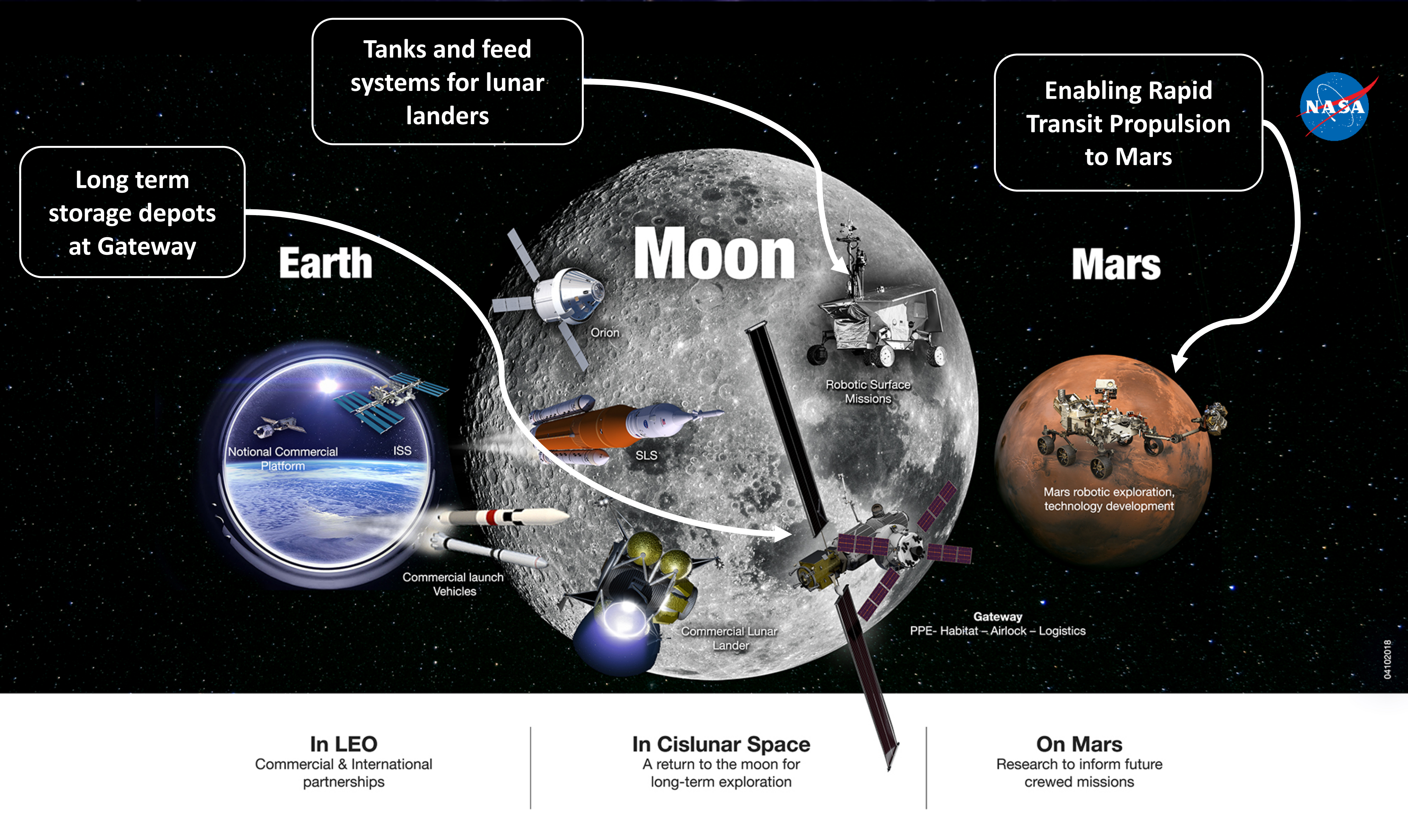
Dayna Ise | Cryo Fluid Management Planning to NAC | 12.07.18

Space Technology Mission Directorate

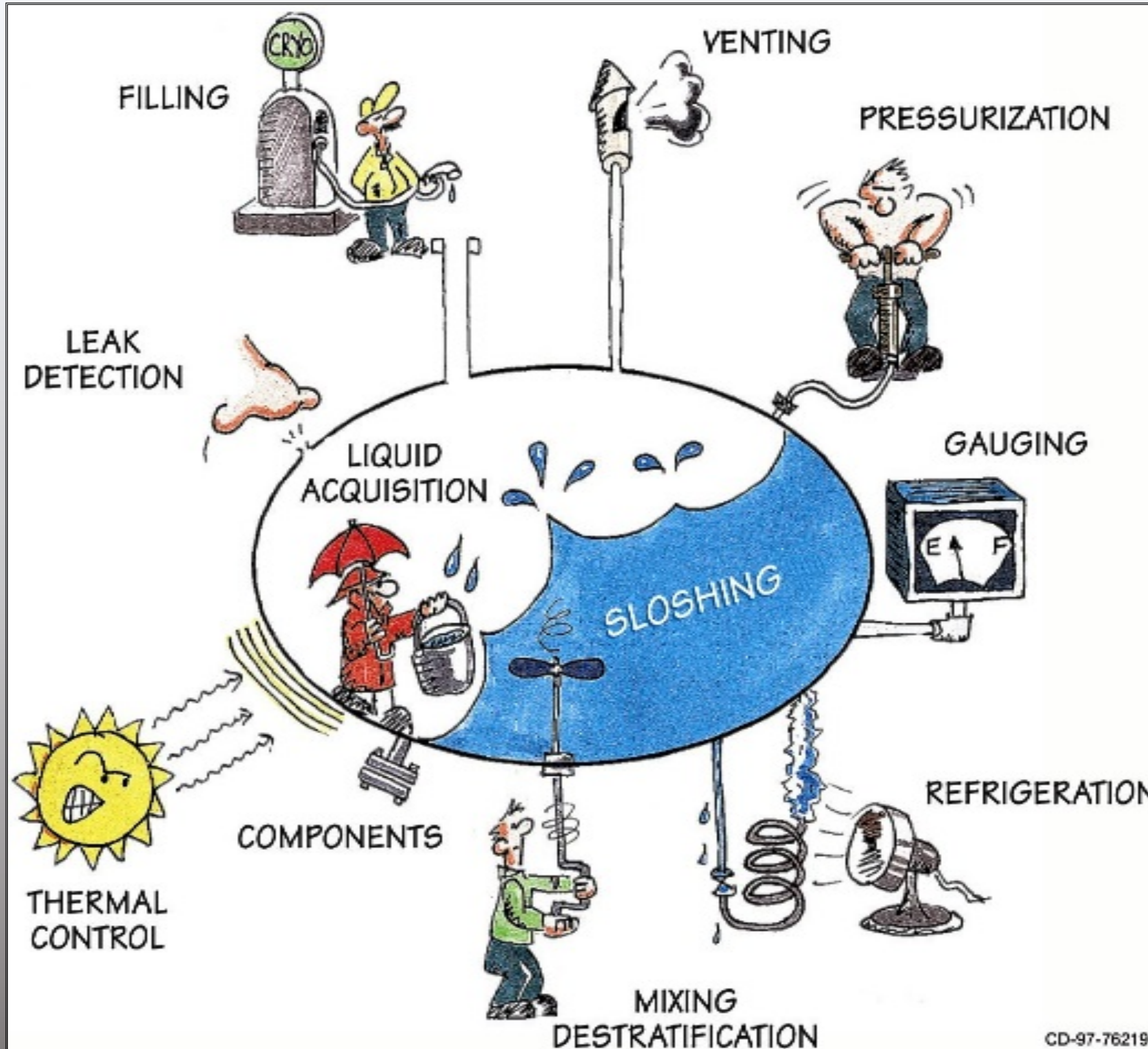
Introduction

- STMD's has a commitment to develop CFM technologies in support of the agency's missions
- There are current activities and future planning that support lunar exploration, Martian exploration, and long term sustainability on the moon and Mars
- These technology development is following a roadmap of discrete tasks that will contribute to an overall portfolio to support agency goals

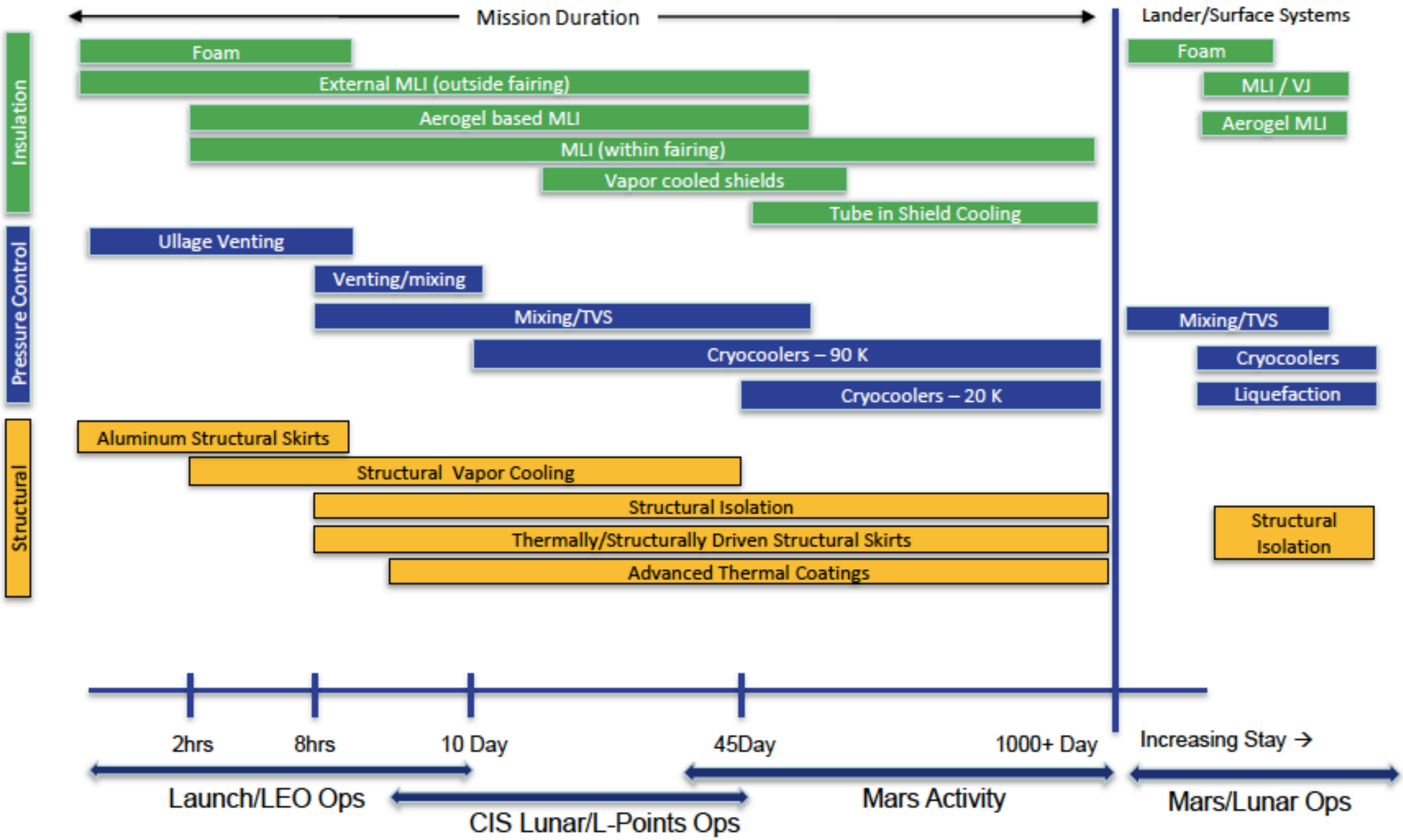
CFM Applications in Support of Agency Missions



Cryogenic Fluid Management—Key Technologies



CFM Technologies Needed by Mission Duration

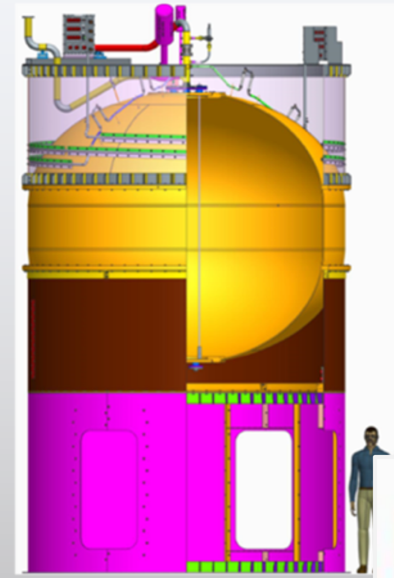


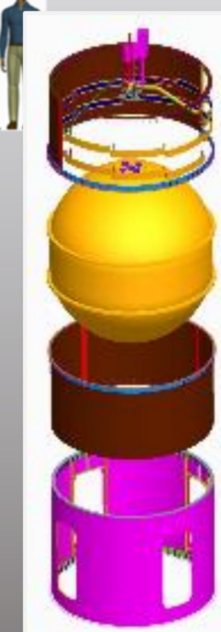
Maturity Levels of CFM Technologies

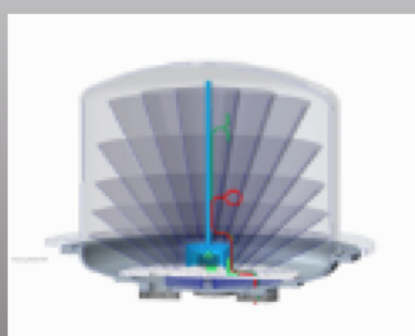
CFM Elements				
Technologies	Current TRL	Gravity Dependant (Y/N)	Path to TRL 6	"Cross Cutting" or "Fluid Specific"
Low Conductivity Structures	6	No	Ground Test	Cross Cutting
High Vacuum Multilayer Insulation	5	No	Ground Test	Cross Cutting
Tube-On-Shield BAC	5	No	Ground Test	Cross Cutting
Valves, Actuators & Components	5	No	Ground Test	Cross Cutting
Vapor Cooling	5	No	Ground Test	Fluid Specific
Helium Pressurization	5	Yes	Flight Demo	Cross Cutting
MPS Line Chilldown	5	Yes	Flight Demo	Cross Cutting
Pump Based Mixing	5	Yes	Flight Demo	Cross Cutting
Thermodynamic Vent System	5	Yes	Flight Demo	Cross Cutting
Tube-On-Tank BAC	5	Yes	Flight Demo	Cross Cutting
Unsettled Liquid Mass Gauging	5	Yes	Flight Demo	Cross Cutting
Liquid Acquisition Devices	5	Yes	Flight Demo	Fluid Specific
Advanced External Insulation	3	No	Ground Test	Can Be Both
Automated Cryo-Couplers	4	No	Ground Test	Cross Cutting
Cryogenic Thermal Coating	3	No	Ground Test	Cross Cutting
High Capacity, High Efficiency Cryocoolers 90K	3	No	Ground Test	Cross Cutting
Soft Vacuum Insulation	3	No	Ground Test	Cross Cutting
Structural Heat Load Reduction	3	No	Ground Test	Cross Cutting
Propellant Tank Chilldown	3	Yes	Flight Demo	Cross Cutting
Transfer Operations	4	Yes	Flight Demo	Cross Cutting
High Capacity, High Efficiency Cryocoolers 20K	3	No	Ground Test	Fluid Specific
Liquefaction Operations (MAV & ISRU)	3	No	Ground Test	Fluid Specific
Para to Ortho Cooling	4	No	Ground Test	Fluid Specific
Propellant Densification	4	No	Ground Test	Fluid Specific
Autogenous Pressurization	4	Yes	Flight Demo	Fluid Specific

Current Technology Development

- Current funded activities that are applicable to the CFM roadmap include:
  - Cryogenic thermal coatings
  - Automatic Cryo-couplers
  - Low Conductivity Structures (SHIIVER)
  - Propellant Densification
  - High Vacuum MLI (IFUSI)
  - Vapor Cooling (eCryo)
  - Unsettled liquid mass gauging (RRM-3)





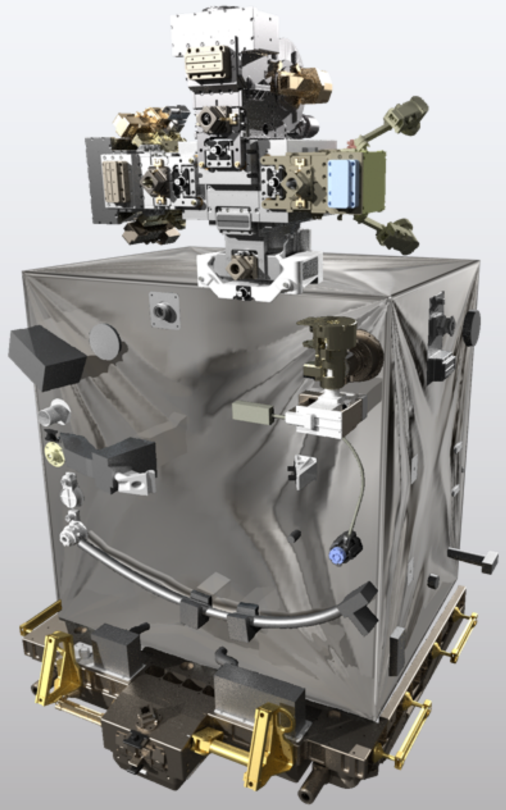


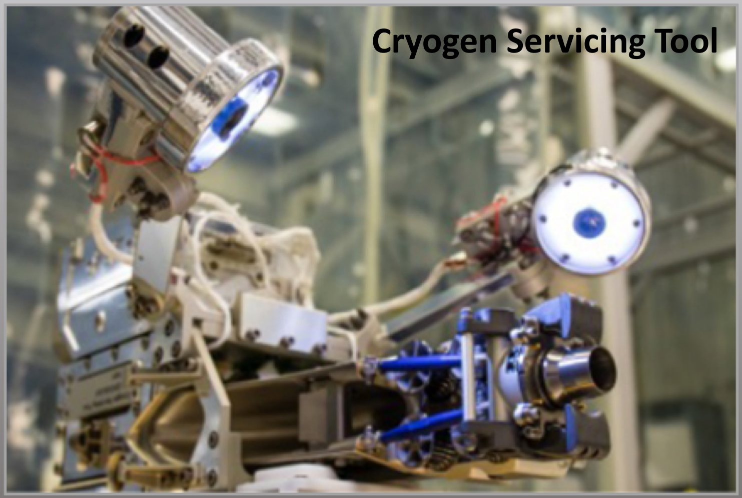
Radio Frequency Mass Gauging

SHIIVER –type Test Configuration

Current CFM Technology Development—RRM3

- As an exterior payload on the International Space Station, the Robotic Refueling Mission 3 (RRM3) will demonstrate innovative methods to store, transfer, and replenish cryogenic fluid in space.
- In addition to replenishing cryo methane, RRM3 will store it for six months with zero boil off to demonstrate the efficient use of these important consumables.





Cryogen Servicing Tool

- Launched aboard Falcon 9 December 4, 2018.
- Launch operations 2019 through 2020

FY19 CFM Work—Cryocoolers

- Low Leak Valve Work: This task continues work that was initiated in FY18 to develop low leakage valves for use with cryogenic hydrogen. Deliverables are the final design of the 8” pre-valve and the preliminary design of the 3” disconnect valve.
- High Capacity Cryocooler (20K 20W): The focus of the Cryocooler project is on advancing the technology capability and flight readiness of a 20 Watt, 20 Kelvin reverse turbo-Brayton cycle cryogenic cooler which will enable zero boil-off of liquid hydrogen for space applications.
- 90K Cryocooler: Design, build, and test prototype recuperator and turbo-alternator components for the 150W/90K RTB Cryocooler. Provide conceptual design of a non-Reverse Turbo-Brayton cycle 120-150 W class 90 K cryocooler system that provides cooling to a NASA tube-on-tank broad area cooled shield.
- High Efficiency and High Capacity 90K Cryocooler: Integrate all RTB components at a system level and perform 150W/ 90K cryocooler acceptance testing. Demonstrate performance and summarize against key parameters prior to hardware delivery to NASA.

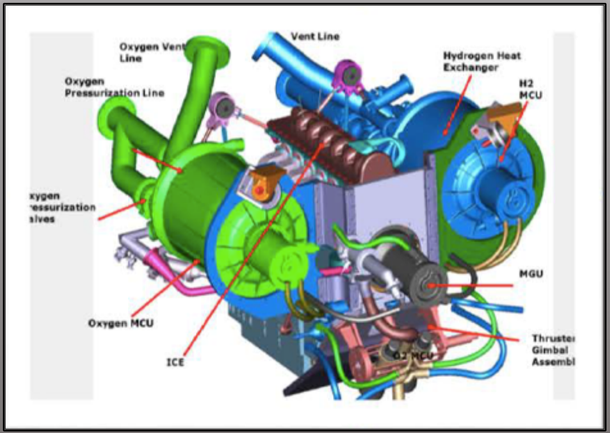
20W 20K Cryocooler Components and Breadboard

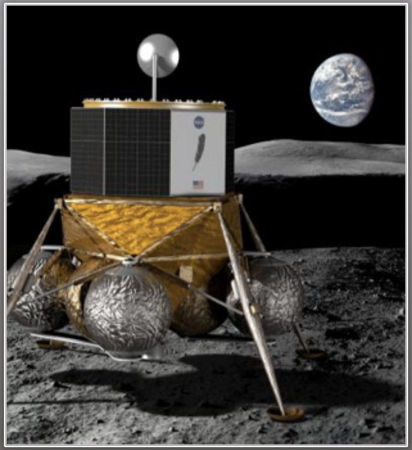
FY19 CFM Work—Tipping Points

- Blue Origin Tipping Point Award for a Lunar Lander CFM Development
  - A 24-month baseline effort culminating in integrated propulsion ambient testing at NASA and a separate microgravity experiment on Blue Origin's New Shepard suborbital vehicle.
  - The integrated system will use a cryogenic main lander engine thrust chamber with cryogenic RCS systems and CFM technologies. The demo with include full scale integrated propulsion system demonstration with model validation as well as a separate microgravity experiment increase in TRL.

- United Launch Alliance Integrated Vehicle Fluids flight demonstration
  - IVF system is proposed to eliminate the need for batteries, helium pressurization, and hydrazine or other storable RCS using already existing vehicle fluids.
  - Flight demo of IVF major elements including zero-g operation, power generation, and operations of both LO2/LH2 thrusters and H2/O2 ACS thrusters

ULA Integrated Vehicle Fluids Assembly

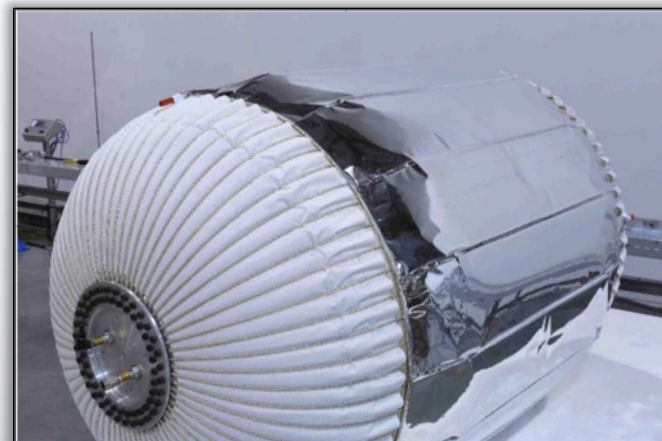




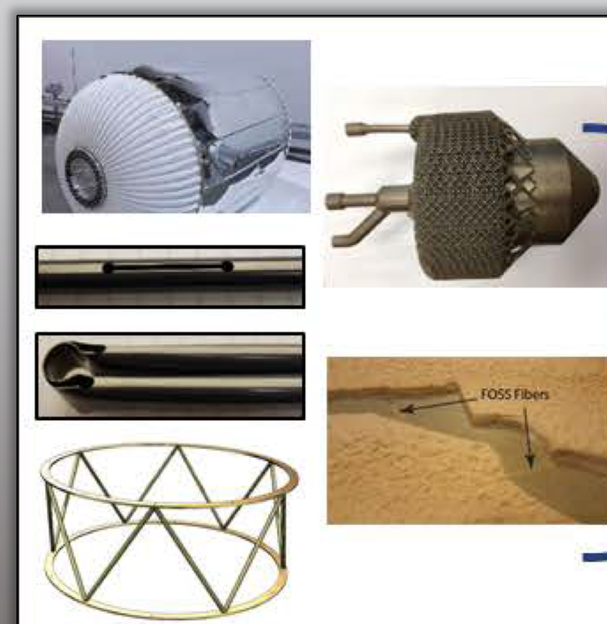
Blue Origin Lunar Lander Concept

FY19 CFM Work—Tipping Points

- Paragon CELSIUS is layered soft-goods system that combines Multi-Layer Insulation (MLI), Micro-Meteoroid and Orbital Debris (MMOD) protection, and fairing functions (exposure to free stream).
  - This will be a two-stage test campaign to continue development of CELSIUS systems. The leading edge shield and integrated cover design will be subject to a maximum dynamic pressure (~17 psi) via rocket sled testing.
  - After lessons learned from this testing are addressed, and an integrated test article is manufactured, it will be integrated with a launch vehicle, launched, and deployed at the design Max-Q pressure



- ULA Cryo Fluid Management Technology Demo
  - Ground test of Low-Boiloff technologies—a follow on activity to ULA's CRYOTE-3 work
  - The testing will include LN2 chilled cold walls, the CELSIUS thermal insulation system on the sidewalls, long duration measurement of temperatures and heat transfer and thermodynamic vent system with vapor cooling.
  - Tank will be supported using low-conductivity tension straps and utilize a fiber optic sensing system.



Current Coverage of CFM Technologies

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Near Term Planning Activities

- STMD intends to continue to fill out the CFM portfolio utilizing next year's Tipping Point Awards and Announcement of Collaborative Opportunity Awards.
- STMD is also working proposed technologies to be demonstrated on Lunar payloads
  - Small development projects on CLPS landers
  - Larger projects as part of in-line lander development work
  - Larger project that can be demonstrated as mid- to large-size lander payloads
- A large, multi-technology lunar demo could include CFM demonstrations:
  - Cryocoolers for active storage of propellants
  - ISRU to manufacture the propellants
  - Kilopower to provide power for those activities

Gaps in Roadmap

- The following items don't have coverage in any of the current activities. STMD is working with subject matter experts and industry to further develop these technologies:
  - Soft Vacuum Insulation
  - Liquefaction
  - Para to Ortho
  - Tube on shield broad area cooling
- Some of these technologies have broad industry interest. The next round of Tipping Points has the potential to pursue development of these technologies.

CFM-Related Key Technology Challenges

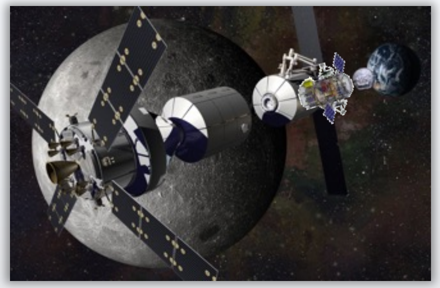
- STMD had identified Key Technology Challenges that support the agency’s vision and guidance.
  - Demonstrate a system capable of converting and liquifying hydrogen and oxygen from water at a rate of at least one ton per day in space and on the lunar surface
  - Demonstrate a system capable of autonomous transfer and storage of tens of tons of cryogenic hydrogen with negligible losses for up to a year in space and on the lunar surface.
  - Complete sufficient analysis and testing to select a suitable rapid transit propulsion system for further development to ultimately enable round trips to Mars for human-scale spacecraft in one year or less, and comparably rapid access to other solar system destinations for robotic spacecraft (this might include nuclear electric and other propulsion concepts)

Agency Missions

- CFM Technology Development are needed for each of key technology challenges:

- Gateway Storage/Depot
  - Transfer Operations
  - Long term, zero boil-off storage
- Lunar surface operations
  - Lunar ISRU
  - Lunar Storage
- Enabling Rapid Transit to Mars
  - Nuclear Thermal
  - Other cryogenic stages

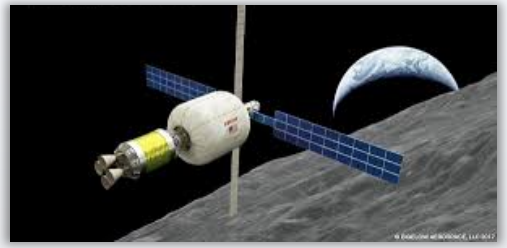
Enabling Technologies Needed at Gateway



LOX Storage Demonstration at Gateway

<u>Relies on Gateway for data and power. Storage demonstration.</u>

- Autogenous pressurization.
- Multilayer Insulation
- 90 K Cryocoolers
- Tube-on-tank
- Unsettled Mass Gauge
- Thermodynamic Vent



Propellant Tanker Delivery at Gateway

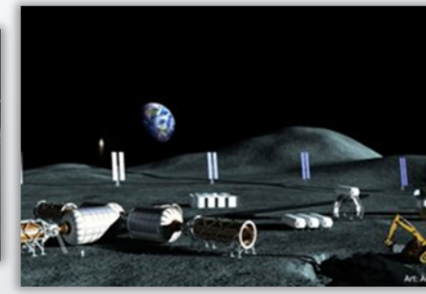
<u>Tanker flies to Gateway to transfer fluid to demo tank.</u>

- Transfer Operations
- Line-chilldown (Transfer system)
- 2 phase flow meter
- Automated Cryo-coupler
- Transfer line chilldown
- Propellant tank chilldown

Add Depot Tanks at Gateway

<u>Add additional storage volume near Gateway, with own spacecraft bus.</u>

- 2 phase flow meter
- Propellant tank chilldown
- Cryogenic Thermal Coating
- Sun Shields



Bring Propellant from Lunar Surface

<u>Deliver propellant as payload to Gateway from the lunar surface.</u>

- No new technologies

Enabling Technologies Needed for Lunar

Passive Lunar Lander

Storage type: Passive
No re-fueling
No return mass
Helium Pressurization
Technology Needed:

- High Vacuum MLI
- Low Conductivity Structures
- Line Chilldown
- Valves, actuators and components

Active Lunar Lander

Storage type: Active
No re-fueling
No return mass
Helium Pressurization
Technologies Needed:

- All listed for passive lander, plus:
- Pump-based Mixing
- Thermodynamic Vent Systems
- Liquid mass gauging

Human Lunar Lander

Storage type: Active
Ascent Stage re-fuelable
Ascent Vehicle: 10 tons
Helium Pressurization
Technologies Needed:

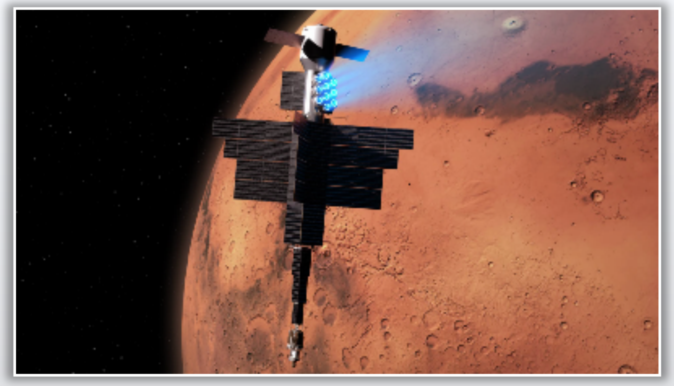
- All listed for active lander, plus:
- 90K Cryo-coolers
- Tube on Tank BAC

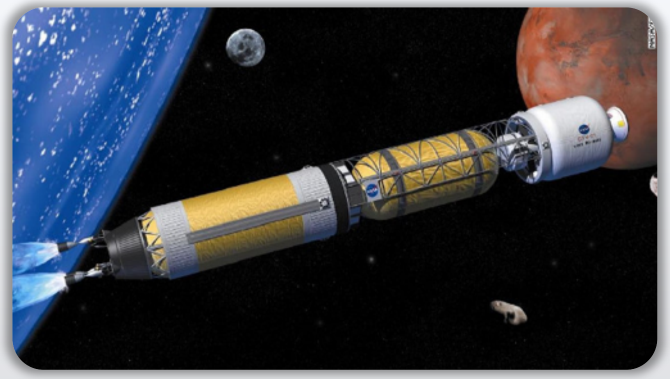
Reusable Lunar Lander

Storage type: Active
Fully re-fuelable
Ascent Vehicle: 5 tons
Autogenous Pressurization
Technologies Needed:

- All listed for Human Lander, plus:
- 2-phase flowmeter
- Autogenous Pressurization
- Automated Cryo couplers
- Transfer Operations
- Tube on Tank BAC

Enabling Technologies Needed for Rapid Transit to Mars





- Preliminary analysis of missions to Mars indicate a requirement of approximately 3 years of cryogenic storage of Hydrogen. Enabling technologies for this are:
  - Cryocoolers (20K 20W)
  - Tube on Tank Broad Area Cooling
  - Low Conductivity Structure
  - Low Leak Valves and Components
  - Automated Cryo-couplers
  - Autogenous Pressurization
  - High Vacuum MLI

Conclusion

- STMD is committed to supporting the agency missions and stated goals for exploration
- To that end, STMD has identified key technology challenges that will need to addressed to enable these missions
- STMD has a roadmap to further advance these technologies through ground and flight demonstration
- Current STMD activities provide substantial coverage for most technologies on the roadmap