LIVING OFF THE LAND: HOW ISRU CAN BENEFIT EARLY HABITATION LIFE SUPPORT SYSTEMS

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Introduction: The adage 'living off the land' is often used to describe in-situ resource utilization (ISRU), where space resources benefit a customer within a local proximity. One such customer might be early habitation elements being proposed for the National Aeronautics and Space Administration (NASA) Artemis lunar missions. Two concepts are currently under development by the Japanese Space Agency (JAXA) and Italian Space Agency/Agenzia Spaziale Italiana (ASI), with both planning to use open-loop life support system (LSS) architectures necessitating the resupply of water and oxygen [1, 2]. Development of an Excel model suggests pilot-scale ISRU systems may provide similar relief from Earth-based consumable resupply as regenerative LSS, enabling fulfillment of a 'living off the land' paradigm.

Near-Term Habitation Concepts: The JAXA pressurized rover (PR) and ASI multi-purpose habitat (MPH) are the first two habitation elements being proposed to permanently reside on the lunar surface (see Figures 1 & 2) [3, 4].

Figure 1. JAXA PR concept.

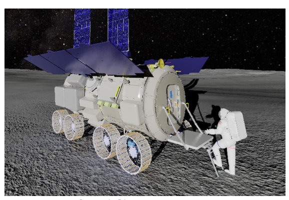

Figure 2. ASI MPH concept.

Each concept is being designed to support a crew of two for one mission per year lasting from 7 to 28-days [1, 5-7]. Both concepts are targeting deployment in the early 2030's with a 10-year system life [1, 5, 7]. The two concepts have different architectures for supporting the expected extravehicular activity (EVA) cadence of three EVAs per 7-day period, with the PR depressurizing its full cabin volume and MPH utilizing an airlock [1, 5, 8]. These mission characteristics and physical architectures collectively influence the habitation LSS demands for water and oxygen.

Modeling Demand and Consumable Impact: An Excel model was created to calculate habitation LSS demand for water and oxygen by combining crew metabolic needs and typical mission demands with user-entered mission characteristics, EVA architecture, and habitat design assumptions. The model also supports the comparison of open-loop, regenerative, and ISRU-supplied LSS architectures to conduct trade space or breakeven investigations for a particular habitat concept and mission context [9]. In applying this model, a cursory assessment of water and oxygen demand for PR and MPH can be made (see Figure 3).

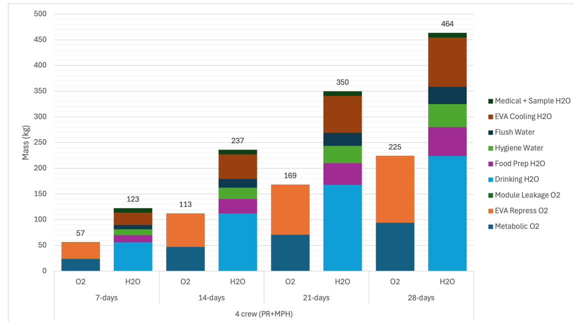

Figure 3. Water and oxygen demand for the PR and MPH.

This model suggests water for crew drinking and EVA cooling systems accounts for 62-68% of all water mass demand and >58% of needed oxygen mass is based upon the habitation element's EVA architecture vice metabolic demand. Over the projected lifetimes of the PR and MPH, nearly 4,640 kg of water and 2,250 kg of oxygen may be needed to support crewed missions.

Logistical Impact of Earth-based Resupply. Raw consumable demand does not reflect the additional mass of tankage and packaging materials to support transportation. By leveraging assumed similarities with water and oxygen delivery to the International Space Station (ISS), the model enables calculation of total transported mass. For an open-loop LSS architecture, the transported mass of water increases ~18% and oxygen increases ~160%, bringing the collective delivered mass supporting both elements to nearly 12,000 kg.

Impacts of Regenerative Life Support Alternatives. The inefficiencies of Earth-based resupply of water and oxygen suggests regenerative LSS may hold advantages. Such systems have been used aboard the ISS with water and urine processor assemblies (WPA/UPA) and an oxygen generation assembly (OGA) providing most of the water recovery and oxygen production respectively. The Excel model allows analysis of several combinations of regenerative LSS (i.e., OGA only vs. use of a WPA + UPA) and its effects on water and oxygen demand. Initial analysis suggests regenerative LSS architectures can reduce the total transported mass demands for the PR and MPH by 26-48%, with the most significant reductions coming from the use of both a WPA and UPA while relying on oxygen resupply from Earth. While such savings seem promising, these systems carry a combined initial mass of ~2,000 kg and require significantly more power (~4.3 kW_e) and pressurized volume (~4.7 m^3) than open-loop LSS [10-12]. Additionally, the systems require more crewed maintenance and occasional resupply of complex spare parts and non-LSS consumables (i.e., filter media, sorbent material, etc.).

ISRU Alternatives for Resupply: Several ISRU concepts have been proposed for demonstration in Artemis, including water ice processing plants, carbothermal plants, and molten regolith electrolysis (MRE) systems. While ISRU goals are focused on large-scale propellent production, several initial ISRU concepts target pilot production rates of 1,000 kg of oxygen per year, correlating to ~1,125 kg of water extraction/production for the water ice concept. ISRU pilot systems which forgo oxygen liquefaction and operate at reduced duty cycles could meet or exceed LSS demands while providing a path for lower risk demonstration of early-stage ISRU. Rough mass and power estimates of conceptual pilot ISRU systems, omitting liquefaction, were compiled from previous studies in Table 1.

Table 1. ISRU pilot concept estimates for 1,000 kg O_2/yr production without liquefaction systems.

Concept	Mass (kg)	Power (kW_e)
Water Ice [13]	919	4.88
Carbothermal [14]	906	2.34
MRE [15]	518	18.42

These conceptual ISRU pilot systems average nearly 60% less mass than all combined regenerative LSS solutions, while being capable of producing more than four times the highest per-year oxygen demand for early habitats. Currently, the Excel model does not assume caching of excess water or oxygen product, nor does it scale ISRU systems, but it does allow for comparative mass and cost analyses of ISRU concepts against open-loop and regenerative LSS architectures.

Assessing the Benefit of ISRU: The benefit of ISRU in meeting early habitation demand is best captured through equivalent system mass (ESM) and cost analyses. ESM is an approach, developed to compare LSS technologies, that considers the fractional mass impacts of supporting pressurized volume, power, and thermal systems in addition to crew time and mission duration [16]. Complimentary to ESM, the Advanced Missions Cost Model (AMCM) provides a means of considering design, development, test and evaluation into full lifecycle system cost [17]. The Excel model includes ESM and AMCM approaches to enable comparison of ISRU-supplied, regenerative, and open-loop LSS architectures. Figure 6 depicts a cursory benefit analysis for 4-crew early habitation missions occurring in 7-day increments and representing up to a maximum of ten 28-day missions over a 10-year system life (i.e., up to 280 mission-days).

Conclusion & Forward Work: This analysis identifies open-loop consumable resupply becomes the costliest option at an estimated ~$1.5B USD lifecycle

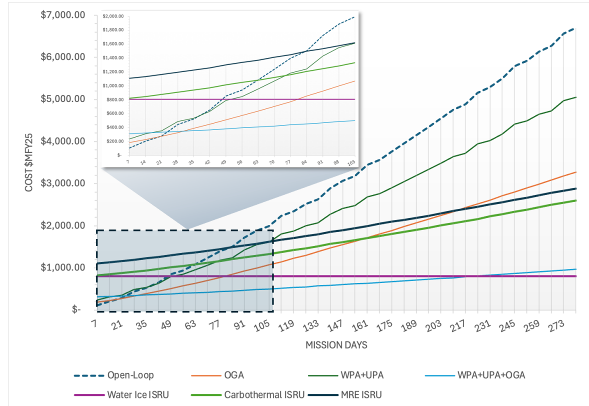

Figure 6. AMCM lifecycle cost comparison of open-loop, regenerative, and ISRU-supplied consumables.

cost with just three 28-day missions (i.e., 84 mission-days). All regenerative LSS options show a benefit over an open-loop architecture within 42 mission-days. While ISRU options are expected to be higher initial cost, they show comparable fiscal advantages to open-loop resupply between 49 and 84 mission-days and advantages over certain regenerative LSS between 49 and 217 mission-days. The variability of these advantages is dependent upon the ISRU architecture chosen and the sensitivity of the AMCM to qualitative determinations on anticipated development complexity. Other cost models and sensitivity analyses should be applied with updated ISRU pilot system concepts in future modeling efforts. Additionally, the mass and cost impacts of spares and maintenance items should be considered across the trade space. Despite the identified model improvements, the relationships observed suggest ISRU pilot systems could offer similar benefits as regenerative LSS to early habitation concepts within as little as three Artemis missions.

References: [1] C. Yamazaki *et al.*, *53rd ICES*, Jul. 2024. [2] W. F. Schneider *et al.*, *ICES 2020*, Jul. 2020. [3] JAXA, Nov. 2024. [4] Thales Alenia Space, Mar. 2024. [5] D. W. Harris *et al.*, Jan. 2022. [6] D. E. Lee, Aug. 2019. [7] N. Genco, Oct. 2024. [8] C. Stromgren *et al., IEEE Aero*, Mar. 2023. [9] J. E. Johnson, *54th ICES (preprint)*, Jul. 2025. [10] C. Lynch *et al., ASCEND 2023*, Oct. 2023. [11] R. M. Bagdigian & D. Cloud, *SAE*, Jul. 2005. [12] R. M. Bagdigian *et al.*, *45th ICES*, Jul. 2015. [13] D. L. Linne, J. E. Kleinhenz, & A. Paz, *AIAA ASCEND*, Nov. 2020. [14] G. Sanders, J. Kleinhenz, & D. Linne, *COSPAR*, Jul. 2022. [15] S. S. Schreiner, 2015. [16] J. A. Levri, *et al.*, Sep. 2003. [17] L. Guerra & R. Shishko, 1999.