EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION

Technology, Innovation, and Engineering Committee Report
NASA Advisory Council Meeting

Mr. Michael Johns | Committee Chairman | October 1, 2024

TI&E Committee Hybrid Meeting Attendees: Sept. 5, 2024

- Heshmat Aglan, Tuskegee University
- Mike Gazarik, University of Colorado (virtual)
- Michael Johns, Kratos SRE
- Rebecca Kramer Bottiglio, Yale University (virtual)
- Andrew Rush, Star Catcher
- Mitchell Walker, Georgia Institute of Technology

TI&E Committee Meeting Presentations: Sept. 5, 2024

- Welcome to NASA’s Glenn Research Center
  - Wanda Peters, Acting Deputy Director, NASA Glenn
- Space Technology Mission Directorate (STMD) Update
  - Clayton Turner, Acting Associate Administrator, STMD
- 2024 Shortfalls Ranking Process and Results Overview
  - Alesyn Lowry, Director for Strategic Planning and Integration, STMD
  - Michelle Munk, Acting Chief Architect, STMD
- NASA Nuclear Systems Update
  - Anthony Calomino, Space Nuclear Technologies Lead, STMD
  - Lindsay Kaldon, Fission Surface Power Project Manager, NASA Glenn
  - Kurt Polzin, Chief Engineer for NASA's Space Nuclear Propulsion Project, NASA Marshall
- Cryogenic Fluid Management Portfolio Update
  - Lauren Ameen, Deputy Manager, Cryogenic Fluid Management Portfolio Project, NASA Glenn
- Commercial Lunar Payload Services Intuitive Machines-2 Technology Demonstrations Overview
  - Mark Thornblom, Deputy Program Manager, Technical Integration Game Changing Development (GCD) program, NASA Langley
- Early Career Initiative presentation on Mitigating Arc Inception via Transformational Array Instrumentation (MAI TAI)
  - Meghan Bush, Principal Investigator, MAI TAI, NASA Glenn

National Aeronautics and Space Administration

NASA Glenn

For the Benefit of All

Dr. Wanda Peters

Acting Deputy Center Director

www.nasa.gov

National Aeronautics and
Space Administration

NASA Space Technology Update

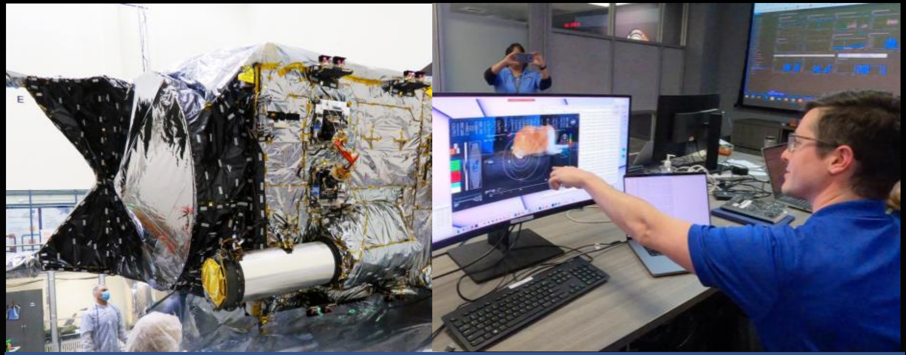
NAC TI&E Meeting

Clayton Turner

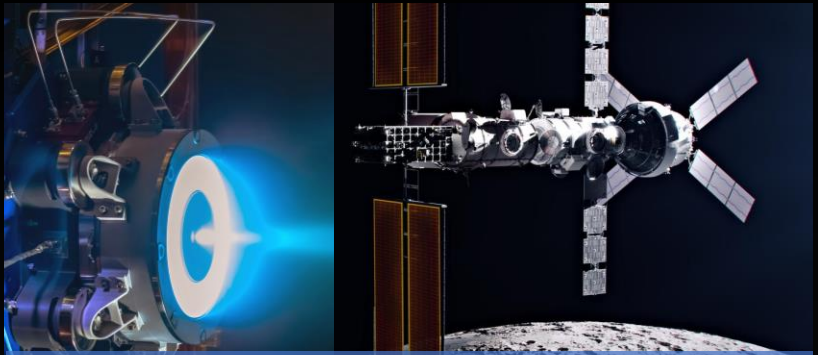
Associate Administrator (Acting),
NASA Space Technology Mission Directorate

September 5, 2024

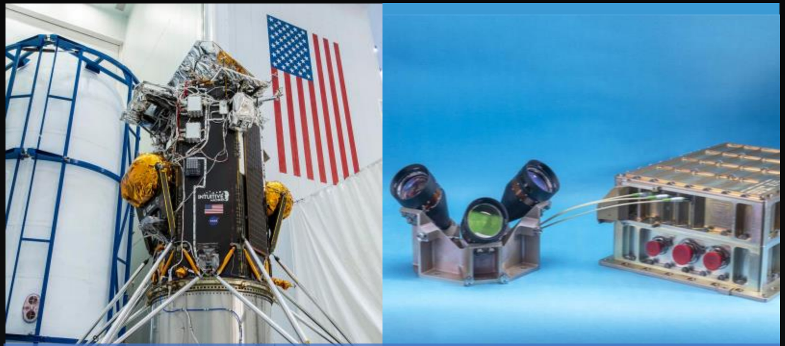
Recent Tech Highlights



Deep Space Optical Communications

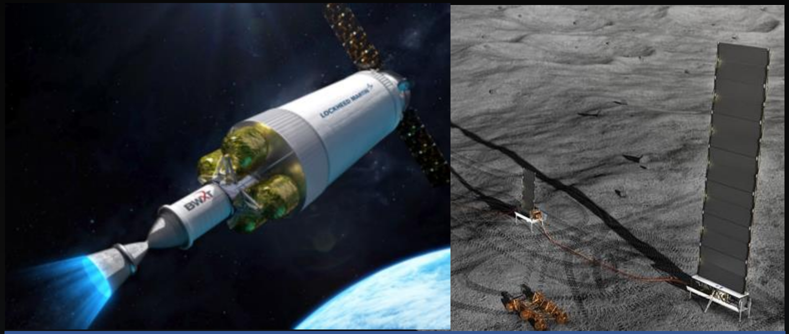


Solar Electric Propulsion



Intuitive Machines 1 CLPS Payloads

Cryogenic Fluid Management Demo



Space Nuclear Technologies

Starling Swarm Demo

Cooperative Robotic Scouts

Solar Sail Deployment

Flight Opportunities

National Aeronautics and
Space Administration

Civil Space Shortfall Ranking
NAC TI&E

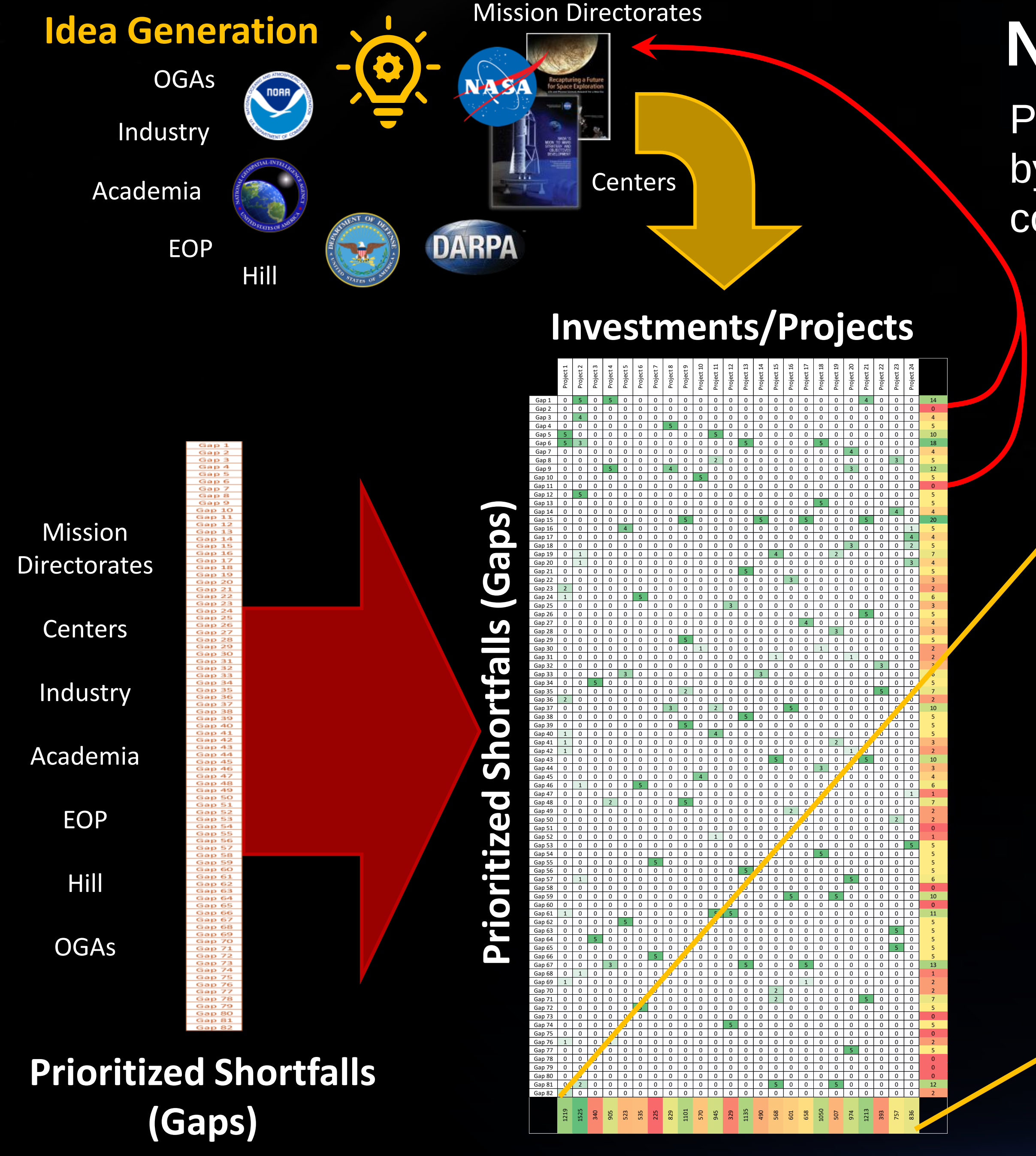
2024 Feedback Results

NASA's Space Technology Mission Directorate

September 5th, 2024

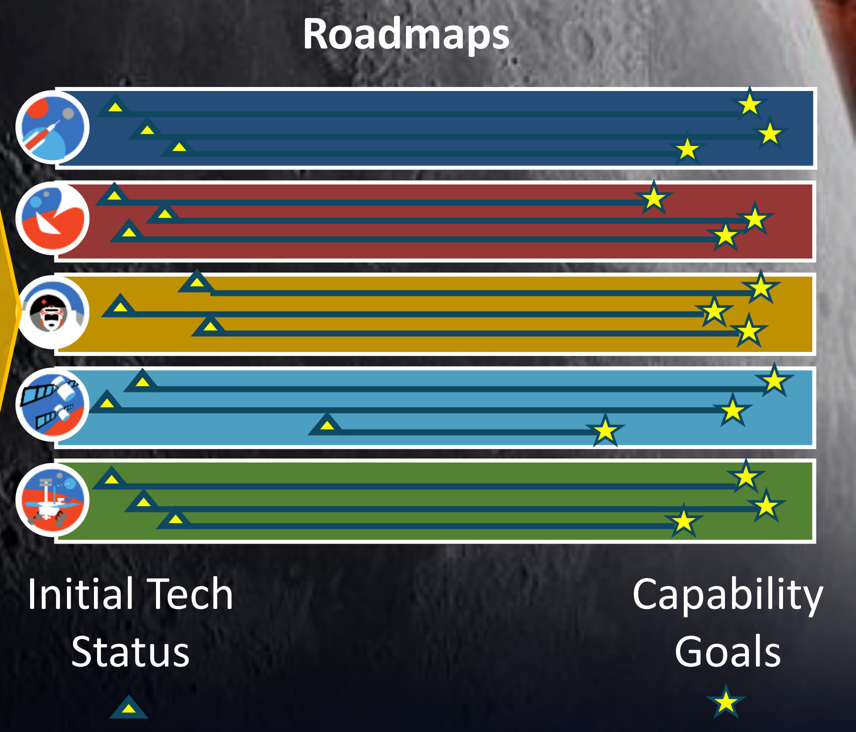
National Tech Base Priorities

Publicly-transparent, rigorously-developed process by which we establish our priorities based on comprehensive prioritized needs of our stakeholders



Projects

Project	
Project 2	1525
Project 1	1219
Project 21	1213
Project 13	1135
Project 9	1101
Project 18	1050
Project 20	974
Project 11	535
Project 4	905
Project 24	836
Project 8	393
Project 23	757
Project 17	658
$$$	
Project 16	601
Project 10	570
Project 15	568
Project 6	829
Project 5	523
Project 19	507
Project 14	490
Project 22	393
Project 3	340
Project 12	329
Project 7	225



Weighting Approach

- The integrated list utilized weights that reflect STMD's primary customers and their demand for future capabilities as well as other stakeholders' roles in partnering to provide solutions for such capabilities
- NASA inputs received $^{2}/_{3}$ of the overall weight and external scores received the remaining $^{1}/_{3}$
- STMD considered the following tenets of its investment strategy, in priority order, and developed the percentage weight for each stakeholder group
  1. Align with the Administration and the NASA Administrator's priorities that address the Blueprint Objectives (Artemis)
  2. Focus on investments that support science priorities identified in the Decadal Surveys
  3. Foster creation and growth of the space economy through partnering with industry and supporting small business innovation
  4. Engage NASA's workforce to deliver innovative solutions to the nation's toughest technology challenges
  5. Encourage transformative, cross-cutting technologies that benefit NASA as well as other government agencies
  6. Empower a broad community of innovators and academia through emphasis on early-stage investments

Integrated Top 30 Shortfalls Compared to Stakeholder Group Rank

Higher Ranking Shortfalls			>	Lower Ranking Shortfalls		
1	30	60	90	120	150	180

Not Ranked (NR)

Integrated Rank	Shortfall ID	Category	Stakeholder Group Rank								
			Academia	Small Industry	Large Industry	OGA	Other	NASA Centers	ESDMD	SMD	Other MDs
1	1618: Survive and operate through the lunar night	Thermal Management Systems	4	2	2	2	9	6	4	9	1
2	1596: High Power Energy Generation on Moon and Mars Surfaces	Power	13	1	1	40	20	4	21	NR	16
3	1554: High Performance Onboard Computing to Enable Increasingly Complex Operations	Avionics	80	28	21	27	13	3	34	1	56
4	1557: Position, Navigation, and Timing (PNT) for In-Orbit and Surface Applications	Communication and Navigation	9	11	15	29	67	10	28	NR	3
5	1545: Robotic Actuation, Subsystem Components, and System Architectures for Long-Duration and Extreme Environment Operation	Autonomous Systems and Robotics	34	27	28	63	10	40	13	9	49
6	1552: Extreme Environment Avionics	Avionics	176	49	6	38	23	54	6	9	62
7	1519: Environmental Monitoring for Habitation	Advanced Habitation Systems	20	101	72	75	61	49	17	19	13
8	709: Nuclear Electric Propulsion for Human Exploration	Propulsion: Nuclear	43	131	23	4	52	32	7	NR	7
9	1304: Robust, High-Progress-Rate, and Long-Distance Autonomous Surface Mobility	Autonomous Systems & Robotics	27	42	30	121	91	34	25	25	66
10	1520: Fire Safety for Habitation	Advanced Habitation Systems	23	24	78	12	12	12	29	55	14
11	1531: Autonomous Guidance and Navigation for Deep Space Missions	Autonomous Systems & Robotics	47	67	24	3	89	42	64	23	15
12	1591: Power Management Systems for Long Duration Lunar and Martian Missions	Power	40	12	10	52	24	68	35	NR	27
13	702: Nuclear Thermal Propulsion for Human Exploration	Propulsion: Nuclear	36	114	36	14	78	62	7	NR	11
14	1559: Deep Space Autonomous Navigation	Communication and Navigation	62	129	27	5	120	38	64	23	10
15	1527: Radiation Countermeasures (Crew and Habitat)	Advanced Habitation Systems	5	23	22	6	2	5	63	NR	6
16	1526: Radiation Monitoring and Modeling (Crew and Habitat)	Advanced Habitation Systems	6	53	41	81	1	13	27	38	35
17	879: In-space and On-surface, Long-duration Storage of Cryogenic Propellant	Cryogenic Fluid Management	21	37	3	95	22	1	59	NR	2
18	1548: Sensing for Autonomous Robotic Operations in Challenging Environmental Conditions	Autonomous Systems & Robotics	42	17	26	90	16	44	14	26	57
19	1558: High-Rate Communications Across The Lunar Surface	Communication and Navigation	25	73	29	77	162	20	5	NR	51
20	1626: Advanced Sensor Components: Imaging	Sensors and Instruments	18	75	12	45	160	22	NR	18	68
21	792: In-space and On-surface Transfer of Cryogenic Fluids	Cryogenic Fluid Management	17	29	4	51	26	2	62	NR	29
22	1569: High-Mass Mars Entry and Descent Systems	Entry Descent and Landing	152	156	48	117	5	33	16	NR	12
23	1525: Food and Nutrition for Mars and Sustained Lunar	Advanced Habitation Systems	8	32	116	41	45	30	11	NR	58
24	1571: Navigation Sensors for Precision Landing	Entry Descent and Landing	14	62	37	23	4	31	45	28	9
25	1573: Terrain Mapping Capabilities for Precision Landing and Hazard Avoidance	Entry Descent and Landing	30	31	9	12	8	11	45	28	53
26	1562: Advanced Algorithms and Computing for Precision Landing	Entry Descent and Landing	54	65	45	23	3	25	45	28	8
27	1597: Power for Non-Solar-Illuminated Small Systems	Power	85	26	5	39	125	47	93	12	20
28	1568: Entry Modeling and Simulation for EDL Missions	Entry Descent and Landing	101	115	76	60	15	50	45	5	45
29	1516: Water and Dormancy Management for Habitation	Advanced Habitation Systems	49	98	127	158	53	69	26	51	22
30	1524: Crew Medical Care for Mars and Sustained Lunar	Advanced Habitation Systems	12	64	94	1	11	21	58	NR	17

ESDMD and SMD provided ranked lists (numbers shown above) in addition to shortfall scores (used for integrated list).
ESDMD and SMD did not score all shortfalls. Unscored shortfalls were also not ranked.

National Aeronautics and Space Administration

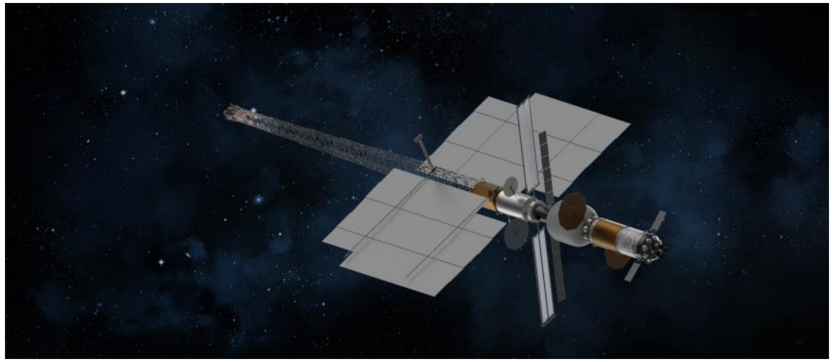
Nuclear Electric Propulsion

Space Technology Mission Directorate
Space Nuclear Propulsion
Dr. Kurt Polzin, SNP Chief Engineer | 9/5/2024

Challenges for Nuclear Electric Propulsion (NEP)

The need for coordinated, realistic technology maturation

For high-power NEP



NASA Engineering & Safety Center Findings[1]

- The majority of critical technologies for NEP systems are relatively immature.
- TRLs in the literature are often overestimated and a proper baseline assessment to gauge resources required for advancement has been a consistent issue.
- The majority of critical technologies are at a relatively high level of advancement degree of difficulty (AD2 > 4) for maturation, strongly suggesting use of a dual development approach.
- Non-advocate reviews should occur at the start of a technology program and at all key milestones.

National Academies of Science, Engineering, and Medicine Findings[2]

- For NEP systems, the fundamental challenge is to scale up the operating power of each NEP subsystem and to develop an integrated NEP system suitable for the baseline mission. This requires, for example, scaling power and thermal management systems to power levels orders of magnitude higher than have been achieved to date.
- There has been, low, intermittent, and unfocused investments over the past several decades
- Regarding Hall thrusters and scaling to 100 kW_e thrusters: "... although ground testing of high-power Hall thrusters has revealed that interactions between the test facility, the thruster, and its conducting plasma plume can impact the performance and lifetime measurements in ways that are not fully understood as of this writing."

[1] *Independent Assessment of the Technical Maturity of Nuclear Electric Propulsion (NEP) and Nuclear Thermal Propulsion (NTP) Systems*, NASA Engineering & Safety Center, 2020

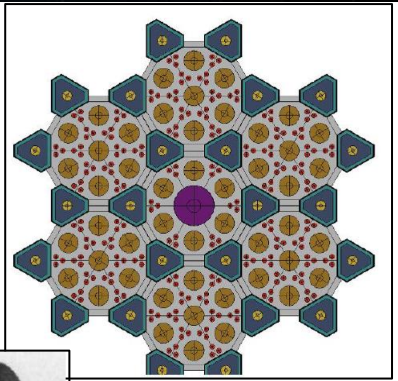
[2] *Space Nuclear Propulsion for Human Mars Exploration*, National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., 2021. DOI: 10.17226/25977

There are recognized challenges to developing an NEP system

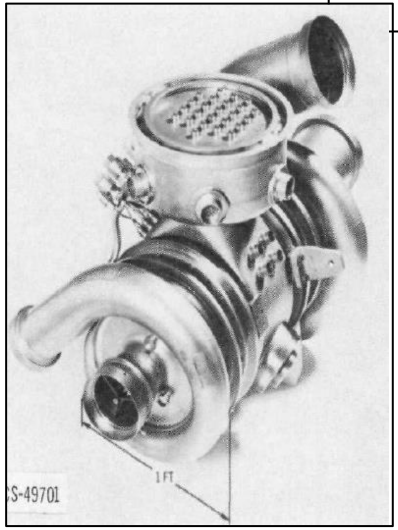
NEP Technology Maturation

Improve Both Low and High-Power Cases

National Academies of Science, Engineering, and Medicine Recommendation[2]



- Subscale in-space flight testing of NEP systems cannot address many of the risks and potential failure modes associated with the baseline mission NEP system. With sufficient M&S [modeling & simulation] and ground testing, **including modular subsystem tests at full scale and power**, flight qualification requirements can be met by the cargo missions that will precede the first crewed mission to Mars. Fully integrated ground testing may not be required." [emphasis added]



- NASA tech maturation plan developed to guide investments

  Key to plan is building and testing hardware **<u>at power and scale</u>**
  - High temperature reactor components/heat extraction methods (SNP-funded effort)
  - High temperature Brayton (FSP-funded effort)
  - High temperature-capable electrical generator (SNP-funded effort)
  - Pushing limits on radiator temperatures (Two SNP-funded efforts through SBIR Phase III's)

- Leveraging other investments
  - Electric aircraft (power handling), additive manufacturing (complex structures/heat exchangers), terrestrial microreactors (HALEU-fueled power reactor technology), NTP high-temperature nuclear materials (SNP-funded)

Funding tech maturation activities & leveraging other activities (FSP and others) to make progress through hardware fabrication and demonstration

TI&E Committee Finding on NEP

Short Title of Finding:

Finding:

The Committee has been following the nuclear propulsion portfolio with great interest and has encouraged a balanced portfolio of investments between NTP and NEP. The committee notes the significant progress with NTP and the DRACO partnership and commends STMD for increasing funding of NEP, consistent with NAS recommendations, to address the Critical Technology Elements necessary for the NEP architecture.

CRYOGENIC FLUID MANAGEMENT PORTFOLIO PROJECT (CFMPP)

Project Update for the NASA Advisory Council (NAC)

Technology, Innovation and Engineering (T&IE) Committee

Lauren M. Ameen

Deputy Project Manager

NASA Glenn Research Center

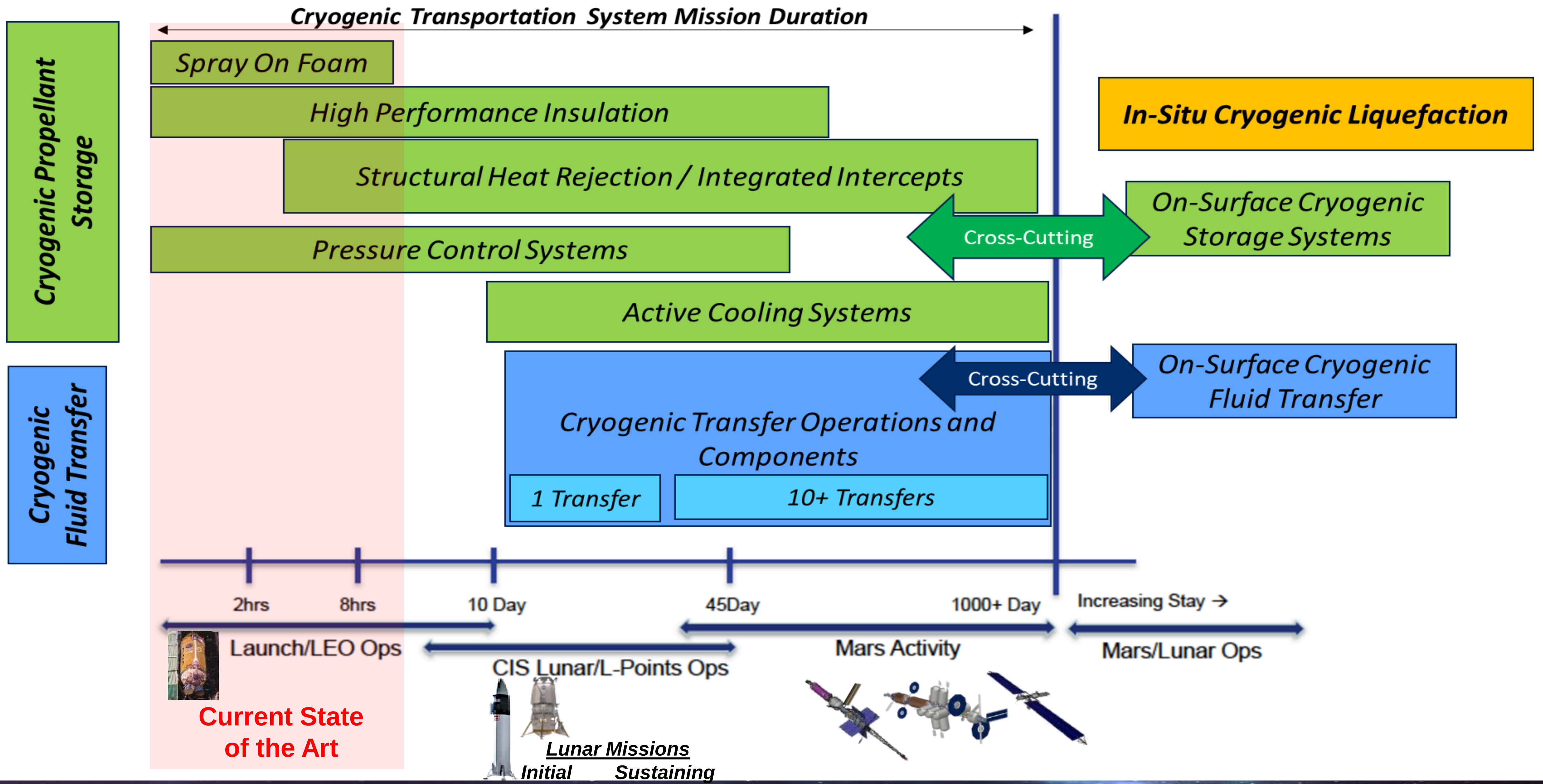
September 5, 2024

Cryogenic Fluid Management Technology Pulls

Photo Credit: NASA

- **Interest for cryogenic propulsion systems is nearing an all-time high across both the government and industry**
- **Moon to Mars will push cryogenic mission durations from months to years**
- **Enabling CFM technologies at TRL ≥ 6 for Mars and Cis-lunar transportation, ISRU, and Surface Systems operations are required for the Moon to Mars Campaign**
  - Advanced cryogenic propellant storage and transfer integrated systems, operable in microgravity environments, are required for **all** proposed mission architectures
- **Increasing cryogenic mission duration drives the need for more advanced CFM technology**
  - Current CFM capabilities support missions on the order of days

CFM Technology Capability Needs



Cryogenic Fluid Management Portfolio Project (CFMPP)

System Demonstration Complexity

Technologies Portfolio

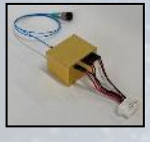
Scope: Design, development, testing, and evaluation of critical-need cryogenic components enabling long-duration CFM storage and propellant transfer

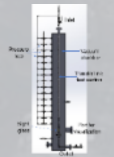
Major Activities:

Hydrogen low-leakage valves and cryo-couplers

Radio Frequency Mass Gauge (RFMG)

Next-generation FOSS (fiber optics sensing system)



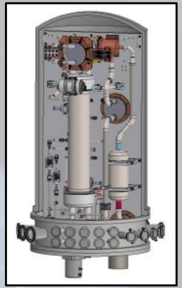


Reduced Gravity Cryogenic Transfer (RGCT)

Subsystems Portfolio

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

Major Activities:

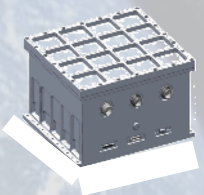


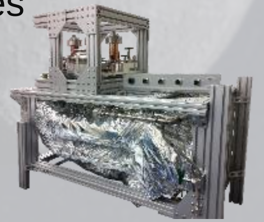
20W/20K Cryocooler

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

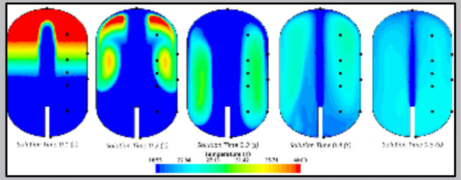
Two-Stage Cooling Demonstration

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

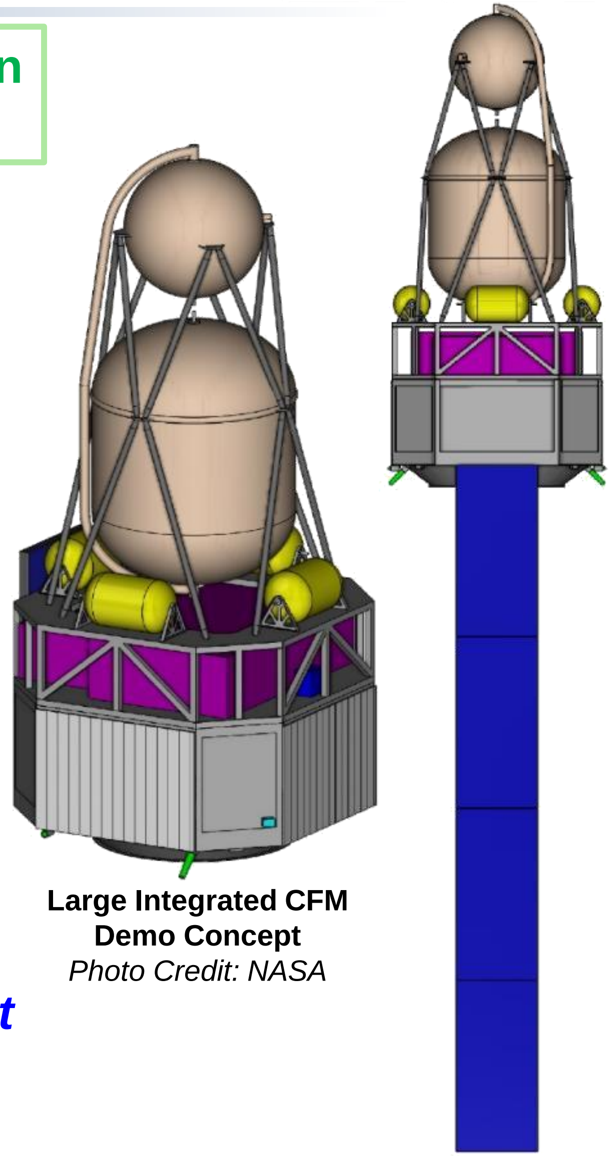


System Validation

CFMPP Approach for Integrated Flight Demonstration

Integrated system-level microgravity flight demo must be conducted to buy-down technical risk (increase TRL) for future long-duration cryogenic missions

- **CFMPP has been developing the gov't reference concept mission and requirements supporting remaining technology shortfall closure**
  - Mission pull need in the mid-2030s, with intent to build-upon cislunar CFM advancements
- **Demo concept defines appropriate scale and operational duration required to provide sufficient data enabling TRL 6+ maturation**
  - CFMPP has baselined LH2 cryogen for demonstration → maximized cross-cutting technology gap closure to LO2/LCH4 systems
- **Concept Highlights:**
  - Large LH_2 Flight Demonstrator, Class D Mission
  - Mission lasts up to 8 months, providing flight data critical for design model validation
  - Integrated cryogenic demo mission phases will include:
    - Cryogenic active and passive storage operations
    - Cryogenic transfer system operations
- ***CFMPP will continue Pre-Formulation of Government reference mission concept scope in FY25 while establishing budget baseline with STMD***



Large Integrated CFM Demo Concept
Photo Credit: NASA

TI&E Committee Finding on CFM Flight Experiment

Short Title of Finding:

Finding: The Committee recognizes enabling CFM technologies at TRL ≥ 6 for Mars and Cis-lunar transportation, ISRU, and Surface Systems operations are required for the Moon to Mars Campaign. STMD has been advancing the CFM portfolio through tipping points and other STMD programs. The Committee encourages and supports STMD moving forward with the necessary flight demo(s) to mature this capability as soon as budget allows.

National Aeronautics and
Space Administration

Commercial Lunar Payload Services
Intuitive Machines-2
Technology Demonstrations Overview

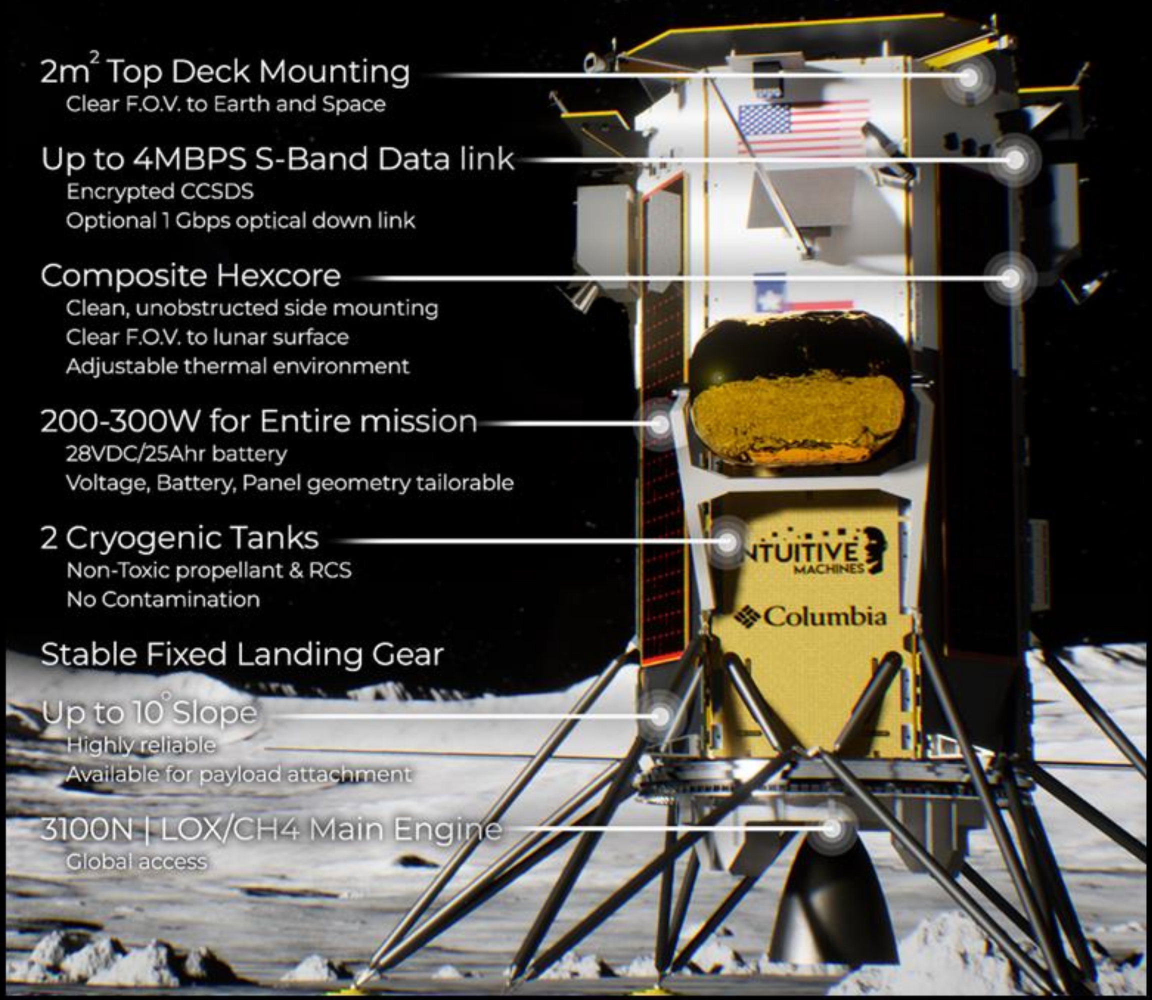
Technology, Innovation and Engineering (TI&E) Committee

Open Session

Mark Thornblom
Game Changing Development
Space Technology Mission Directorate
Deputy Program Manager, Integration
09.05.24

Intuitive Machine NOVA-C Mission Profile

IM NOVA-C Lander



NOVA-C Capabilities as a Service

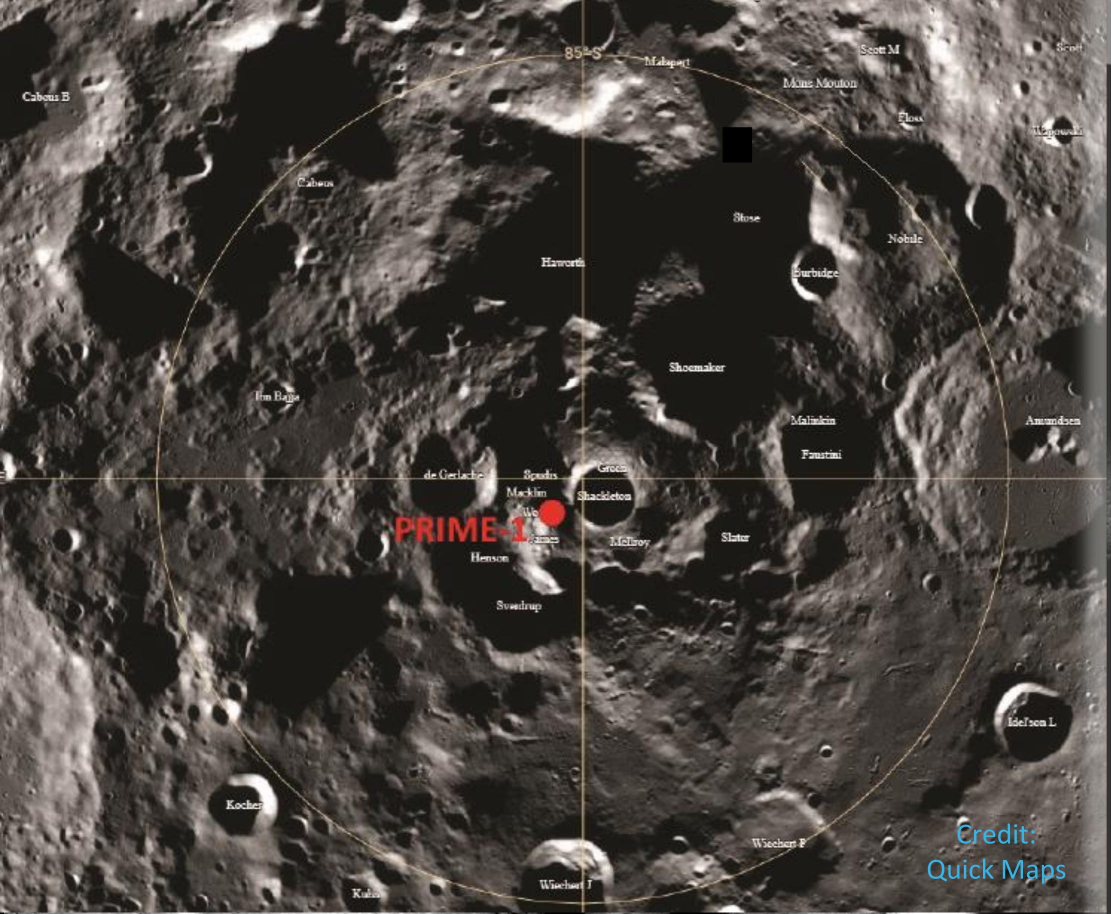
Landing Location	Nova-C	Nova-D	Nova-M*
Equatorial	130-250 kg	500-2500 kg	5,000-10,000 kg
South Pole	130-250 kg	500-2500 kg	5,000-10,000 kg
North Pole	130-250 kg	500-2500 kg	5,000-10,000 kg

	MAPP Rover	µNova Hopper	µNova-LX Hopper
Range (Max Distance from Lander)	2.5 km	25 km	25 km
Payload Mass	5 kg	1 kg	8 kg

Source: Intuitive Machines Lunar Access Services User's Guide- www.intuitivemachines.com

IM-2 NASA Payloads Overview

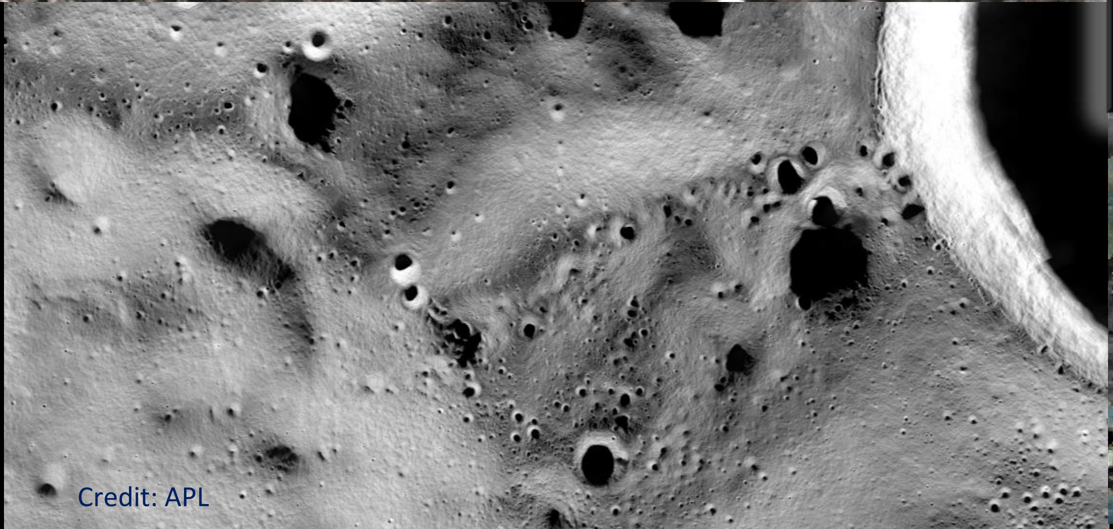
IM-2 Mission planned for FY25 Quarter 1

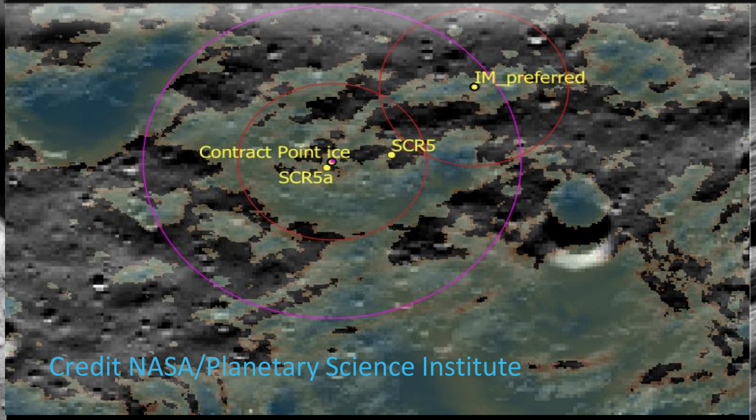


Credit: Quick Maps

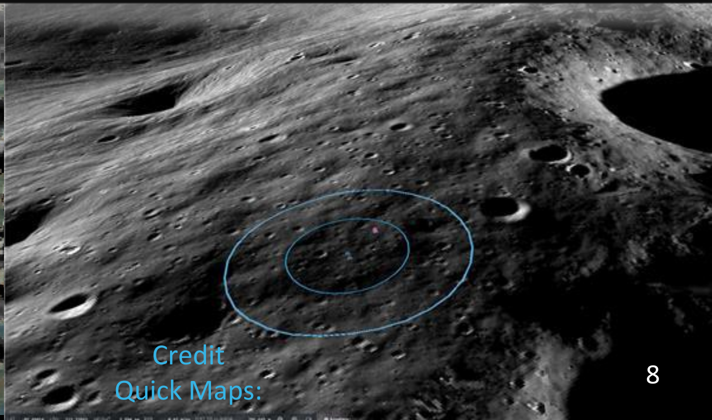
Click image to play video

Credit: APL:

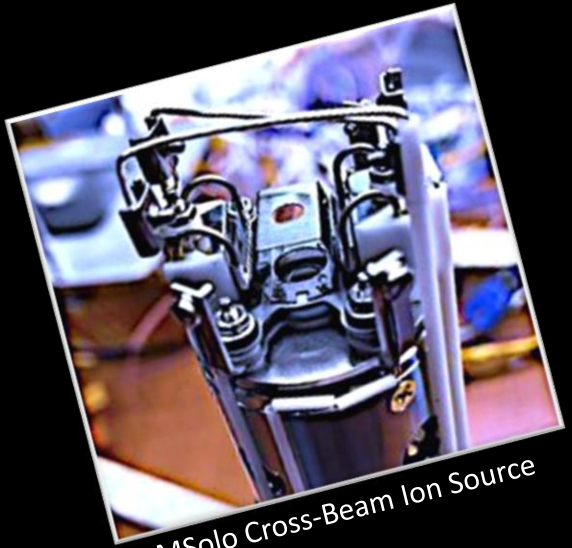

Credit: APL



Credit NASA/Planetary Science Institute


Credit Quick Maps:

PRIME-1


MSolo Cross-Beam Ion Source


TRIDENT Drill Tip

PRIME-1 is the combination of two high-TRL instruments; Mass Spectrometer observing lunar operations (MSolo) and The Regolith and Ice Drill for Exploring New Terrain (TRIDENT). PRIME-1 will drill at a south pole lunar landing location where orbiting assets indicate the potential to find water ice. PRIME-1's MSolo instrument will analyze for volatiles present in lunar regolith down across a one-meter vertical profile. Demonstration of the PRIME-1 system will buy down engineering risk to the VIPER mission

https://twitter.com/NASAMoon/status/1471889928762109953

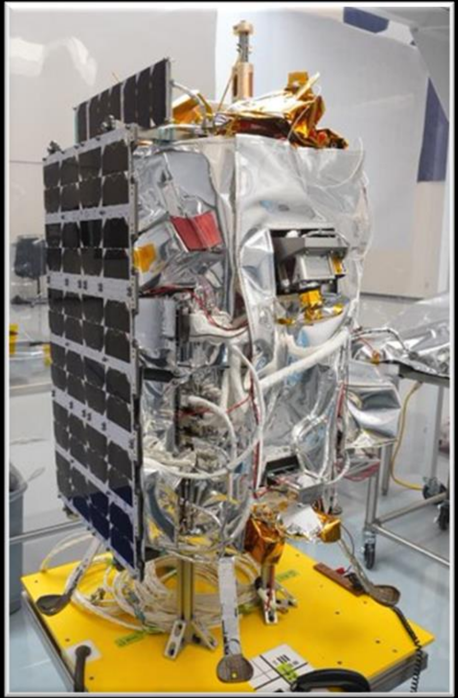
Objective #1	TRIDENT will drill into the lunar subsurface up to a meter deep and deliver regolith cuttings to the surface for water and other volatiles evaluation by MSolo
Objective #2	MSolo will measure within its field of view, the composition of gases emanating near the TRIDENT drill before, during and after drilling activities


PRIME-1 Hardware Integrated to NOVA-C Spacecraft panel ready for installation

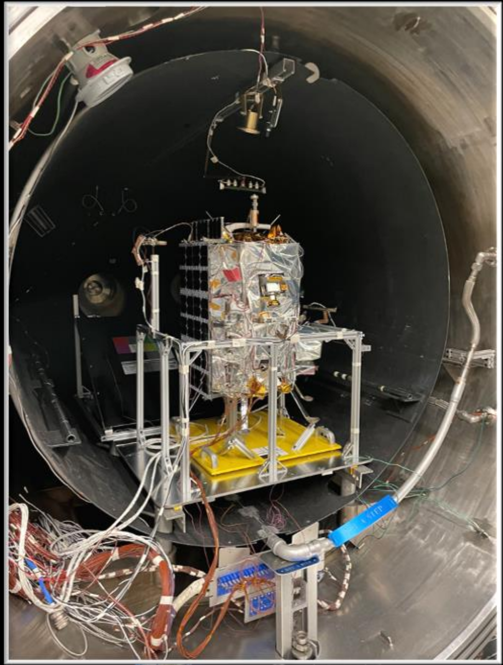
Lunar Deployable Hopper Tipping Point

The lunar deployable hopper project will develop and demonstrate a small robotic hopper, deployed as a secondary payload from the IM-2 Nova-C lander, that can provide access to extreme environments and locations of interest on the lunar surface. μNova Hopper is designed to hop into and out of permanently shadowed regions (PSRs), providing a first look into undiscovered regions that may provide the critical science needed to sustain human presence on the Moon. This demonstration drives a commercial venture for IM and helps establish a space economy ecosystem economy.

https://www.youtube.com/watch?v=Ckcrn1btv8M



μNova Hopper vehicle on test stand



μNova tested in a TVAC Chamber

Objective #1	Enable robotic access to extreme lunar environments for scientific exploration
Objective #2	Enable regional exploration of wider areas than small rovers or other mobility platforms can cover

Nokia LTE Tipping Point

The overall goal of the LTE-TP project is to revolutionize lunar surface communications by leveraging advances in terrestrial communications technology to both improve the quality of communications (lower power, better range, higher bandwidth) while simultaneously reducing cost and providing an on-going commercial communication solution for the lunar economy (both surface and orbital). Future uses of the LTE network will be utilized for both human and robotic missions.

MAPP rover testing with LTE

Objective #1	Adapting Nokia's LTE technology for the lunar demonstration.
Objective #2	Integrate and test Nokia's LTE technology on Intuitive Machines (IM)s Nova-C lander/rover.
Objective #3	Demonstrate Nokia’s LTE technology on the lunar surface at short and long range
Objective #4	Provide a post mission lunar propagation model based on the lunar surface test results

Flight Hardware Integration with IM-2 lander

MAI TAI

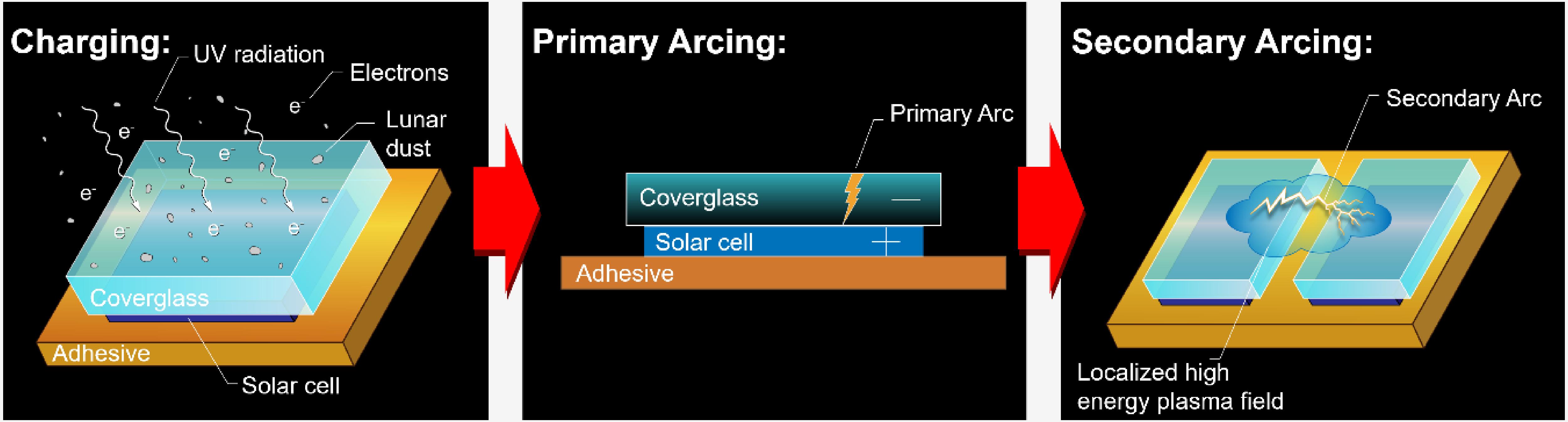
Mitigating Arc Inception via Transformational Array Instrumentation

Meghan Bush, NASA GRC, Photovoltaics and Electrochemical Systems Branch

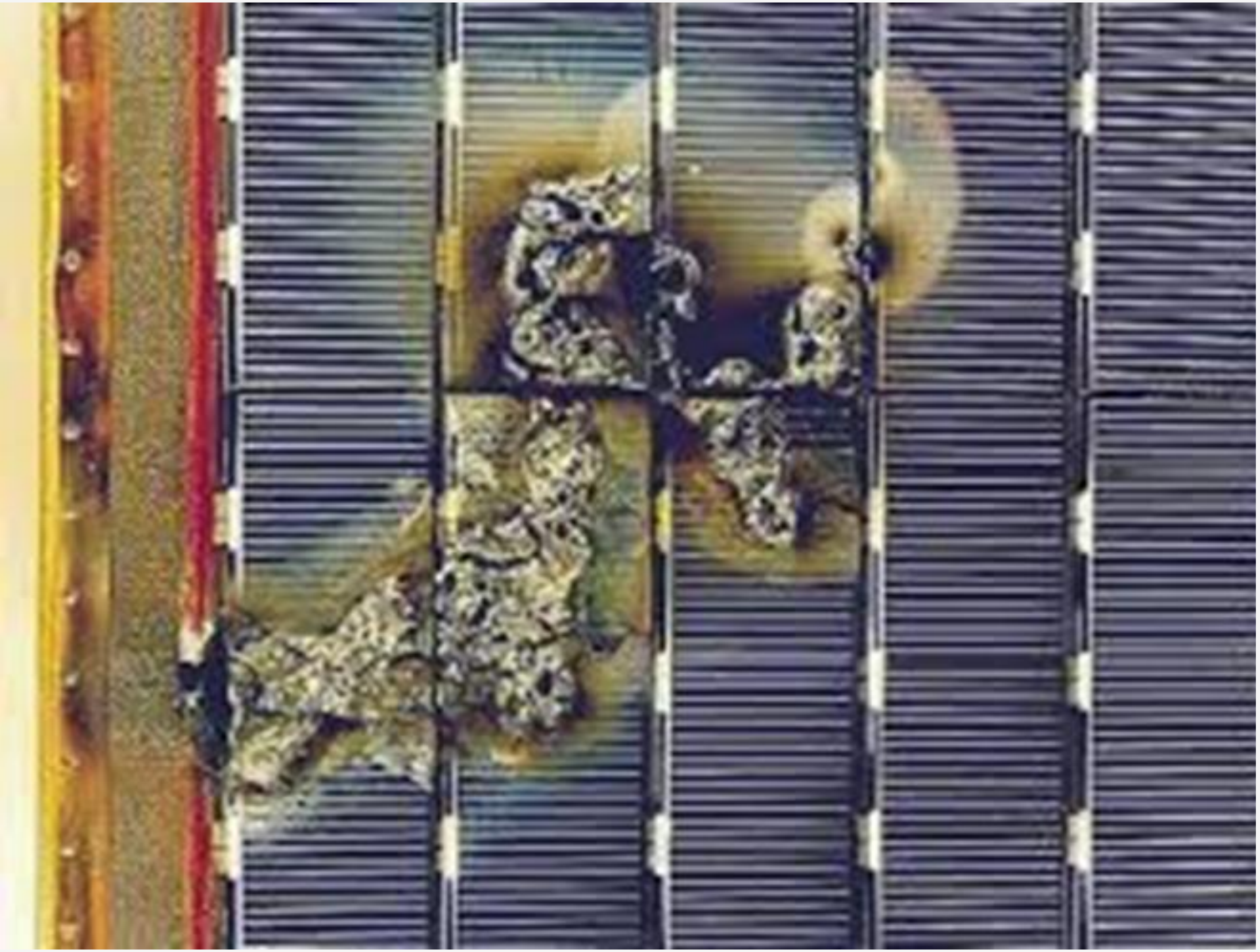
NAC Technology, Innovation, and Engineering Meeting

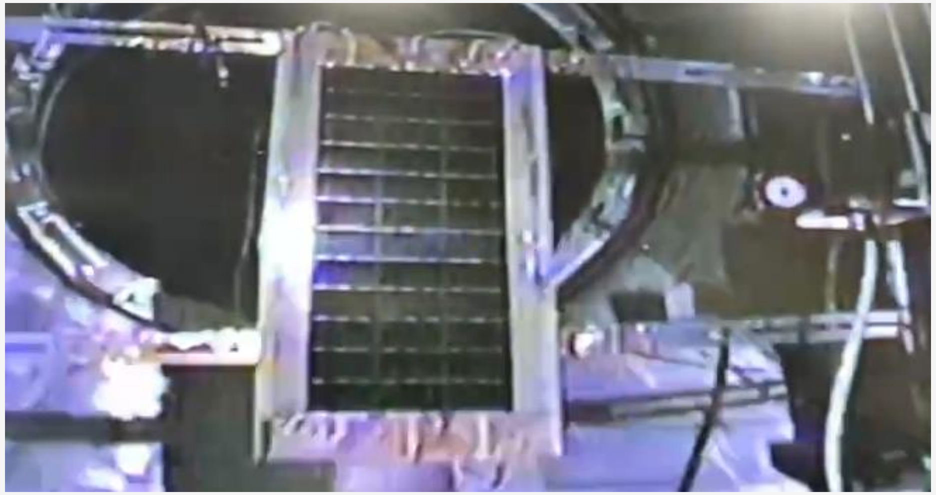
September 5, 2024

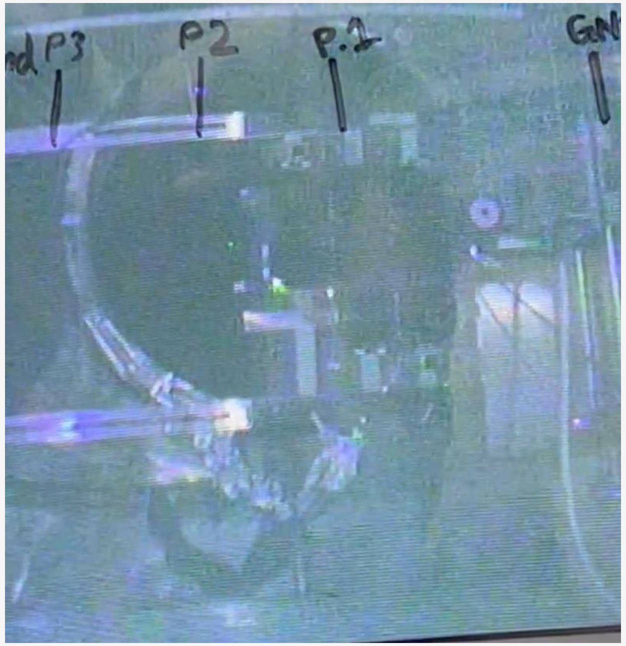
Spacecraft Charging



Secondary Arcing







slow motion

real time