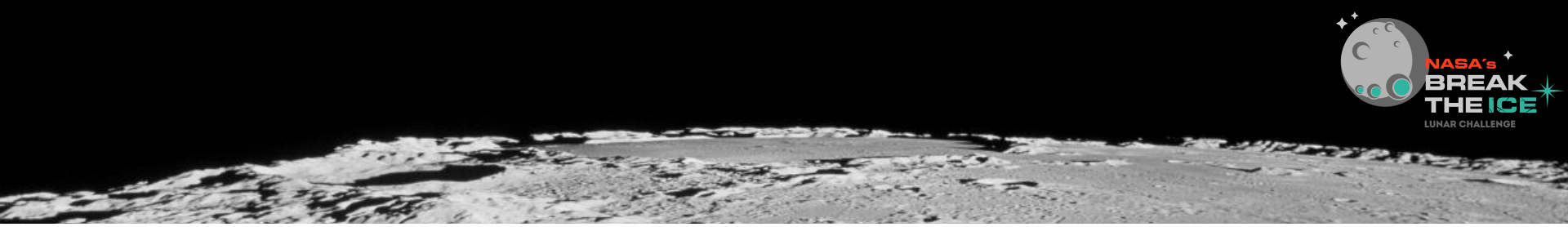


NASA's BREAK THE ICE LUNAR CHALLENGE

Phase 2 Overview Webinar and Q&A

July 12th 2 – 3 pm (Central)

Agenda

- Welcome, Introductions & Housekeeping
- Introduction to NASA Centennial Challenges
- Break the Ice Lunar Challenge Overview
- Phase 1 Review
- Phase 2 Overview and guidelines
- Challenge Website and registration
- Q&A

Introductions

Denise Morris
Program Manager (Acting)
NASA Centennial Challenges

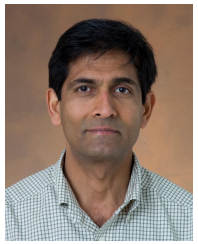
Pete Carrato
Fellow Emeritus
Bechtel Corporation

Chris Frangione
Challenge Consultant
Jacobs Space Exploration Group

Oliver Gerland
Director, Strategy & Product
Ensemble

Mark Hilburger
Principal Technologist
NASA

Kurt Leucht
Subject Matter Expert
NASA KSC



Hari Nayar
Subject Matter Expert
NASA JPL

Jerry Sanders
ISRU Systems Capability Lead
NASA

Naveen Vetcha
Challenge Manager
Jacobs Space Exploration Group

Webinar Instructions

- Panelists will be able to speak and screen share as needed throughout the webinar; attendees will be unable to speak but are welcome to participate through the chat and Q&A features

- Questions can be submitted through Q&A feature in your participant taskbar

- Questions will first be reviewed by our moderators and then shared during the live Q&A at the conclusion of the event

- Challenge rules document is the official document. Do not use the contents of this presentation as reference.

- Recording will be shared at https://breaktheicechallenge.com/resources-media/


NASA
Centennial Challenges Program
Daring you to ask…
What if?
NASA
CENTENNIAL
CHALLENGES

ABOUT US:

- NASA's first prize program
- Established to conduct prize competitions in support of the Vision for Space Exploration and ongoing NASA programs
- Inspired by Orteig Prize and Ansari XPRIZE, among others
- Established (per NASA Prize Authority, 51 USC 20144): "to stimulate innovation in basic and applied research, technology development, and prototype demonstration that have the potential for application to the performance of the space and aeronautical activities of the Administration."
  - https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title51-section20144&num=0&edition=prelim
  - First competition opened in 2005

NASA
CENTENNIAL
CHALLENGES

NASA Prizes, Challenges, and Crowdsourcing

NASA Solve

- **Centennial Challenges Program**
- **NASA Tournament Lab**
- **Space App**
- **Citizen Science**
- **NASA Education**
- **NASA @ Work**

NASA CENTENNIAL CHALLENGES

Centennial Challenges

3D-Printed Habitat
$3.1M

CO_2 Conversion
$1M

Vascular Tissue
$500K

Space Robotics
$1.9M

COMPLETED

Cube Quest
$5M

Watts On The Moon
Up to $5 M

Break the Ice Lunar
Up to $3.5 M

Deep Space Food
Up to $3 M

ACTIVE

NASA CENTENNIAL CHALLENGES


NASA's
BREAK
THE ICE
LUNAR CHALLENGE

NASA CENTENNIAL CHALLENGES

Challenge Structure

Break the Ice Lunar Challenge

Total Prize Purse: $3.5M

Phase 1 – System Architecture

Status: Complete

Design a system architecture for excavation of icy regolith inside a permanently shadowed region (PSR) and delivery of water to a storage plant located outside the PSR at the lunar south pole.

Duration: 11/2020 – 8/2021 (including judging)

Prize Purse: $500K

First place - $125K

Second place - $75K

Third place - $50K

10 runners up - $25K each

Phase 2 – Design, Build, Test, and Compete

Status: Ongoing

Design, build, and perform long-duration tests of icy regolith excavation and transportation systems. Team will perform the long-duration tests at a facility of their choosing.

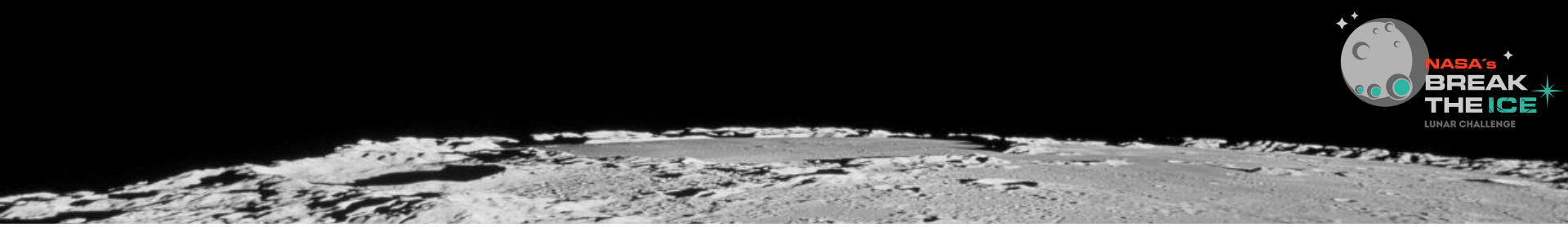
Perform short duration testing of excavation and transportation systems in lunar-like surface and gravity conditions. All teams will test their systems in a face-to-face competition at a facility chosen and prepared by NASA.

Teams did not have to compete in Phase 1 to participate in Phase 2.

Duration: 6/2022 – 5/2024 (including judging)

Prize Purse: $3M

Other Prizes: Opportunities to test excavation system(s) in a NASA dusty TVAC facility



Where we've been….

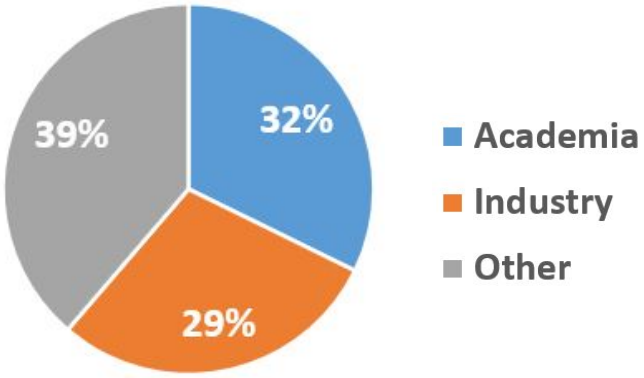
Phase 1 Overview

Teams were given a mission scenario and were asked to submit System Architectures, Excavation Plans, and Mission Animations that met the constraints and requirements provided in the official rules.

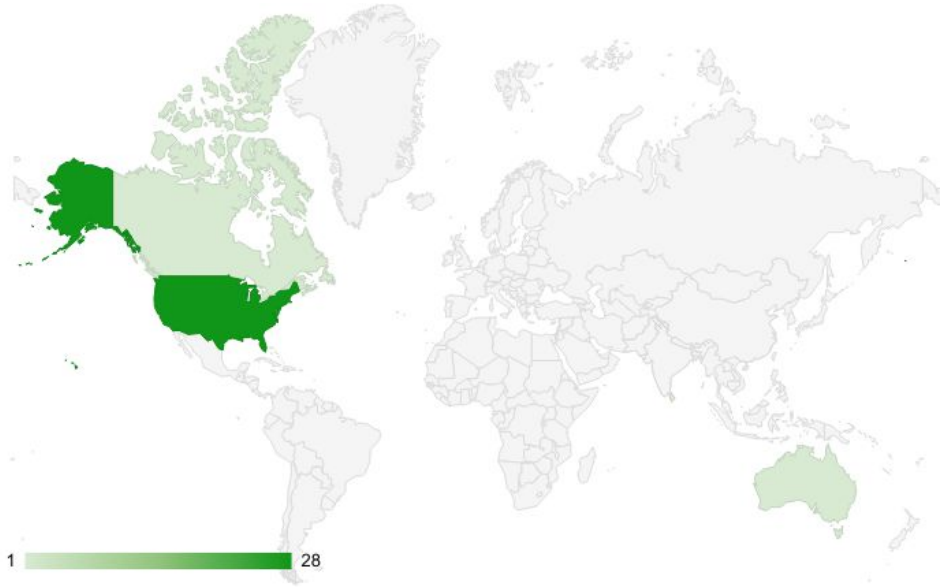
- **Timeline**: 9-months total (including judging) (11/2020 – 8/2021)
- **Submissions**:
  - Received a total of 31 eligible submissions
  - Submissions from four countries and 17 US states
- **NASA Awards**: $500K
  - 1st place - $125K, 2nd place - $75K, 3rd place - $50K, and 10 runners up each received $25K

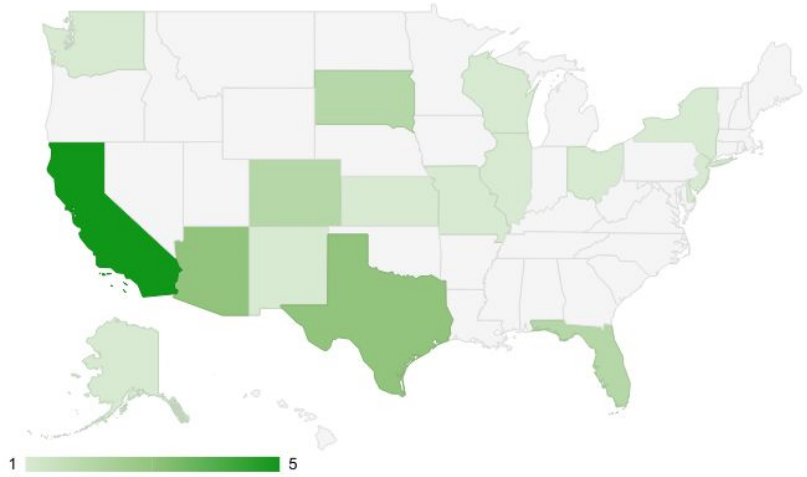
Phase 1 Submission Metrics

- 31 eligible submissions
- US (28), Australia (1), Canada (1), and Sri Lanka (1)
- Submission from 17 US states: Alaska, Arizona, California, Colorado, Delaware, Florida, Illinois, Kansas, Missouri, New Jersey, New Mexico, New York, Ohio, South Dakota, Texas, Washington, Wisconsin.



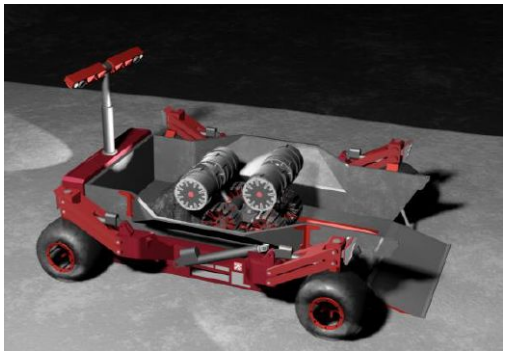
"Other" refers to individual or group of inventors with or without affiliations to organizations.





Phase 1 Winners

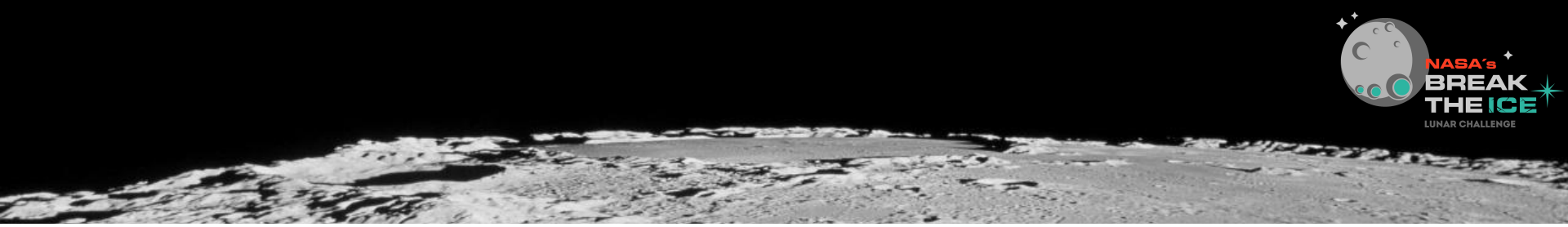
	Team/Organization	Location
1st Place	Redwire Space	Jacksonville, FL
2nd Place	Colorado School of Mines	Golden, CO
3rd Place	Austere Engineering	Littleton, CO
Runner-ups	AggISRU/Texas A&M University	College Stations, TX
	Aurora Robotics/Univ. of Alaska Fairbanks	Fairbanks, AK
	Lunar Lions/Columbia University	Columbia, NY
	OffWorld Robotics	Pasadena, CA
	Oshkosh Corporation	Oshkosh, WI
	Rocket M	Mojave, CA
	Space Trajectory/South Dakota State Univ.	Brookings, SD
	AA-Star	Redmond, WA
	LIQUID	Altadena, CA
	Terra Engineering	Gardena, CA



Redwire Space

Colorado School of Mines

Austere Engineering



Where we are now….

Phase 2 Overview

Goal of Phase 2 is to further the development of technologies that can excavate and transport large quantities of icy regolith by testing them in lunar relevant conditions and scenarios.

- *Challenge Requirement:* Teams will design, build, and demonstrate prototype excavation and transportation systems that meet the requirements listed in the rules.
- *Eligibility:* Phase 2 is open to any team that meets the eligibility criteria in the rules. Participation in Phase 1 is not a requirement to participate in Phase 2.
- *Structure:* Phase 2 will include three levels, with finalists demonstrating performance in simulated lunar surface and gravity conditions at a NASA prepared facility.
- *Prize:* Total prize purse of $3M. In addition, NASA will also award limited number of opportunities to test the winning concepts in a TVAC facility.

Phase 2 Structure

Level 1	Level 2	Level 3
Up to 10 prizes $50K each	1st Place ($300K), 2nd Place ($200K), 3rd Place ($125K), Up to 5 Runners up ($75K each)	1st place ($1M), 2nd place ($500K), and TBD number of TVAC test opportunities
Teams will develop detailed engineering designs and long duration demonstration test plans for the icy regolith excavation and transportation systems	Teams will build the icy regolith excavation and transportation systems and perform long duration demonstration tests at a facility of their choosing	Teams will bring their prototype systems to a test site chosen and prepared by NASA. Prototype systems will be tested in simulated lunar surface and gravity conditions.
All teams that submit compliant deliverables by the deadline will move to Level 2	Up to 15 teams will be chosen to move to Level 3	Teams will win cash prizes and potential TVAC test opportunities

Phase 2 Timeline

Activity	Date
Phase 2 Registration Opened	6/2/2022
Webinars to support registered and potential Teams	6/2022 – 9/2022
Phase 2 Registration Deadline	9/30/2022
Level 1 submission deadline	11/4/2022
Level 1 Winners announcement	12/5/2022
Deadline to start long duration testing	9/15/2023
Level 2 submission deadline	10/27/2023
Level 2 Winners announcement & Selection of Teams for Level 3	12/2023
Deadline for teams to confirm Level 3 participation	3/2024
Level 3 competition & Winners Announcement	5/2024

Registration and Eligibility

Registration

- Teams must register on the challenge website and submit all required forms and supporting documents
- Teams may participate in Phase 2 even if they did not participate in Phase 1

Eligibility Requirements – Competition open for international participants

- Individuals must be U.S. citizens or permanent residents of the United States and be 18 years of age or older
- Organizations must be an entity incorporated in and maintaining a primary place of business in the United States
- Teams must be comprised of otherwise eligible individuals or organizations and led by an otherwise eligible individual or organization
- Team leaders must be a U.S. Citizen or permanent resident
- International teams are allowed to compete but are not eligible to win cash prizes

Phase 2 Technology Gaps

Key technology gaps exist for NASA related to excavation of icy regolith and delivery of acquired resources (such as water) that could be addressed through a challenge. Phase 2 of the Break the Ice Lunar Challenge seeks to address the following technology gaps:

- Excavation of large quantities of icy regolith
- Delivery of large quantities of acquired resources
- Hardware and equipment that is lightweight and energy efficient
- Hardware and equipment that is reliable and durable
- Hardware and equipment that operates well in extreme lunar environmental conditions, including:
  - Reduced gravity
  - Complex terrain including rocks, craters, slopes, and loose granular soil

Prototype Design Considerations

Teams are to design, build, and test a terrestrial full-scale prototype robotic icy regolith excavation and transportation system, and should address the following design considerations.

Prototype systems must be:

- Capable of **excavating** and **delivering** large quantities of icy regolith
- Capable of **transferring materials** from one machine or subsystem to another as needed during excavation, transportation, and delivery operations
- Capable of **operating in extreme lunar environments** such as temperatures, lighting conditions, vacuum, low gravity, dust, and complex & rugged terrain
- **Lightweight and energy efficient**
- **Reliable and durable**

Prototype Requirements 1/2

The full-scale robotic icy regolith excavation and transportation system prototypes shall:

- Have mass less than 10,000 kg
- Fit inside a 6-meter-diameter, 10-meter-long cylindrical volume
- Includes:
  - All icy regolith excavation equipment
  - All icy regolith transportation equipment (can be the same robot that conducts excavation)
  - Any spare parts, tools, and equipment needed for repair and maintenance during the long-term durability demonstration testing
  - Any tools and equipment needed to maintain the test area during the long-term durability demonstration testing

Prototype Requirements 2/2

- Icy-regolith excavation and transportation equipment **restrictions**:
  - Can not use wired umbilical power; only onboard power sources will be allowed
  - Can not use wired communications; only wireless communications equipment will be allowed
  - Can not employ any physical processes, gases, fluids, or consumables that would not work in a lunar environment. For example:
    - *Air-filled or foam filled rubber tires are not allowed, as they would not maintain their integrity in the vacuum of the lunar surface*
    - *Ultrasonic sensors are not allowed, as they would not function in a vacuum*
  - Pneumatic systems are allowed only if the gas is stored and supplied onboard the robot itself
  - Hydraulic fluid systems are allowed only if the power and mass of a heating system is included in the design that would be required to keep the fluid from freezing in the extreme lunar environment

- Electronic and mechanical components are not required to be space qualified

Long-Term Durability Testing Requirements

Teams will perform a long-term durability demonstration test of their working prototype system with the following requirements:

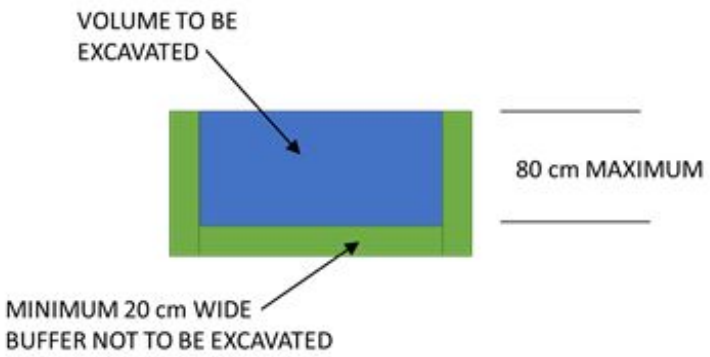
- Operate all prototype equipment over a period of **15 full, 24-hour-long Earth days**, or until equipment fails
- Performed at a terrestrial location of each Team's choosing under **ambient conditions**
- Include both an **excavation** test component and a **transportation** test component - the transportation test will haul the material that was excavated during the excavation test
- Excavation test must extract **simulated regolith as defined in the rules**
- Teams will target excavating **12,000 kg of simulated regolith**
- Transportation test must be performed in an area that complies with the requirements provided in the rules
- Human intervention with the systems is allowed during the long-term durability demonstration with the caveats provided in the rules

Icy Regolith Simulant Requirements

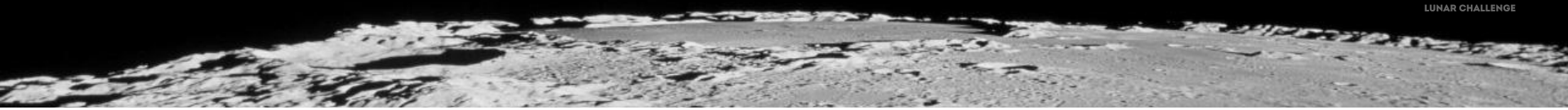
Concrete materials will be used to simulate the assumed mechanical properties of **4% water weight lunar icy regolith**.

- Made from Controlled Low Strength Materials following the guidance provided in the American Concrete Institute report ACI 229R
- Verified to have an unconfined compressive strength at the start of excavation testing of 1.5 to 2.0 MPa
- Placed in one continuous pour
- Dry regolith over burden shall not be simulated
- The geometry of the icy regolith simulant should be as follows:
  - Depth to be excavated shall not be more than 80 cm
  - Width and length shall be any dimensions necessary to accommodate the equipment under test
  - A minimum of 20 cm of additional buffer area (an area not to be excavated) shall surround the volume to be excavated

Side view of icy-regolith simulant bed (buffer area shown in green)



Transportation Demonstration Area Requirements



Area used for transportation demonstration shall meet the following requirements:

- Minimum **one-way travel distance of 500 meters** from Excavation Site to Delivery Site
- Transportation equipment shall repeatedly **drive on the same path** throughout the Durability Demonstration Test, and drive this path in both directions equally
- The surface of the transportation demonstration area should simulate the surface conditions the Team assumed in designing the icy-regolith transportation system
- The designated delivery location for the simulated regolith must be capable of receiving and weighing the material that was hauled and delivered by the prototype robotic icy regolith transportation system
- Teams are to target a **delivery rate of 800 kg every 24 hours**

Data Collection Requirements

The following data must be collected by the Team during the long-term durability demonstration

- At least one **live video stream** that is accessible to the Centennial Challenges Judging Panel (1080 or better resolution)
- **Detailed photos** of each major piece of hardware and equipment performing normal operations
- **Mass** of each piece of equipment, including spare parts and repair and maintenance tools (whether used or unused during the demonstration), and total system mass
- **Energy** used by each piece of equipment, and total system energy
- **Runtime** of each piece of equipment, total system runtime, and total number of icy regolith excavation and transportation robots
- **Total distance traveled** by icy-regolith transportation equipment during transportation of material from the excavation location to the delivery location
- **Total amount (kg) of icy regolith simulant excavated and delivered**
- **Compressive strength** of icy regolith simulant at the beginning and end of the 15-day test period
- List of parts replaced, breakdowns, issues requiring human intervention, along with job-hours spent on repairs on the prototype icy regolith excavation and transportation equipment
- List of any maintenance or repair to the Transportation Demonstration Area

Level 1 Deliverables

Deliverable	Description
Submission Title	A title for the Team's prototype
Team Information	Curriculum Vitae and headshot for each Team Member
Technical Abstract	A brief description of the excavation and transportation system(s
Intellectual Property	Must explain who owns the intellectual property of the proposed system
Team Intro video	Video introduction of the Team
Legal documentation	Eligibility Requirements Document and Media form
Detailed Design Report	Contains detailed description of the Team's prototype systems and its design
CAD Models and/or Drawings	Viewable CAD models of the Team's prototype systems
Durability Demonstration Test Plan	Details of the Team's plan for performing the long-duration demonstration testing

Level 1 Evaluation

- Deliverables will be evaluated by the Judging Panel in order to determine whether they are compliant with the rules.
- Teams will receive a standard go or no-go decision from the Judging Panel.
- The evaluation of deliverables and team compliance notification will take approximately 2 full weeks from submission.
- If a Team is considered not compliant, they will be notified of areas of design that require additional attention. Non-compliant teams may then resubmit the deliverables for further assessment and evaluation.
- There is no limit to the number of times a Team may resubmit material before the submission deadline. However, each submission requires approximately 2 full weeks for evaluation by the Judging Panel.
- Teams that fail to submit deliverables will be disqualified and will not be allowed to continue further in the competition.

Level 2 Deliverables

Deliverable	Description
Durability Demonstration Test Report	Details of the Team's long-duration demonstration testing and outcomes
Durability Demonstration Time-Lapse Video	A short video showing Team's prototypes excavating, transporting, and delivering the icy regolith simulant
Safety analysis	Document must identify any potentially hazardous material or other safety concerns

Level 2 Evaluation

Factor	Description	Maximum Score
Mass efficiency	Total regolith simulant excavated and delivered per total landed mass. A factor will be applied that takes into account how closely the Team's prototype robotic icy regolith excavation and transportation systems meet the target delivery rate of 800 kg every 24 hours throughout the entire 15-day Durability Demonstration Test.	40
Energy efficiency	Total regolith simulant excavated and delivered per total energy used. A factor will be applied that takes into account how closely the Team's prototype robotic icy regolith excavation and transportation systems meet the target delivery rate of 800 kg every 24 hours throughout the entire 15-day Durability Demonstration Test.	30
Reliability & Durability	The extent to which the Team's prototype robotic icy regolith excavation and transportation systems handle the operational challenges of the long-term durability demonstration test. Reliability & Durability will be judged based on information provided by the Teams in their Durability Demonstration Test Report.	15
Lunar Simulation Fidelity	The extent to which the Team's Transportation Demonstration Area simulates the physical and environmental details of the anticipated lunar surface. Lunar Simulation Fidelity will be judged based on information and justification provided by the Teams in their Durability Demonstration Test Plan and Durability Demonstration Test Report.	15

Level 3 Competition

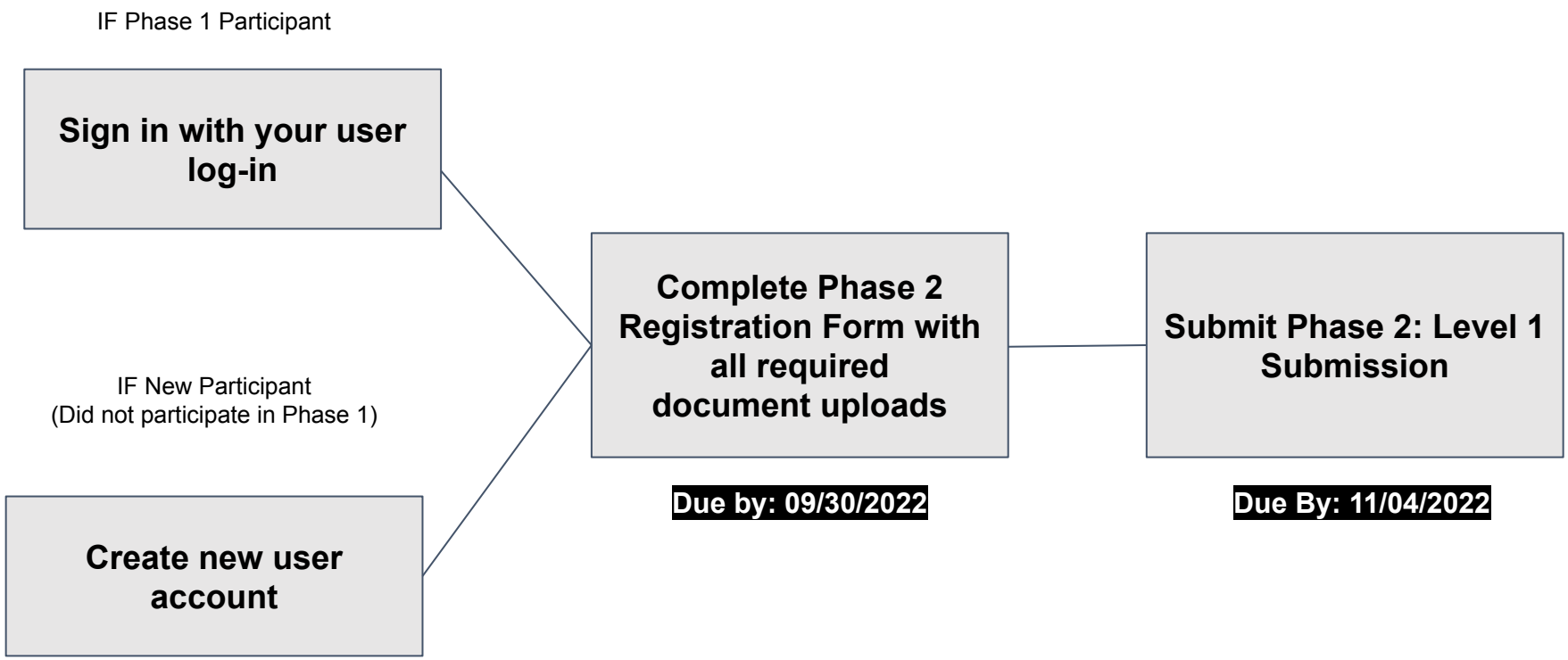
- Competition will take place over a span of few days at a site chosen and prepared by NASA

- Competition will include:
  - *Excavation Competition*:
    - Teams will be required to excavate simulated icy lunar regolith. All teams will be given a fixed amount of time to excavate as much material as possible from a regolith simulant bed.
    - The excavation competition will further challenge the Teams by introducing a simulated lunar gravity that is $1/6^{th}$ of the Earth's gravity. This will be simulated by connecting the Team's robotic excavation system to a gravity-off-load device.
  - *Transportation Competition*:
    - The transportation competition will take place on a course. A course consisting of loose granular material will be constructed that includes obstacles including, ramps of various slopes (up to 30 degrees) and cross slopes (up to 15 degrees). Other obstacles may include large rocks or boulder to hinder navigation. Teams will be allowed fixed amount of course time.
    - No gravity-off-load will be used for the transportation competition.

- Detailed testing requirements and judging criteria will be developed and be made available on the challenge website in 2023.

Challenge Registration

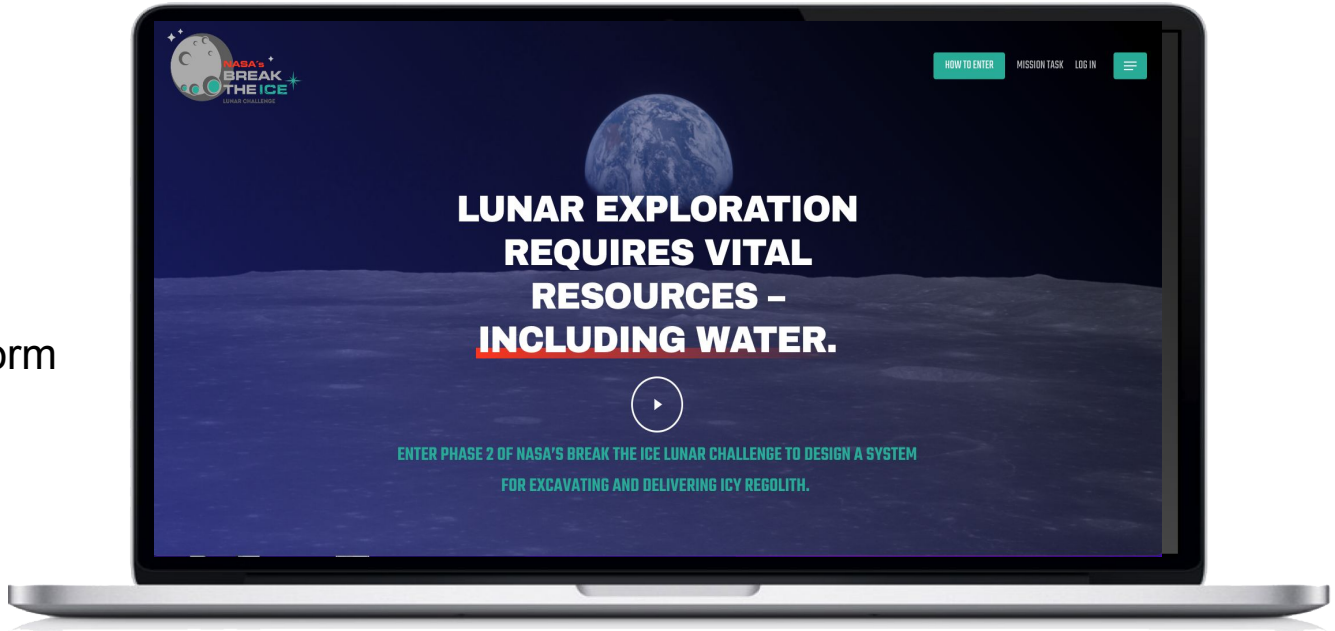
REGISTER YOUR TEAM BY SEPTEMBER 30, 2022



Challenge Website Demo

Key Pages to Review:

- Mission Task
- How to Enter Phase 2
- FAQ
- Forums
- Judging
- Phase 2 Registration Form
- Rules & Requirements



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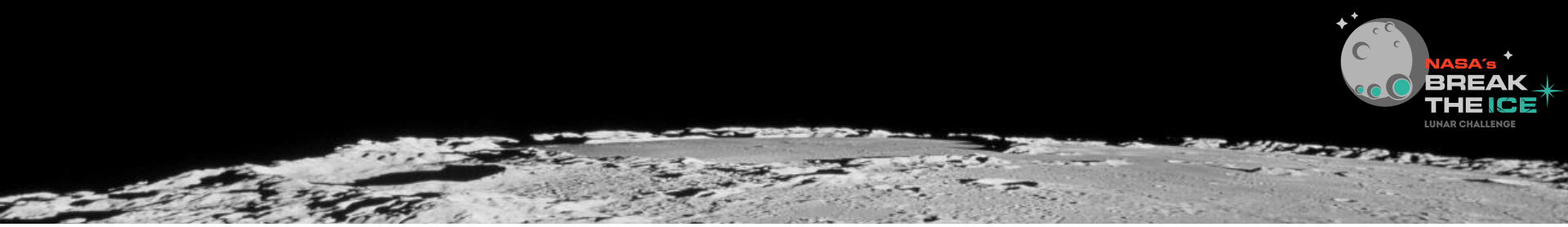


Q&A

SUBMIT YOUR QUESTIONS VIA THE Q&A CHAT BOX

Next Steps

- Complete the required paperwork and submit the supporting documents and forms by September 30, 2022

- Stay Connected

  Challenge Website: https://breaktheicechallenge.com/

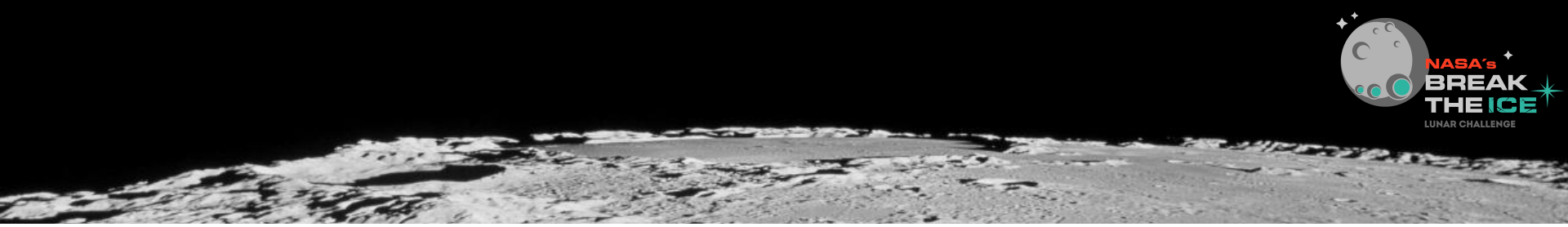
  @NASAPrize

  @NASAPrize

  /NASAcc

- Questions: Email at admin@breaktheicechallenge.com

***NOTE**: Any questions or inquiries sent to any other contact or sent directly to any of the Challenge Administrators will not be answered. This includes NASA, NASA Centennial Challenges, NASA Centers, and NASA Tournament Labs.*



THANK YOU