



CRYOGENIC FLUID MANAGEMENT PORTFOLIO PROJECT (CFMPP)

**[C40r1B] NASA's Cryogenic Fluids for Aerospace Propulsion Applications
*Overview and 2024-2025 Highlights***



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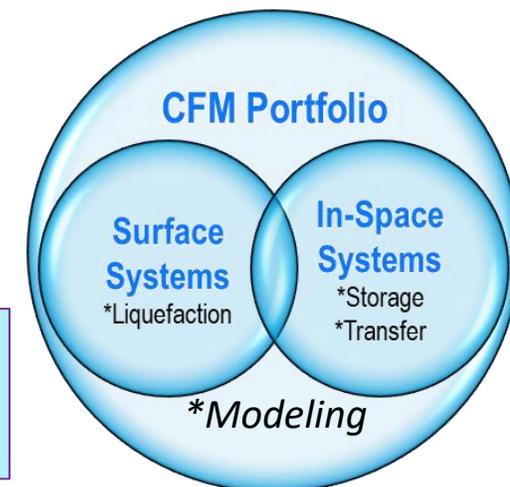
CFM Portfolio Project (CFMPP)



- **CFMPP is a NASA Space Technology Mission Directorate (STMD) Portfolio Project initiated in 2021**
 - ~20 individual CFM technology development activities
 - Includes flight and ground activities related to Lunar/Mars exploration
 - Strong combination of In-house and contracted developments; large and small businesses
- **CFMPP closes technology gaps, with focus on integrated CFM systems development and demonstration, to advance the national goals of landing and exploring the Moon and Mars**
 - Technology enters project ~ TRL 4, completes with end state of TRL 6 / 7
- **Partnered leadership and execution by MSFC and GRC**
 - Other NASA participating Centers include KSC, LaRC, ARC, AFRC, and JSC

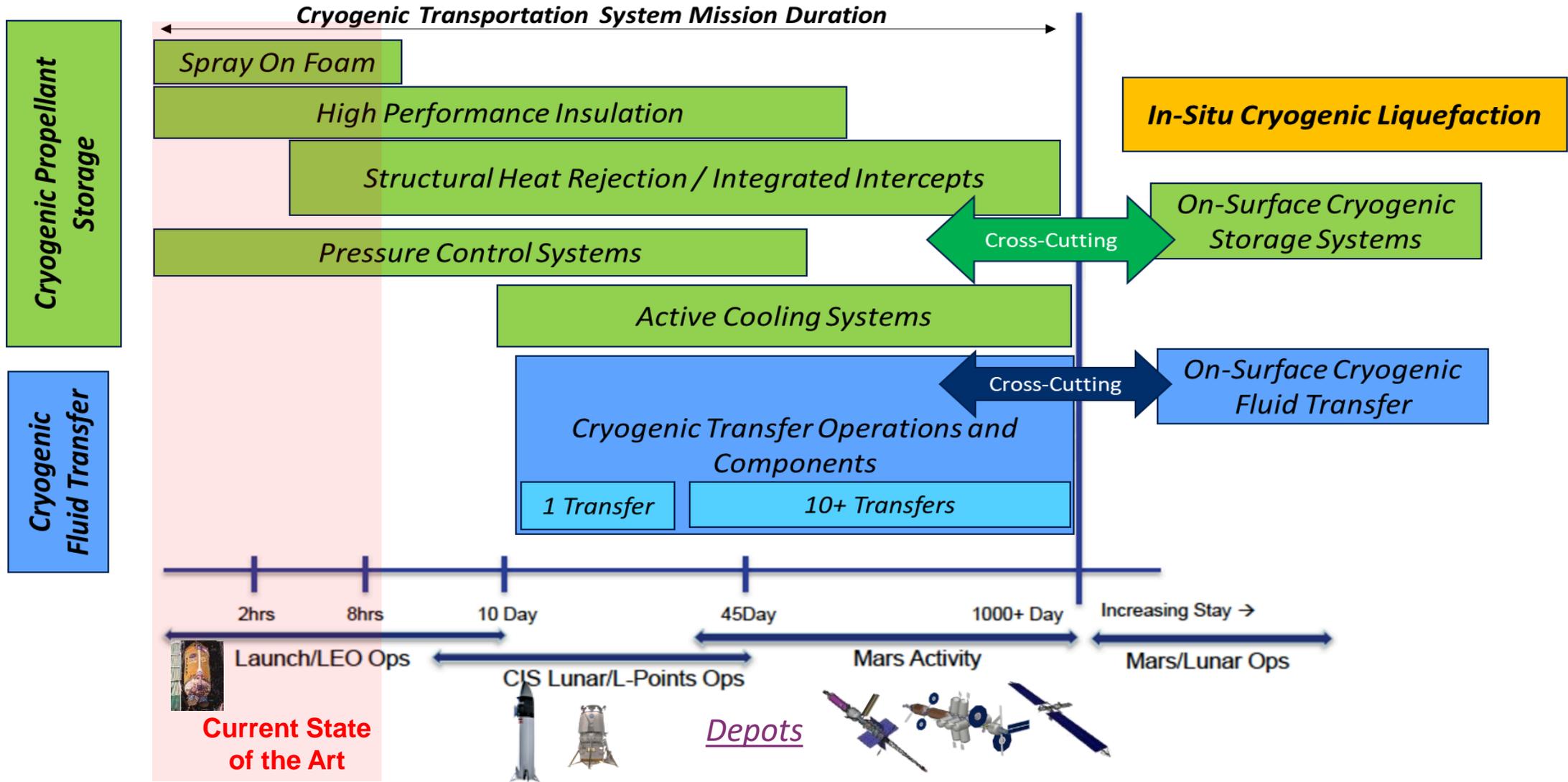
Portfolio Project Charter

Mature CFM technologies essential to NASA's future missions in science and exploration which utilize both chemical and nuclear in-space propulsion, landers, and in-situ resource utilization





CFM – State of the Art vs Where We Need to Go





Cryogenic Fluid Management Portfolio Project (CFMPP)



System Demonstration Complexity

Technologies Portfolio

Scope: Design, development, testing, and evaluation of critical-need cryogenic components enabling long-duration CFM storage and propellant transfer

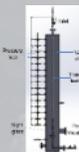
Major Activities:

Hydrogen low-leakage valves and cryo-couplers



Radio Frequency Mass Gauge (RFMG)

Next-generation FOSS (fiber optics sensing system)



Reduced Gravity Cryogenic Transfer (RGCT)

Subsystems Portfolio

Scope: Design, development, and testing of complex systems of technologies to address technical challenges for specific CFM mission needs

Major Activities:

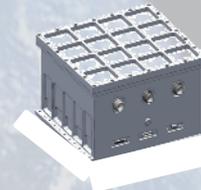


20W/20K Cryocooler

150W/90K Cryocooler

Cryocooler Electronics

Alternate Cryocooler Studies



Images by Creare LLC

Demonstrations Portfolio

Scope: Design, build, and test integrated flight and ground systems comprised of multiple CFM subsystems, enabling TRL 5+ maturation for many technologies

Major Activities:



Tipping Point Demo Contracts

Ground System Demonstrations



Two-Stage Cooling Demonstration

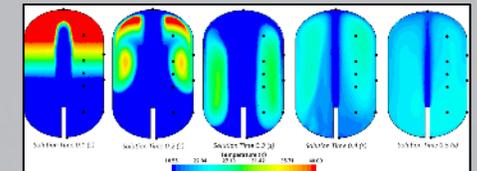
CryoFILL Liquefaction Demonstration



Modeling Portfolio

Scope: Develop, enhance, validate, and demonstrate Computational Fluid Dynamics (CFD) and Nodal tools to address capability gaps for predicting cryogenic fluid behavior in 1-G and microgravity environments for use as design tools for future NASA missions

Testing and demo activities across the CFMP project used within modeling tools to predict CFM behavior at a flight vehicle scale in a relevant microgravity environment



System Validation



FY2024 CFMPP Highlights



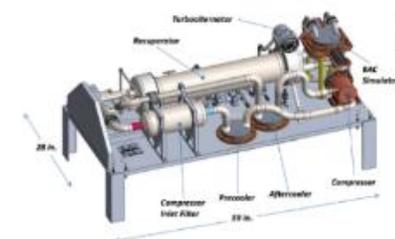
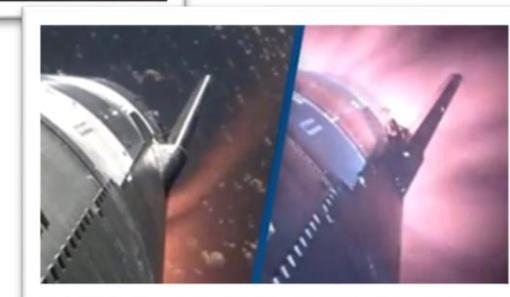
- **SpaceX Flight Demonstration Completed in March 2024**
 - Conducted large-scale propellant transfer, moving several metric tons of propellant from one tank to another within Starship, while in space; completed with NASA Tipping Point contract
- **RFMG technology flight demonstrated on IM-1 mission**
 - Conducted large-scale propellant transfer, moving several metric tons of propellant from one tank to another, while in space; joint Intuitive Machines / NASA demonstration
- **NASA Low Leakage Valve Technology Contract awarded to Sierra Space**
 - Executed technology development contract for advancing cryogenic low leakage valve technology; contract awarded in parallel for continued MSFC in-house valve development efforts
- **NASA flight cryocooler development system reaches TRL 5**
 - 90K cryocooler system reached development milestones through successful performance and environmental testing;
 - System delivered to GRC for additional testing in integrated system



SpaceX Starship #3 Flight Test



Credit: Intuitive Machines



150W/90K Cryocooler Design



Low-leakage relief valve during LH2 testing

- **Complete Tipping Point contracts and Ground Demos**

- Conduct remaining 2020 Tipping Point flight demonstrations
- Conduct Two-Stage Cooling hydrogen storage testing
- Conduct oxygen liquefaction demonstration with 90K cryocooler



Eta Space Cryogenic Spacecraft and Rocket Lab Electron Launch Vehicle

- **Continue cryocooler development activities**

- Test 90K cryocooler at GRC; conduct 20K cryocooler testing for TRL 5
- Grow NASA in-house cryocooler expertise to support Lunar and Mars mission needs
- Expand cryocooler industry base and foster alternative cryocooling technologies



ULA Vulcan

- **Continue technology and modeling work**

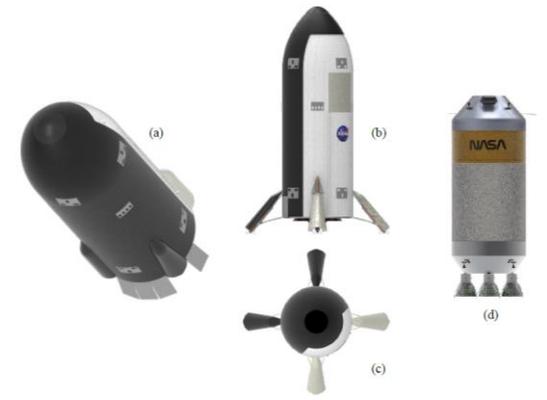
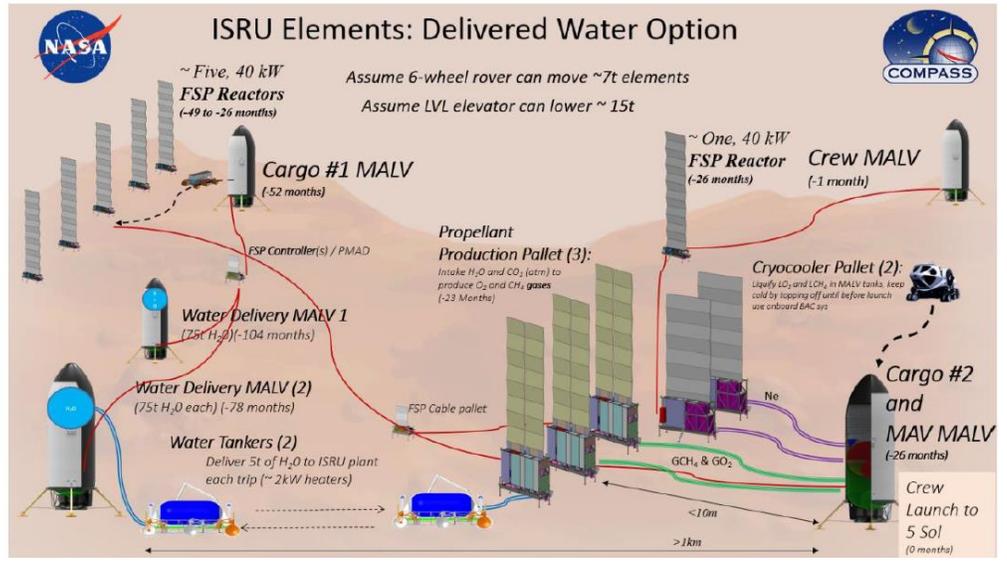
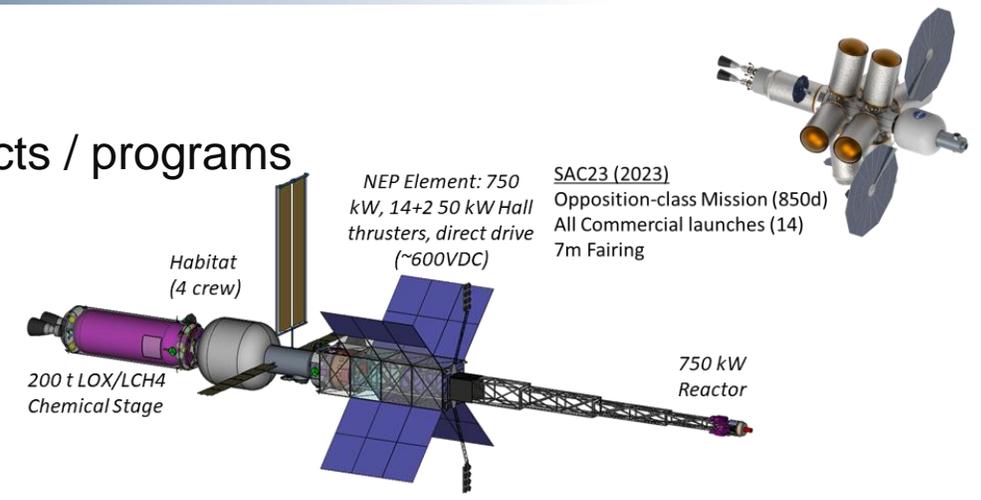
- Complete Low-leakage valve Critical Design Reviews and progress to manufacturing
- Complete RFMG Next-Gen advanced reviews and unit testing
- Further design tool validation within Modeling portfolio



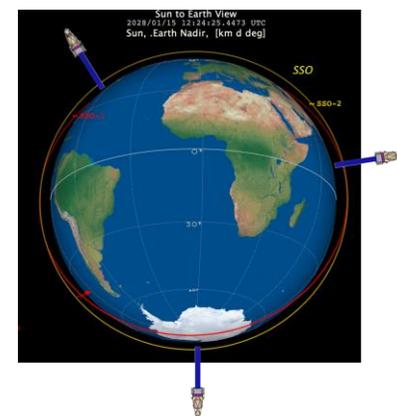
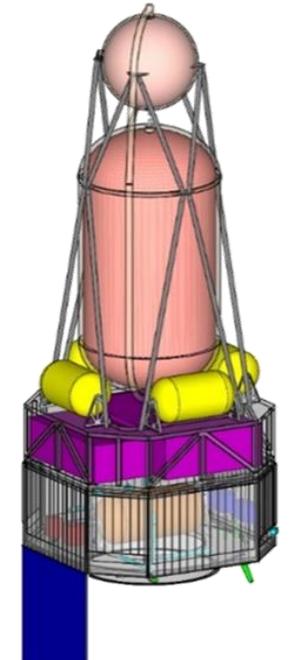
20K Engineering Model Cryocooler System

• Identify and foster CFMPP partnerships

- Document collaborations and cross-dependency with other projects / programs
 - Human Landing System Program, Mars Campaign Office
 - Advanced H2 Aviation Applications
 - Science Missions
- Leverage partnerships to identify CFMPP office prioritization



- **Refine CFM flight mission requirements to achieve CFM capability goals**
 - CFM Capability Goals: ‘Demonstrations of cryogenic storage and transfer systems in microgravity’
 - Flight demonstration(s), beyond current Tipping Point and HLS Missions, are required to meet goals
 - CFMPP continuing pre-formulation work to refine Government Reference mission concept requirements
 - LH2 Loading concept (KSC) and spacecraft definition refinement
 - Supports CFM STMD roadmap development and provides basis of ‘demonstrative value’ for alternative cryogenic mission approaches





Questions?

And Thanks!



Backup

On-Orbit Large-Scale Cryogenic Propellant Management and Transfer Demonstration

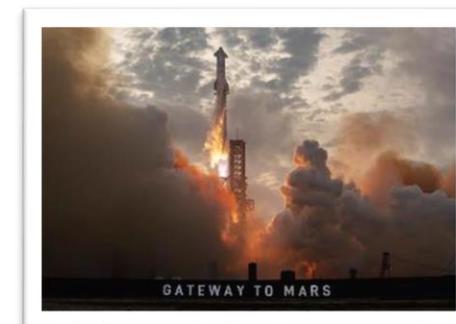
Overview: Demonstration of large-scale on-orbit cryogenic fluid transfer of liquid oxygen (up to 3 metric tons) between tanks on a Starship in orbit and management to provide a basis for operational use of in-space refueling technology.

Mission Overview:

- Demonstration conducted as part of a Starship flight
- Active settling maneuver with settled transfer between propellant tanks located within Starship (*not ship-to-ship*)
 - Flight-3 included special demonstration hardware specific to Tipping Point
- ≤ 1 day mission duration

Flight Demonstration Completed on Starship Flight-3 on March 14, 2024!

- Conducted the large-scale propellant transfer, moving several metric tons of propellant from one tank to another, while in space
- Storing and transferring cryogenic propellant in orbit has never been attempted on this scale before. This is a huge milestone toward providing NASA with the technologies it will need for both a long-term presence on the moon and its boldest missions to deep space destinations such as Mars and beyond.



Radio Frequency Mass Gauge (RFMG) Technology

Measures tank RF spectrum to provide tank fill level; the spectrum changes with fill level, since the dielectric fluid (ϵ) slows the speed of light

- Tech has been in development for over 15 years at Glenn Research Center

RFMG successfully flew and operated onboard the Intuitive Machines IM-1 Nova-C (Odysseus) lunar lander as part of Commercial Lunar Payload Services Program!

- Mission Objectives:
 - Support pre-flight and flight operations during CLPS Program with Intuitive Machines (IM-1) Nova C lander.
 - Demonstrate RFMG system operations at multiple fluid levels for both liquid oxygen (LOX) and liquid methane (LCH4) propulsion tanks throughout IM-1 mission.
- NASA team participated multiple in pre-launch activities, including RF fluid simulations and propellant tanking during wet-dress rehearsals

This technology was actively used on throughout IM-1 mission, where it not only provided critical data to advance the RFMG technology but also assisted the IM-1 team during maneuvers and the lunar landing.

Propellant loading of IM-1 tank at LC 39A



Credit: Intuitive Machines



FY24 Highlight: Low-Leakage Hydrogen Valves



NASA in-house team at Marshall Space Flight Center has developed a *patented* valve technology that utilizes a seat and poppet concept enabling self-alignment, greatly reducing leakage rates.

• **Activity Goal:**

- Develop valves that are more tolerant of imperfections and reduce internal leakage rates by an order of. Traditional internal leakage rates up to 2000 Standard Cubic Inches per Minute (SCIM)
- Low-leakage rates are required for future long-duration cryogenic missions

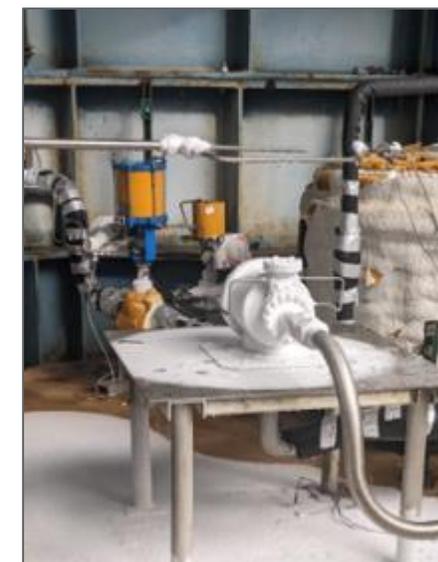
• **In 2023, CFMPP successfully developed and tested a relief valve design on small scale at MSFC**

- Test results indicated leakage rates under 10 SCIM
- Achieved TRL 4 criteria; extensible to cryo-coupler designs



• **CFMPP started new activity in 2024 to continue valve technology development and begin tech transfer and infusion with industry**

- Procure a high-fidelity prototype valve from a commercial partner which will enable a future test campaign to bring the low-leakage valve design to TRL 6 except for the electromechanical actuator
- *Sierra Space contract and continued in-house developments started in October 2024*



Low-leakage relief valve during LH2 testing