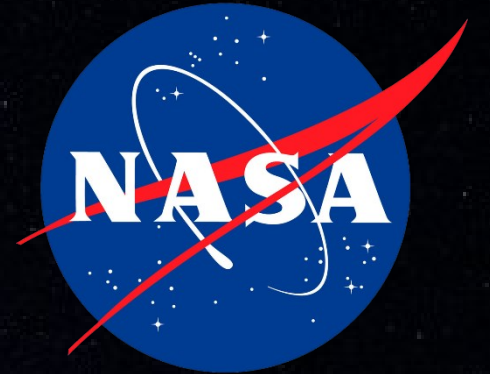


NASA Cryogenic Fluid Management Flight Demonstration Summary: SpaceX 2020 Tipping Point



Sean M. Kenny
NASA Marshall Space Flight Center
CFM Project Sub-Systems Portfolio Lead

July 2023

<https://www.nasa.gov>

CRYOGENIC FLUID MANAGEMENT PORTFOLIO PROJECT OVERVIEW



- **Primary goal of the Cryogenic Fluid Management Portfolio Project (CFMPP) is to close technology gaps essential to NASA's future missions in science and exploration**
 - CFM technologies are essential for chemical and nuclear in-space propulsion, landers, and in-situ resource utilization
- **The CFMPP is a Technology Demonstration Mission (TDM) portfolio project within NASA's Space Technology Mission Directorate (STMD) comprised of twenty-four individual CFM technology development activities**
 - Co-managed between Marshall Space Flight Center and Glenn Research Center
- **TRL Objectives**
 - Technology end-state to be at least TRL6 with goal of TRL 7
 - Minimum TRL 4 for inclusion as an activity within the CFMP Project
- **Primary goal of the CFMPP is to close technology gaps leading to a system-level Integrated CFM Flight Demonstration due to gravity dependent-nature of cryogenic fluid behavior**
 - There is a need to mature CFM technologies and integrated system operations, leading to a system-level integrated Large CFM Flight Demonstration (LCD)
- **Project portfolio activities include non-flight demo related activities (ex. ISRU liquefaction)**
- **CFM technical goals and objectives are defined in Key Performance Parameters (KPPs) for based on SOA capabilities, captured in project plan.**

Cryogenic Fluid Management (CFM) Portfolio Project Office

Objective: 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

CFMP is a TDM portfolio project comprised of twenty-four individual CFM technology development activities, spread across four portfolio areas
Technology entrance minimum of **TRL 4**, with project end state objective of **TRL 7**

CFMPP was established to consolidate management and integration of TDM CFM technology development activities
NASA MSFC partnering with GRC for management and execution of the portfolio project

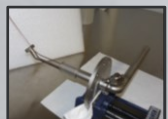
System Demonstration Complexity

Technologies Portfolio

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

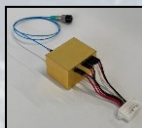
Major Activities:

Hydrogen low-leakage valves and cryo-couplers



Radio Frequency Mass Gauge (RFMG)

Next-generation FOSS (fiber optics sensing system)



Solar White thermal coatings

Subsystems Portfolio

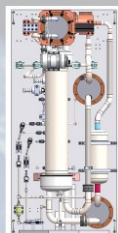
Scope: Design, development, and testing of complex systems of technologies to address technical challenges for specific CFM mission needs

Major Activities:

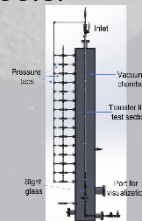
20W/20K Cryocooler

90W/150K Cryocooler

Cryocooler Electronics and alternate generic 20W Cryocooler



Reduced Gravity Cryogenic Transfer (RGCT)



Demonstrations Portfolio

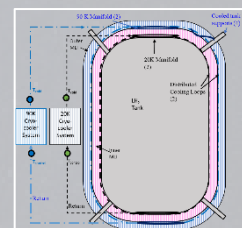
Scope: Design, build, and test integrated flight and ground systems comprised of multiple CFM subsystems, enabling TRL 5 - 7 maturation for many technologies

Major Activities:

Large CFM Demonstration
Concept Planning

Tipping Point Contract Demonstrations

Two-Stage Cooling Demonstration



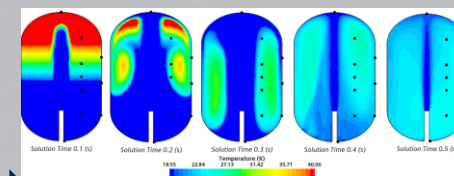
CryoFILL Liquefaction Demonstration



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 portfolio are used within modeling tools to predict CFM behavior at a flight vehicle scale in a relevant environment including microgravity



System Validation

CFM TECHNOLOGY PRIORITIZATION FOR FLIGHT DEMONSTRATIONS



- **Focus on CFM Moon to Mars in-Space Developments**
 - Current state-of-the-art for Mars in-space transportation CFM storage is limited to NASA Lunar experience (10 days)

Long Term Storage Hardware and Operations

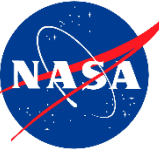
- Primary Focus
 - Cryocooler development & Operations
 - Tube on Tank / Tube on Shield Hardware and Operations
- Secondary Focus
 - Reduced Heat Load Structures
 - TVS (Spray)
 - Mixing Pump
 - Insulation
 - Pressurization / Venting Ops
- Enabling
 - Mass Gauging

Transfer (0G) Hardware and Operations

- Primary Focus
 - Low Leakage Valves
 - TVS (Injector)
 - Transfer, Chill, Press Ops, Venting (unsettled)
 - Liquid Acquisition Devices (LAD)
- Secondary Focus
 - Cryocouplers
- Enabling Technologies
 - Mass Gauging

Long Term Duration (9 month+ travel time to Mars)

CRYOGENIC FLUID MANAGEMENT PORTFOLIO PROJECT OFFICE



Blue Origin

- 2019 Tipping Point (Liquefaction)

United Launch Alliance

- 2020 Tipping Point
- Smart Prop (CCSC)

Lockheed Martin

- 2020 Tipping Point

Oxeon

- 2019 Tipping Point (Liquefaction)

ARC

- Tipping Point SME (Eta Space)
- Spectral Mass Gauging

Vandenberg AFB

- Potential Launch Site (LM)

SpaceX

- 2020 Tipping Point
- 2019 Tipping Point (Cryo-Couplers)

Armstrong Flight Research Center

- Sensuron ACO
- Flight Opportunities Program (RGCT Flight)

Paragon

- 2019 Tipping Point (CELSIUS)

NASA Glenn Research Center

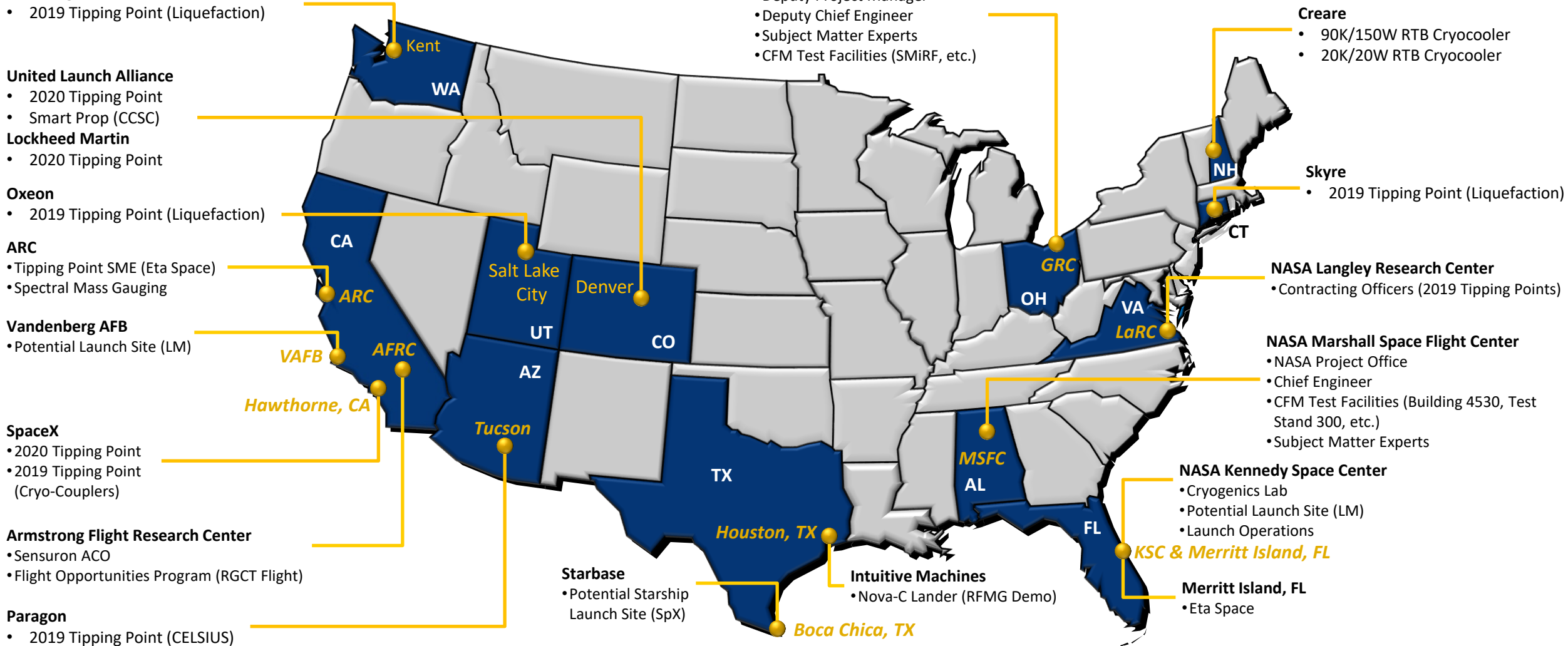
- Deputy Project Manager
- Deputy Chief Engineer
- Subject Matter Experts
- CFM Test Facilities (SMiRF, etc.)

Creare

- 90K/150W RTB Cryocooler
- 20K/20W RTB Cryocooler

Skyre

- 2019 Tipping Point (Liquefaction)



NASA Langley Research Center

- Contracting Officers (2019 Tipping Points)

NASA Marshall Space Flight Center

- NASA Project Office
- Chief Engineer
- CFM Test Facilities (Building 4530, Test Stand 300, etc.)
- Subject Matter Experts

NASA Kennedy Space Center

- Cryogenics Lab
- Potential Launch Site (LM)
- Launch Operations

KSC & Merritt Island, FL

- Merritt Island, FL
- Eta Space

Starbase

- Potential Starship Launch Site (SpX)

Intuitive Machines

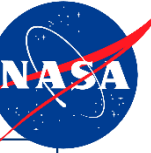
- Nova-C Lander (RFMG Demo)

WHAT IS A TIPPING POINT CONTRACT?



- Jim Reuter, associate administrator of NASA's Space Technology Mission Directorate (STMD):
 - “These promising technologies are at a ‘tipping point’ in their development, meaning NASA’s investment is likely the extra push a company needs to significantly mature a capability,”
 - “These are important technologies necessary for sustained exploration of the Moon and Mars. As the agency focuses on landing astronauts on the Moon by 2024 with the Artemis program, we continue to prepare for the next phase of lunar exploration that feeds forward to Mars.”
 - “We are excited to see our investments and collaborative partnerships bring about new technologies for the Moon and beyond while also benefiting the commercial sector.”
- “The majority of the funding will help mature cryogenic fluid management technologies via in-space demonstrations ... The ability to store these super-cold liquids, whether they are launched from Earth or produced in space, for an extended period and transfer propellant from one tank to another, is crucial for establishing sustainable operations on the Moon and enabling human missions to Mars.”
- These tipping points are truly partnerships with contributions from each company combined with contract award to complete demonstrations.
 - Much of the scope is intended to advance a commercial capability
 - Most of specifics are understandably proprietary
 - Each company had the opportunity to seek expertise within NASA to assist in achieving the tipping point objectives which in the case of SpaceX included advanced modeling and analysis capabilities at MSFC and Glenn.

2020 TIPPING POINTS – SPACEX CONTRACT SUMMARY



SpaceX of Hawthorne, California, \$53.2 million

Large-scale flight demonstration to transfer 10 metric tons of cryogenic propellant, specifically liquid oxygen, between tanks on a Starship vehicle. SpaceX will collaborate with Glenn and Marshall.

- Contract goals (from contract SOW):
 - “...to advance cryogenic fluid transfer and gauging technology through technology risk assessment, design and prototype testing, and on-orbit demonstration.
- Tipping Point Objectives will be complemented by a series of ground tests and on-orbit demo.
- Primary demonstration objective will be Header-to-Main LOX tank transfer
- Approach
 - Transfer operations: Transfer 10 mT from the LOX header tank to the LOX main tank
 - Instrumentation and onboard video to characterize performance and monitor propellant fill levels
 - Tank pressure control and propellant management (settled)
 - Transfer line chill-down and flow-control
 - Ground testing for comparison between ground and flight test data as well as anchoring thermal/fluid models
- Schedule
 - Original dates to be updated. Tipping Point Demonstration is dependent on Starship Orbital Launch Success.

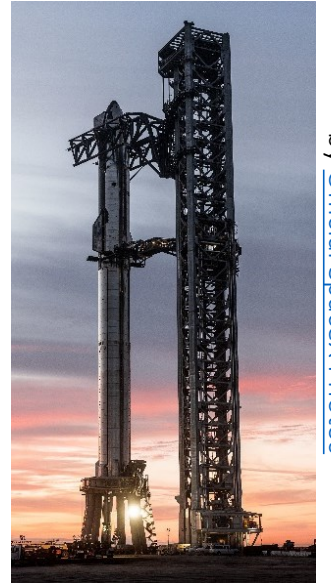
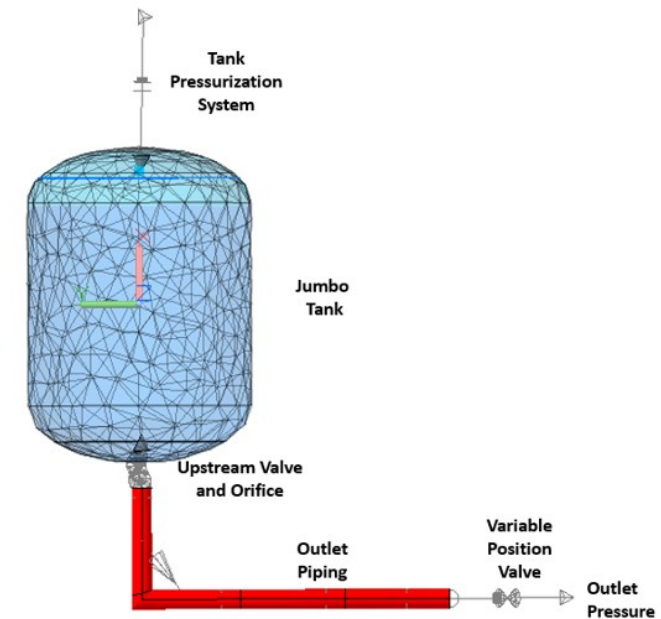


Photo Source: [Some rights reserved](#)
by [Official SpaceX Photos](#)

NASA BENEFIT EXAMPLE



- Use of the data from this CFM Flight Demonstration to validate improved modeling and analysis tools for current and future cryogenic missions
- Example: Predicting, Controlling, and Measuring transferred cryogenic propellant
 - There is uncertainty in propellant initial thermodynamic state post ascent / pre-transfer
 - Temperature and pressure due to:
 - Dynamic liquid to gas interactions (Slosh)
 - Aero-heating
 - Etc.
 - There is a possibility of Two-Phase Flow which is a challenge to predict
 - Data will improve validation of Dyer's Model using Thermal Desktop
- Just one of many uses for data



1) Modeling of a Large Scale Liquid Oxygen Propellant Transfer Test," D. Hauser, B. Wendt, M. Faykus, L. Blackmore, H. Tani, G. Thome, 2023 Space Cryogenics Workshop, Hawaii

MAHALO!
THANKS FOR ATTENDING!