Key Findings and Path Forward from the Oxygen from Regolith (O2fR) Collaborative Systems Interface Study. P. A. Burke, A. Coburger, M. Nord, J. Berdis, R. Miller, C. A. Hibbitts, The Johns Hopkins University Applied Physics Laboratory, Space Exploration Sector, 11100 Johns Hopkins Rd., Laurel, MD, 20723 (Paul.Burke@jhuapl.edu).

Introduction: The Oxygen from Regolith (O2fR) Collaborative Systems Interface Study explores strategies for managing interactions at system interfaces of lunar in-situ resource utilization (ISRU) technologies. Last year, the Lunar Surface Innovation Consortium (LSIC) In-Situ Resource Utilization (ISRU) Focus Group (FG) introduced the O2fR Collaborative Systems Interface Workbook, which is a framework to aid the ISRU community in identifying and quantifying upstream and downstream system parameters and mapping dependencies across ISRU subsystems.

September 2024 O2fR Workshop: In September 2024, the LSIC ISRU Focus Group held the virtual Collaborative Systems Interface Workshop, with over 130 participants [1]. In the weeks prior to the workshop, the participants (from across industry and academia) were introduced to the workbook and given an opportunity to respond to survey questions and apply the workbook to their specific ISRU technology or subsystem. During the workshop, participants presented their responses to the interface surveys and engaged in discussions about the interface parameters which were relevant to their systems [2]. The workshop provided participants with the opportunity to explore how concepts in the workbook can influence their interface design and encourage smooth system integration and interoperability with other subsystems from other designers. The workshop report and survey highlighted several key findings, presented in the subsequent section.

Key Findings from the O2fR Workshop and Survey Results: After studying the participant feedback and input via the survey results and workbooks, the LSIC ISRU team identified several key takeaways, including:

- Standardized interfaces will be needed to ensure interoperability between technologies and subsystems developed by different organizations
- There exists a need for technology developers to have clear mission requirements and an understanding of end-users to inform their design
- Modularity will be key to scaling up demonstration ISRU systems
- Terrestrial testbeds could present a cost-efficient, assessable way to test ISRU systems before flying
- Digital twins and modeling approaches could also be useful in the design process of ISRU systems

The workshop and resulting reponses demonstrated that there is value in collecting this data, as well as a need for further workbook development and community participation to ensure that the oxygen from regolith ISRU community is able to interface and operate across multiple subsystems.

Development of an Integrated Data Worksheet: As one of the first steps taken since the September 2024 workshop, the LSIC ISRU team has begun to build an Integrated Data Worksheet. The Integrated Worksheet collects all interface data received in the participant-developed O2fR Collaborative Systems Interface Workbooks. The Integrated Data Worksheet is a sortable and searchable spreadsheet, which allows users obtain data and filter on upstream/downstream interfaces, interface parameter quantity and units, institution/organization, material, scale, and more. This worksheet will enable ISRU stakeholders, operators, designers, and customers to collaborate, share data, and interface with each other's work. As the LSIC ISRU team collects additional responses in the form of O2fR Collaborative Systems Interface Workbooks, the Integrated Data Worksheet will only grow larger and more comprehensive in its scope.

Path Forward: Insights from the workshop and feedback from the community have influenced the planned activities in the year ahead. The LSIC ISRU Focus Group aims to continue enabling oxygen from regolith ISRU development by supporting technology developers and stakeholders via interface design and identification of potential upstream and downstream mismatches. Logistically, LSIC ISRU has maintained a database of interface parameters, providing opportunities to facilitate application of the workbook to ISRU systems [2]. As LSIC ISRU continues to focus on systems engineering and integration, we also intend to explore how system interface studies could be used to influence standardization and modularity in ISRU subsystems. The team has also started to further define the ISRU system interface trade space. Additional work will be done to enable more participants (from a diverse range of ISRU subsystems) complete the Workbook and "plug into" the O2fR Collaborative Systems Interface ecosystem.

Participating as a Stakeholder: All ISRU stakeholders which are interested in the concept of the Oxygen from Regolith (O2fR) Collaborative Systems Interface Study are encouraged to participate. The LSIC

ISRU Confluence page maintains a database of all related documents, including: O2fR Collaborative Systems Interface Workbook template, ReadMe, workbooks completed by organizations, a white paper, and the Integrated Data Worksheet [2]. The LSIC team are available to demonstrate the workbook and discuss how specific interfaces and subsystem could fit into the Systems Interface Study. Participation will enable future interactions and networking via discussions with upstream and downstream systems.

Conclusion: The O2fR Collaborative Systems Interface Study has made significant progress in coordinating lunar ISRU subsystem interactions through the development of the O2fR Workbook, which provides a clear framework for understanding, defining, and managing complex connections. A recent workshop yielded valuable community feedback and data, which will inform ongoing ISRU development and community-driven interface designs. Looking ahead, the LSIC ISRU FG will continue to support ISRU development and maintain a database of O2fR System Interface information, facilitating collaboration, data sharing, and collective progress among ISRU stakeholders and interface designers.

References: [1] Anthony Coburger, et al., 2024. "Oxygen From Regolith (O2fR) Collaborative Systems Interface Workshop Report." *Johns Hopkins Applied Physics Laboratory. Ver 1.0.* [2] LSIC ISRU Team. 2024. "Oxygen from Regolith (O2fR) Collaborative Systems Interface Database." LSIC Confluence. https://lsic-wiki.jhuapl.edu/x/PgaXBg