This subtopic includes technologies for long term cryogenic propellant storage and distribution applications in-space as well as on the lunar surface. These technologies will impact cryogenic systems for space transportation orbit transfer vehicles, space power systems, spaceports, spacesuits, lunar habitation systems, robotics, and in situ propellant systems. Each of these applications has unique performance requirements that need to be met. The sizes of these systems range from the small (less than 20m$^3$ for supercritical air and payload cooling) to very large (greater than 3400m$^3$ for LOX and LH$_2$ propellant storage). Advanced cryogenic technologies are being solicited for all these applications. Proposed technologies should offer enhanced safety, reliability, or economic efficiency over current state-of-the-art, or should feature enabling technologies to allow NASA to meet future space exploration goals.

Technology focus areas are divided as follows: passive and active thermal control, pressure control, and propellant feed line conditioning. Innovative concepts are requested for cryogenic insulation systems, fluid system components, and instrumentation. Cryogenic propellants such as hydrogen, methane, and oxygen are required for many current and future space missions. Operating efficiency and reliability of these cryogenic systems must be improved considering the launch environment, operations in a space environment, and system life, cost, and safety. This subtopic solicits unique and innovative concepts in the following technologies:

1) Thermal Control

Passive Thermal Control:

Successful passive thermal control is enabling for all aspects of Cryogenic Fuel Management. The propellant boil-off losses attributable to the passive thermal control subsystem are influenced by Multi-Layer Insulation (MLI) design, MLI to tank attachment techniques and materials, tank to vehicle support structure and attachments, tank
size and configuration, tank and insulation penetrations, insulation venting provisions for launch and ascent, flight and surface environments, vehicle orientation in those environments, and thermal control surface coatings and materials.

Applications/Technology Maturity: The Earth Departure Stage (EDS) and the Lunar Surface Access Module (LSAM) descent stage require LH\textsubscript{2} and LO\textsubscript{2} storage durations of 5 to 95 days in Low Earth Orbit (LEO).

The LSAM ascent stage requires LO\textsubscript{2} and LCH\textsubscript{4} storage durations of up to 95 days in LEO and up to an additional six months on the lunar surface.

Development Needs: Passive thermal control development needs include; integration of MLI with micro-meteoroid protection, tank support structure, and other insulation penetrations. Other development needs include; characterization of the potential advantages of subcooled propellants, investigation of options such as shading, advanced materials, mechanisms and other techniques for passive thermal control on the lunar surface.

**Active Thermal Control:**

Active thermal control combines the passive thermal control technology element with active refrigeration (cryocoolers) to allow storage periods from a few months to years with reduced boil-off losses.

Applications/Technology Maturity: Flight-type 20K (LH\textsubscript{2}) cryocoolers of sufficient cooling capacity (20 watts) to eliminate LH\textsubscript{2} boil-off do not exist, and thus the development of 20K cryocoolers is a long-lead technology item. State-of-the-art cryocoolers in the 80K range (LO\textsubscript{2}/LCH\textsubscript{4} temperatures) have been developed for cooling sensors and have flown on numerous satellites. However, the integration of these cryocoolers into an active thermal control system for propellant storage of LO\textsubscript{2} and LCH\textsubscript{4} and LH\textsubscript{2} is a technology issue.

Development Needs: Flight cryocooler to propellant tank integration techniques for large space-based storage systems, distributed cooling shields integrated with MLI and development and testing of active cooling techniques for tank penetrations and supports is required. Development of flight-type 20K, 20 watt capacity cryocoolers designed for integration into large space-based LH\textsubscript{2} storage systems is also required for application to Mars missions.
2) Pressure Control

Controlling cryogenic propellant tank pressure in low gravity with minimum boil-off losses without settling the propellants can be accomplished with a thermodynamic vent system (TVS). A TVS subsystem typically consists of a pump for circulation and mixing, a Joule Thompson expansion device/heat exchanger for heat removal, valves and a vent line.

Applications/Technology Maturity: A TVS will be required for the EDS, LSAM and the LO$_2$/LCH$_4$ version of the Orbital Maneuvering Systems (OMS) and Reaction Control Systems (RCS) for the CEV.

Development Needs: EDS, LSAM and CEV development needs include innovative TVS configurations and applications, system integration and control and modeling of low-gravity fluid dynamics and heat transfer for specific TVS designs. EDS, LSAM and CEV vehicle advanced development needs include integrated system testing with LH$_2$, LO$_2$ and LCH$_4$ to determine the effect of internal tank hardware configuration on fluid mixing.

3) Propellant Feed Line Conditioning:

Maintaining vapor-free liquid propellant between the tank outlet and the OMS/RCS engine inlet is a significant technology challenge. For lunar in situ cryogenic applications, systems are needed to store and transfer to warm tanks in the dusty lunar surface environment.

Applications/Technology Maturity: Propellant feed line conditioning will be required for all vehicles with a cryogenic OMS/RCS. Specific feed line configuration, routing and heat loads for each vehicle must be addressed.

Development Needs: CEV, EDS and LSAM vehicle development needs includes integrated system testing with LH$_2$, LO$_2$ and LCH$_4$ to address vehicle specific feed line routing and heat loads, and couplings for lunar in situ propellant systems.