CRYOGENIC
FLUID MANAGEMENT

National Aeronautics and
Space Administration

WHAT'S CRYOGENIC FLUID MANAGEMENT?

Cryogenic Fluid Management (CFM) is a term used to describe a suite of technologies that store, transfer, and measure ultra-cold fluids—such as liquid hydrogen, liquid oxygen, and liquid methane. These cryogens are the most common propellants in use in space exploration, making cryogenic fluid technologies integral to NASA's future exploration and science efforts.

NASA's vision for space exploration and science requires high-performance chemical, electric, and nuclear propulsion solutions. The agency will use cryogens for Earth-to-orbit transportation, human missions to the Moon and Mars, planetary exploration, and in-situ resource utilization (ISRU) production—all of which will require propellant depots on the surface and in space to refuel those cryogenic propellant systems.

While critical for today's space flight vehicles, traditional chemical propellants are not ideal for missions to deep space. The performance required for NASA's boldest missions to the Moon and Mars will require the use of cryogens as a propulsive solution. Beyond exploration missions, NASA will continue to use cryogenics to enable infrared and X-ray astronomy, biological sciences, and fundamental investigations into the origins of our universe.

What makes cryogenic fluid storage challenging is a continual loss of cryogens over time due to their propensity to boil off at warmer temperatures. Through a multilayer insulation, the amount of loss can be controlled for short periods of time, thus minimizing the loss of propellant. This passive control measure alone will not prevent the loss of cryogens.

With cryocoolers to actively control heat—similar to how a refrigerator functions—from going into the propellants, little to no propellant is lost. The result is what's commonly referred to as a "zero-boiloff system," which eliminates the need for oversized tanks and extra propellant; both add weight and require the launch vehicle to burn more propellant.
Each kilogram of propellant mass saved means more payload mass can be carried to deep space, which is critical to the success of NASA's *Artemis* deep space missions.

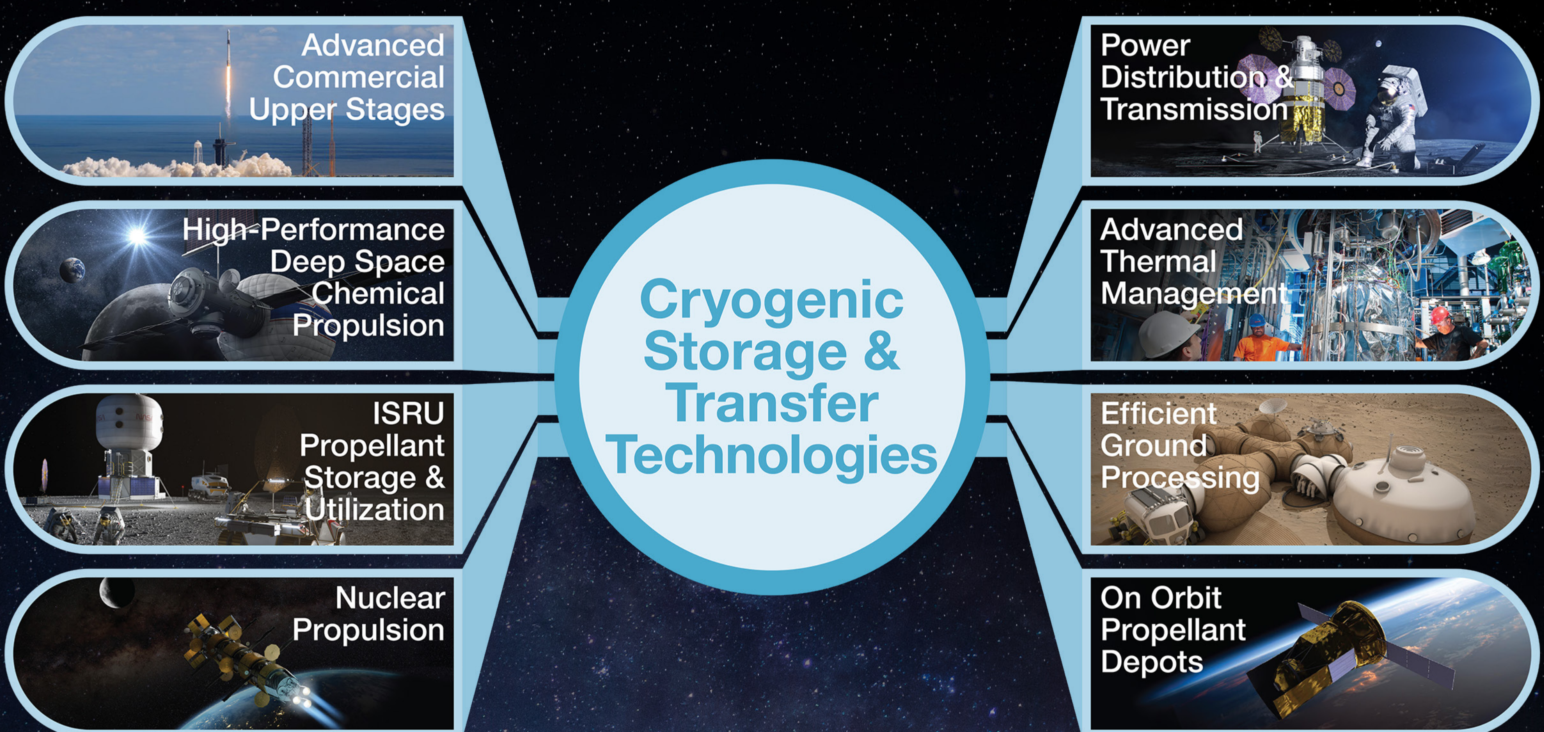
WHY IT'S IMPORTANT?

NASA explores the unknown in air and space, solving mysteries of Earth, the solar system, and beyond. For the agency to achieve its Moon to Mars goals, it needs cryogenic technology to keep hydrogen and other fluids cold for long periods of time while in deep space. This is critical to preventing boil off and ensuring the cryogens remain in usable condition.

Venting or active cooling must be utilized to prevent over-pressurization in propellant tanks. Venting propellant in zero-gravity environments is likely to cause unacceptable losses of propellant. Certain long-term space cryogenic storage technologies have been developed mainly for thermal management of scientific instruments for telescopes and other applications. These developments have not been applied to cryogenic propellant storage at the scale needed for the Mars architecture. Other CFM technologies that would ensure safe, reliable cryogenic storage and supply to the propulsion systems include low-leakage valves, liquid acquisition and transfer, and mass gauging.

The agency will use the knowledge and experience it has gained from the Moon and during operations in low-Earth orbit to prepare for humanity's next giant leap — sending astronauts to Mars. It all starts with U.S. companies delivering scientific instruments and technology demonstrations to the lunar surface. NASA will then land the first woman and first person of color on the Moon under Artemis, establishing sustainable exploration and science efforts there by the end of the decade, including a small lunar space station called the Gateway.

These long-duration missions require cryogenic fuel that will power exploration for the benefit of all. Developing architecture on the Moon and Mars to enable explorers to go — and stay — requires safe storage of propellants.



CFM OBJECTIVES

- Mature CFM technologies vital to NASA's future missions in science and exploration, which utilize both chemical and nuclear in-space propulsion, landers, and in-situ resource utilization
- Increase CFM technology readiness and integrate into a large, system-level flight demonstration
- Enable industry demonstrations of their respective CFM technologies developed under NASA's Tipping Point *contracts*, which are milestone-based, firm fixed-price contracts

STRATEGY

NASA and American industry have developed and tested numerous technologies to enable long-term CFM, which are essential for establishing a sustainable presence on the Moon and for enabling future crewed missions to Mars. Implementation of the Tipping Point technologies will require in-space flight demonstrations to advance CFM and help the agency and its partners better understand low-gravity fluid behavior. Further technology development will forge a path to a larger CFM demonstration mission in the early 2030s with some version of high-capacity active cooling and fluid transfer.

WHAT'S AHEAD

CFM technology development and demonstration is a significant emphasis area for NASA's Space Technology Mission Directorate (STMD). STMD is focused on developing key areas required for long-term cryogenic propellant in-space storage and transfer. NASA is performing extensive technology maturation and risk reduction for key CFM technologies, laying the groundwork for a system-level spaceflight demonstration that integrates major CFM technologies prior to mission infusion for cryogenic propulsion stages.

The Cryogenic Fluid Management portfolio is led by NASA's Marshall Space Flight Center in Huntsville, Alabama, and Glenn Research Center in Cleveland, Ohio. This work is managed by NASA's Technology Demonstration Missions (TDM) Program, part of NASA's *Space Technology Mission Directorate*, which oversees a portfolio of technology demonstration projects across NASA centers and American industry partners.

Learn more about CFM.

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