# OVERVIEW OF NASA ISRU PLANS, PRIORITES, AND ACTIVITIES.

G. B. Sanders[1] and Dr J. E. Kleinhenz[2], [1]NASA Johnson Space Center, Houston, TX, 77058, USA, [2]NASA Glenn Research Center, Cleveland, OH 44135, USA

**Introduction:** The National Aeronautics and Space Administration (NASA) of the United States of America (US) has initiated the Artemis Moon to Mars program to send astronauts (the first woman and person of color) back to the lunar surface, create a sustainable human lunar exploration program, and lead the first human exploration mission to the Mars surface in the 2030's [1]. A major objective of this program is to characterize the resources that exist on the Moon and Mars, and learn how to utilize them for sustained and affordable exploration. Commonly known as In Situ Resource Utilization (ISRU), the search for, acquisition, and processing of resources in space has the potential to greatly reduce the dependency on transporting mission consumables and infrastructure from Earth, thereby reducing mission costs, risks, and dependency on Earth.

**ISRU is Enabling:** Through the extraction and processing of resources into mission commodities such as rocket propellants, life support consumables, and fuel cell reactants, ISRU enhances and evolves the cis-lunar, lander, and surface transportation systems required for human exploration; expanding and enhancing *HOW* humans can explore and return from the Moon. Through the extraction and processing of resources into metals, silicon, and other manufacturing and construction feedstock, ISRU enhances and allows for the expansion of critical infrastructure using in situ manufacturing and construction capabilities that influence *WHAT* humans can do on the Moon and in cis-lunar space. Because of this, ISRU supports and enables commercial involvement beyond NASA and governmental agencies by both lowering the cost of sustained transportation to/from/on the Moon as well as supporting the market required for needing these transportation systems.

**Strategic Framework:** To achieve this vision, NASA's Space Technology Mission Directorate (STMD) ensures the coordinated development of ISRU and other critical space and surface infrastructure elements such as propulsion, power, manufacturing, construction, and robotics through the Strategic Technology Architecture Roundtable (STAR) process. Through STAR, an integrated framework and process has been created allowing for capabilities and technologies to be linked and assessed, gaps to be identified, specifications and metrics to be established, and provide a means to prioritize and implement technology development and missions. A critical part of the STAR effort has been the establishment of the Strategic Framework that organizes all work under four major Thrusts (Go, Land, Live, and Explore) and identifies the driving Outcomes for each of these Thrusts. From the Thrusts and Outcomes, all work can be categorized and linked between Capability Areas, and Technology Gaps can be identified and addressed (Figure 1.)

| Thrusts | Outcomes |
|---|---|
| **Go** Rapid, Safe, and Efficient Space Transportation | • Develop nuclear technologies enabling fast in-space transits.<br>• Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications.<br>• Develop advanced propulsion technologies that enable future science/exploration missions. |
| **Land** Expanded Access to Diverse Surface Destinations | • Enable Lunar/Mars global access with ~20t payloads to support human missions.<br>• Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies.<br>• Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards. |
| **Live** Sustainable Living and Working Farther from Earth | • Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities<br>  • Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations.<br>  • Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface.<br>  • Technologies that enable surviving the extreme lunar and Mars environments.<br>  • Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources.<br>• Enable long duration human exploration missions with Advanced Life Support & Human Performance technologies. |
| **Explore** Transformative Missions and Discoveries | • Develop next generation high performance computing, communications, and navigation.<br>• Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions.<br>• Develop technologies supporting emerging space industries including: Satellite Servicing & Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies.<br>• Develop vehicle platform technologies supporting new discoveries.<br>• Develop transformative technologies that enable future NASA or commercial missions and discoveries |

*Figure 1. Strategic Framework and STAR Framework*

**ISRU Envisioned Future**: To drive the development of technologies and capabilities, the STAR process starts with establishing a 'grand vision' of where each Outcome and Capability is aiming to be considered complete. For ISRU, the Envisioned Future is "Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar and Mars Surface". This involves starting with 10's of metric tons of products, but evolves into 100's to 1000's of metric tons of water, oxygen, propellants, construction and manufacturing feedstock, and commodities for habitat and food production and operations. For ISRU, the 'Prospect to Product' philosophy starts with Destination Reconnaissance & Resource Assessment, followed by Resource Acquisition, Isolation, and Preparation, leading into Resource Processing (which is further subdivided into mission consumables and feedstocks for construction and manufacturing). The ISRU Envisioned Future also considers what resources are available and attempts to address what and when these resources will be evaluated and harnessed, as well as considering which products/commodities can be obtained for early use and which ones require more time and/or users of refined products.

**It Takes an Architecture**: ISRU does not exist on its own. By definition, it requires customers/users to use the products/commodities produced by ISRU systems.  Also, for an ISRU capability to exist, it must obtain products and services from other systems and infrastructure.  An important aspect of the STAR process and the ISRU Envisioned Futures Priorities strategy is to identify and link all of these systems and capabilities to achieve the desired end state (Figure 2).

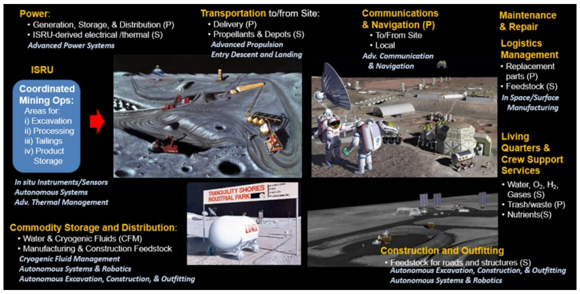


*Figure 2. ISRU as Part of a Larger Architecture*

**ISRU Capability Drivers:** The guiding principles for NASA's Space Technology Development for Artemis are to develop critical technologies and capabilities that enable (i) a sustainable Lunar surface presence, (ii) the future goal of sending humans to Mars, and (iii) promoting critical technologies to enable future science and commercial missions. It is a major goal of the Artemis campaign to establish some sort of base camp at the lunar South Pole by approximately the end of the decade.  The ISRU Envisioned Futures Priorities strategy is aligned with the Artemis campaign to develop and demonstrate ISRU capabilities in this timeframe that could lead to sustained surface operations, infrastructure growth, and commercial operations in the next decade (Figure 3).

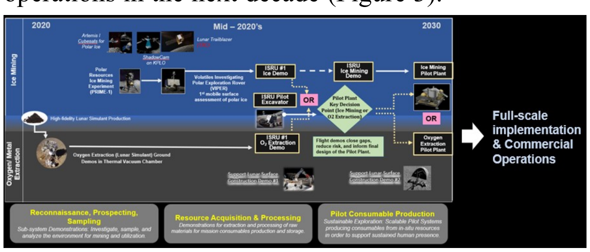


*Figure 3. ISRU Dual Path to Full Implementation and Commercialization*

**State of the Art and Gaps**:  To achieve the envisioned future, an extensive effort was performed to understand the State of the Art (SOA) for ISRU going back decades, and to assess the SOA against the near and long-term goals and objectives of the ISRU Strategic Outcome objectives.  While the released ISRU Envisioned Futures Priorities only includes a top-level definition of both the SOA and Gaps, further information on these for ISRU can be found in the ISRU Gap Assessment Study performed for the International Space Exploration Coordination Group (ISECG) [2].  To provide further guidance to industry and academia, a top level assessment was performed and provide that divides critical areas of ISRU capabilities and technologies into 3 categories: Significant Funding, Partially Covered/More Required, and Limited/No Funded Activities.

**Envisioned Future Priorities- Next Steps for ISRU**:  While a significant amount of work over a broad range of technology areas has been performed over the last several years for lunar ISRU, to reach the envisioned future for ISRU, a lot more work is required at the technology level leading to both systems and technology demonstrations in the near future.  To guide investments within NASA, industry, and academia, 5 specific areas of high priority were identified.  These are:

1. Complete development of the Water and Oxygen Mining Paths and close technology gaps, with emphasis on oxygen extraction from Highland regolith and parallel paths for polar water mining.
2. Expand development of metal extraction and feedstock for manufacturing and construction, with emphasis on aluminum and initial/easy to obtain/make construction feedstocks leading to more refined metals and other regolith resources.  Also, evaluate biologically inspired/derived technologies in bio-mining, bio-plastic, and other feedstock commodities.
3. Ensure the resource assessment needed for future ISRU commercial operations is coordinated with both near/long-term science objectives as well as Artemis mission locations of interest.
4. Initiate NASA and industry-led system-level analyses, integration, and testing activities for ISRU capabilities.  While significant work has been performed at the technology and subsystem level, it is now important to understand how these technology investments can be leveraged and utilized in actual systems and applications
5. Initiate lunar ISRU technology flight demonstrations leading to initial 'Pilot Plant' end-to-end production capability demonstrations, led by industry.

**References:**

[1] NASA's Plan for Sustained Lunar Exploration and Development (2020) https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf.

[2] ISRU Gap Assessment Study for ISECG (2021) https://www.globalspaceexploration.org/wordpress/wp-content/uploads/2021/04/ISECG-ISRU-Technology-Gap-Assessment-Report-Apr-2021.pdf