This subtopic includes technologies for waste heat management, movement, and rejection; technologies including lightweight and/or high-temperature radiators, heat pipes, heat sinks, etc. Also includes cryo-coolers and related low-temperature systems. These technologies will impact space solar power systems, spacesuits and habitation systems, robotics, and surface systems.

Spaceport operations, both on Earth as well as extraterrestrial, are heavily dependent upon a wide range of cryogenic systems, including liquid oxygen, liquid nitrogen, liquid helium, and supercritical breathing air. Each above application has unique performance requirements that need to be met. Sizes of these systems range from the small (3400 m³ for LOX and LH₂ ground 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 systems, storage and distribution components, refrigeration systems, advanced instrumentation, and advanced operational concepts.

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. Innovative concepts are requested for cryogenic insulation systems, fluid system components, and instrumentation. Although this subtopic solicits unique and innovative concepts in the cryogenic components and instrumentation areas, there is an emphasis at this time for:

- Advanced thermal switches to isolate heat transfer from a de-powered cryocooler;
- Advanced low-gravity submersible pumps designed specifically for moving cryogen heat that enters the tank wall to the heat exchanger coupled to the cryocooler;
- Advanced tank support systems capable of supporting tanks during the launch environment, but decoupling on-orbit to minimize thermal loads;
- Advanced cryocoolers which are reliable, lightweight, and capable of removing significant heat at liquid hydrogen temperatures;
- Low heat leak cryogenic quick disconnects capable of sealing against the vacuum of space;
- Long-life, low power valves capable of sealing at cryogenic temperatures and being cycled many times.
without consuming pressurant gas;

- Liquid acquisition devices capable of preventing gas ingestion into engine feed lines in low gravity;
- Methods for cryogenic fluid acquisition and transfer in zero gravity;
- Methods of determining liquid remaining in propellant tanks in low gravity;
- High accuracy differential pressure transducers, which can be read submerged in liquid cryogen;
- On-orbit leak detectors;
- Lightweight, low-power temperature sensors which can be placed internally to the storage tank with a minimum number of feed-throughs;
- New technology valves for cryogenic applications, including LOX, LH\textsuperscript{2} and LHe, that minimize thermal losses and pressure drops. Components include shutoff and flow-control valves. Valves should be adaptable to electromechanical actuation and range in size from \( \frac{1}{2} \) to 6 inches;
- Integrated heat exchangers in large-scale storage systems designed to provide for zero boiloff and densification of liquid hydrogen and liquid oxygen;
- Advanced low-temperature materials for cryogenic containment;
- Insulation materials capable of retaining structural integrity while accommodating large operating temperatures ranging from cryogenic to elevated temperature conditions.

Thermal management systems are needed for the rejection of heat to hot environments for daytime operations on the lunar surface, large space radiators to dissipate heat from power and propulsion systems, thermal control for mobile systems, cryogenic propellant storage and handling for in-space refueling, and long-term cryogen storage for propellant depots.

Thermal management concepts include advanced heat sinks, heat pipes, and interface materials with high thermal conductivity that are electrically isolative. Innovative methods of increasing the specific thermal capacitance of the power systems are also sought:

- Qualified heat pumps to reject heat to hot environments;
- Multi-zone thermal control systems for spacesuits and mobile systems;
- Lightweight deployable low temperature radiators for use on the lunar surface;
- Concepts for the thermal management of advanced power system component designs for operation in deep space, lunar, and Martian environments.