# NASA STTR 2021 Phase I Solicitation

## T14.01 Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage

**Lead Center: GRC**

**Participating Center(s): JSC**

Scope Title:

**Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage**

### Scope Description:

This subtopic seeks technologies related to cryogenic propellant (e.g., hydrogen, oxygen, and 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:

- A piecewise-smooth set of correlations for use in lumped node codes that models the complete cryogenic pool boiling curve for heat transfer between fluid and wall encountered in cryogenic storage (e.g., hot spots along the tank wall) or transfer systems. Six submodels should be developed, including (1) onset of nucleate boiling, (2) nucleate boiling heat transfer coefficient (HTC), (3) critical heat flux (CHF), (4) transition boiling HTC, (5) Leidenfrost point, and (6) film boiling HTC. There should be seamless coupling between all five submodels such that the boiling curve is a smooth function (heat flux as a function of wall superheat). Both quenching and heating configurations must be modeled. The model must be anchored to experimental cryogenic pool boiling data for helium, hydrogen, argon, nitrogen, oxygen, and methane. The complete cryogenic pool boiling model should be validated against cryogenic experimental data across the range of fluids, with a target accuracy of 25%. The quenching and heating pool boiling models and implementation scheme should be a deliverable. Phase I should have an emphasis on developing the CHF model for all cryogens while Phase II should include the remaining five models as well as microgravity applications.
- 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.
- Advance nonliquid 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 cislunar 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 the art, the deliverable test article will support an electrical current density of at least 300 mA/cm$^2$ for at least 500 hr, support transient currents >750 mA/cm$^2$ for at least 30 sec, and support slew rates >50 A/cm$^2$/s. Providing test data for the electrolyte performance degradation rate when operated as intended is required with test times >5,000 hr 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 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.

**Expected TRL or TRL Range at completion of the Project:** 2 to 4
**Primary Technology Taxonomy:**
Level 1: TX 14 Thermal Management Systems
Level 2: TX 14.1 Cryogenic Systems
**Desired Deliverables of Phase I and Phase II:**

- Hardware
- Software
- Prototype

**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 cm$^2$ 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 to 3,015 psia as possible to illustrate the potential viability range for lunar applications.

**State of the Art and Critical Gaps:**

Cryogenic Fluid Management (CFM) 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 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. There are no complete cryogenic data-based pool boiling curves for propellants of interest.

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; CFM 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 the art for specific applications such as ISRU, lunar fuel cell power systems, or regenerative fuel cell energy storage systems. As 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 offline without active thermal control. This would enable a longer period between missions to refuel and recover the electrochemical system.

**References:**

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

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

3. 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.)

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