" or identified by the Department of Commerce as "Terrorist Supporting Countries," and countries under Sanction or Embargo by the United States are not eligible to participate. This includes: Afghanistan, Belarus, Myanmar, Central African Republic, China, Congo, Cuba, Cyprus, Eritrea, Haiti, Iran, Iraq, North Korea, Lebanon, Libya, Russia, Somalia, South Sudan, Sudan, Syria, Venezuela, Zimbabwe.

4.3. Insurance and Indemnification

Each team member agrees to assume any and all risks and waives claims against the Colorado School of Mines and its related entities, except in the case of willful misconduct, for any injury, death, damage, or loss of property, revenue, or profits, whether direct, indirect, or consequential, arising from each team member's participation in the Challenge, whether such injury, death, damage, or loss arises through negligence or otherwise. For the purposes of this section, the term "related entity" means a contractor or subcontractor at any tier, and a supplier, user, customer, cooperating party, grantee, investigator, or detailee.

Team agrees to obtain any and all insurance policies and coverage required by its local, state, or Federal governments to conduct any and all virtual activities related to or required by participation of team and the team members in the challenge. The team and all team members agree to indemnify Colorado School of Mines against third-party claims for damages arising from or related to Challenge activities.

4.4. Use of Names, Trademarks, and Insignias

Team may not use the name, trademark or insignia of CSM on its printed materials related to the participation of team in the challenge without CSM's prior written consent, whichever Party is applicable.

Team agrees that unauthorized use of such names, trademarks, and insignias shall result in elimination from participation in the challenge if team continues unauthorized use after being notified to cease and desist by CSM, as applicable.

4.5 Delay, Cancellation or Termination

The competitor team acknowledges that circumstances may arise that require the challenge to be delayed indefinitely or cancelled. Such delay or cancellation, and/or the termination of the challenge, shall be within the full discretion of CSM, and the team accepts any risk of damage or loss due to such delay, cancellation, and/or termination.