NASA STTR 2020 Phase I Solicitation

T2.05 Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage

Lead Center: GRC

Participating Center(s): JSC

Technology Area: TA2 In-Space Propulsion Technologies

Scope Description

This subtopic seeks technologies related to cryogenic propellant (e.g. hydrogen, oxygen, methane) production, storage, transfer, and usage to support NASA's in-situ resource utilization (ISRU) goals. This includes a wide range of applications, scales, and environments consistent with future NASA missions to the Moon and Mars. Anticipated outcome of Phase I proposals are expected to deliver proof of the proposed concept with some sort of basic testing or physical demonstration. Proposals shall include plans for a prototype and demonstration in a defined relevant environment (with relevant fluids) at the conclusion of Phase II. Solicited topics are as follows:

- Subgrid Computational Fluid Dynamics (CFD) model that would model spray transport heat transfer and wall interactions during spray heat transfer during cryogenic propellant tank chilldown and fill in microgravity. Three submodels should be developed, including a (1) droplet transport and heat and mass transfer model, (2) fluid-to-wall boiling model covering all pertinent regimes (flash evaporation, film boiling, transition boiling, nucleate boiling, condensation), and (3) model that is used to capture bulk phases (e.g., volume of fluid). There should be seamless coupling between all three submodels. Emphasis should be on cryogenic fluids such as liquid hydrogen, oxygen, methane, and nitrogen. Phase I should have an emphasis on 1-g while Phase II should include microgravity applications. Models must be anchored to experimental cryogenic data.
- Develop and demonstrate methodologies for recovering propellant from lunar and Martian descent stages that have low fill levels (< 5%) of liquid oxygen, hydrogen, and/or methane mixed with helium. Methodologies can assume liquid extraction (for a short amount of time) or vapor extraction. Possible uses of the fluids could include fuel cells, life support/breathing air, or other applications. Methodologies should focus on the amount of propellant that might be extractable at different purities (prop/helium). Phase I should focus on defining and refining the methodologies for scavenging, as well as defining what should be done to the landers to enable or facilitate later access for scavenging. Phase II should include some sort of a demonstration, perhaps using simulant or similar fluids.
- Develop and defend a proposed relaxed propellant grade specification for liquid oxygen, liquid methane, and/or liquid hydrogen, allowing higher amounts of water contaminants in the oxygen and hydrogen, and higher amounts of water, hydrogen, and carbon monoxide/dioxide in the methane. Starting with assessment of potential impurities coming out of the ISRU production plant, analysis should evaluate the effects on the liquefaction system, pump and pressure-fed propellant feed system, and engine performance, especially potential stability effects. Phase I should conclude with a proposed relaxed propellant specification for at least one propellant (oxygen or methane priority over hydrogen), with identification of the propulsion component (liquefaction, feed system, injectors, etc.) that has the most sensitivity to the impurities and will

therefore drive the limits on the specification. Phase II should include a hardware demonstration of the critical element at a minimum to validate the accuracy of the analytical predictions.

- Advance non-liquid electrolyte technologies for chemical flow cells (e.g., fuel cells, electrolyzers, flow batteries, etc.) that generate electrical power from a chemical reaction or reconstitute a reaction byproduct into fuels and oxidizer for such a chemical flow cell. These electrolytes are required to be cycled through very low temperatures (< 150 K) during storage to survive a lunar night or cis-lunar travel and recover completely (>98%) mechanical, electrical, and chemical performance. Ideally, these electrolytes would be able to process propellants (hydrogen, oxygen, methane, kerosene, etc.) and either tolerate or recover from exposure to standard propellant contaminants with minimal/no performance loss. Due to the potential for high fluid pressures and vibration loads, any proposal will illustrate how the electrolyte could be mechanically supported to operate hermetically under these conditions. To demonstrate that the electrolyte exceeds the State of Art, the deliverable test article will support an electrical current density of at least 300 mA/cm2 for at least 500 hours, support transient currents > 750 mA/cm2 for at least 30 seconds, and support slew rates > 50 A/cm2/s. Providing test data for the electrolyte performance degradation rate when operated as intended is required with test times >5,000 hours significantly strengthening the proposal. It would be beneficial if the electrolyte operated reversibly with equal efficiently. Liquid electrolytes, loose or contained within a support structure, are excluded from this Scope due to the complications that liquid electrolytes pose for an eventual system during launch.

NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight demonstration of relevant technologies in the lunar environment. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS program and providers can be found at this link: https://www.nasa.gov/content/commercial-lunar-payload-services. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin as early as 2020 and flight opportunities are expected to continue well into the future. In future years it is expected that larger and more complex payloads will be accommodated. Selection for award under this solicitation will not guarantee selection for a lunar flight opportunity.

References

1. Kartuzova, O., and Kassemi, M., "Modeling K-Site LH2 Tank Chilldown and no Vent Fill in Normal Gravity" AIAA-2017-4662

2. Chato, D. "LOX Tank Helium Removal for Propellant Scavenging Test" presentation at 2008 AIAA Aerospace Sciences Meeting, Orlando, FL, 2008.

3. Regenerative Fuel Cell Power Systems for Lunar and Martian Surface Exploration (https://arc.aiaa.org/doi/abs/10.2514/6.2017-5368)

4. NASA Technology roadmap (https://gameon.nasa.gov/about/space-technology-roadmap/), §TA03.2.2.1.2. Chemical Power Generation and §TA03.2.2.2.3. Regenerative Fuel Cell Energy Storage (NOTE: This may be a dated link as this Roadmap still references ETDP/ETDD)

5. Commercial Lunar Propellant Architecture: A Collaborative Study of Lunar Propellant Production (https://doi.org/10.1016/j.reach.2019.100026)

6. Linne, et.al. “Feasibility of Scavenging Propellants from Lander Descent Stage to Supply Fuel Cells and Life Support,” AIAA-2009-6511, September, 2009.

Expected TRL or TRL range at completion of the project: 2 to 4

Desired Deliverables of Phase II

Prototype, Hardware, Software

Desired Deliverables Description

Phase I proposals should at minimum deliver proof of the concept, including some sort of testing or physical demonstration, not just a paper study. Phase II proposals should provide component validation in a laboratory environment preferably with hardware (or model subroutines) deliverable to NASA.

Electrolyte technologies for chemical cell product deliverables would be an operational electrochemical test article demonstrating the capability of the electrolyte to support the listed current density by processing the intended propellants when packaged as a flow cell. This test article will have an active area of at least 50 cm2 and would ideally contain multiple cells to demonstrate extensibility to existing stack designs. It would be favorable to include empirical electrochemical performance data of the electrolyte over as much of the pressure range from 5 psia to 3015 psia as possible to illustrate the potential viability range for Lunar applications.

State of the Art and Critical Gaps

Cryogenic Fluid Management is a cross-cutting technology suite that supports multiple forms of propulsion systems (nuclear and chemical), including storage, transfer, and gauging, as well as liquefaction of ISRU produced propellants. Space Technology Mission Directorate (STMD) has identified that Cryogenic Fluid Management (CFM) technologies are vital to NASA's exploration plans for multiple architectures, whether it is hydrogen/oxygen or methane/oxygen systems including chemical propulsion and nuclear thermal propulsion. For spray transport and film condensation, there are significant gaps in modeling. For scavenging, only small scale tests have been conducted to remove residual helium from a liquid oxygen tank.

There is currently no standard on propellant grade specification for an ISRU plant.

Existing electrolytes for space applications are limited to a polymeric membrane based on perfluorinated teflon and ceramic electrolyte. While it has the necessary electrochemical and mechanical properties, the polymeric membrane has very tight thermal constraints due to a high moisture content which complicates thermal system designs for lunar systems during transit. It is also very sensitive to chemical contamination. The ceramic electrolyte has significant mechanical and slew rate limitations, but is more resilient to chemical contamination and has a much larger thermal range which allows storage in very cold environments. Once operational and at temperature, either existing electrolyte technology operates in cold lunar regions. Should an off-nominal event occur during the lunar night that results in a cold-soak, neither existing electrolyte technology has a meaningful chance of recovering from the exposure to the low temperatures.

Relevance / Science Traceability

STMD strives to provide the technologies that are needed to enable exploration of the solar system, both manned and unmanned systems; cryogenic fluid management is a key technology to enable exploration. Whether liquid oxygen/liquid hydrogen or liquid oxygen/liquid methane is chosen by Human Exploration and Operations Mission Directorate (HEOMD) as the main in-space propulsion element to transport humans, CFM will be required to store propellant for up to 5 years in various orbital environments. Transfer will also be required, whether to engines or other tanks (e.g., depot/aggregation), to enable the use of cryogenic propellants that have been stored. In conjunction with ISRU, cryogens will have to be produced, liquefied, and stored, the latter two of which are CFM functions for the surface of the Moon or Mars. ISRU and CFM liquefaction drastically reduces the amount of mass that has to be landed on the Moon or Mars.

NASA already has proton exchange-membrane (PEM) based electrochemical hardware in the International Space Station (ISS) Oxygen Generator Assembly and is developing electrochemical systems for space applications through the Evolved Regenerative Fuel Cell. These system designs could be readily adapted to a solid electrolyte with capabilities beyond the existing State of Art for specific applications such as In Situ Resource Utilization, lunar fuel cell power systems, or regenerative fuel cell energy storage systems. As Commercial Lunar Payload Services (CLPS) companies have identified primary fuel cell power systems as a required technology, it would be helpful to ensure that there are options available that could survive the lunar night when off-line without active thermal control. This would enable a longer period between missions to re-fuel and recover the electrochemical system.