X2.04  Cryogenic Propellant Depots

The focus of this subtopic is to develop and advance enabling technologies required to build and operate an in-space cryogenic propellant depot with the capability to preposition, store, manufacture, and later use the propellants for Earth–Neighborhood campaigns and beyond. In-Space cryogenic or gel propellant production and/or storage technology is quite unique in that it has been studied in detail but little research has been accomplished in space, where the effects of low gravity come into play. The in-space propellant depot will provide affordable propellants and similar consumables to support the development of sustainable and affordable exploration strategies as well as commercial space activities. An in-space propellant depot not only requires technology development in key areas such as cryogenic or gel storage, electrolysis, and fluid transfer, but in other areas such as lightweight structures, highly reliable connectors, and autonomous operations. These technologies can be applicable to a broad range of propellant depot concepts or specific to a certain design. In addition, these technologies are required for spacecraft and orbit transfer vehicle propulsion and power systems, and space station life support. Generally, applications of this technology require long-term storage (>30 days), on-orbit fluid transfer and supply, cryogenic propellant production from water, and unique instrumentation. Components or concept proposals for intelligent modular systems are being solicited to improve the performance, operating efficiency, safety and reliability of cryogenic fluid production, storage, transfer, and handling in a low gravity (10^{-6} g to 10^{-2} g) environment. Specific areas of interest include the following:

- Electrolysis system that manufactures cryogenic propellants from water or ice in a low gravity environment. This system should incorporate innovative techniques and components to provide an automated, safe, and highly reliable process.
- Water storage and transfer interface such as a bladder positive-expulsion system or other innovative techniques.
- Innovative techniques for cryogen storage and transfer.
- Reliable and safe cryogenic storage for extended periods of time. This includes zero boil-off systems, advanced insulations, and thermal control techniques such as vapor cooled shielding, systems using the boil-off for drag make-up and innovative tank designs.
- Automated assembly, operations, and maintenance. This includes cryogenic connects, disconnects and
couplings; robotic assembly and repair; docking of large components; and health monitoring and smart systems.

- Lightweight structures including inflatables, deployables, and advanced composites.
- Suitability of propellant gelation to enhance propellant depot operations.
- Micrometeoroid and space debris protection schemes and associated technologies including advanced lightweight materials, self-healing, integration with other structures and tankage, and possible avoidance techniques.
- Associated propellant tank-set technologies including fluid slosh and orientation in low gravity environments, tank support structure dynamic interaction in orbit, support struts thermal performance, integrated insulation, instrumentation and plumbing penetrations, and coating degradation.
- Schemes for warm tank chill-down including spray nozzle configurations, liquid flow rate and duration, number of gas venting steps, and performance in a low gravity environment.
- Stratification and hot spot management including mixing needs, mixing strategies and performance determination in low gravity environments.
- Low gravity performance and operating life determination of key components such as the liquid pumps, condensers, pressurization, liquid acquisition device, refrigerator, and mass gauging instrumentation.
- Low heat leak valves and lines that are highly reliable with long life.
- Connects and disconnects with small or no fluid and heat leakage. The connects and disconnects should also have small pressure drops, small force and alignment requirements, and long life with high reliability.
- Procedure for the capability for a no-vent fill with consideration given to microgravity condensation and fluid mixing.
- Devices for vapor free acquisition of cryogenic liquids or liquid free venting in a microgravity environment.
- Cryocooler systems with cooling capacity greater than 10 W in the 10–40K range.
- Small and medium scale tank pressure control and/or tank boil-off control technologies for long-term storage of liquid hydrogen in space.
- Instrumentation for monitoring cryogens in low gravity including mass gauging, liquid-vapor sensing, and free surface imaging.

Several options are available to test the technology needed for propellant depots. Technologies can be tested in the laboratory, on Expendable Launch Vehicles, the Space Shuttle, the ISS, a Small Scale Depot, or a Full Scale Depot. Laboratory testing can use sub- or full-scale tank sets for tests carried out on components, subsystems, and integrated systems on the ground. Identified improvements can be incorporated into subsequent tank sets, which may be used on the ground or in orbital tests. In some cases, a "proto-flight" approach may be used, where the original ground-test tank set can potentially be modified for subsequent testing on-orbit. For example, test requirements may be addressed by building a subscale experiment, which simulates the hydrogen fluid systems of the storage facility, evaluating their performance in a vacuum chamber, and then demonstrating microgravity fluid transfer by performing an orbital experiment.