Update On 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: In 2022, The National Aeronautics and Space Administration (NASA) of the United States of America (US) Space Technology Mission Directorate (STMD) released the In Situ Resource Utilization (ISRU) Envisioned Future Priorities (EFP), along with other discipline EFPs, to the public in April for comment [1]. The ISRU EFP is a 'strategic' level document to provide guidance to NASA, industry, academia, and international space agencies on the long-term vision for ISRU, as well as the goals, objectives, state of the art, gaps, and near-term priorities to achieve the vision. Since the release, a significant number of comments have been received through a Request for Information, and interactions at meetings and conferences. Based on comments received, as well as changes to the NASA budget, the release of the NASA Moon to Mars (M2M) Objectives at the International Aeronautical Congress (IAC) in Paris [2], and evolving plans for the Artemis program, an updated version of the ISRU EFP was created and released in March, 2023.

Comments Received: NASA solicited comments in three main ways: 1. Through an official Request for Information in conjunction with the release of the Live EFPs, 2. Through presentations and panels at several conferences, and 3. Through correspondence and telephone conversations. The bulk of the comments received on the ISRU EFP were supportive, and fell into two broad categories:

<u>Refinement of the Existing EFP and Priorities</u>: Comments received focused on wanting more information on: i) technical data and details (such as gaps, metrics, objectives, 'what' is needed vs 'how', and eventual scale), ii) clearer roles and responsibilities between NASA and industry/commercial involvements (ground and flight activities, including demos, Pilot, and Full scale) and within NASA (responsibilities of ISRU, Autonomous Excavation, Construction, and Outfitting, and In Space Manufacturing), and iii) further definition and refining of the plan and priorities (need for master planning, standards, modularity, and interfaces, and to prioritize oxygen/metal pathway over water mining pathway).

<u>Programmatic Influences on ISRU</u>. While the ISRU EFP provides strategic guidance for ISRU development and incorporation into the Artemis architecture, many recognized that there were overarching programmatic influences that needed to be recognized and worked. For example, not just state what the industry/commercial role is in ISRU, but provide increased emphasis, funding, and commitment to ISRU, provide opportunities for large, especially non-aerospace industry involvement, and other commercially-driven ideas such as data buys and an 'industrial' payload services program. After the initial release of the M2M Objectives in April 2022, there were also comments on the need to increase the emphasis on ISRU in updated/later versions of the M2M architecture. For example, recognize further resource mapping missions beyond the VIPER mission is needed, and provide clearer plans on Artemis base camp infrastructure and lunar industrialization plans. A significant non-technical but overarching comment on US Policy was that that commercial ISRU requires clear international polices and norms associated with resource extraction and product ownership before significant investment can occur. Another overarching comment was on the 'ethics' of lunar mining and processing as well as environmental and cultural impacts need to be addressed.

While all the technical refinement and programmatic influence comments did not get fully incorporated into the updated ISRU EFP, there are new ongoing efforts to address them.

Moon to Mars (M2M) Objectives: The version released at the IAC in Paris included significant changes to previously written objectives as well as new objectives for the Artemis program. Eighteen objectives spread across science, transportation, infrastructure, and operations involve or enhance ISRU implementation in four primary categories:

<u>Resource Assessment</u>: While 5 objectives were identified, two are considered key drivers for future needs and missions. **AS-3**: Characterize accessible lunar and martian resources, gather scientific research data, and <u>analyze potential reserves</u> to satisfy science and technology objectives and enable In-Situ Resource Utilization (ISRU) on successive missions. **OP-3**: Characterize accessible resources, gather scientific research data, and <u>analyze potential reserves</u> to satisfy science and technology objectives and enable use of resources on successive missions.

<u>ISRU and Usage</u>: While 5 objectives were identified, two are considered key drivers for future lunar ISRU missions and implementation: **LI-7**: Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy. **OP-11**: Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.

<u>Responsible ISRU</u>: The following objectives can be considered as a start toward performing lunar ISRU ethically and in an environmentally responsible manner.

OP-13: Establish procedures and systems that will minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration. **RT-6**: Responsible Use: conduct all activities for the exploration and use of outer space for peaceful purposes consistent with international obligations, and principles for responsible behavior in space. **SE-7**: Preserve and protect representative features of special interest, including lunar permanently shadowed regions and the radio quiet far side as well as martian recurring slope lineae, to enable future high-priority science investigations.

<u>Recurring Tenets that Enhance ISRU</u>: Six of the 9 recurring tenet objectives can be associated with ISRU missions and implementation (RT-1, 2, 5, 6, 7, & 9).

Time and Spatial Evolution of ISRU on the Moon: The initial ISRU EFP focused primarily on ISRU and resources at the lunar poles, especially the south pole. The updated ISRU EFP now considers more strongly an evolution in time with expansion of lunar resources and products of interest as US lunar exploration, commercial, and strategic efforts move beyond the lunar poles as depicted in Figure 1. The updated ISRU EFP also further defines interests in manufacturing and construction feedstocks beyond the initial oxygen extraction and water mining emphasis of the first version.

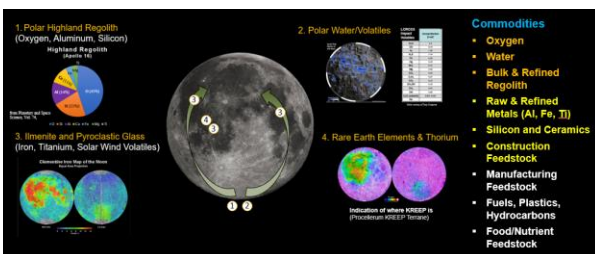

Figure 1. Time and Spatial Evolution of Lunar Resources and Commodities

Plan to Achieve ISRU Outcome: The primary Outcome for NASA's ISRU program is to achieve scalable ISRU production/utilization aimed at producing sustainable commodities on the Moon and Mars. To achieve this, there are three driving objectives.

- Enable Industry to Implement ISRU for Artemis, Sustained Human Presence, and Space Commercialization
- Promote Industry-led ISRU Development thru End-to-End Production of Commodities
- Demonstrate ISRU on Earth and on the Moon/Mars surfaces before mission critical applications are flown

The updated ISRU EFP provides further guidance on how these three driving objectives will be achieved, while attempting to further explain industry and NASA roles. Emphasis is placed on advancing ISRU technologies and systems through solicitations, public-private partnerships, and internal/external investments, as well as supporting and leading efforts that reduce risk and promote investment in establishing ISRU commercial operations.

Existing Gaps in Technologies/Capabilities: The initial ISRU EFP provided a top-level overview of the state of the art and existing gaps to achieve both near and long-term capability objectives. The updated EFP provides functional block diagrams for i) Water Mining, ii) Oxygen (O_2) from Regolith, iii) Metal/Silicon Extraction, iv) Construction Feedstock Production, v) O_2 from the Mars Atmosphere, and vi) O_2/Fuel from Mars Atmosphere and Water Resources. Gaps associated with needed technologies/capabilities are mapped to the appropriate functional blocks in the flow diagrams. Further details on these gaps will be available once NASA provides public access to STARPort. These gaps have been and will continue to be used in solicitations, and progress on closing the gaps through development activities will be tracked.

Envisioned Future Priorities- Next Steps for ISRU: A lot of programmatic and technical activities were performed and accomplished since the initial ISRU EFP was released. Therefore, it is important to continuously reevaluate and update priorities that will be used to guide solicitation and funding decisions.

1. Initiate solicitations to progress ISRU to lunar demonstrations and Pilot Plant missions
2. Initiate NASA and industry-led System-level integration of ISRU and infrastructure capabilities
3. Expand development of metal/aluminum extraction and other feedstocks for Manufacturing and Construction
4. Initiate Mars ISRU technology and system risk reduction development and testing for M2M Objective MI-4
5. Advance lunar polar water/volatile resource mapping activities and water mining technologies
6. Initiate closer ties and coordination with life support systems to advance food, plant, nutrient production with ISRU

References:

[1] NASA Envision Future Priorities. [NASA TechPort - Strategic Framework]

[2] NASA Moon to Mars Objectives. [m2m-objectives-exec-summary.pdf (nasa.gov)]