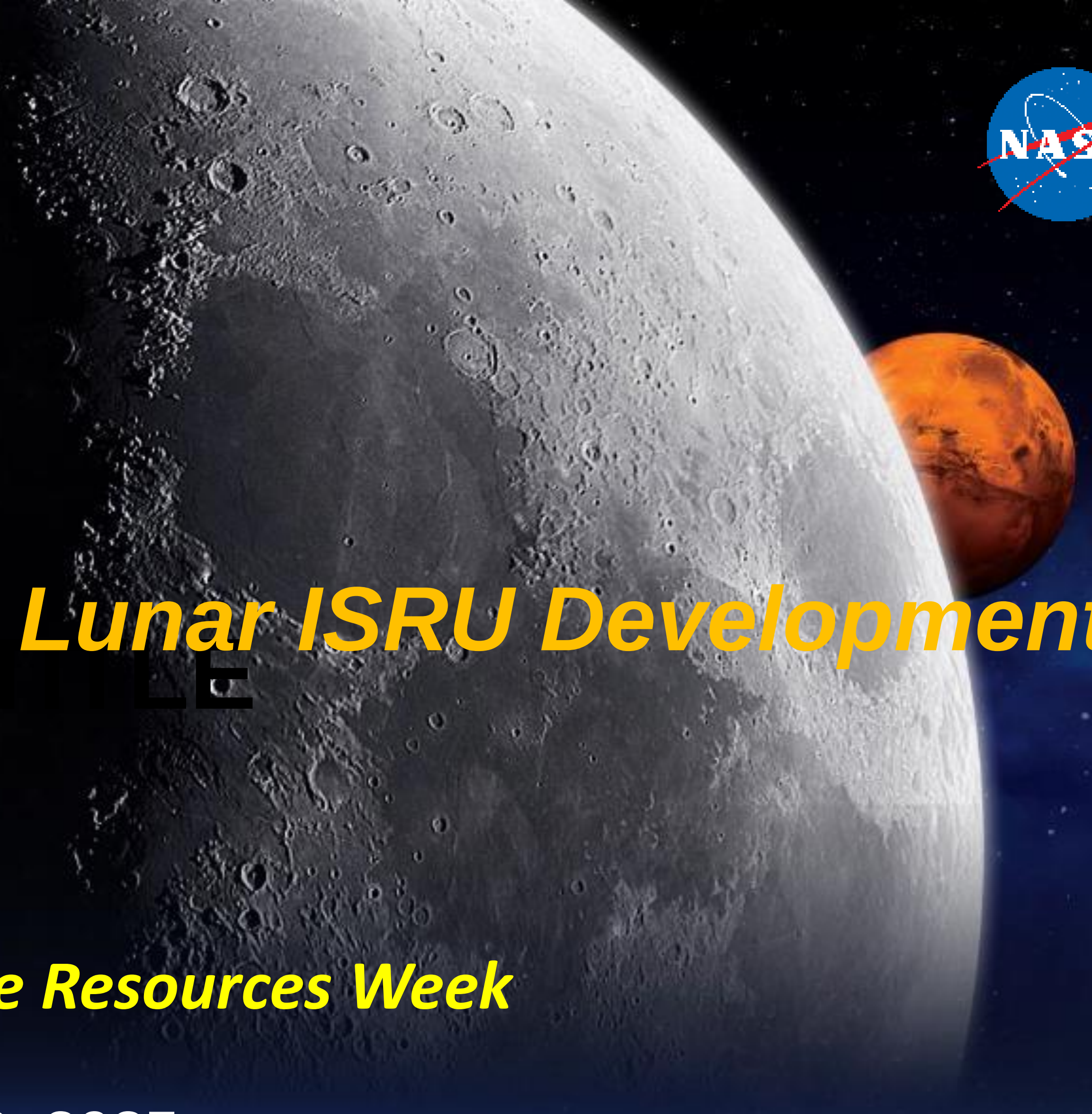
National Aeronautics and Space Administration

EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION



Progress Review of NASA Lunar ISRU Development

2019 to 2025

Luxembourg Space Resources Week

May 19, 2025

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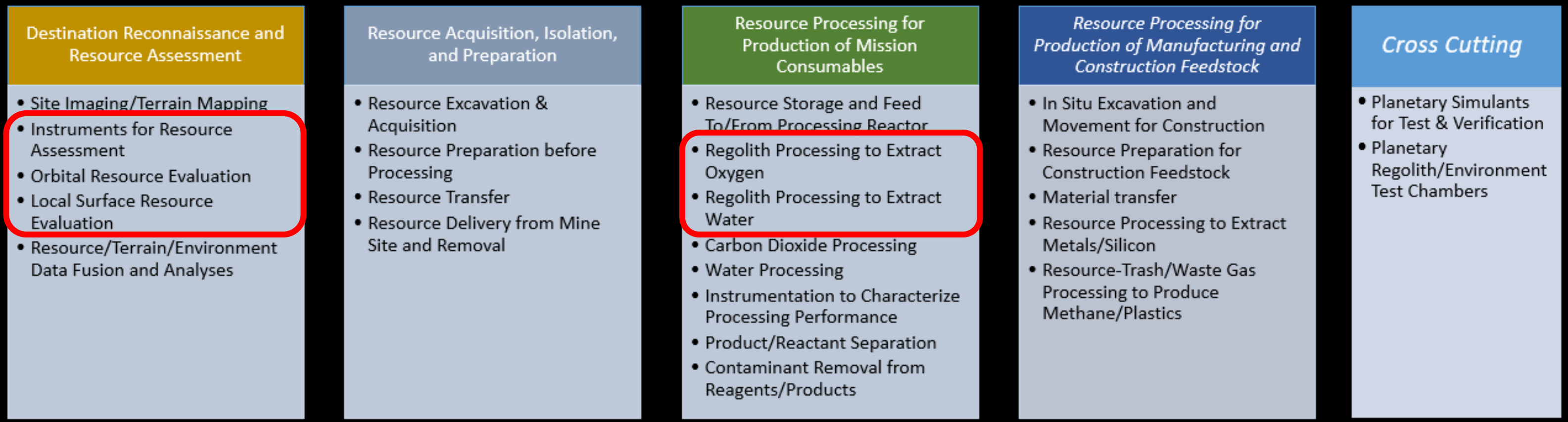
Plan to Achieve ISRU Outcome

*Goal: Scalable ISRU production/utilization capabilities including **sustainable commodities** on the lunar & Mars surface*

Enable Industry to Implement ISRU for Artemis, Sustained Human Presence, and Space Commercialization

Key Objectives

- **Market Transparency:**
  - Define Initial and Long-term Customer Needs for ISRU-derived Products
- **Technology & System Development:**
  - Identify and promote risks, challenges, and gaps; Eliminate Barriers for Commercial use of space resources
  - Utilizing NASA solicitations, public private partnerships, challenges, & internal/external investments
    - Build strong research and university involvement
    - Collaborate and partner with terrestrial resource exploration, mining, and processing; promote spin-in/spin-off
  - Promote extensive ground and low-g aircraft testing
- **Mission Insertion:**
  - Promote resource exploration and flight demonstrations to reduce risk and validate operations and products/commodities (non-mission critical/mission enhancing)
  - Promote investment and development in Industry-led ISRU thru End-to-End ISRU Production of Commodities (i.e. Pilot Plant) and usage
  - Promote collaborations with industry and international partners



Destination Reconnaissance and Resource Assessment	Resource Acquisition, Isolation, and Preparation	Resource Processing for Production of Mission Consumables	*Resource Processing for Production of Manufacturing and Construction Feedstock*	*Cross Cutting*
• Site Imaging/Terrain Mapping • Instruments for Resource Assessment • Orbital Resource Evaluation • Local Surface Resource Evaluation • Resource/Terrain/Environment Data Fusion and Analyses	• Resource Excavation & Acquisition • Resource Preparation before Processing • Resource Transfer • Resource Delivery from Mine Site and Removal	• Resource Storage and Feed To/From Processing Reactor • Regolith Processing to Extract Oxygen • Regolith Processing to Extract Water • Carbon Dioxide Processing • Water Processing • Instrumentation to Characterize Processing Performance • Product/Reactant Separation • Contaminant Removal from Reagents/Products	• In Situ Excavation and Movement for Construction • Resource Preparation for Construction Feedstock • Material transfer • Resource Processing to Extract Metals/Silicon • Resource-Trash/Waste Gas Processing to Produce Methane/Plastics	• Planetary Simulants for Test & Verification • Planetary Regolith/Environment Test Chambers

Commodities

- Oxygen
- Water - Hydrogen
- Bulk & Refined Regolith
- Raw & Refined Metals (Al, Fe, Ti)
- Silicon and Ceramics
- Construction Feedstock
- Manufacturing Feedstock
- Fuels, Plastics, Hydrocarbons
- Food/Nutrient Feedstock

ISRU Technology & System Development

NASA solicitations, Public Private Partnerships, Challenges, Flight Opportunities

Time and Technology Readiness Level (TRL) Advancement

EARLY-STAGE INNOVATION AND PARTNERSHIPS

- Early-Stage Innovation
  - Space Tech Research Grants
  - Center Innovation Fund CIF)
  - Early Career Initiative (ECI)
  - Prizes, Challenges & Crowdsourcing
  - NASA Innovation Advanced Concepts
  - Lunar Surface Technology Research (LuSTR)
- Technology Transfer

SBIR/STTR PROGRAMS

- Small Business Innovation Research
  - SBIR Phase I/II/IIe/III
  - SBIR Ignite
  - SBIR Sequential/CCRPP
- Small Business Technology Transfer

TECHNOLOGY MATURATION

- Game Changing Development (GCD)
- Lunar Surface Innovation Initiative
- Announcement of Collaboration Opportunity (ACO)
- Tipping Point (TP)

TECHNOLOGY DEMONSTRATION

- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

System Modeling and Analysis & System Integration and Testing

University & Public Involvement

ISRU Excavation, & Construction Related Challenges

Printed 3D Habitat Challenge
- Design, build habitat elements, and 3D print a subscale habitat
- Phase III completed 2019

Space Robotics Challenge
- Software for autonomous multi-agent ISRU activities: prospecting, excavating, and delivering
- Phase II completed 9/2021

CO_2 Conversion Challenge
- Convert CO_2 into sugars
- Phase I completed
- Phase II completed 8/2021

Watts on the Moon Challenge
- Solutions for energy distribution, management, and/or storage
- Phase I completed 5/2021

Break the Ice Challenge
- Excavate icy regolith in PSR
- Phase I completed 8/2021
- Phase II now open

Lunar PSR Challenge 2020
– 8 university teams; mobility, power beaming, tether, and wireless charging, instrument, and tower
  – Winner: MTU superconducting cable deployment

Lunar Dust Challenge 2021
- Landing Dust Prevention and Mitigation
- Spacesuit Dust Tolerance and Mitigation
- External Dust Prevention, Tolerance and Mitigation
- Cabin Dust Tolerance and Mitigation

Lunar Forge Challenge 2023
- Producing Metal Products on the Moon

Lunar Surface Technology Research (LuSTR)
- **2020**. Technologies for determining, extracting &/or processing of water from lunarregolith
  – 3 teams selected
- **2021**. Construction and Regolith beneficiation
  – 2 teams selected
- **2023**. Extraction of Metals from Lunar Regolith for Additive Manufacturing
  – 1 teams selected

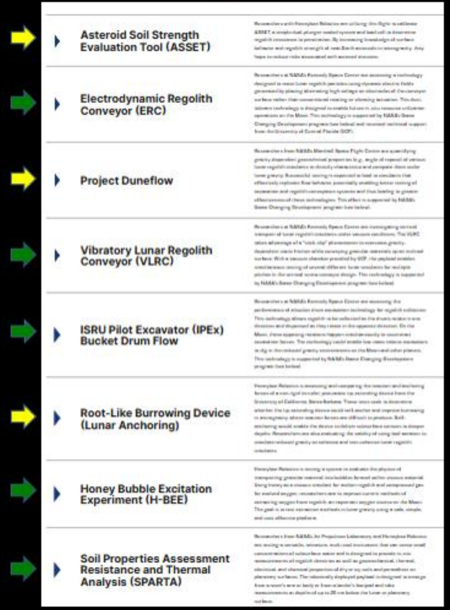
Moon Mars Ice Challenge
- Yearly, university, started in 2017 for Mars ice; added Moon in 2019
- Understand subsurface stratigraphy/hardness
- Extract subsurface water
- 10 teams compete in final 2 day event at LaRC

Lunabotics Robotic Mining Competition
- Started in 2007 following Lunar Excavation Centennial challenge
- Design/build robotic machines to excavate simulated lunar soil
- Teams compete at KSC

Over the Dusty Moon 2022
- Convey regolith 3 m high x 5 m

New Shepard Lunar-G Flights
Flight Opportunities

ISRU



- Asteroid Soil Strength Evaluation Tool (ASSET)
- Electrodynamic Regolith Conveyor (ERC)
- Project Duneflow
- Vibratory Lunar Regolith Conveyor (VLRC)
- ISRU Pilot Excavator (IPEx) Bucket Drum Flow
- Root-Like Burrowing Device (Lunar Anchoring)
- Honey Bubble Excitation Experiment (H-BEE)
- Soil Properties Assessment Resistance and Thermal Analysis (SPARTA)

Dust Mitigation

- PUFFER-Oriented Compact Cleaning and Excavation Tool (POCCET)
- ClothBot: Low-Gravity Transport of Dust Liberated from Spacesuit Fabric
- Electrostatic Dust Lofting (EDL) via Photoionization
- Hermes LunarG

- ✓ Lunar Regolith Characterization
- ✓ Excavation & Transfer
- ✓ Oxygen Bubble
- ✓ Dust Mitigation

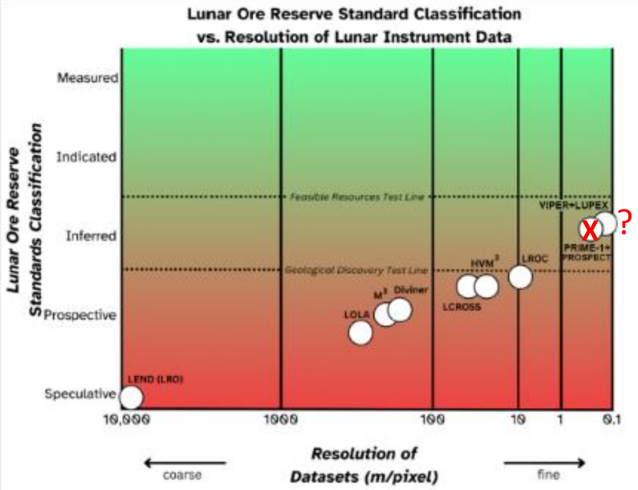
Resource Exploration for ISRU: Missions with Relevant Instruments & Rovers Have Already Started; Some have failed

	2022	2023	2024	2025	2026	2027	2028
Orbital	**- KPLO - ShadowCam (Korea)** ***- Lunar IceCube*** ***- Lunar Flashlight*** ***- LunaH-Map***	- Chandryaan-3 (India)		***- Lunar Trailblazer***		**- Luna-26 (Russia)**	
South Pole			*- IM-1 - Malapert A*	***- IM-2 - STMD-PRIME-1*** - Draper - Schrödinger Basin - Blue Moon Mark 1	**- CP26_Prospect (ESA)** **- Chang'e-7 (China)** **- VIPER?**	**- IM-4 - South Pole (ESA PROSPECT)**	**- Chang'e-8 (China)** **- LUPEX (JAXA/ISRO)?** **- Luna-27 (Russia)** - CLPS?
Equatorial		- Chandryaan-3 (India) *- ispace 1 (Japan)* *- Luna-25 (Russia)*	*- Astrobotic - Gruithusen Domes*	- Blue Ghost 1 - Mare Crissuml - ispace 2 (Japan) - Mare Frigoris - M-3 - Reiner Gamma	- Blue Ghost Mission 2 - Moon Far Side	- CPLS?	- CPLS?

Bold = Water/Ice Related mission *Red Italic* = Failed mission

- **A significant Number of Instruments and Rovers have been developed for Lunar Science that are applicable to Resource Assessment**
  - Some are already manifested
  - Not all are aimed at understanding lunar resources
- **Need to utilize existing instruments to the maximum extent possible before investing in new instrument capabilities**
  - New instruments should fill a gap and be directly tied to critical data needs or concepts of operation
  - No US instruments currently funded for icy regolith sample acquisition and heating
- **Need resiliency in measurements and missions**
  - Mission cancellations and failures can cause significant gaps in knowledge and cause delays
  - Multiple manifesting at different locations can also help advance confidence in geological context of measurements

Missions need to build-off of knowledge gained from previous missions to increase Reserve Estimation



**Patterson R, O'Brien H., Galien L., Vaenciano J., Neal C.R. (2024) Examining the Reserve Potential of Lunar Polar Volatiles. Space Resources Roundtable, Colorado School of Mines; 4-7 June 2024*

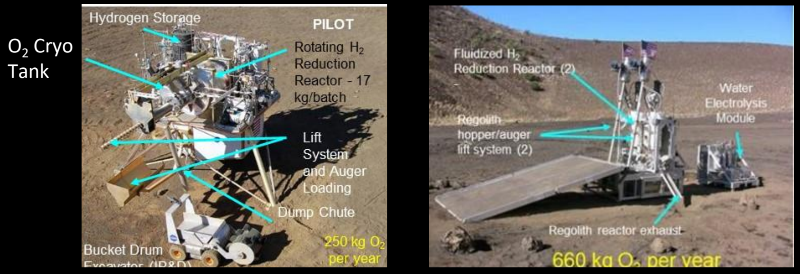
⬜ = Equatorial location
🟦 = Polar location
🟥 = Cancelled
Italics = International

	Astrobotic	IM-1	TO19D Firefly	TO19C Masten	IM-2 PRIME-1	VIPER	CP-11 IM-3	CP-12 Draper	CP-22 IM-4;*Prospect (ESA)*	*Chandrayaan-3 (India)*	*SLIM (JAXA)*	*LUPEX (JAXA)*	*Luna 27 (Russia)*
Landing Location	E	E	E	P	P	P	E	P	P	*P*	*E*	*P*	*P*
Physical Properties/Sample Acquisition													
LISTER - Pneumatic Drill			X					X					
RAC - Regolith Adherence Characterization			X										
EDS - Electrodynamic Dust Shied			X										
LITMS - Magnetotelluric sounder + Heat Probe								X					
PlanetVac - Pneumatic Transfer			X										
SAMPLR - Arm scoop				X									
ColdARM - Arm scoop													
Trident - 1 m Auger Drill					X	X							
Drill - 1.5 m (JAXA)												*X*	
ProSEED Drill - 1 (ESA)									*X*				
Drill - 2 m (Russa)													*X*
Thermal Measurement (Russia)													*X*
CHaSTE - Surface thermal Conductivity & Temp										*X*			
Langmuir Probe										*X*			
High Res Surface Camera NIRVSS)						X							
Subsurface/Indirect Measurment													
NSS Neutron Spec	X			X		X							
NMLS Neutron Spec													
Puli Space NS					X								
LUPEX GPR												*X*	
CADRE GPR							X						
Farside Seismic Suite (FSS)								X					
FLEET passive seismometer													
Lunar Magnetotelluric Sounder (LMS)			X										
Mineral Characterization													
NRVSS - Near IR Spec	X			X		X							
LUPEX NS												*X*	
L-CIRIS - Compact InfraRed Imaging Sensor									X				
XRD/XRF eXTraterrestrial Regolith Analyzer													
Ultra-Compact Imaging Spec - Shorwave IR													
BECA - Gamma Ray Speec w/ Pulsed Neurtons													
Mid IR												*X*	
IR, UV (Russia)													*X*
Gamma Ray Spec (Russia)													*X*
Multispectral microscope							X						
Multi-Band Camera											*X*		
APXS - AlphaParticle X-ray Spec										*X*			
LIBS - Laser Induced Breakdown Spec										*X*			
Volatile - Direct Measurement													
MSolo - Mass Spec					X	X							
PITMS - IonTrap Mass Spec	X												
CRATER - Laser-based Mass Spec													
NIRVSS - Near Infrared Spec				X		X							
Water Analyzer System (REIWA); TGA, Triple Reflection, Optical Resonance, Raman												*X*	
ProSPA: Ion Trap & Mag Sector MS, 6 LED Spec									*X*				
Sample Processing System: GC/MS and Laser MS													*X*
Large Rover w/ Payloads						X						*X*	
MicroRovers													
MoonRanger w/ NSS				X									
MAPP rover - Lunar Outpost					X		X						
Micro Nova Hopper w/ NS					X								
CADRE Rovers (3) w/ GPR							X						
Pragyan rover (India)										*X*			
Hakuto rover (ispace)													
Lunar Excursion Vehicles 1 & 2											*X*		

Lunar ISRU - Oxygen from Regolith – Constellation 2006-2011

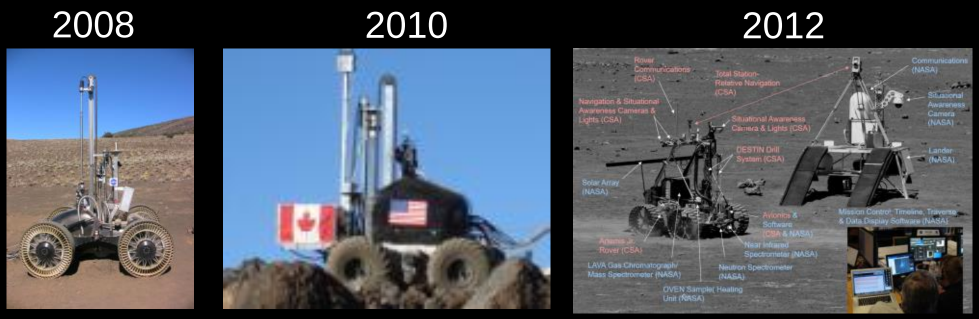
- **First focused effort to advance lunar ISRU**
  - Resource prospecting, regolith excavation, transfer, and processing
- **Oxygen from Regolith**
  - Low risk/low performance – Hydrogen (H_2) Reduction
  - Medium risk/medium performance – Carbothermal (CH_4) Reduction
  - High risk/high performance – Molten Regolith Electrolysis (MRE)
- **Started Search for Lunar Polar Water**
  - RESOLVE → This led to Lunar Prospector (2011-18) → VIPER (2019+)
- **First attempts to evaluate integrated ISRU systems and Concepts of Operation at Analog Sites**
  - 2008: H_2 Reduction @ Mauna Kea, HI
  - 2010: CH_4 Reduction @ Mauna Kea, HI
  - 2012: Lunar Polar Water Prospecting @ Mauna Kea, HI

TRL increase in ETDP	At Start	At End	Delta
System Level			
Lunar Volatile Characterization (RESOLVE)	1	5	4
H_2 Reduction of Regolith	2-3	5	2-3
CH_4 Reduction of Regolith	2-3	5	2-3
Molten Oxide Reduction of Regolith	2	3	1
Trash Processing for Water/Methane Production	2	2-3	0-1
Subsystem Level			
Regolith Transfer & Handling			
Regolith Transport Into/Out of Reactor	2	5	3
Beneficiation of Lunar Regolith	2-3	2-3	0-1
Size Sorting of Lunar Regolith	2-3	2-3	0-1
Oxygen Extraction From Regolith			
H_2 Reduction of Regolith Reactor	3	5	2
Gas/Water Separation & Cleanup	2	4-5	2-3
CH_4 Reduction of Regolith Reactor	3	5	2
CH_4 Reduction Methanation Reactor	3-4	4-5	1-2
MOE of Regolith Anode/Cathode	1-2	3-4	2-3
MOE of Regolith Molten Mat'l Removal	1-2	3	1-2
MOE Cell and Valving	2-3	3	0-1
Water/Fuel from Trash Processing			
Trash Processing Reactor	2	2-3	0-1
In-Situ Energy Generation, Storage, and Transfer			
Solar Thermal Energy for Regolith Reduction	2	5	3



Hydrogen (H_2) Reduction - 2008

CH_4 Reduction - 2010


2008 2010 2012

RESOLVE (NASA – CSA)

Lunar Oxygen & Metals from Regolith – Results to Date (1 of 2)

- **Highest TRL Oxygen Extraction from Regolith technology is Carbothermal Reduction**
  - Breadboard system tested in Hawaii in 2010 with mare-like material demonstrating technology and concept of operation
  - New prototype Carbothermal reactor built and tested with highland simulants through Tipping Point with Sierra Space
  - Breadboard and prototype reactors tested under lunar environmental conditions with laser at JSC to TRL 5
    - Single melts demonstrated that are equivalent to a production rate of 140 kg O_2/yr.
    - 5 consecutive melt operations were performed under lunar vacuum/thermal conditions
    - Oxygen extraction demonstrated >20 g O_2/kW-hr thermal; O_2 production yield of >20% gm O_2 per gm regolith; >99.7% recovery of the carbon used in melt.
  - Integrated Reactor/Solar concentrator system to be tested in 2025 through collaboration between NASA & Sierra Space

- **Molten Regolith Electrolysis (MRE) TRL has significantly improved for Oxygen and Metal Extraction (Fe, Si, Al)**
  - Both Lunar Resources and Blue Origin are advancing MRE for iron, silicon, and aluminum extraction and purification from highland regolith
  - Lunar Resources - MRE iron reactor tested under lunar environmental conditions (at KSC) in single melt/electrolysis operation to demonstrate oxygen production under lunar conditions.
    - 25 kg of lunar highland simulant was processed over 36 hours (24 hrs of electrolysis) and measured oxygen production rate matched theoretical levels
  - Blue Origin - MRE and purification reactors (Fe, Si, & Al) under development along with solar cell and aluminum wire fabrication subsystems
    - Integrated system lunar environmental testing planned for 2026

- ➢ **Technologies being developed for lunar operations also have interest for terrestrial applications and clean iron/steel**
  - Funding from DOE and Partnerships with terrestrial industry are growing

Lunar Oxygen & Metals from Regolith – Results to Date (2 of 2)

- **Hydrogen/Carbon Monoxide (H_2/CO) Reduction of mare Regolith technology has advanced to TRL 5.**
  - Two Breadboard systems (Lockheed Martin & JSC) tested in Hawaii in 2008 with mare-like material demonstrating technology and concept of operation
  - MMOST system from Pioneer Astronautics (now Redwire) included size sorting/beneficiation, H_2 reduction for oxygen, and separate CO reduction for metal extraction

- **Other Oxygen/Metal Technologies advancing to TRL 4 showing promise**
  - Vacuum Vapor Pyrolysis is showing promise from multiple companies with either cryo-distillation, electro/magnetic separation, or removal of oxygen via solid oxide transport
  - All steps for hydrochloric reduction and subsequent Molten Salt Electrolysis (MSE) of aluminum chloride demonstrated in Lunar Forge Big Ideas Challenge. Approach is viable for both terrestrial and lunar reduction of highland anothorsite

- **Technologies are advancing with IR&D and/or venture capital funding**
  - Public-Private Partnerships: Tipping Points and Announcement of Collaborative Opportunities (ACOs)
  - Private Investment (with and without NASA funded efforts)

Lunar Polar Ice/Water Mining – Results to Date (1 of 2)

- **Excavation & Delivery**
  - Loose Regolith Excavation and Delivery demonstrated to TRL 5 in simulated mission
    - Arm/scoops and mobile excavators (Bucket drum, Bucket wheel, and Bucket ladder) developed and demonstrated
    - ISRU Pilot Excavator (IPEx) bucket drum excavator demonstrated in simulated mission (10 mt in 5 days)
  - Hard Icy Regolith Excavation and Delivery demonstrated to TRL 5 in simulated excavation and delivery – Break the Ice Challenge
    - 15 Teams: 15 days of ops at developers' site; Excavate 12,000 kg (800 kg/day). Each delivery = 500 m traverse
    - 6 Teams: 2 days of competition at Alabama A&M (timed performance)

- **Icy Regolith Processing**
  - Icy Regolith Processing Reactor Subsystem demonstrated to TRL 4 – Lunar Auger Dryer ISRU (LADI)
    - Continuous processing with regolith plugs at each end; Aimed at goal of 1.78 kg/hr water extraction rate and 75% water extraction efficiency
    - Cancelled before progressing to TRL 5 due to budget cuts but technology/concept validated
  - Contained Subsurface Material Reactor/Core demonstrated to TRL 5/6 – Planetary Volatile Extractor (PVEx)
    - Coring drill contains icy regolith. Inner core wall is heated (via electrical or thermal fluid) and water/volatiles sublimate and are captured in a coldtrap
    - Initial design was 1 meter core w/ 2.5 cm inner diameter. Large IDs examined. Performance contingent on icy regolith properties and core diameter & length; (5 cm ID, 0.5 m L, 4 to 6 wt% water, 43 to 56% water extraction)

Lunar Polar Ice/Water Mining – Results to Date (2 of 2)

- **Water Capture and Cleanup**
  - Water Capture (Paragon Space & GRC)
    - Cold trap/Freeze distillation primary method advanced to TRL 3/4 with both active and passive cooling designs.
    - Data obtained up to 0.1 kg/hr water vapor flow testing sufficient to proceed to prototype/flight design
  - Water Cleanup (Paragon Space & JSC)
    - First step in water cleanup is cold trap/freeze distillation of water vapor released from lunar icy regolith
    - Absorption and membrane separation to further remove contaminants demonstrated at mission relevant rates
    - Significant progress but more work on material compatibility and mixed contaminants required
- **Water Electrolysis**
  - Proton Exchange Membrane (PEM) technology has a high TRL as long as the water is sufficiently clean.
    - Multiple vendors and projects have advanced the TRL sufficiently for use in system breadboards/prototypes
    - Cathode-fed, Anode-fed, non-flow PEM electrolyzers allows for system-level trades and configurations to evaluate
  - Solid Oxide Electrolysis (SOE) of water (H_2O) and carbon dioxide (CO_2) has advanced to TRL 5
    - OxEon has demonstrated scale, performance, and operation under lunar and Mars environmental conditions at mission relevant scale (each stack up to 0.9 kg/hr O_2 & 0.12 kg/hr H_2) – 1000’s of hours of operation
    - Combination of individually or jointly electrolyzing CO_2 and H_2O allows for system-level trades and configurations
  - Alkaline Electrolysis of dirty water has unresolved corrosion issues at this time

➢ **Top-Level Results**

- Significant advancements have been made
- Technologies are advancing with IR&D and/or venture capital funding; No current NASA technology development work on icy regolith processing
- Final designs will be based on icy regolith resource information not currently available

Main Takeaways

- **A significant amount of development has occurred over the last 6 years since the start of the Artemis program wrt understanding, extracting, and processing lunar resources into usable products**
  - Industry is interested in commercial operations and is investing in technology development and flight opportunities
  - Flight demonstrations can proceed with reasonable risk for oxygen/metal extraction from regolith
  - Lunar water/volatile extraction is lacking sufficient resource knowledge to proceed without significant risk

- **Resource Exploration**
  - A significant number of instruments and mobile assets have been developed for flight; several have been manifested
    - Instruments for subsurface material collection and heating to measure water/volatiles still need to be developed to flight
  - Several important resource exploration related missions have failed, cancelled, or delayed.
  - A resilient resource exploration campaign is needed to understand and map lunar water before commercial extraction is possible

- **Oxygen and Metal Extraction from Regolith**
  - Polar Highland Regolith: Two extraction approaches – Carbothermal Reduction and Molten Regolith Electrolysis have demonstrated operation under simulated lunar environmental conditions to TRL 5/6.
  - Equatorial Mare Regolith: Hydrogen/Carbon Monoxide (H_2/CO) Reduction demonstrated to TRL 5/6
  - Regolith excavation, transportation, and preparation (size sorting/mineral separation) demonstrated to TRL 4/5
  - Technologies have spin-in/spin-off potential for terrestrial mining and metal processing

- **Lunar Polar/Water Mining**
  - Performance and viability of water excavation and extraction techniques are highly dependent on the form, concentration, and distribution of water/ice and volatiles in lunar polar regolith (which are currently unknown)
  - Two technologies for water extraction to TRL 4 to 6 that could be used for initial tests.

BACKUP

Resource Exploration for ISRU

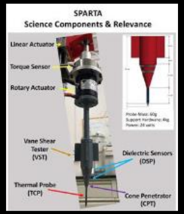
Flight Missions

⬜ = Equatorial location
🟦 = Polar location
🟥 = Cancelled
Italics = International

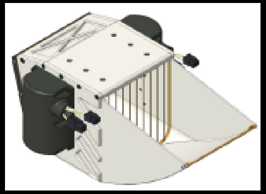
	Astrobotic	IM-1	TO19D Firefly	TO19C Masten	IM-2 PRIME-1	VIPER	CP-11 IM-3	CP-12 Draper	CP-22 IM-4;*Prospect (ESA)*	*Chandrayaan-3 (India)*	*SLIM (JAXA)*	*LUPEX (JAXA)*	*Luna 27 (Russia)*
Landing Location	E	E	E	P	P	P	E	P	P	*P*	*E*	*P*	*P*
Physical Properties/Sample Acquisition													
LISTER - Pneumatic Drill			X					X					
RAC - Regolith Adherence Characterization			X										
EDS - Electrodynamic Dust Shied			X										
LITMS - Magnetotelluric sounder + Heat Probe								X					
PlanetVac - Pneumatic Transfer			X										
SAMPLR - Arm scoop				X									
ColdARM - Arm scoop													
Trident - 1 m Auger Drill					X	X							
Drill - 1.5 m (JAXA)												*X*	
ProSEED Drill - 1 (ESA)									*X*				
Drill - 2 m (Russa)													*X*
Thermal Measurement (Russia)													*X*
CHaSTE - Surface thermal Conductivity & Temp										*X*			
Langmuir Probe										*X*			
High Res Surface Camera NIRVSS)						X							
Subsurface/Indirect Measurment													
NSS Neutron Spec	X			X		X							
NMLS Neutron Spec													
Puli Space NS					X								
LUPEX GPR												*X*	
CADRE GPR							X						
Farside Seismic Suite (FSS)								X					
FLEET passive seismometer													
Lunar Magnetotelluric Sounder (LMS)			X										
Mineral Characterization													
NRVSS - Near IR Spec	X			X		X							
LUPEX NS												*X*	
L-CIRIS - Compact InfraRed Imaging Sensor									X				
XRD/XRF eXTraterrestrial Regolith Analyzer													
Ultra-Compact Imaging Spec - Shorwave IR													
BECA - Gamma Ray Speec w/ Pulsed Neurtons													
Mid IR												*X*	
IR, UV (Russia)													*X*
Gamma Ray Spec (Russia)													*X*
Multispectral microscope							X						
Multi-Band Camera											*X*		
APXS - AlphaParticle X-ray Spec										*X*			
LIBS - Laser Induced Breakdown Spec										*X*			
Volatile - Direct Measurement													
MSolo - Mass Spec					X	X							
PITMS - IonTrap Mass Spec	X												
CRATER - Laser-based Mass Spec													
NIRVSS - Near Infrared Spec				X		X							
Water Analyzer System (REIWA); TGA, Triple Reflection, Optical Resonance, Raman												*X*	
ProSPA: Ion Trap & Mag Sector MS, 6 LED Spec									*X*				
Sample Processing System: GC/MS and Laser MS													*X*
Large Rover w/ Payloads						X						*X*	
MicroRovers													
MoonRanger w/ NSS				X									
MAPP rover - Lunar Outpost					X		X						
Micro Nova Hopper w/ NS					X								
CADRE Rovers (3) w/ GPR							X						
Pragyan rover (India)										*X*			
Hakuto rover (ispace)													
Lunar Excursion Vehicles 1 & 2											*X*		

Prototype Hardware

- **Instruments for Physical/Geotechnical Characterization**
  - Soil Properties Assessment Resistance & Thermal Analysis (SPARTA) – JPL – SMD
  - SPARTA Blue Origin Flight – JPL - FO
- **Instruments for Ice/Volatile Characterization**
  - Honeybee PVEx Drill – SSEVI RESOURCE project - TRL 4/5
  - Light Water Analysis & Volatile Extraction (Light WAVE) – NASA JSC – GCD – TRL 5

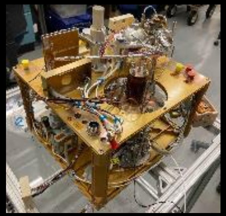


SPARTA – JPL (TRL 5)



MEERCAT- KSC (TRL 4)

PVEx – Honeybee Robotics (TRL 5/6)



Light WAVE – JSC (TRL 5)

Flight Hardware

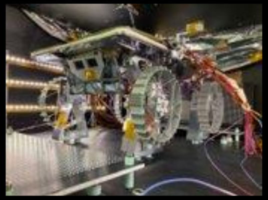
ProSPA & PROSPECT – ESA (TRL 7)

PRIME-1: TRIDENT Drill & MSolo (TRL 9)

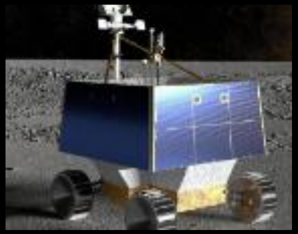
MoonRanger - Astrobotic

MAPP – Lunar Outpost

Micro-NOVA Hopper – IM



CADEE - JPL



VIPER

LUPEX