



CRYOGENIC FLUID MANAGEMENT PORTFOLIO PROJECT (CFMPP)

CFMPP Office Cryocooler Technology Strategy



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NASA/MSFC/ST23

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NASA Cryocooler Technology Need



• Long duration cryogenic missions (Months to Years):

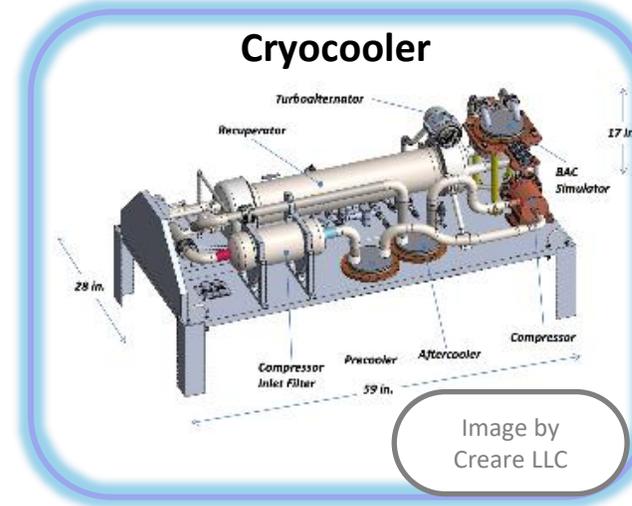
- Propellant Storage: LOX & LH₂ or LCH₄ (Methane)
 - Space Nuclear Propulsion (SNP)
 - Nuclear Thermal Propulsion (NTP)
 - Nuclear Electric Propulsion (NEP)
 - Traditional Chemical Propulsion
- On-Orbit Operations (Types of vehicles & missions)
 - Tanker / Receiver
 - Cryogenic Depot
 - Aggregation Missions
- ISRU (In Space Resource Utilization on Moon & Mars)
 - Liquefaction, Storage, & Transfer
 - LH₂, LOX, LCH₄

• Active Cooling is required: Cryocooler is the powered component

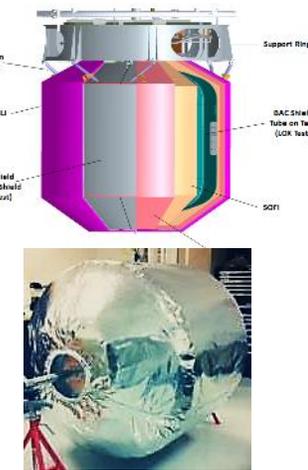
- Uses thermodynamic refrigeration cycles to transport heat from a cold zone to a warm zone

• Active cooling systems also require:

- Passive thermal management: Insulation & Low conductivity structure
- Coolant Distribution: Broad Area Cooling (**BAC**) Tube-on-Tank & Tube-on-Shield
 - NTP baseline BAC uses 'Nested' BAC with 20K on tank and 90K on shield within MLI
- Power: Solar Panels, etc.
- Heat Rejection: Radiators

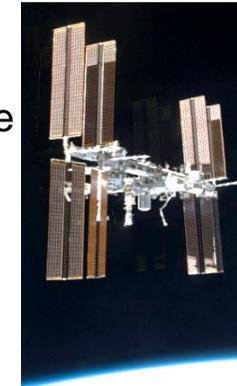
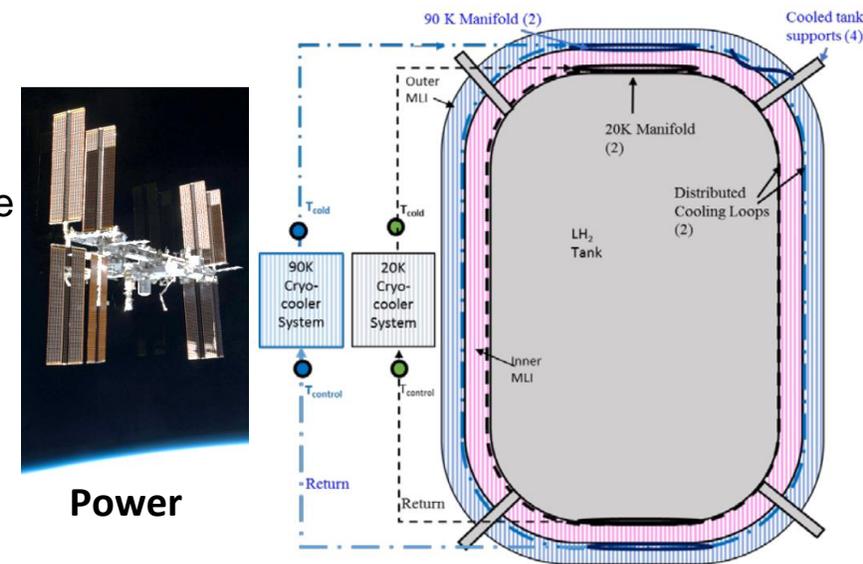


Insulation



Heat Rejection (Radiators)

BAC



Power



Propellant Summary

Space Nuclear Propulsion

Nuclear Electric (NEP) Hybrid:

- See below

Nuclear Thermal (NTP):

- Liquid Hydrogen

NEP or SEP/Chemical Hybrids

Solar Electric (SEP)

Chemicals:

- Methane and LOX

EP:

- Xenon or Krypton

All-Chemical

- Methane and LOX

Moon to Mars Architecture Definition Document (ESDMD-001 Rev-B) 3.4.3.1 “How” to Get to Mars and Back?

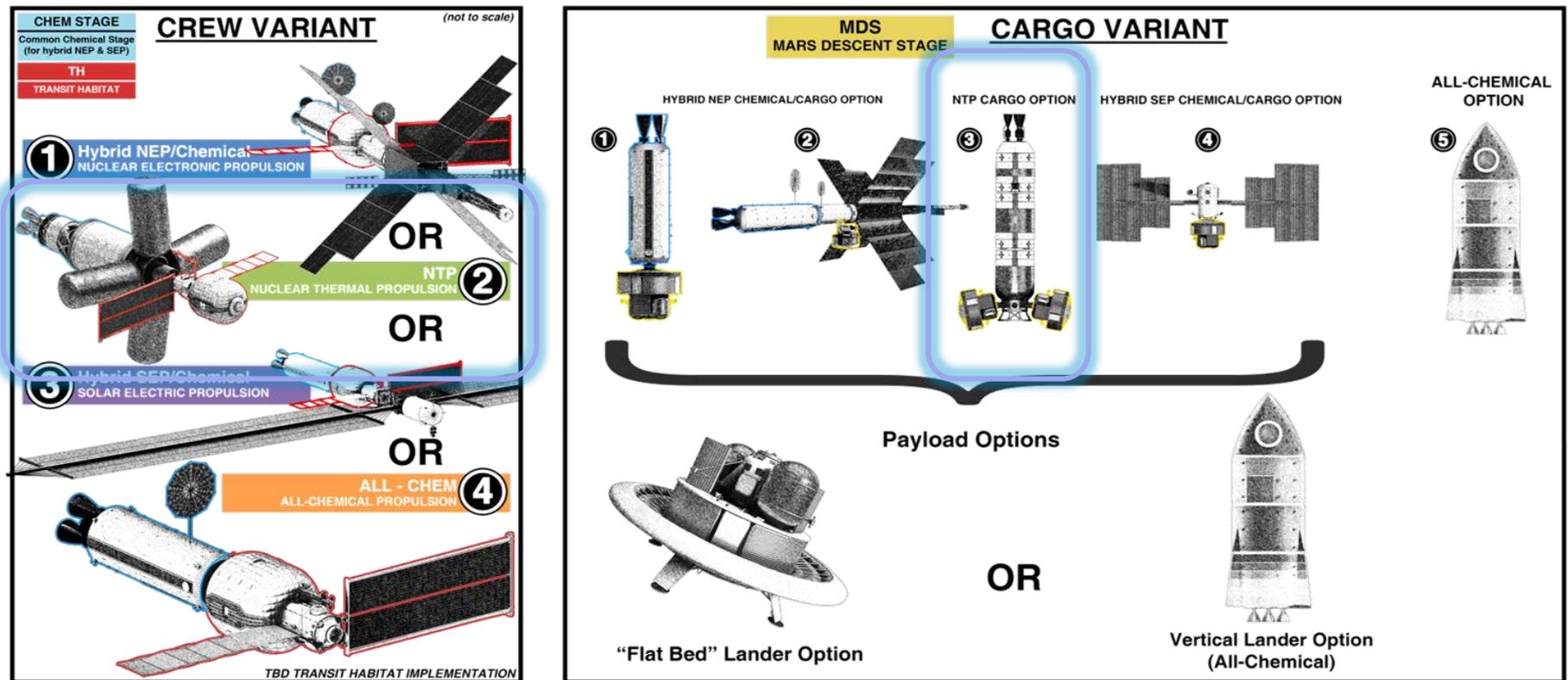


Figure 3-22. Major Mars Architecture Transportation Options Trade Space



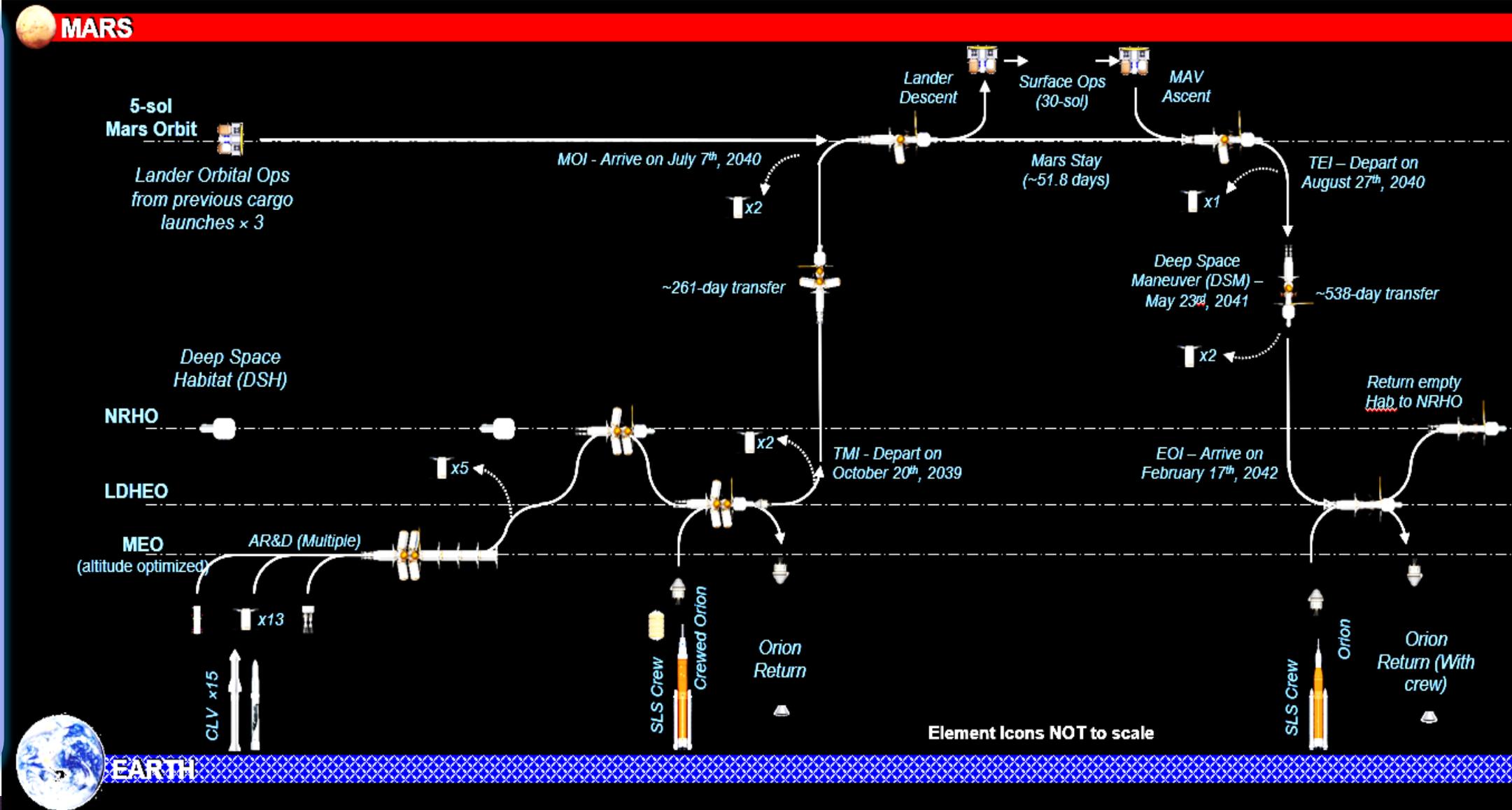
NASA Cryocooler Technology Reference Mission



Mission Duration Drives Cryocooler Design Life

~ 5 years of operation (Includes aggregation)

~ 120 Start/stop cycles defined by mission CONOPS (Assumes shutdown for each propulsive maneuver)





Performance

- Refrigeration Power, “Lift”
 - NTP Mission: 50W each for 90K and 20K

Efficiency

- Key Performance Parameters (KPP)
 - Power & Thermodynamic Efficiency
 - **~20% COP relative to Carnot**
(at 300K Heat Rejection Interface Temp.)
 - Mass Efficiency (Mass/Watts_{lift})

System Integration

- Flexible Packaging for improved thermal management
- Broad Area Cooling interface
 - Coolant circulation for Tube-on-Tank or Tube-on-Shield
- Thermal Management
 - Minimize parasitic heat
 - Heat Rejection

Reliability

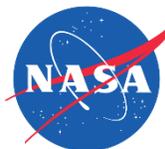
- Operational life ~5 years
- Duty Cycle >120 start/stop
- Closed cycle cryocoolers are more reliable
(Working fluid is closed cycle, ‘not prop’)
 - Sealed from contamination
 - More predictable and controllable operating conditions

Applicability to Hard & Soft Cryogenics

- Cycle + Working Fluid must be efficient at Target Temps
- Investment in Technologies applicable to all Reference missions and vehicles
 - Technology commonality between applications:
(Design Processes, Manufacturing Processes, Cycles, Configurations, Components, Interfaces, etc.)
 - Delivers the Best Value and Return on technology investment

“Hard Cryogenics” = Hydrogen

“Soft Cryogenics” = Oxygen, Methane



Key Performance Parameters



1. Design target temperature, Kelvin
2. Heat Removal, Refrigeration Power, or “Lift”, Watts
3. Power Efficiency stated in two ways:
 - (Coefficient of Performance, COP) or % of Carnot
 - (Watts needed to power the cooler / Watts of heat removed) [Lower is Better]
4. Mass Efficiency (Cryocooler Mass, KG / Watts of heat removed) [Lower is Better]

CURRENT TECHNOLOGY DEVELOPMENTS

20 Kelvin Cryocooler	Threshold	Goal
Lift (W)	17	20
W_{in}/W_L (TMU)	80	60
kg/W (TMU)	5.5	4.4
Assumption: 285K Heat Rejection Temp		

90 Kelvin Cryocooler	Threshold	Goal
Lift (W)	120	150
W_{in}/W_L (TMU)	15	8
kg/W (TMU)	0.8	0.5
Assumption: 300K Heat Rejection Temp		

FUTURE TECHNOLOGY INVESTMENTS (CACHE)

20 Kelvin Cryocooler	Threshold	Goal
Lift (W)	45	50
COP	15	20
kg/W (TMU)	5.5	4.4
Assumption: 285K Heat Rejection Temp		



20 Kelvin 20 Watt Cryocooler Status



Technology Description:

- The 20W 20K Cryocooler addresses the need for zero boil off storage of Liquid Hydrogen (LH₂), critical for Nuclear Thermal Propulsion as well as LH₂-based architectures for exploration and enable ISRU liquefaction.
- Thermodynamic Cycle: Reverse Turbo-Brayton (RTB)

Objectives:

- Design, build, and demonstrate a 20W 20K RTB cryocooler with a specific mass of 4.4 kg/W and a specific power of 60 W/W.

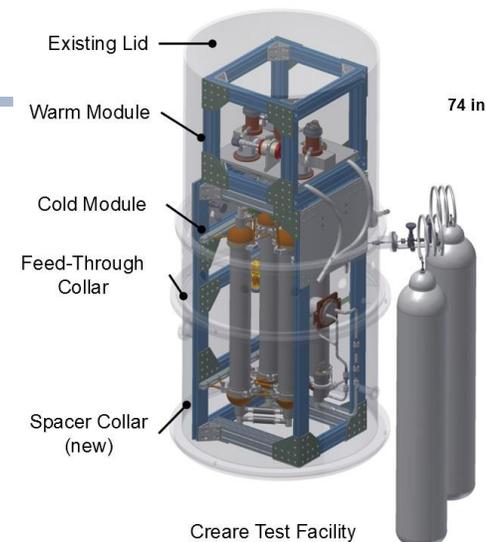
Scope / Status:

- Development under SBIR with CREARE LLC (Contact: Mark Zagarola)
- All Components developed and integrated with initial performance verification completed
- Current Work and Next steps:
 - Full operating range characterization in flight-like configuration through August, 2025
 - Vibration & Thermal Vacuum Testing (with post test functional verification)

TRL 6 Achievement in 2026

Mission Pull:

- Nuclear Thermal Propulsion as well as LH₂-based architectures for exploration
- ISRU (LH₂)



20W 20K Cryocooler Vacuum Chamber Model



Images by
Creare LLC

20W 20K Cryocooler Configured for Test



90 Kelvin 150 Watt Cryocooler TMU Status

(Thermo-Mechanical Unit)



Technology Description:

- 90K High Capacity Cryocoolers are an enabling technology for the long duration storage of cryogens as well as ISRU liquefaction of LOX & LCH₄
- The Reverse Turbo-Brayton (RTB)

Objectives:

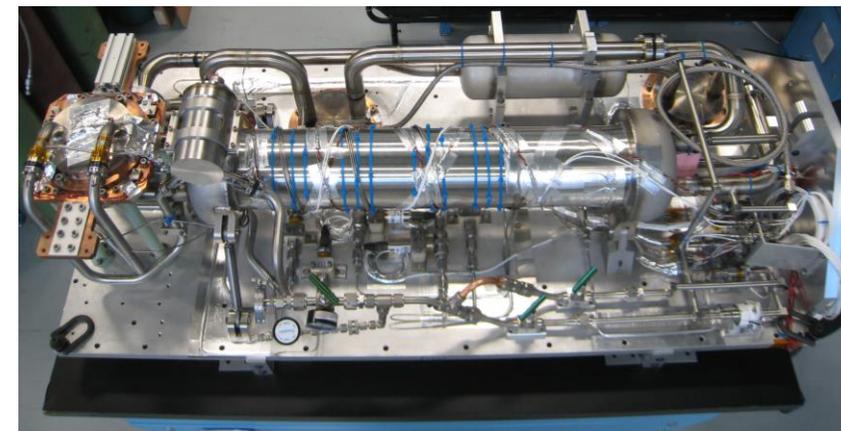
- Design, build, demonstrate a 150W / 90K RTB cryocooler having a specific mass of 0.4 kg/W and a specific power requirement of 8.0 W/W.

Scope / Status [Complete!]:

- Development was performed under SBIR contracts with CREARE LLC
 - Contact Mark Zagarola @ Creare
- All Components developed and integrated with initial performance verification completed (Brassboard)
- Flight-like integration into Engineering Model (EM)
- Full operating range characterization in flight prototype configuration
- Performed vibration testing on EM and repeat functional testing
- Delivered to NASA for “CryoFILL” integrated liquefaction system demonstration

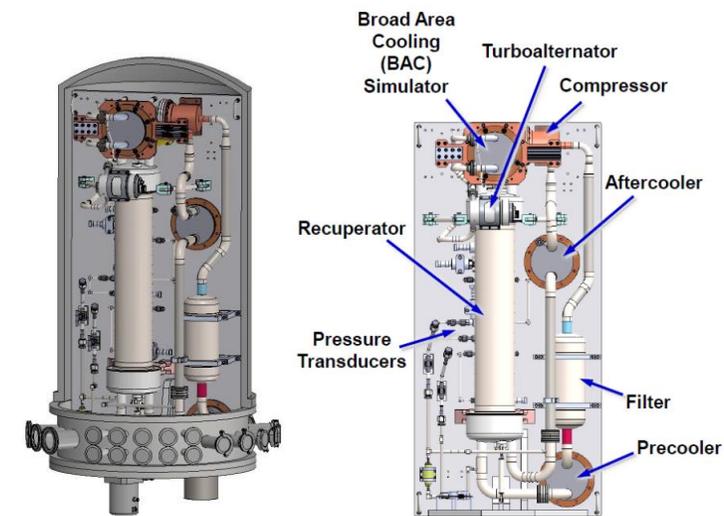
Mission Pull:

- Nuclear Thermal Propulsion (Staged BAC cooling application), ISRU (LOX)
- Mars architecture studies (NEP, SEP, Hybrid, All-Chemical)



150W/ 90K Cryocooler

Images by
Creare LLC



150W/ 90K Cryocooler in Vacuum Test Chamber



90 Kelvin 150 Watt Cryocooler CCE Status

(Cryocooler Control Electronics)



Technology Description:

Prototype Cryocooler Control Electronics Unit (CCE)

- Designed to operate the Creare 90K 150W RTB TMU
- Operate in defined environments (Mars Transit Missions)
- Achieve power and weight efficiency requirements (KPPs)

Objectives:

- Design, build, demonstrate a 150W / 90K RTB CCE (~1600 Watts input power) enabling its required performance (specific mass of 0.4 kg/W and a specific power requirement of 8.0 W/W)

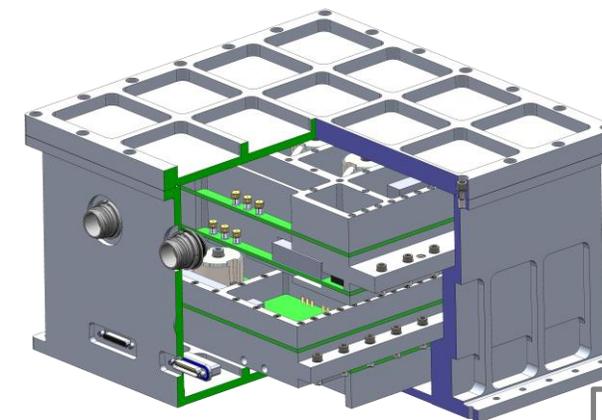
Scope / Status:

(Development under SBIR Ph III, CREARE LLC, Contact: Mark Zagarola)

- ✓ Completed Detailed Engineering Model Design (“EMCCE”)
- ✓ Completed Test Planning, Simulators, Facilities, etc. (PDR Level)
 - ✓ Include Assessment of applicability to 20K / 20W TMU
- ✓ Perform Developmental Testing (component, breadboard)

Current and Next Steps: (Contract awarded November 2024)

- Fabricate EMCCE – Feb 2026
- Perform Demonstration Phase Testing (TRL 5) – May 2026
 - Test using simulated TMU
- Perform Environmental Testing (TRL 6) – July 2026: Vibration, EMI, TVAC testing

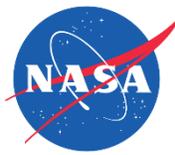


Images by
Creare LLC

Key functions

- Power conversion and conditioning
- Turbomachine speed control
- System level controls
- Telemetry processing

- Total mass: 21 kg
- Total volume: 18 liters
- Conductively cooled through baseplate
- Low EMI



Future Cryocooler Technology Investment: **CACHE** (Cryogenic Active Cooling for Human Exploration)



Approach:

Utilize NextSTEP-3 BAA to solicit proposals to develop cryocooler and control electronics for Mars missions

Objectives:

- Develop active cooling technologies to enable future missions
 - Requirements derived from Mars Architecture Studies
 - Mature Prototype Cryocooler Technology to TRL-6
 - Mitigate risk factors for TRL 7+ flight Demo
 - Address human rated flight certification
 - Predictable and flight certifiable performance and reliability
 - Enhance NASA institutional knowledge
 - Smart Buyer / Operator
- Assure availability of high capacity cryocoolers for future NASA missions

Scope of CACHE:

Prior or Current NASA funded technologies are not eligible

Two contracts with Options (multiple awards possible): (Firm Fixed Price, FFP)

First Contract: “Concept Development & Detailed Design”

- Base Scope includes Concept Development & Preliminary Design
- Option CLIN includes Detailed Design
- A Special Studies CLIN will allow for Risk Reduction, Developmental Testing, Etc
 - FFP RFP’s to be requested during contract execution as needed

Second Contract: “Build, Verification, & Demonstration with Environmental Testing” (*Only awardees from first contract are eligible to propose*)

- Base Scope: Fabrication, Assembly & Acceptance Test
 - Parts, Components, Assemblies & Integrated System
- Option CLIN: Performance Testing (TRL-5)
- Option CLIN: Environmental Testing (TRL-6)

Schedule:

- Anticipated RFP Release 4Q FY25 (July)
- Anticipate completion of both contracts by 2030

NextSTEP <https://www.nasa.gov/humans-in-space/nextstep/>



NASA Cryogenic Propellant Active Cooling Summary



- The NASA CFM Portfolio Project is enabling long duration cryogenic missions through maturation of critical technologies
- Technology KPP's and requirements derived from current Mars Architecture Studies
- Current Cryocooler investments are progressing primarily via SBIR contracts with Create LLC
- CFMPP will continue to mitigate risks for infusion for a TRL 7 demonstration opportunity
 - Will target risks that impact performance, reliability & life
- Stakeholders include
 - Earth/Moon missions, Transit and Surface
 - Depots, Aggregation Architectures, ISRU
 - HLS Sustaining Missions
 - Mars Mission Architecture Studies
 - Nuclear Thermal, Nuclear Electric/Chemical
 - Solar Electric/Chemical
 - All-Chemical
- CFMPP will be soliciting proposals for alternative cryocooler technical solutions under CACHE RFP

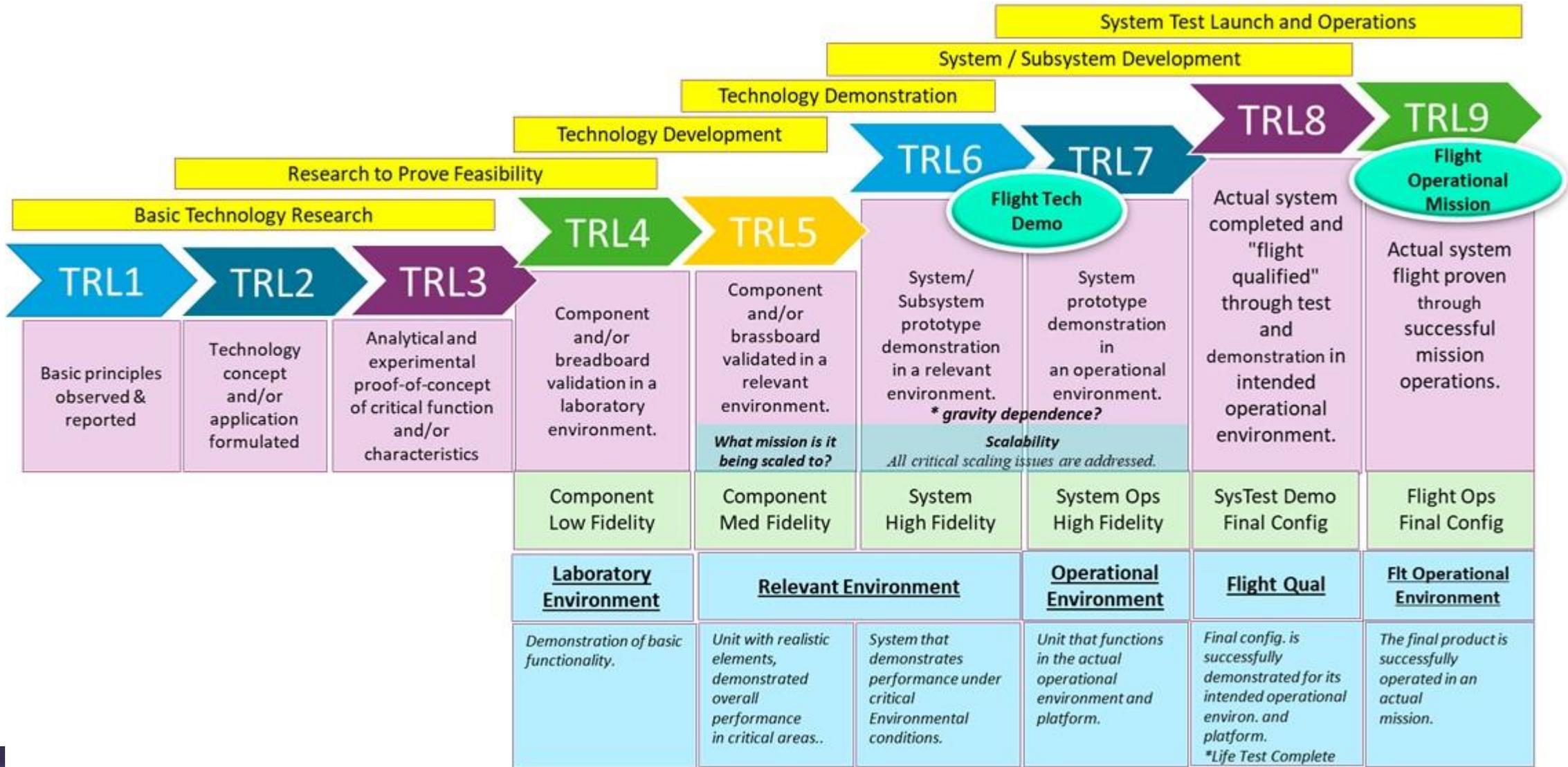


NextSTEP <https://www.nasa.gov/humans-in-space/nextstep/>



Backup

TRL Maturity Chart



** If unit/system is gravity dependent, it can not reach higher TRL until testing in low-g environment.*



NASA Cryocooler Technology Reference Missions



Moon to Mars Architecture Definition Document (ESDMD-001 Rev-B)

Mission Duration Drives Cryocooler Design Life (Longest Selected)

~ 5 years of operation (Includes aggregation)

~ 120 Start/stop cycles defined by mission CONOPS

Mission Duration Knob	WHO We Send	WHAT We Do	WHERE We Go	WHEN We Go	WHY We Go	HOW We Get There & Back
Fast Roundtrip High Energy Reference Mission 0	Analysis Assumption: Number of Crew Range of 2 – 6	Analysis Assumption: 75t Total Landed Payload Light footprint: Minimal surface infrastructure, crew live in rover, 10 kWe Fission Surface Power (no return propellant ISRU)	Analysis Assumption: Single Mars Surface Site +35° N Latitude	Analysis Assumption: 2039 crew departure to meet “by 2040” boots on Mars	Science Inspiration National Posture	Mission Time: 760d or less in Deep Space, fixed 50 sols in Mars Orbit, w/30 sols on Mars Surface (870-900 days total crew time off Earth)
Moderate Duration Moderate Energy Reference Mission 1		>75t Total Landed Payload Light Footprint: Plus leverage additional capacity if available				Mission Time: 850d in Deep Space, fixed 50 sols in Mars Orbit, w/30 sols on Mars Surface (960-1020 days total crew time off Earth)
Long Duration Minimum Energy Reference Mission 2		Mission Time: 950-1100d in Deep Space, no less than 50 sols in Mars Orbit, w/30 sols on Mars Surface (1090-1250 days total crew time off Earth)				

Figure 3-23. SAC22 Humans to Mars Reference Missions for Transportation System Assessments