# NASA SBIR 2008 Phase I Solicitation

## X7 Cryogenic Systems

The Exploration Systems architecture presents cryogenic storage, distribution, and fluid handling challenges that require new technologies to be developed. Reliable knowledge of low-gravity cryogenic fluid management behavior is lacking and yet is critical for Altair and Ares in the areas of storage, distribution, and low-gravity propellant management. Additionally, Earth-based and lunar surface missions will require success in storing and transferring liquid and gas commodities. Some of the technology challenges are for long-term cryogenic propellant storage and distribution; cryogenic fluid ground processing and fluid conditioning; liquid hydrogen and liquid oxygen liquefaction processes on the lunar surface. Furthermore, specific technologies are required in valves, regulators, instrumentation, modeling, mass gauging, cryocoolers, and passive and active thermal control techniques. The technical focus for component technologies are for accuracy, reduced mass, minimal heat leak, minimal leakage, and minimal power consumption. The anticipated technologies proposed are expected to increase reliability, increase cryogenic system performance, and are capable of being made flight qualified and/or certified for the flight systems and dates to meet Exploration Systems mission requirements.Â

# Subtopics

### X7.01 Cryogenic Storage for Space Exploration Applications

**Lead Center: ARC**

**Participating Center(s): GRC, GSFC, KSC, MSFC**

This subtopic includes technologies for long-term cryogenic propellant storage applications in-space, on the lunar surface, and on the Earth. These technologies will impact cryogenic systems for space transportation orbit transfer vehicles, space power systems, spaceports, spacesuits, lunar habitation systems, robotics, in situ propellant systems, and launch site ground operations. Each of these applications has unique performance requirements that need to be met. Innovative concepts are requested for cryogenic insulation systems, fluid system components, and cryogenic conditioning systems.

Long term storage (14 days) of $LO_2$/ $LH_2$ cryogenic propellants in low-gravity with minimal propellant loss is required to support space transportation orbit transfer vehicles. The Earth Departure Stage (EDS) and the Altair (Lunar Lander) descent stage require $LH_2$ and $LO_2$ storage durations of 14 days in Low Earth Orbit (LEO). Long-term storage (224 days) of $LO_2$/ $LCH_4$ cryogenic propellants in low-gravity and reduced gravity with minimal propellant loss is required to support space transportation orbit transfer vehicles. The Altair (Lunar Lander) ascent stage requires $LO_2$ and $LCH_4$ storage durations of up to 14 days in LEO and up to an additional 210 days on the lunar surface. Long term storage (224 days) of $LO_2$ cryogenic propellant on the lunar surface and liquefaction of resource with minimal propellant loss is required to support space power systems, spaceports, spacesuits, lunar habitation systems, robotics, in situ propellant systems. Long term storage (6 months) of $LO_2$/ $LH_2$/ $LCH_4$ cryogenic propellants in 1-g on the surface of the Earth with minimal propellant loss is required to support launch site ground operations. Passive and active thermal control, and pressure control/ thermodynamic venting technologies are sought after.

**In-space Storage and Lunar Surface Storage**

Passive thermal control serves to limit the heat leak into the cryogenic storage system ($LH_2$ loss 2 loss 4 loss

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 ($LH_2$ loss 2 loss 2) cryocoolers of sufficient cooling capacity (20 watts) to eliminate $LH_2$ 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 ($LO_2$/$LCH_4$ 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 $LO_2$ and $LH_2$ is a technology issue. Active thermal control development needs include: flight-type 20K, 20 watt capacity cryocoolers designed for integration into space-based $LH_2$ storage systems, integrated refrigeration and storage systems, innovative heat exchanger concepts, flight cryocooler to propellant tank integration techniques for large space-based storage systems, distributed cooling shields integrated with MLI, circulator development, development and testing of active cooling techniques for tank penetrations and supports is required.

Pressure control utilizes thermodynamic venting in low-gravity or direct venting in partial gravity to enable selective venting of vapor if necessary (ratio of kilograms of TVS mass per watt of heat removal from $LH_2$2 4 2, $LO_2$ and $LCH_4$ to determine the effect of internal tank hardware configuration on fluid mixing.

**Earth-based Storage**

Passive and active thermal control serves to limit the heat leak into the cryogenic storage system and eliminate cryogen boil-off, but not limited by mass or reliability typically associated with flight systems ($LH_2$ loss 2 loss 4 loss

### X7.02 Cryogenic Fluid Transfer and Handling

**Lead Center: KSC**

**Participating Center(s): GRC, GSFC, JSC**

Cryogenic fluid transfer and handling for spacecraft propulsion systems, launch facility ground processing, and Lunar surface systems are critical to the advancement of NASAâ€™s exploration goals. Technology development in cryogenic fluid transfer and handling directly supports the Lunar Lander, Ground Operations, Ares, and Lunar Surface Systems programs. Specifically, for Earth-based applications, propellant conditioning and cryogenic densification technologies are required. Propellant conditioning systems are needed to help control the state of the propellant that is loaded into the flight tank at the launch pad. Other technologies are primarily for active control of cryogenic propellants for densification or subcooling on the launch pad as well as liquefaction on the lunar surface.

Component technologies for cryogenic fluid transfer include regulators, valves, umbilicals, quick disconnects, pumps, distribution line insulation materials and techniques, and thermal standoffs for $LH_2$, $LO_2$, $LCH_4$ and cold

GHe (~90K). Cryogenic components using advanced actuation technologies such as piezoelectric ceramics which demonstrates reduced heat flux into the cryogenic fluids as compared to conventional electromechanical actuators is highly desirable. Operating ranges for these components should include but are not limited to normal boiling point (NBP) $LH_2$ and NBP $LO_2$ components rated for 50 - 100 psia, NBP $LO_2$ and below NBP $LCH_4$ components rated for 100 - 400 psia, and cold GHe (~90K) components rated for 400 to 4,500 psia. The technical focus for these components are for reduced thermal mass, minimal heat leak, minimal leakage, and minimal power consumption. Analytical tools for the design and/or analysis of cryogenic fluid transfer components are also needed. These tools should focus on providing analytical capabilities, which directly correspond to cryogenic fluid component design or thermal analysis.

Advanced transfer systems capable of delivering high quality of liquid over a wide flow range between 100 GPM and 1000 GPM are sought. Liquid oxygen pumps that minimize fluid heating while allowing for a range of flowrates are also needed. Propellant subcooling or densification systems for LOX, $LH_2$ and $LCH_4$ are required, to provide for extended storage duration on orbit prior to boil off. These systems should be sized to accommodate the Altair propulsion system. Densification systems should offer reliability and efficiency benefits over past systems. Anti-stratification concepts to ensure homogeneous fluid conditions in the flight tank are needed, and better transfer line insulation to minimize heat leak are required. Connections and recirculation systems to maintain propellant state in the flight tank are also desired.

On the lunar surface, oxygen may be produced via an in situ resource utilization reactor. Efficient liquefaction of this oxygen will depend on integration of the liquefier with the gas production stream. Open cycle liquefaction systems must interface with the high-pressure electrolysis systems at the output of the reactor. Compact, low temperature radiators capable of rejecting 50-100W of heat at 140K to deep space are needed for passive cooling prior to the final liquefaction steps. High efficiency, low mass recuperative heat exchangers are needed for effective heat transfer between gas streams. Innovative heat rejection systems designed for the lunar thermal environment are needed. Heat pumps to increase the high temperature heat rejection point of the cycle can also be proposed.

Next, hydrogen cooling and/or liquefaction are required for lunar surface applications involving regenerative fuel cell systems. Efficient 20K cryocooler technology is needed. Reliquefaction systems should be capable of meeting hydrogen flowrates around 1 gram/second. Open cycle hydrogen cooling systems with low temperature isentropic expansion from 3000 psi to the desired storage pressure are needed. Heat switch technology to control energy flow during the lunar day/night cycle will also be considered.

### X7.03 Cryogenic Instrumentation for Ground and Flight Systems

**Lead Center: GRC**

**Participating Center(s): JSC, KSC, MSFC**

This subtopic includes technologies for reliable, accurate cryogenic propellant instrumentation needs in-space, on the lunar surface, and on the Earth. These technologies will impact cryogenic systems for space transportation orbit transfer vehicles, space power systems, spaceports, lunar habitation systems, in situ propellant systems, and launch site ground operations. Innovative concepts are requested to enable accurate measurement of cryogenic liquid mass in low-gravity storage tanks with and without propellant settling, to enable the ability to detect in-space and on-pad leaks from the storage system, and address other cryogenic instrumentation needs. 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. 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.

Mass Gauging technologies will principally impact cryogenic systems for space transportation orbit transfer vehicles. Mass gauging provides accurate measurement of cryogenic liquid mass ($LH_2$, $LO_2$, and $LCH_4$) in low gravity storage tanks, and is critical to allowance of smaller propellant tank residuals in assuring mission success. Both low-gravity mass-gauging (measurement uncertainty

Leak detection technologies impact cryogenic systems for space transportation orbit transfer vehicles, lunar surface, and launch site ground operations. These systems will be operational both in atmospheric conditions and in vacuum with multiple sensor systems distributed across the vehicle or a region of interest to isolate leak location. Methane and hydrogen leak detection sensors with milli-second response times and 1 ppm detection sensitivity in air are desired for ground and launch operations.

Other cryogenic instrumentation needs include minimally invasive cryogenic liquid flow measurement sensors for rocket engine feed lines, and sensors to detect and quantify two-phase flow (bubbles) within the feed lines.