Space Resource Utilization Considerations for a Lunar Habitation Customer

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The Habitation Customer

Habitation life support systems may be a customer of in-situ produced oxygen (O_2) and water (H_2O). Despite lower demand than proposed propellant business cases, habitation customers may hold significant value in lunar O_2 and H_2O delivery with projected combined values of $20M USD or more per mission. **As current habitation concepts balance environmental control and life support system (ECLSS) complexity with logistical dependencies, a limited opportunity may be available for a small-scale space resource utilization (SRU) customer.** Understanding the demands for extraction, processing, and storage and delivery for habitation ECLSS are necessary to tap into this potential early-stage market.

ECLSS Balancing Act

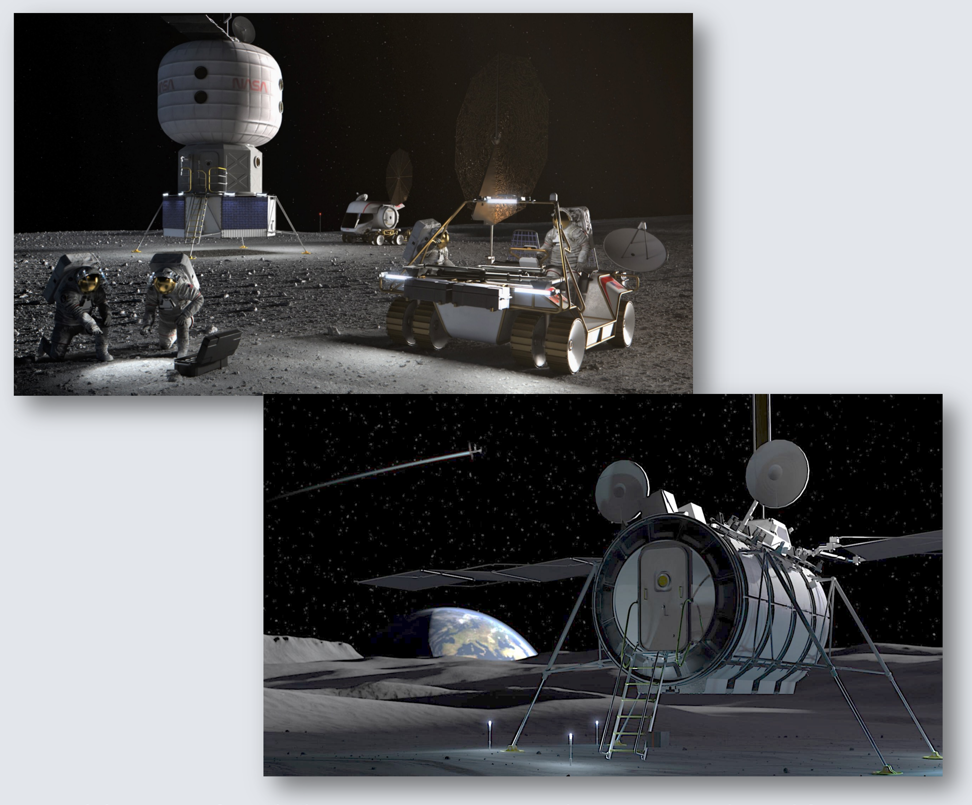
Regenerative Life Support

- Higher initial mass
- Less consumable resupply
- More spare parts & maintenance

Crew size + mission duration

Open-loop Life Support

- Lower initial mass
- More consumable resupply
- Less spare parts & maintenance



Initial lunar surface habitation concepts evaluating open-loop life support architectures (top: NASA's lunar surface habitat[1], bottom: Agenzia Spaziale Italiana (ASI) Multi-Purpose Habitat for Artemis[2]).

Extraction: *What are the consumable demands?*

The quantity of raw material that needs to be extracted for processing is a factor of customer demand. **Demand from habitation ECLSS may provide an opportunity to quantify and minimize extraction losses at small scales.** Pilot-scale demonstration systems may meet initial habitation ECLSS demands while enabling an understanding of the most profitable SRU architectures for propellant production.

Minimum Habitation ECLSS Demands[3]

Consumable	Metabolic demand per crewmember per day (CM-d)	Total Mission Metabolic Demands		
		2 Crew, 30-days	4 crew, 30-days	4 crew, 60-days
Oxygen (kg)	0.895	53.7	107.4	214.8
Water (kg)	3.217	193.0	386.0	772.0

Other Consumable Demands = Gases for vehicle leakage and contingencies + Water for radiation protection, laundry, showering, etc. + Gasses & water for payload and spacesuit demands + Reactants for fuel cell-based power systems

Processing: *What level is required?*

Processing needs of extracted materials is dependent upon customer delivery specifications. Decreased processing is likely to increase profitability while allowing for incremental advances in process efficiency. **Gaseous oxygen for habitation ECLSS comes with less stringent processing specifications than for propellant.**

Comparison of Oxygen Procurement Specifications[4]

Constituent	Breathing O_2	Propellant O_2
Purity by vol. (min.)	99.500%	99.989%
Moisture	10 ppm	3 ppm
Total hydrocarbons as CH_4	50 ppm	23 ppm
Alkynes	--	0.05 ppm
Nitrous oxide	4 ppm	1 ppm
Halogenated hydrocarbons	2 ppm	1 ppm
Chlorinated hydrocarbons	0.2 ppm	0.1 ppm
CO_2	10 ppm	1 ppm (combined)
CO	10 ppm	

Other Specifications to Consider

- ISO 15859 *Space Systems – Fluid Characteristics, Sampling, and Test Methods*
- *Spacecraft Maximum Allowable Concentrations (SMAC)*
- *Environmental Protection Agency National Primary Drinking Water Regulations*
- *NASA Spacecraft Water Exposure Guidelines (SWEG)*

Storage & Delivery: *How can consumables be delivered?*

Storage and delivery of in-situ produced consumables for habitation ECLSS is expected to be simpler than for propellant due to smaller quantities and no need for cryogenic storage. **Modified versions of International Space Station storage solutions for gas and water may be leveraged for simplified delivery to a local habitation customer.**

Gas Transfer[5]

Nitrogen Oxygen Recharge System (NORS) tanks hold ~29 kg O_2

Water Transfer[6]

Russian EдB water containers hold ~22 kg H_2O

Existing gas and water transfer methods aboard ISS. (left: a NORS tank prepares for flight[7], right: Crews train on Russian EдB water container[8]).

Notional Delivery Distances[9]

- Excavation to Processing: ~5.2 km
- Processing to Habitation: ~6.2 km
- Excavation to Habitation Customer: ~11.4 km

Conclusion & Forward Work

The smaller SRU demand of habitation ECLSS provides unique opportunities to investigate SRU system scalability and efficiency with simpler approaches than for propulsion consumable use-cases. Further work is needed in identifying SRU product delivery specifications for ECLSS, although some standards currently exist outside of a SRU context and can be leveraged.

References

[1]Kessler, P., Prater, T., Nickens, T., & Harris, D. (2022). Artemis Deep Space Habitation—Enabling a Sustained Human Presence on the Moon and Beyond. *2022 IEEE Aerospace Conference (AERO)*, 01–12. https://doi.org/10.1109/AERO53065.2022.9843393

[2]Agenzia Spaziale Italiana (ASI). (2024). Multi-Purpose Habitat. Obtained from: https://www.thalesaleniaspace.com/en/news/meet-federica-vagnone

[3]Ewert, M. K., Chen, T. T., & Powell, C. D. (2022). *Life Support Baseline Values and Assumptions Document* (Technical Paper NASA/TP-2015–218570/REV2; p. 235). National Aeronautics and Space Administration. https://ntrs.nasa.gov/citations/20210024855

[4]Schlüter, L., Cowley, A., Pennec, Y., & Roux, M. (2021). Gas purification for oxygen extraction from lunar regolith. *Acta Astronautica*, *179*, 371–381. https://doi.org/10.1016/j.actaastro.2020.11.014

[5]Gentry, G. J. (2016, July 10). International Space Station (ISS) Environmental Control and Life Support (ECLS) System Overview of Events: 2015-2016. *46th International Conference on Environmental Systems*. ICES, Vienna, Austria. https://ttu-ir.tdl.org/server/api/core/bitstreams/7f9c616d-49dd-4872-91de-16b3eacd4539/content

[6]Andreychuk, P., Romanov, S., Zeleznyakov, A., Bobe, L., Kochetkov, A., Arakcheev, D., & Sinyak, Y. (2020, July 31). The Water Management on the Russian Segment of the International Space Station and Prospective Space Stations. *ICES 2020*. International Conference on Environmental Systems, Virtual Event. https://hdl.handle.net/2346/86448

[7]NASA. (2020, July 21). *NORS Tanks Prepared for Commercial Resupply Flight to International Space Station*. https://www.nasa.gov/image-article/nors-tanks-prepared-commercial-resupply-flight-international-space-station/

[8]ESA. (2008, October 1). *Learning about the Russian fluid container "ЕДВ" during ATV training at EAC*. https://www.esa.int/ESA_Multimedia/Images/2008/01/Learning_about_the_Russian_fluid_container_EDV_during_ATV_training_at_EAC

[9]Kleinhenz, J. E., & Paz, A. (2020, November 16). Case Studies for Lunar ISRU Systems Utilizing Polar Water. *ASCEND 2020*. ASCEND 2020, Virtual Event. https://doi.org/10.2514/6.2020-4042