Oxygen from Regolith (O2fR) Collaborative Systems Interface Study: Updates and Path Forward P. A. Burke, A. Coburger, J. Berdis, R. Miller, N. A. Rotunda, M. Kinczyk, C. A. Hibbitts. The Johns Hopkins University Applied Physics Laboratory, Space Exploration Sector, 11100 Johns Hopkins Road, Laurel, MD, 20723 (Paul.Burke@jhuapl.edu, Anthony.Coburger@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. The Lunar Surface Innovation Consortium (LSIC) In-Situ Resource Utilization (ISRU) capability area 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.

Community Engagement: In 2024, the LSIC ISRU Focus Group held the virtual Collaborative Systems Interface Workshop [1]. The workshop 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 ISRU technology or subsystem. Participants presented their responses to the interface surveys and engaged in discussions about the interface parameters which were relevant to their systems [2]. In the workshop, participants explored how the workbook can influence their interface design and encourage interoperability with subsystems from other designers.

The LSIC ISRU team has continued to engage the community with O2fR outreach, presenting a community update and hosting a workshop at the 2025 ASCEND Conference. During the ASCEND workshop, the community demo'ed the workbook and provided inputs to the study [3, 4].

All ISRU stakeholders are invited and encouraged to participate in the Oxygen from Regolith (O2fR) Collaborative Systems Interface Study. 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 ISRU team will be available to demo the workbook and discuss how specific ISRU interfaces fit into the larger system. Participation will also provide opportunities for future engagement via discussions with upstream and downstream subsystem developers.

Key Findings from the O2fR Systems Interface Study:

- Establishing common standards and interfaces is crucial for enabling efficient logistics, ensuring interoperability, reducing costs, and establishing early lunar infrastructure.
- 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 findings demonstrate 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.

Implications for Lunar Infrastructure: A system-of-systems perspective is essential for orchestrating the interdependent elements of an ISRU pilot plant and the unique role each plays in the ISRU operations. Each subsystem-excavation, beneficiation, transportation, storage, elevating, and reactor feeding-has its own functional requirements and constraints, but must operate in close coordination to ensure efficient, continuous processing. Without deliberate integration and interface management, mismatches in throughput, material quality, or operational timing could compromise the overall system's ability to achieve its production goals.The O2fR Systems Interface workbook allows users and integrators of these systems to effectively study upstream and downstream interfaces.

Path Forward: Insights from the workshops 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. The LSIC ISRU CA 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. Additional work will be done to enable more participants (from a diverse range of ISRU subsys-

tems) complete the Workbook and "plug into" the O2fR Collaborative Systems Interface ecosystem

Development of an Integrated Data Worksheet: As one of the first steps taken since the September 2024 workshop, the LSIC ISRU team created an initial 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.

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 tracking complex connections. Community engagement via workshops yielded valuable feedback and data, which will inform ongoing ISRU development and community-driven interface designs. Looking ahead, LSIC 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, interface designers, and infrastructure integrators.

References: [1] Anthony Coburger, et al., 2024. *Oxygen From Regolith (O2fR) Collaborative Systems Interface Workshop Report*. JHU/APL. [2] LSIC ISRU Team. 2024. LSIC Confluence. [3] Coburger A., et al. (2025) ASCEND 2025, AIAA. [4] Burke, Paul et al. ASCEND (2025) Session.