

The background is a dark blue space scene. At the top, a large, reddish-orange planet (Mars) is partially visible. Below it, a large, blue and white Earth is shown, with a rocket launching from its surface, leaving a white trail. In the foreground, there is a silhouette of a lunar or Martian landscape with a rover, an astronaut, and a small dome-shaped habitat.

Building a Sustained International Future for Space Resources Session

US/NASA Advancing Space Resources: Commercially and Internationally

Gerald Sanders

NASA ISRU System Capability Lead

LUXEMBOURG
**SPACE
RESOURCES
WEEK**

esric

esa

LSA LUXEMBOURG
SPACE AGENCY

LUXEMBOURG
INSTITUTE OF SCIENCE
AND TECHNOLOGY

LIST

What are the Barriers to International & Commercial ISRU?

Today: There is Neither a Production Capability or Market



Barriers

Resource Uncertainty

- Resource Exploration
- Reserve Estimation

Mining Technology Readiness

- Demonstrated Scale
- Demonstrated Operations

Customers

- Known users/market
- Market growth potential

Sustainable Operations

- Reliable/Cheap Transportation
- Logistics and Maintenance
- Infrastructure

Regulatory

- Legal Framework
- Product/Property Rights
- Standards
- Taxes

What Can/Should Be Done?

- Increase global resolution of resource information
- Campaign of resource exploration missions (Gov. & Industry)
- Agreement/standards for reserve estimation (ex JORC/NI43-101)
- Government/industry partnerships & space mining institute
- Spin-in/Spin-off Technologies into Terrestrial Applications
 - Incentives for insertion; greener/safer innovations
- Demonstrate technologies, production rate, and product quality
- Terrestrial market use of technology/capability
- Demonstrate product usage
- Develop space transportation & infrastructure growth around ISRU
- Gov. as anchor tenant once demand has been established
- Enable bootstrapping through stepwise incentives
- Utilize additive manufacturing for high wear parts
- Governments help establish initial transportation, power, communication, and surface infrastructure
- Establish common interfacing standards
- Establish international agreements (**Artemis Accords**)
- Establish stable legal and regulatory framework
- Establish tax incentives/flow-through shares
- Enable ownership enforcement

Overcoming Resource Uncertainty



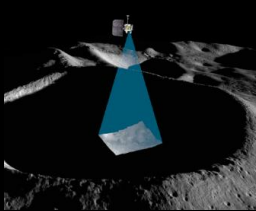
On-going & Planned Missions Are a Good Start

Orbital



Lunar Reconnaissance Orbiter

Korean Pathfinder
Lunar Orbiter (KPLO)
& ShadowCam



Artemis I Cubesats

Lunar Trailblazer



Surface – Ground Truth



PRIME-1

VIPER



PROSPECT - ESA

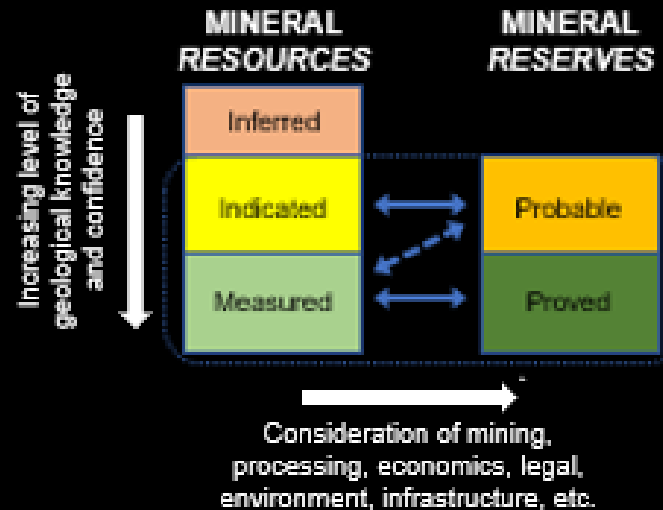


LUPEX - JAXA

China:
Chang'e 7, 8

Russia:
Luna 26, 27

A Coordinated International Lunar Resource Campaign is Needed



AS-3^{LM}

Characterize accessible lunar and Martian resources, gather scientific research data, and analyze **potential reserves** to satisfy science and technology objectives and enable In-Situ Resource Utilization (ISRU) on successive missions.

OP-3^{LM}

Characterize accessible resources, gather scientific research data, and analyze **potential reserves** to satisfy science and technology objectives and enable use of resources on successive missions.

- A coordinated no-obligation campaign for lunar polar resource *science* was addressed by the International Space Exploration coordination Group (ISECG)
- Several studies and workshops have been held on the subject: LWIMS, LEAG Volatiles SAT, LSSW-17 & 18
- A new lunar polar resource campaign strategy is needed that enables understanding of resource *RESERVES* not just science

IAC-22.D3.1.14.x73338

The Moon Needs an International Lunar Resource Prospecting Campaign

Clive R. Neal^{a*}, Antonino Salmeri^b, Angel Abbud-Madrid^c, James D. Carpenter^d, Anthony Colaprete^e, Karl A. Hibbitts^f, Julie Kleinhenz^g, Mathias Link^h, Gerald Sandersⁱ

Significant Amount of Development Achieved – Reaching TRL5/6 Soon Across the Value Chain

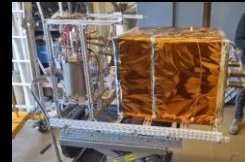
Water Mining, Cleanup, & Electrolysis



Lunar Auger
Dryer –
NASA JSC



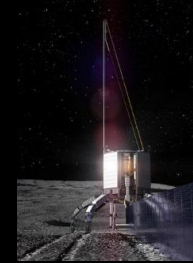
IHOP water cleanup & electrolysis – Paragon Space



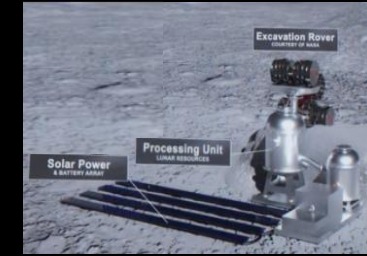
Lunar water
collection &
Electrolysis –
CSM & OxEon



Carbothermal Reduction – Sierra Space



Molten Regolith Electrolysis – Blue Origin



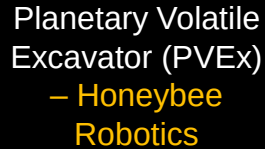
Molten Regolith Electrolysis – Lunar Resources



Hydrogen/Carbothermal Reduction – Pioneer Astronautics



Loose Regolith Excavation – NASA KSC



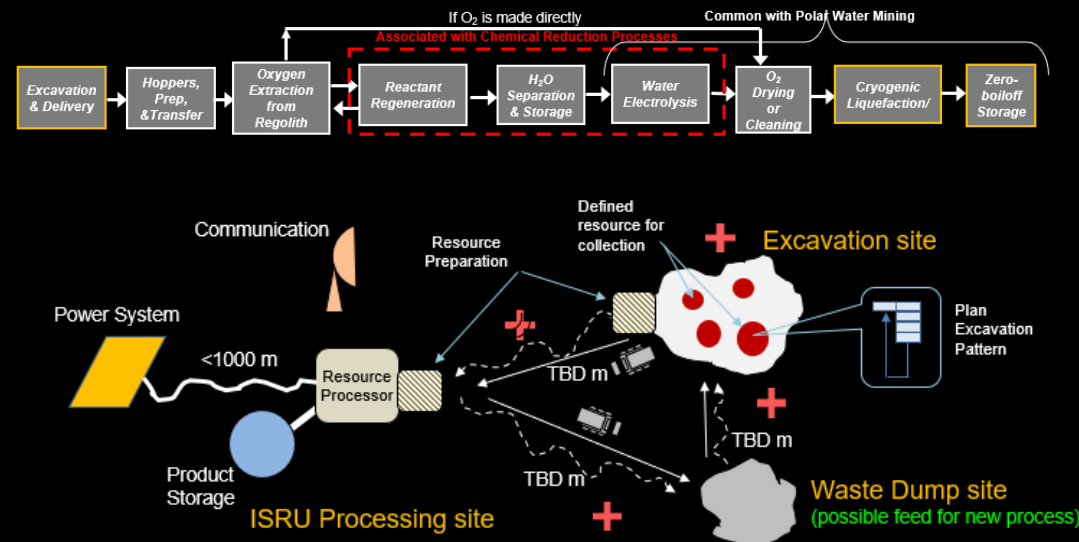
Planetary Volatile Excavator (PVEx) – Honeybee Robotics



Plans Underway for Integrated System Ground Development (Pilot Plant)

- Establish Framework for agreed upon requirements, standards and interfaces
- Modularity and Clean Interfaces across Full Value Chain
- ISRU System Level and ISRU in Complete Surface Infrastructure
- **Establish a coordinated virtual/physical integration and testing location(s) – Environmental & Analog**

‘Proving Grounds’ and International Framework Should Be Pursued



15' Dia. – NASA JSC



20'x40' Dia. –
NASA MSFC

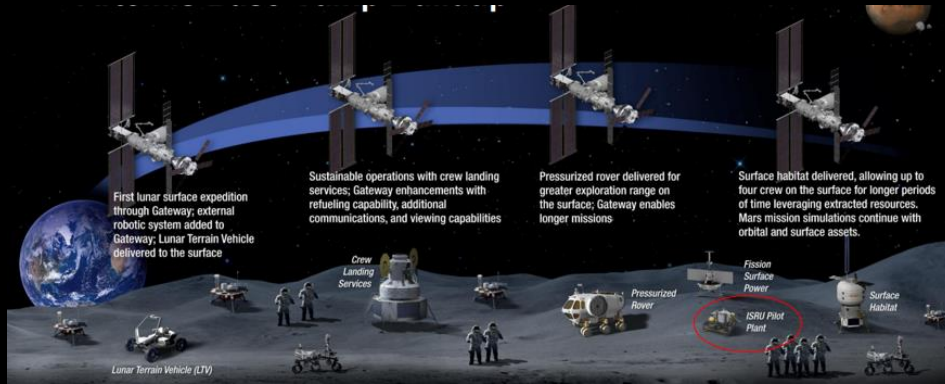


Analog Facility & Industrial Park. – NASA JSC & Texas A&M

Customers: Promote ISRU Development & Capabilities



Artemis Campaign



- ISRU Demos and Pilot Plant in Artemis Campaign Architecture Concept Document (ACD) Foundational Segment
- No usage yet identified for Pilot Plant product

Foster Market Development & Demand



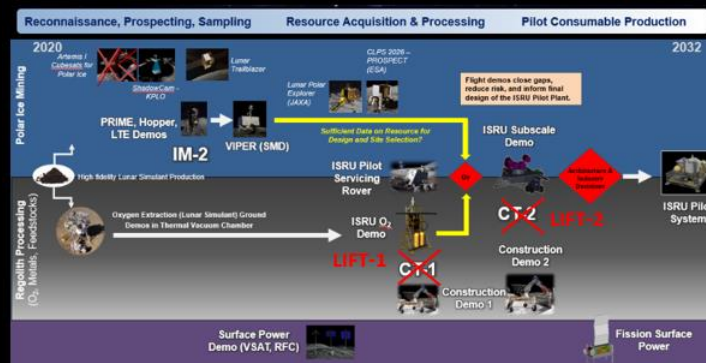
LunA-10
10-year Lunar Architecture



Goal: To achieving a thriving lunar economy in 10 years

LSIC Supply-Demand Workshop

Missions to Reduce Risk/Verify Resources, Capabilities, & Products



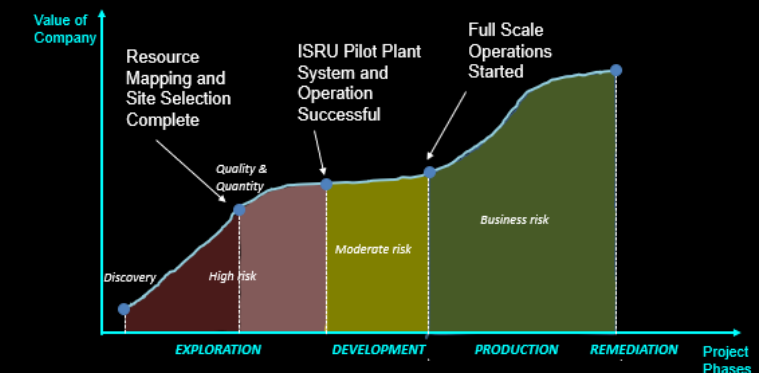
Ground and Flight Development to End-to-End System (Pilot Plant)

Break 'Chicken and Egg' Problem

Lunar Infrastructure Foundational Technology-1 (LIFT-1) Demonstration



Demonstrations of Foundational Technologies starting with Oxygen from Regolith



Government Support in Exploration Phase

Customers: Collaborative - Competition



Consortiums to Promote Industry - Commercialization



Commercial
Advisory
Board (CAB)

*Growing number of Forums for
Promoting Teaming and Customer-
Supplier Relationships*

Government/Space Agencies Seeking to Collaborate on ISRU Development & Usage



*A Framework is Needed to Promote
Collaboration while Enabling
Competition and Industrial Teaming*

Sustainable Operations



Establishing Support Infrastructure

Transportation to/from Site:

- Delivery (P)
- Propellants & Depots (S)

Power:

- Generation, Storage, & Distribution (P)
- ISRU-derived electrical /thermal (S)

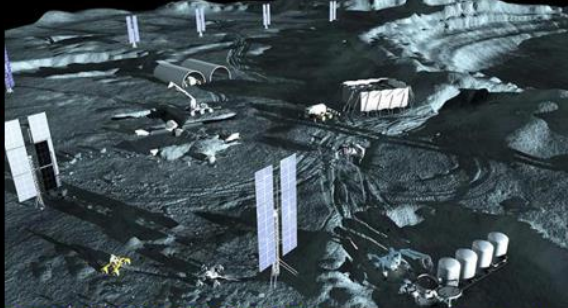
Communications & Navigation (P)

- To/From Site
- Local

Space Mining

Coordinated Mining Ops:
Areas for:
i) Excavation
ii) Processing
iii) Tailings
iv) Product Storage

P = Provided to ISRU
S = Supplied by ISRU
Italic = Other Disciplines



Maintenance & Repair Logistics Management

- Replacement parts (P)
- Feedstock (S)

Living Quarters & Crew Support Services

- Water, O₂, H₂, Gases (S)
- Trash/waste (P)
- Nutrients(S)

Commodity Storage and Distribution:

- Water & Cryogenic Fluids (CFM)
- Manufacturing & Construction Feedstock

Construction and Outfitting

- Feedstock for roads and structures (S)

Significant NASA and Private Investments in Infrastructure Needs:

- Transportation (CLPS, HLS)
- Power: Solar, Nuclear, & Fuel Cells
- Mobility platforms (micro-rovers, LTV)
- Robotics & Autonomy
- Communication Relay Satellites (Moonlight, Crescent)
- High Speed Space Computers
- In Space Manufacturing
- Surface Construction

Interfaces/Standards Consortiums*



Public-Private Partnerships*



Lunar Surface Innovation
C O N S O R T I U M

- Tipping Points/ACOs
- NASA Center encouraged to partner



Applicability & Partnerships for Terrestrial Mining & Processing*



*Organizations and Companies shown are not meant to be a full and exhaustive list

Regulatory: Aiming Toward Establishing Stable Legal and Regulatory Frameworks



Overarching Legal Framework for Space Resources



- **Art. I:** “Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States”
- **Art. II:** “Outer space, including the moon and other celestial bodies, is not subject to national appropriation”
- **Art. IX:** State parties “shall conduct all their activities in outer space . . . with due regard to the corresponding interests of all other States Parties to the Treaty.”

Non-Binding Agreement on Conduct for Space Resources



Space Resources

The ability to extract and utilize resources on the Moon, Mars, and asteroids will be critical to support safe and sustainable space exploration and development.

The Artemis Accords reinforce that space resource extraction and utilization can and will be conducted under the auspices of the Outer Space Treaty, with specific emphasis on Articles II, VI, and XI.

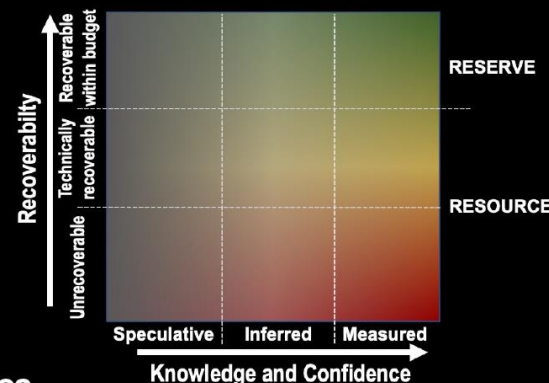
UN Activities on Space Resources



UN Working Group on Legal Aspects of Space Resource Activities

26.03.2024 Luxembourg
Expert Meeting
collecting preliminary inputs for consideration at the international conference in Vienna in 2024

Methodology for Quantitative Lunar Resource Assessment



National Laws for Space Resources



US

Luxembourg

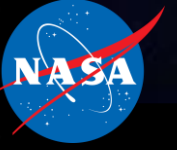
Japan

UAE

Presentation Take-Ways



- **Ground truth polar resource missions are coming soon**
 - However, we know we'll need more data/missions to determine the potential water/volatile reserves
 - A coordinated international campaign is needed with government agencies and industry
- **Significant progress has been made in developing Lunar ISRU technologies**
 - We are about to start building and testing systems
 - We need to establish frameworks for requirements, interfaces, integration, and testing to promote industry and international involvement
- **Progress is being made on establishing customers and markets**
 - There are significant government, industry, and consortium efforts to develop and reduce the risk on the Supply side; Still need to develop and incentivize the markets
- **Progress is being made on the Infrastructure and partnerships needed for Sustainable Operations on the Lunar Surface**
 - Public-Private Partnerships and applicability to Terrestrial markets and needs are critical
- **Significant progress has been made toward establishing Stable Legal and Regulatory Frameworks**
 - Implementing Sustainable and Responsible Space Mining practices will be critical

The background of the slide is a composite image showing the planet Mars rising over the horizon of the Moon. Mars is a reddish-orange sphere with visible surface features, positioned in the upper center. The Moon's dark, cratered surface fills the lower half of the frame, with its horizon line curving across the middle. The sky is a deep black with scattered white stars.

Thank You

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On-going & Potential Space Resource Partnerships and Collaborations*

International Agencies Interested in Space Resource Collaboration



Industry



Terrestrial Mining



Interfaces/Standards Consortia



DARPA

LunA-10 10-year Lunar Architecture



*Organizations and Companies shown are not meant to be a full and exhaustive list