National Aeronautics and
Space Administration

Game Changing Development Program Office

Preventing Stored Propellant From Boiling Off in Space

NASA**facts**

To expand human presence into the solar system and onto the surface of Mars, NASA must store high-specific-impulse liquid hydrogen and oxygen (LH_2 and LO_2) in orbiting storage depots, on launch vehicle upper stages, and on Mars for months at a time. However, cryogenic propellants are liquids only at extremely low temperatures. Because heat radiated from the Sun and the Earth causes LH_2 and LO_2 to pressurize and because flight tanks weigh less if operated at lower pressures, the propellant tanks are vented and propellant is boiled off. This results in less propellant for propulsion. To make up for these losses during the long space missions envisioned, NASA would need to use oversized propellant tanks, but the cost to launch such tanks could very well be prohibitive. The application of Zero Boil-Off (ZBO) technology using 20 K (–423.7 °F) cryocoolers for LH_2 propellant will prevent vaporization and keep reasonably sized storage tanks cold enough to store adequate propellant quantities for long periods of time.

The objectives of the 20-Watt, 20-Kelvin (20-W, 20-K) Cryocooler for Thermal Control of Space-Based Liquid Hydrogen Project are to design, fabricate, acceptance test, and deliver a prototype 20-W, 20-K cryocooler that can be used in a NASA ZBO LH_2 test. Achieving 20 W of cooling is central to NASA's efforts to achieve ZBO, and as shown in the table, it will be a dramatic advancement over the state of the art.

The 20-W, 20-K cryocooler will use a reverse turbo-Brayton cycle, which expands (and cools) gaseous helium in a tubing network. The cooled helium will be distributed via broad-area tubing to the propellant tank heating sources.

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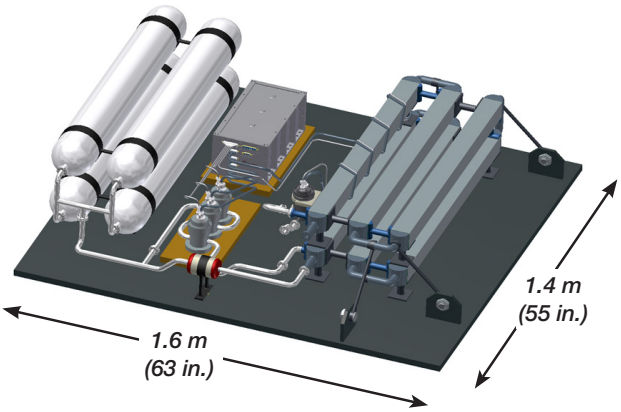
Performance	20-W, 20-K	Comparison to SOA
Lift (cooling capacity of cryocooler), W	20	20 times >
Specific power (input electrical power needed per watt of lift), W/W	60	1/6th
Specific mass (mass of cryocooler per watt of lift), kg/W	4.4	1/4th

Comparison of 20-W, 20-K cryocooler with state-of-the-art (SOA).

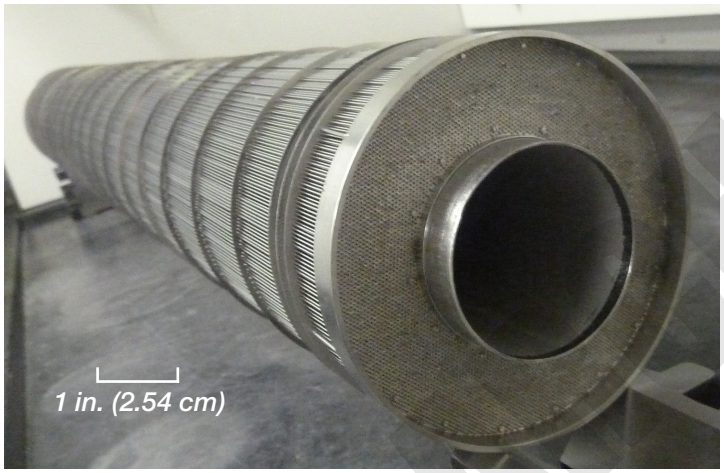


Three-dimensional model of the 20-W, 20-K cryocooler, showing its main components. The model does not show the broad-area tubing that distributes the cooled helium.

In preparation for this 20-W, 20-K cryocooler development, the greatest technology challenge was addressed: advancing recuperator heat exchanger technology. A microtube and shell configuration was designed, fabricated, and thermal performance tested. This is a design that has over 6300 tubes that are 0.56 mm in diameter in each of five recuperator modules in the cryocooler assembly. Testing showed that the design has met goals for performance, cost, and size, and that the microtube and shell design is ready for the development of the prototype 20-W, 20-K cryocooler.

Recent testing in NASA Glenn Research Center's Small Multi-Purpose Research Facility (SMiRF) demonstrated the integration of a cryocooler with a cryogenic tank. Testing proved that there was only a small loss in cooling capacity when a reverse turbo-Brayton-cycle crycooler was integrated with a cryogenic tank. The results were encouraging—the cryocooler system kept the propellant pressures and temperatures nearly constant throughout the tank and fluid. The tests successfully demonstrated reduced boil-off with LH_2 as well as ZBO and robust tank pressure control of LO_2 by a 15-W, 77-K reverse turbo-Brayton-cycle cryocooler system of the same technology that will be used in the current development.

After the 20-W 20-K development, expected to be 2 years, NASA plans to integrate the 20-W, 20-K prototype cryocooler with a propellant tank and use it in a ZBO LH_2 test that will validate the cryocooler system's performance in a spacelike environment.



Microtube bundle in a recuperator module.

The tests are expected to result in a verified prototype cryocooler that can be used as the technological foundation for the larger cryocoolers needed to keep a large LH_2 propellant tank at 20 K with ZBO. Results will be used to calibrate cryogenic propellant storage performance models and to estimate the performance of future, higher capacity versions of the cryocooler.

NASA Glenn's LO_2 ZBO test article being lowered into SMiRF for testing in October 2013. SMiRF simulates the vacuum and temperature extremes of space.

Michael P. Doherty/NASA Glenn Research Center
michael.p.doherty@nasa.gov

David W. Plachta/NASA Glenn Research Center
david.w.plachta@nasa.gov

National Aeronautics and Space Administration

John H. Glenn Research Center
Cleveland, OH 44135
www.nasa.gov/glenn

www.nasa.gov

In December 2014, NASA awarded Creare the contract to design, manufacture, and test a 20-W, 20-K cryocooler. **The 20-Watt, 20-Kelvin Cryocooler for Thermal Control of Space-Based Liquid Hydrogen Project** is funded by the Game Changing Development Program, which seeks to identify and rapidly mature innovative/high-impact capabilities and technologies for infusion in a broad array of future NASA missions.

For more information on each of Game Changing's Projects, the Web site link is here:
http://gameon.nasa.gov