



**TENTH JOINT MEETING  
of the  
SPACE RESOURCES ROUNDTABLE  
and the  
PLANETARY & TERRESTRIAL MINING SCIENCES  
SYMPOSIUM**

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**Colorado School of Mines  
Golden, Colorado, USA  
June 11-14, 2019**



## Message

Welcome to the Tenth Joint Meeting of the Space Resources Roundtable (SRR) and the Planetary and Terrestrial Mining Sciences Symposium (PTMSS). We are also celebrating 20 years of the first SRR held in 1999 at the Colorado School of Mines, where a few space resources enthusiasts gathered to discuss what was then an obscure topic of interest in space circles. Oh, what a difference twenty years make!

As we can see from the large number of participants and variety of topics presented at this year's meeting, this is undoubtedly the most exciting time for the space resources 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 the Moon, Mars, and asteroids by space agencies around the world and the commercial space sector. Legislation has been advanced in the USA and Luxembourg for commercial space-resource exploration and utilization, while a broader legal framework is being actively pursued at the international level. Several start-up companies have appeared in the past few years positioning themselves in the various links of the space resources value chain, highlighting the growing interest and excitement around this topic. 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 sufficiently clear that the use of space resources will enable both further exploration and commercialization of space.

This increased attention calls for greater involvement from our 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 and to help make the next 20 years even more exciting and productive.



**Angel Abbud-Madrid**  
President & Chair, SRR XX



**Dale Boucher**  
Chair, PTMSS XVI

## Sponsors

On behalf of the SRR and PTMSS Steering Committee, we would like to express our appreciation to this year's sponsors.



# Program Schedule

**TUESDAY, JUNE 11, 2019**

7:30 AM		<b>Continental Breakfast (Room 102, CTLM Building)</b>
8:00	Opening Remarks	Angel Abbud-Madrid and Dale Boucher
<b>Technical Session 1 – Setting the Scene</b>		
<b>Session Chair: Angel Abbud-Madrid (Colorado School of Mines)</b>		
8:30	<b>Economics and Exploration: A Bit of Historical Perspective on our New Age of Exploration</b> Dan Britt, University of Central Florida	
8:50	<b>Current NASA ISRU Strategic Vision</b> Diane Linne, NASA GRC and Jerry Sanders, NASA JSC	
9:10	<b>New Insights for Enabling In Situ Resource Utilization (ISRU)</b> Mathias Link, Luxembourg Space Agency, Luxembourg	
9:30	<b>Developing Standardized Terminology Reference Guidelines and Resource and Reserve Reporting Codes for the Space Resource Industry</b> Sophia Casanova, University of New South Wales, Sydney, Australia	
9:50		<b>Break</b>
<b>Technical Session 2 – Economics, Business, Law, and Policy</b>		
<b>Session Chair: Melissa Sampson (Ball Aerospace)</b>		
10:10	<b>The Space Commodities Exchange: Financial Infrastructure to Grow a Sustainable Space Economy</b> Bruce Cahan, Urban Logic, Inc.	
10:30	<b>Lifetime Embodied Energy: A New Value System for the ISRU Space Economy</b> George Lordos, Massachusetts Institute of Technology	
10:50	<b>Business Case Analysis of Lunar Thermal Mining</b> Robert Shishko, NASA Jet Propulsion Laboratory	
11:10	<b>A Preliminary Estimate of Future Potential U.S. Military Supply and Demand for In-Space Water-Based Fuel</b> Jason Aspiotis and Aiden O’Leary, Booz Allen Hamilton Inc.	
11:30	<b>Policy and Legal Processes and Precedent for Space Mining</b> Morgan Bazilian, Colorado School of Mines and Corey Christensen, Hogan Lovells	
11:50	<b>Mining Law for Outer Space - How Will It Work?</b> Wayne White, Spacebooster, LLC.	
12:10		<b>Lunch (Atrium, Marquez Hall)</b>

<b>Technical Session 3 – Individual Poster Presentations (Short Talks)</b>	
<b>Session Chair: Angel Abbud-Madrid (Colorado School of Mines)</b>	
1:10	<b>SRR Student Scholarships Award Ceremony</b>
1:20	<b>Developing Resource Exploration Strategies for Lunar Polar Volatiles</b> Sophia Casanova, University of New South Wales, Sydney, Australia
1:25	<b>Interdisciplinary Collaboration on Borehole Core Testing for Extraterrestrial Material</b> Frida Vonstad, University College London, United Kingdom
1:30	<b>Sensitivity of Private Space Station Profitability to Market Demand and Use of Space Resources</b> Nicholas Campbell, CENKI, University of Colorado
1:35	<b>Power Beaming for Rovers in Lunar Permanently Shadowed Regions</b> Ross Centers, Colorado School of Mines
1:40	<b>Mechanical Property of Gravel Produced from Lunar Soil Simulant by Rapid Sintering Using Single-mode Microwave</b> H. Kanamori, Japan Aerospace Exploration Agency, Japan
1:45	<b>Cryogenic ISRU Robot Survival in Lunar Permanently Shadowed Regions</b> Curtis Purrington, Colorado School of Mines
1:50	<b>Drilling Automation – Building an Advanced Robotic System for Directional Drilling</b> Emmanuel Akita, The University of Oklahoma
1:55	<b>A New Water Extraction Method to Generate and Control Water Reservoir in Planetary Environments</b> Gordon Wasilewski, Space Research Centre, Polish Academy of Sciences, Poland
2:00	<b>Poster Session and Break (CTLM)</b>

<b>Technical Session 4 – Space Manufacturing and Processing Technologies</b>	
<b>Session Chair: Paul van Susante (Michigan Technological University)</b>	
2:30	<b>Strategic Regolith Processing on the Moon and Mars</b> Kevin Cannon, University of Central Florida
2:50	<b>Characterization of Hawaiian Basalt Aggregate and the Effects of Chemical Composition on Sinterability: Implications for Future Lunar/Mars ISRU Applications</b> Kyla Defore, Pacific International Space Center for Exploration Systems, Hawaii
3:10	<b>Additive Manufacturing and Resource Extraction Using Lunar Regolith</b> Akbar Whizin, Southwest Research Institute
3:30	<b>Simulant and Environment Requirements for ISRU Manufacturing Technology Development</b> Hunter Williams, Colorado School of Mines
3:50	<b>Technology Development to Enable In-Situ Resource Derived Fuel Utilization and Transfer</b> James Bultitude, Orbit Fab, Inc.
4:10	<b>Cislunar Industries Space Foundry Lab Module: A Commercial Microgravity Metallurgical Research Service and Production Facility</b> Gary Calnan, Cislunar Industries S.A., Luxembourg
4:30	<b>Break</b>
4:40	<b>Roundtable Discussion</b>





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### Cislunar Autonomous Positioning System

Peer-to-Peer Navigation  
Scalable with Affordability  
No Dedicated Satellites

### Systems

Ground/Flight Software  
Automation  
Guidance & Control  
Lander Design

## WEDNESDAY, JUNE 12, 2019

7:30 AM		<b>Continental Breakfast (Room 102, CTLM Building)</b>	
<b>Technical Session 5 – Mars Resources</b>			
<b>Session Chair: Laurent Sibille (Southeastern Universities Research Assoc./Swamp Works)</b>			
8:00		<b>Reconnaissance Needs for Future Human Exploration of Mars</b> Richard Davis, NASA Headquarters	
8:20		<b>Report from the Mars Subsurface Water Ice Mapping (SWIM) Project</b> Nathaniel Putzig, Planetary Science Institute	
8:40		<b>Poly-Hydrated Sulfate Mining and Water Extraction on Mars: Experimental Results and System Requirements</b> Paul Van Susante, Michigan Technological University	
9:00		<b>Moon to Mars Ice &amp; Prospecting Challenge (MMIP) – West Virginia University</b> Karan Sah, Nathan Owen, Bertrand Wieliczko, and Derek Roesch	
9:05		<b>Moon to Mars Ice &amp; Prospecting Challenge (MMIP) – Carnegie Mellon University</b> Ismael Mercier	
9:10		<b>Lessons Learned from the Moon to Mars Ice and Prospecting Challenge</b> Richard Davis, NASA Headquarters	
9:15		<b>HexHab - 3D Printed Mars Habitat Construction and Outfitting Sequence Timeline</b> Samuel Ximenes, Exploration Architecture Corp.	
9:35		<b>K-Town: Portrait of a Thousand-Person Colony on Mars</b> Jeff Greenblatt, Emerging Futures, LLC	
9:55		<b>Membrane Bioreactors for In Situ Carbon Upcycling</b> Johan Vanneste, Colorado School of Mines	
10:15		<b>Break</b>	
<b>Technical Session 5 (continued) – Mars Resources</b>			
<b>Session Chair: Forrest Meyen (Draper Laboratory)</b>			
10:35		<b>MOXIE Delivered!</b> Michael Hecht, Massachusetts Institute of Technology Haystack Observatory	
10:55		<b>A Scroll Filter System for In-Situ Resource Utilization CO<sub>2</sub> Acquisition of the Martian Atmosphere</b> Juan Agui, NASA Glenn Research Center	
11:15		<b>Experimental Design and Preliminary Analysis of Mars CO<sub>2</sub> Rapid Cycle Adsorption Pump</b> Jared Berg, NASA Glenn Research Center	

11:35	<b>The Advanced Organic Waste Gasifier (AOWG)</b> Stacy Carrera, Pioneer Astronautics
11:55	<b>Fuel Production on Mars with the Sabatier Electrolyzer</b> Zehua Pan, Colorado School of Mines
12:15	<b>Design and Modeling of an Electrochemical Device Producing Methane, Oxygen and Polyethylene from In-Situ Resources on Mars</b> Jeff Greenblatt, Emerging Futures, LLC
12:35	<b>Lunch (Atrium, Marquez Hall)</b>
<b>Technical Session 6 – Providing Lunar Access and Surface Infrastructure</b>	
<b>Session Chair: Jerry Sanders, NASA Johnson Space Center</b>	
1:30	<b>Deep Space Systems Commercial Lunar Payload Services Overview</b> Stephen Bailey, Deep Space Systems
1:50	<b>Overview of the OrbitBeyond Z-01 Lunar Lander Mission</b> Jon Morse, Orbit Beyond, Inc.
2:10	<b>An Integrated Robotic and Human Approach to Lunar Exploration</b> David Murrow, Lockheed Martin
2:30	<b>Draper’s Vision-Based Navigation Enhanced Lunar Lander &amp; ISRU Opportunities</b> Forrest Meyen, Draper Laboratory
2:50	<b>Break</b>
<b>Technical Session 6 (continued) – Providing Lunar Access and Surface Infrastructure</b>	
<b>Session Chair: Diane Linne, NASA Glenn Research Center</b>	
3:10	<b>Commercial Lunar Surveying and Payload Mobility Services: The Lunar Outpost Mobile Autonomous Prospecting Platform (MAPP)</b> A.J. Gemer and Justin Cyrus, Lunar Outpost, Inc.
3:30	<b>NASA Requirements Development for Lunar In-Situ Surface Construction of Infrastructure</b> Robert Moses, NASA Langley Research Center
3:50	<b>Concepts for an In-Situ, Reusable Construction System for Lunar Landing and Launch Pads</b> Elizabeth Scott, Colorado School of Mines
4:10	<b>Lunar Infrastructure for Landing and Launch Risk Mitigation</b> James Mantovani, NASA Kennedy Space Center
4:30	<b>Roundtable Discussion</b>
5:30	<b>Banquet (Table Mountain Inn)</b>

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## THURSDAY, JUNE 13, 2019

7:30	<b>Continental Breakfast (Room 102, CTLM Building)</b>
<b>Technical Session 7 – Cislunar and Lunar Infrastructure</b>	
<b>Session Chair: Julie Kleinhenz, NASA Glenn Research Center</b>	
8:00	<b>Moon Direct: A Cost-Effective Plan to Enable Lunar Exploration and Development</b> Robert Zubrin, Pioneer Astronautics
8:20	<b>Robotic Lunar Surface Operations 2</b> Brent Sherwood, NASA Jet Propulsion Laboratory
8:40	<b>Developing Cislunar Enabling Infrastructure</b> Bradley Cheetham, Advanced Space
9:00	<b>Commercialization and Human Settlement of the Moon and Cislunar Space Enabled by ISRU, Fission Surface Power, and LANTR Propulsion Systems</b> Stanley Borowski, NASA Glenn Research Center (Retired)
9:20	<b>Satellite Beamed Power for the Moon and Mars</b> Michael Hecht, Massachusetts Institute of Technology Haystack Observatory
9:40	<b>The Use of Lunar Resources for Energy Generation on the Moon</b> Elliot Carol, Lunar Resources, Inc.
10:00	<b>Break</b>
<b>Technical Session 8 – Lunar Resources</b>	
<b>Session Chair: Thomas Crafford (USGS Mineral Resources Program)</b>	
10:20	<b>First Steps Toward a USGS Assessment of Lunar Regolith as a Resource</b> Lazlo Kestay, U.S. Geological Survey Astrogeology Science Center
10:40	<b>Proving Water Reserves on the Moon</b> George Sowers, Colorado School of Mines
11:00	<b>Oxygen Production System for Refueling Human Landing System Elements</b> Diane Linne, NASA Glenn Research Center
11:20	<b>Investigation of Properties of Icy Lunar Regolith in Cryogenic Temperature Environments on the Moon</b> Wenpeng Liu, Colorado School of Mines
11:40	<b>State-of-the-Art of Molten Regolith Electrolysis: One-Step Oxygen and Metals Production Anywhere on the Moon</b> Laurent Sibille, NASA Kennedy Space Center

12:00	<b>Architecture for a Farm in a Moon Village with In-Situ Materials for Infrastructure</b> Tony Muscatello, NASA Kennedy Space Center
12:20	<b>Silicon Alkoxides and Lunar Development</b> Stephen Gillett
12:40	<b>Lunch (Atrium, Marquez Hall)</b>
	<b>Technical Session 9– Lunar Excavation and Drilling Technologies</b>
	<b>Session Chair: Dale Boucher (Deltion Innovations, Ltd)</b>
1:40	<b>Material Characterization While Drilling on Moon: Review of the Preliminary Atmospheric Test Results</b> Deep Joshi, Colorado School of Mines
2:00	<b>APEX - An In-Situ Resource Utilization Excavation Research Tool</b> Phillip Abel, NASA Glenn Research Center
2:20	<b>Experimental Facility to Measure Power and Forces to Excavate Lunar Regolith Simulants</b> Margaret Proctor, NASA Glenn Research Center
2:40	<b>Excavation of Planetary Regolith in Non-Easily Accessible Places Using Wireline Technology</b> Karol Seweryn, Space Research Centre, Polish Academy of Sciences, Poland
3:00	<b>RASSOR Excavator for ISRU Lunar Mining</b> Drew Smith, NASA Kennedy Space Center
3:20	<b>Break</b>
3:30	<b>Roundtable Discussion</b>
4:30	<b>Tour of Space Resources Laboratories</b>
6:00	<b>Reception (CSM Geology Museum)</b>



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**FRIDAY, JUNE 14, 2019**

7:30 AM	<b>Continental Breakfast (Room 102, CTLM Building)</b>
<b>Technical Session 10 – Resources on Small Bodies</b>	
<b>Session Chair: Leslie Gertsch (Missouri University of Science and Technology)</b>	
8:00	<b>SHEPHERD, a Gas-Filled Enclosure for Asteroid Handling and Resource Utilization</b> Bruce Damer and Carlos Calva, FlowSpace
8:20	<b>Overview of Area-of-Effect Softbot (AoES) Surface Operations on Rubble Pile Asteroids</b> Donald Kuettel III, University of Colorado at Boulder
8:40	<b>Roadmap to The Solar System - TransAstra's Plans for Achieving Practical Asteroid ISRU through Incremental Technology Development</b> Joel Sercel, TransAstra Corp.
9:00	<b>The Optical Mining Testbed (OMTB): A Practical Large-Scale Laboratory Device for Rapidly Maturing the Technology of Asteroid ISRU</b> Chris Dreyer, Colorado School of Mines
9:20	<b>ISRU Explorations with WINE (The World Is Not Enough)</b> Vincent Vendiola, Honeybee Robotics
9:40	<b>Break</b>
<b>Technical Session 11 – Planetary Excavation, Drilling, and Extraction Technologies</b>	
<b>Session Chair: Chris Dreyer (Colorado School of Mines)</b>	
10:00	<b>A Review of Extra-Terrestrial Regolith Excavation Concepts and Prototypes</b> Robert Mueller, NASA Kennedy Space Center
10:20	<b>Consolidated Material Mining for ISRU</b> Jason Schuler, NASA Kennedy Space Center
10:40	<b>Subsystem Testing and Results of the Planetary Volatiles Extractor (PVEX)</b> Vincent Vendiola, Honeybee Robotics
11:00	<b>Drilling and Pneumatic Transfer of Titan Surface Materials</b> Ralph Lorenz, Johns Hopkins Applied Physics Laboratory
11:20	<b>Final Roundtable Discussion</b>
12:30	<b>ADJOURN</b>

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## Credits

### Joint Technical Steering Committee

**Angel Abbud-Madrid**, Colorado School of Mines  
**Dale Boucher**, Deltion Innovations, Ltd.  
**Leslie Gertsch**, Missouri University of Science and Technology  
**Louise Prockter**, Lunar and Planetary Institute

### Session Chairs

**Angel Abbud-Madrid**, Colorado School of Mines  
**Dale Boucher**, Deltion Innovations, Ltd.  
**Thomas Crafford**, USGS Mineral Resources Program  
**Chris Dreyer**, Colorado School of Mines  
**Leslie Gertsch**, Missouri University of Science and Technology  
**Julie Kleinhenz**, NASA Glenn Research Center  
**Diane Linne**, NASA Glenn Research Center  
**Forrest Meyen**, Draper Laboratory  
**Melissa Sampson**, Ball Aerospace  
**Jerry Sanders**, NASA Johnson Space Center  
**Laurent Sibille**, Southeastern Universities Research Association/NASA KSC Swamp Works  
**Paul van Susante**, Michigan Technological University

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