



XXIII SPACE RESOURCES ROUNDTABLE

Conference Program

**Colorado School of Mines
Golden, Colorado, USA
June 6-9, 2023**

Message

On behalf of the Steering Committee of the 2023 Space Resources Roundtable, welcome to the twenty-third edition of this conference that started back in 1999 with just a few enthusiasts in the space resources field. As we can now see from the record number of presentations and variety of topics covered at this year's meeting, this is undoubtedly the most exciting time for this community.

Interest is now coming from a variety of players with a wider set of objectives. New studies and projects incorporating ISRU technologies are being conducted for cislunar space, the Moon, Mars, and asteroids by space agencies around the world and the commercial space sector. As we gather for this meeting, oxygen is being extracted from the Martian atmosphere and surface prospecting equipment is expected to be launched to the Moon this year. Legislation has been advanced in several countries for commercial space-resource exploration and utilization. The Artemis Accords now include 25 countries that have agreed to extract and utilize space resources to support safe and sustainable space exploration, while a broader legal framework is being actively pursued at the international level. Most large aerospace companies and dozens of start-ups that have appeared in the past few years are positioning themselves in the various links of the space resources value chain, highlighting the growing interest and opportunities in this field. As current plans focus on the Moon as a destination for renewed robotic and human exploration, as well as paving the way to the Red Planet, it is now abundantly clear that the use of space resources will enable both further exploration and commercialization of space.

This increased interest calls for greater involvement from our rapidly growing community. Our expertise is needed more than ever to provide the scientific, technical, economic, business, legal, and policy guidance to integrate space resources into public and private space initiatives. We invite all meeting participants to actively contribute to this discussion to ensure an exciting and productive future in this field.



– Angel Abbud-Madrid
President & Chair, SRR XXIII, 2023

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Keynote Speakers

Wednesday, June 7, 8:00 AM



Peter Garretson

The Scramble for the Skies: Why Nations Care About Space Resources

Abstract: The inner solar system contains vast material and energy wealth that will affect the relative standing and wealth of nations. This talk will explore the scale of space resources in the inner solar system, why they matter to the future of power in the international system, and why it matters to our collective future.

Peter Garretson is a Senior Fellow in Defense Studies with the American Foreign Policy Council and co-director of its Space Policy Initiative and host of the Space Strategy Podcast. He was previously the director of Air University's Space Horizons Task Force, an Air Force think tank for space, and was a founder and deputy director of the U.S. Space Force's Schriever Scholars Strategy Seminar, America's premier military space strategy program. He is the author of *Scramble for the Skies: The Great Power Competition to Control the Resources of Outer Space*. His latest book is *The Next Space Race: A Blueprint for American Primacy*.

Thursday, June 8, 8:00 AM



James L. Reuter

NASA Space Technology Update

James L. Reuter is the NASA Associate Administrator for the Space Technology Mission Directorate (STMD). He provides executive leadership and management of technology programs within STMD, with an annual investment value of more than \$1 billion. During his almost four-decade career at NASA, Mr. Reuter has held several leadership positions, including: STMD deputy associate administrator, senior executive for technical integration at NASA's Marshall Space Flight Center, chair of the

standing review board of the NASA Exploration Systems Division, deputy manager of the Space Shuttle Propulsion Office, and environmental control and life support manager for the International Space Station. Mr. Reuter has received numerous NASA awards and honors, including a Presidential Rank Award, Distinguished Service Medal, Outstanding Leadership Medal, NASA Exceptional Achievement Medal, and NASA Exceptional Service Medal.

Program Schedule

TUESDAY, JUNE 6, 2023

7:30	Continental Breakfast (CSM Ben Parker Student Center)	
8:00	Opening Remarks	Angel Abbud-Madrid, SRR President
Session 1 – National Plans & Priorities Panel		
Session Chair: Angel Abbud-Madrid, Colorado School of Mines		
8:20	Update on NASA ISRU Plans, Priorities, and Activities Gerald Sanders, NASA Johnson Space Center	
8:30	The Lunar Surface Innovation Consortium ISRU Focus Group Jodi Berdis, Johns Hopkins University Applied Physics Laboratory	
8:40	SpaceResources.Lu - Recent Developments Bob Lamboray, Luxembourg Space Agency (LSA)	
8:50	JAXA’s Concept of a Lunar ISRU Plant Jun Shimada, Japan Aerospace Exploration Agency (JAXA)	
9:00	Panel Discussion	
Session 2 – Economic Considerations & Business Cases		
Session Chair: Michael Nord, John Hopkins University Applied Physics Laboratory		
9:25	Is There a Role for Royalties in a Lunar Resources Project? Ben McKeown, University of New South Wales, Australia	
9:40	Enabling an Increase in Starship’s Payload Capacity to Low Earth Orbit Using Lunar Derived Liquid Oxygen (LULOX) as Entry Descent & Landing (EDL) LOX Alice Miller and Nicholas Bennett, Helios and University of New South Wales	
9:55	Propellant and Capital Efficient Trans-Mars Injections Using Lunar Propellant, Transforming the SpaceX Mars Project Nicholas Bennett, University of New South Wales, Australia	
10:10	Coffee Break	
10:30	A General Model of ISRU Technology Valuation and Technology Portfolio Construction for Crewed Mars Missions George Lordos, MIT	
10:45	When the Price is Right: Stochastic Modeling of an Asteroid Mining Business Case Matthew Rehberg, Colorado School of Mines	

11:00	ESRIC Commercialization –Start-up Support Programme Lari Cujko, European Space Resources Innovation Centre, Luxembourg
Session 3 – Resource Prospecting & Exploration	
Session Chair: Leslie Gertsch, NASA Glenn Research Center/MST	
11:15	A Simplified Classification Scheme for Lunar Resources and Reserves Laszlo Keszthelyi, U.S. Geological Survey, Astrogeology Science Center
11:30	Ore Minerals, the Mineralogical Barrier, and the Elementome in Space Kevin Cannon, Colorado School of Mines
11:45	Genetic Geological Modelling for Lunar Resources: West Tranquillitatis Ilmenite Deposit Abigail Calzada Diaz, European Space Resources Innovation Centre, Luxembourg
12:00	Lunch (CSM Ben Parker Student Center)
1:10	“Hyperfluorescence”: A New Technique for Space Resource Assessment and Utilisation Nigel Spooner, University of Adelaide, Australia
1:25	Subsurface Water Ice Mapping (SWIM) to Support the International Mars Ice Mapper (I-MIM) Mission Nathaniel Putzig, Planetary Science Institute
Session 4 – Flown & Manifested Space Missions	
Session Chair: George Sowers, Colorado School of Mines	
1:40	MOXIE: A Martian Year of ISRU on Mars Michael Hecht, MIT Haystack Observatory
1:55	CAPSTONE: A Summary of a Highly Successful Mission Currently Operating in the Cislunar Environment Thomas Gardner, Advanced Space
2:10	Polar Resources Ice Mining Experiment-1 (PRIME-1): NASA’s First Polar Drilling and Volatiles Detection Mission Jacqueline W. Quinn, NASA Kennedy Space Center (KSC)
2:25	VIPER Mission Traverse Planning – Design, Strategies, and Dynamics Kimberly Ennico Smith, NASA Ames Research Center
2:40	Coffee Break
3:00	Test Campaign to Baseline Flight Telemetry for the Trident Lunar Drill on PRIME-1 and VIPER Missions Isabel King, Honeybee Robotics

3:15	The Canadian Lunar Rover Mission Peter Visscher, Canadensys Aerospace Corp., Canada
3:30	SAMPLR Mission Progress Report Alejandro Levi, Maxar Space Robotics
3:45	No Risk, No Reward - AstroForge and the First Commercial Deep-Space Mission Matt Gialich, AstroForge
4:00	Roundtable Discussion
5:00-7:00	Poster Session & Reception (CSM Ben Parker Student Center)



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THE NEXT LEAP

2023

MISSION 1 IS A GO

SHACKLETON RIDGE
First sale of space resources



2024

MISSION 2 IS A GO

REINER GAMMA
NASA science and exploration mission

2025

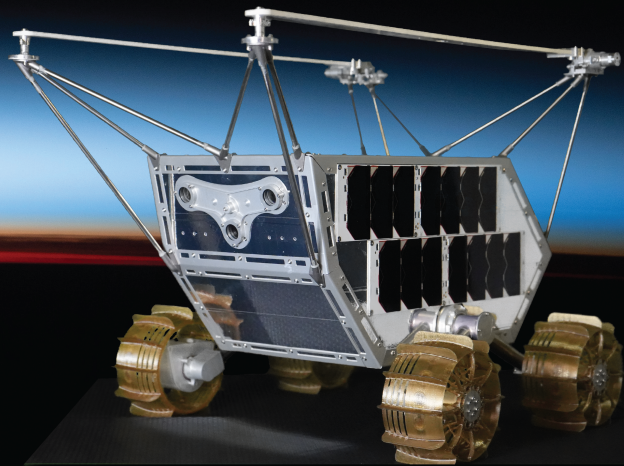
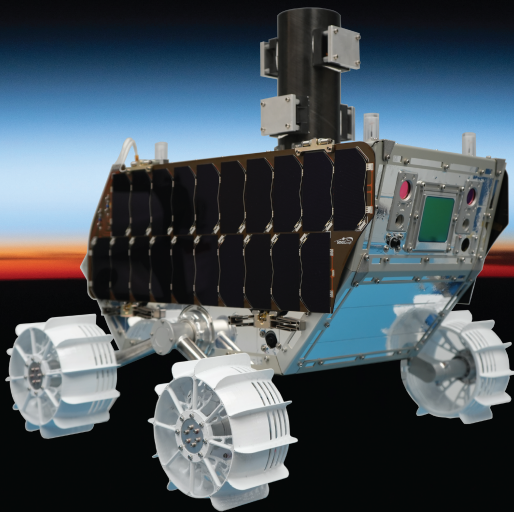
MISSION 3 IS A GO

Location announced soon
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2026

MISSION 4 IS A GO

TRAILBLAZER: MOON TO MARS
ASA ISRU mission



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WEDNESDAY, JUNE 7, 2023

7:30	Continental Breakfast (CSM Ben Parker Student Center)
8:00	KEYNOTE PRESENTATION: The Scramble for the Skies: Why Nations Care About Space Resources Peter Garretson, Senior Fellow, Defense Studies, American Foreign Policy Council
Session 5 – Power	
Koorosh Araghi, NASA Johnson Space Center	
8:40	A Portable Scalable High Energy Density Source to Power Space Resources Utilization Missions and a Lunar Grid Robert Moses, Tamer Space, LLC
8:55	Lunar Power Architectures for Lunar Exploration Melissa Sampson, Lockheed Martin
9:10	Rechargeable Batteries with Improved Discharge Capacity at -40C to -60C for Surviving the Lunar Night Brian Elliott, TDA Research
Session 6 – Mining & Robotics	
Session Chair: Paul van Susante, Michigan Technological University	
9:25	Mining Technologies to Advance Lunar ISRU Objectives Douglas Morrison, Centre for Excellence in Mining Innovation (CEMI), Canada
9:40	OffWorld's Celestial and Terrestrial Swarm Robotic and ISRU System Kyle Acierno, OffWorld
9:55	Astronaut Lunar Drill (ALD) and Vacuum Sealable Container (VSC) for Artemis Leo Stolov, Honeybee Robotics
10:10	Coffee Break
10:30	Experimental Investigation of Bucket Excavation Force Reduction with an Ultrasonic Leading Edge Erin Rezich, NASA Glenn Research Center
10:45	ISRU Pilot Plant Deployment with the Flexible Logistics & Exploration (FLEX) Rover Andrew Welter, Venturi Astrolab
11:00	Lunar Outpost Oceania Leads Australia's Moon to Mars Trailblazer Rover Lunar Mission A.J. Gemer, Lunar Outpost

11:15	The Lunar Mobility Vehicle as an Enabler for the Lunar Economy Ross Rickards, Lockheed Martin
11:30	Remote Construction Experiment for Utilizing Water Resources on the Moon Masataku Sutoh, Japan Aerospace Exploration Agency (JAXA)
11:45	Autonomy & Operations Capabilities for Lunar Missions: Highlights of an AI Lunar Surface Demonstration and the ESA-ESRIC Space Resources Challenge Kaizad Raimalwala, Mission Control, Canada
12:00	Lunch (CSM Ben Parker Student Center)
Session 7 – Regolith & Granular Mechanics	
Session Chair: Kevin Cannon, Colorado School of Mines	
1:00	Development of a Doppler Radar System to Determine Plume-Surface Interaction Ejecta Velocities Austin Langton, NASA Kennedy Space Center (KSC)
1:15	Electron-Beam Lunar Dust Mitigation (ELDM) Technology Xu Wang, University of Colorado, Boulder
1:30	Photoelectric Current Density Measurement for Lunar Daytime Simulation: Guiding Large-Scale Experiment Design Seungsoo Park, Korea Institute of Civil Engineering and Building Technology
1:45	Dielectrophoresis Affects Particle Motion in Electrostatic Travelling Waves: A Potential Application for Lunar Soil Beneficiation Yue Yu, Imperial College London, England
2:00	Ground Testing of Electrostatic Transport of Lunar Regolith Simulants with Applications to Electrostatic Sieving Daoru Han, Missouri University of Science and Technology
2:15	Dynamics and Granular Mechanics of Zero Gravity Excavation of C-Type Rubble Pile Asteroids Curtis Purrington, Karman+
2:30	Coffee Break
2:50	NASA Kennedy Space Center Swamp Works 10th Anniversary: Innovative Research & Technology Development Summary Robert Mueller, NASA Kennedy Space Center
3:05	Development of Modeling Tools for Testing Thermo-Hydro-Mechanical Behavior of Lunar Regolith Zoheir Khademia, Outward Technologies

3:20	Lunar Regolith Hopper Design and Testing Under Atmosphere and Vacuum Conditions Elijah Sierra, Michigan Technological University
3:35	Overview of the ASCE ASD Space Engineering and Construction Technical Committee – Lunar Infrastructure Engineering, Design, Analysis, and Construction Guidelines: Lunar Structural Loads Subgroup Ian Jehn, Colorado School of Mines
3:50	Roundtable Discussion
5:00-8:00	Banquet (Friedhoff Hall, Green Center)

Based in Luxembourg, the European Space Resources Innovation Centre is the world's first innovation centre entirely dedicated to space resources. Launched in 2020, it is a unique place where technologies, businesses and people meet to drive the future of space resources utilization in support of space exploration and the creation of an in-space economy.

Ambitious, mission-driven research and applications, world-class scientists, and state-of-the-art facilities unique in Europe are key to success.

The ESRIC Start-up Support Programme (SSP) is the first worldwide incubation programme entirely dedicated to space resources utilization. The SSP aims to support early-stage ventures and start-ups designing novel technologies for space resources applications.



Find us during the conference!



Abigail Calzada Diaz
Lunar Geologist



Lari Cujko
Start-up Support
Programme Lead



Dennis Harries
Geochemist specialised
in astromaterials



Delia Malaut
Community
Manager



Marek Wilgucki
CEO Four Point Space



Marek Rozehnal
CEO Lightigo Space

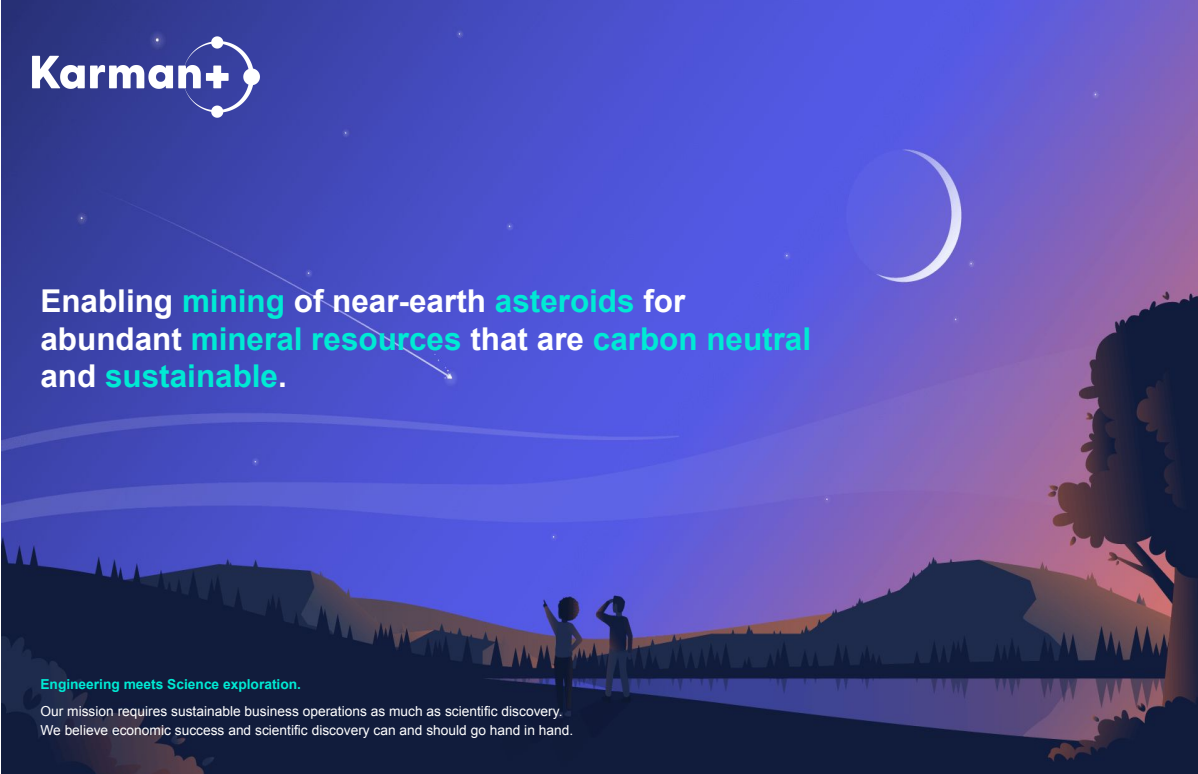
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THURSDAY, JUNE 8, 2023

7:30	Continental Breakfast (CSM Ben Parker Student Center)
8:00	KEYNOTE PRESENTATION: NASA Space Technology Update James Reuter, NASA Associate Administrator, Space Technology Mission Directorate (STMD)
Session 8 – Ices & Volatiles	
Session Chair: Julie Kleinhenz, NASA Johnson Space Center	
8:40	Dynamic and Resilient Operations in the Arctic: Cold Regions and Space Research Synergy Zachary Zody, United States Army Corps of Engineers
8:55	Subsurface Water Extraction from Extreme Environments Jack Schultz, Honeybee Robotics
9:10	Testing of a Rover-Mounted Instrumented Percussive Cone Penetrometer in Icy Layered Lunar Regolith Simulant Paul van Susante, Michigan Technological University
9:25	Demonstration of Lunar Ice Miner System Components Sai Kiran Hota, Advanced Cooling Technologies Inc.
9:40	Sublimation Loss from Open-Gap Lunar Water Extraction Timothy Krause, Universities Space Research Association
9:55	Quantifying Gas Leak Rates through Regolith Feed Columns in Vacuum Beau Compton, NASA Glenn Research Center
10:10	Coffee Break
10:30	Thermal Measurements of Icy Lunar Regolith Simulant: Water Content Analysis Under Atmospheric Conditions George Johnson, Michigan Technological University
10:45	An Overview of SRU Research at Imperial College London Joshua Rasera, Imperial College London, England
Session 9 –Resource Extraction & Processing I	
Session Chair: Laurent Sibille, Engineering & Research Consulting, NASA KSC	
11:00	The Mars Air Refinery Ivan Ermanoski, Arizona State University

11:15	MOXIE Commissioning and Laboratory Operations at the MIT Haystack Observatory Parker Steen, MIT Haystack Observatory
11:30	Scale Up and Coupling of the MOXIE Solid Oxide Electrolyzer for Mission-Scale Lunar and Martian Applications Joseph Hartvigsen, OxEon Energy
11:45	Test-Demonstrated Advantages of Solid-Oxide Water Electrolysis for Scaled-Up Hydrogen Production on the Moon David Dickson, Colorado School of Mines
12:00	Advancement of ISRU Technologies and Systems: Water Collection, Purification, and Electrolysis Jordan Holquist, Paragon Space Development Corporation
12:15	Lunch (CSM Ben Parker Student Center)
Session 10– Resource Extraction & Processing II	
Session Chair: Christopher Dreyer, Colorado School of Mines	
1:15	Hydrogen Reduction of Ilmenite for the Production of Oxygen and Metals from Lunar Regolith: Current Research at ESRIC Dennis Harries, European Space Resources Innovation Centre, Luxembourg
1:30	Carbothermal Reduction Demonstration: Laser Driven Reaction in a Thermal-Vacuum Environment and Project Status Aaron Paz, NASA Johnson Space Center
1:45	Exploring the Challenges of Molten Regolith Electrolysis and Oxygen Production on the Lunar Surface Michael Nord, Johns Hopkins University Applied Physics Laboratory
2:00	GALORE (Gaseous Lunar Oxygen from Regolith Electrolysis): Successful Demonstration of a Cold-Walled Molten Regolith Electrolysis Reactor Design in a Vacuum Environment Kevin Grossman, NASA Kennedy Space Center (KSC)
2:15	ISRU Iron Alloys: Properties and Testing on Iron Produced by Hydrogen Reduction of Lunar Regolith Simulant Peter Corwin, Colorado School of Mines
2:30	World's First Demonstration of Continuous Metal Casting in Microgravity for ISAM and SM&L Joe Pawelski, CisLunar Industries

2:45	Casting & Annealing Experiments of Lunar Mare & Anorthosite Regolith Simulants Kyla Edison, Colorado School of Mines
3:00	Roundtable Discussion
4:00-6:00	Poster Session & Reception (CSM Ben Parker Student Center)



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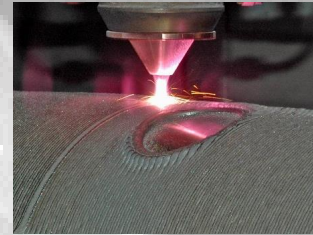
FRIDAY, JUNE 9, 2023

7:30	Continental Breakfast (CSM Ben Parker Student Center)	
Session 11 – Space Manufacturing & Construction		
Session Chair: Robert Mueller, NASA Kennedy Space Center		
8:00	Efficient Truss Structures from Regolith Glass Richard T. Wainner, Physical Sciences, Inc.	
8:15	Armstrong UMV Concept for Lunar Surface Construction John Suh, New Horizons Studio, Hyundai Motor Group R&D Division	
8:30	Vacuum Sintering of Highland Simulant CSM-LHT-1G Laurent Sibille, Engineering & Research Consulting, NASA KSC	
8:45	Sintering of Lunar Regolith Simulant in Vacuum by Microwave Sintering for ISRU Construction Young-Jae Kim, Korea Institute of Civil Engineering and Building Technology	
9:00	Laser Processing for Lunar Base Construction: Implications of Experimental Trials John Culton, University of Adelaide, Australia	
9:15	Solar Additive Manufacturing with Lunar Regolith Alan Carter, Outward Technologies	
9:30	Parametric Mechanism Design through Numerical Optimization and Physics Simulation Alexander Schepelmann, NASA Glenn Research Center (GRC)	
9:45	Development of the Advanced Regolith Ground Operations (ARGO) Test Bed – A Robotic Excavation and Construction Test Facility with Simulated Lunar Environments Evan Bell, NASA Kennedy Space Center (KSC)	
10:00	Coffee Break	
Session 12 – Resources & Human Exploration		
Session Chair: Angel Abbud-Madrid, Colorado School of Mines		
10:20	NASA’s Habitation Development Status: Current Concepts and ISRU Opportunities James Clawson, Stellar Solutions, Inc., NASA Headquarters	
10:35	Engineered Bioremediation of Water Obtained from In Situ Resource Utilization Garrett Roberts Kingman, NASA Ames Research Center (ARC)	
10:50	Final Roundtable Discussion	
12:00	ADJOURN	



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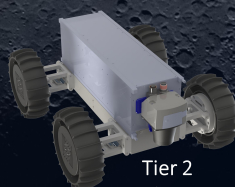
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POSTER PRESENTATIONS

Posters will be up during the entire conference with dedicated poster sessions on
Tuesday and Thursday afternoons

Location: Ballrooms D&E (CSM Ben Parker Student Center)	
1	Practical Aspects of Terrestrial Mining for Use in Extraterrestrial ISRU Concepts Martin Meinshausen
2	Intuitive Machines: Commercially Enabling International Lunar Scientific Exploration Ben Bussey, Intuitive Machines
3	Orbital Debris and the Tragedy of the Commons: An Economic Framework to Address the Free Rider Problem Jeffrey Cleveland, Colorado School of Mines
4	New Value in Old Geoscience Data David Butler, SLB
5	Introduction to a Bosch Process Architecture for ISRU and Terrestrial Applications Beau Compton, NASA Glenn Research Center
6	Poke the Moon Ben Thrift, Colorado School of Mines
7	Evaluation of Commercial High-Power DC-DC Converters for Lunar & Space Environment Kenneth Liang, Orbital Mining Corporation
8	Thermal Analysis of a Heat Pipe Nuclear Reactor for Space Applications using CFD K. Fernandez-Cosials, Texas A&M University
9	The Impact of Abrasion Resistant Materials on Performance and Tool Life of Lunar Surface Exploration and Mining Units: An Experimental Study Muhammad Ishaq, Colorado School of Mines
10	Efficacy and Wear of a Bucket Ladder for ISRU Regolith Excavation in Vacuum Parker Bradshaw, Michigan Technological University
11	Lunar Alloy Metal Production Plant (LAMPP) - NASA 2023 Big Idea Challenge Ian Jehn, Colorado School of Mines
12	Lunar In-Situ Aluminum Production via Molten Salt Electrolysis (LISAP-MSE) Daoru Han, Missouri University of Science and Technology
13	Testing and Application of Regolith Parts Made by Additive Manufacturing Technologies David Purcell, Colorado School of Mines
14	Project KHEPRI: Feasibility Study of Mining Asteroid Bennu Saanjali Maharaj, University of Toronto, Canada
15	Optical Mining at Mines – Precursory Results Timofey Broslav, Colorado School of Mines

16	Brick by Brick: Study of Modular Block Construction for Lunar Habitats Nerma Caluk, Florida International University
17	Ejecta Assessment for Optimizing Natural Landing Pad Selection Joshua Menges, Colorado School of Mines
18	Regolith Simulant Preparation and Geotechnical Characterization for Plume Surface Interaction Testing Austin Langton, NASA Kennedy Space Center (KSC)
19	Lunar Site Preparation via Rocket Terrain Autonomous Multi-Pulse Preparation (TAMP) Regolith Compaction Jonathan Slavik, Astrobotic Technology
20	Lunar Landing Pad Site Preparation Christopher Dreyer, Colorado School of Mines
21	Low Mass Method for Lunar Regolith Surface Compaction Chuck Carey, Michigan Technological University
22	Lunar Development & Test Facility, JSC B351 Koorosh Araghi, NASA Johnson Space Center (JSC)
23	A Standardized Mobile Platform for Lunar ISRU Activities Lennart Fox, Neurospace GmbH, Germany
24	RIDER and SPIDR: Open-Access Complementary Facilities for Planetary Terramechanics Investigations Daniel Britt, University of Central Florida
25	Pressure Fused Granular Icy Lunar Regolith Simulant Demonstration Daniel Johnson, Colorado School of Mines
26	Light Water Analysis and Volatile Extraction (Light WAVE) Aaron Paz, NASA Johnson Space Center (JSC)
27	Lunar Water Extraction Via Lunar Auger Dryer ISRU (LADI) Jacob Collins, NASA Johnson Space Center (JSC)
28	The Mars Water Ice Prospector Mission (MWIPM) Ben Jackson, Colorado School of Mines
29	Vertical Lunar Regolith Conveying as a Flight Experiment in Simulated Lunar-Gravity Aaron Olson, NASA Kennedy Space Center (KSC)
30	Three General Lunar Regolith Conveyance Systems in Atmosphere & Vacuum Conditions Elijah Sierra, Michigan Technological University
31	Modular Regolith Transport Solution for the Moon Mateo Rejón López, TU Delft, The Netherlands
32	The Pulse-Elevator: Simple Any-Directional Transport of Granular Materials Patrick Harkness, University of Glasgow, Scotland

Credits

Technical Steering Committee

Angel Abbud-Madrid, Colorado School of Mines
Kevin Cannon, Colorado School of Mines
Christopher Dreyer, Colorado School of Mines
Leslie Gertsch, NASA Glenn Research Center
George Sowers, Colorado School of Mines

Session Chairs

Angel Abbud-Madrid, Colorado School of Mines
Koorosh Araghi, NASA Johnson Space Center
Kevin Cannon, Colorado School of Mines
Christopher Dreyer, Colorado School of Mines
Leslie Gertsch, NASA Glenn Research Center
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