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

Mr. Michael Johns | Committee Chairman | August 10, 2022

TI&E Committee Scope

“The scope of the Committee includes all NASA programs focused on technology research, innovation, and engineering.”

–NAC Committee on Technology, Innovation, and Engineering Terms of Reference

TI&E Committee Hybrid Meeting Attendees: KSC, Aug. 2-3, 2022

- Mike Gazarik, Ball Aerospace
- Kathleen C. Howell, Purdue University (virtual)
- Michael Johns, Kratos SRE
- Rebecca Kramer Bottiglio, Yale University (virtual)
- Andrew Rush, Redwire
- Brad Tousley, Raytheon
- Mitchell Walker, Georgia Institute of Technology
- Mary Ellen Weber, Stellar Strategies, LLC

TI&E Committee Tour of KSC: Aug. 2, 2022

- Applied Physics Lab & Applied Chemistry Lab
- Blue Origin Factory
- SpaceX Hangar X
- Artemis-1 at VAB
- ULA’s Horizontal Integration Facility

TI&E Committee Hybrid Meeting Presentations: Aug. 3, 2022

- Welcome to Kennedy Space Center
  - Ms. Janet Petro, Director, Kennedy Space Center
- Space Technology Mission Directorate (STMD) Update
  - Jim Reuter, Associate Administrator, STMD
- NASA Nuclear Systems Update
  - Dr. Anthony Calomino, Space Nuclear Technologies Lead, STMD
- Early Career Initiative Overview and Researcher Presentation
  - Ms. Jenn Gustetic, Director, Early Stage Innovations & Partnerships, STMD
  - Dr. Chris Biagi, Principal Investigator for the Capacitive Mass Gauging for Cryogenic Fluids in Micro-G (CAPMAG) project
- 2016 Space Technology Research Institutes Updates
  - Synthetic Biology/The Center for the Utilization of Biological Engineering in Space (CUBES), Dr. John Hogan, Program Manager, Ames Research Center
  - The Institute for Ultra-Strong Composites by Computational Design (US-COMP), Dr. Emilie Siochi, Program Manager, Langley Research Center
- Office of Technology, Policy, and Strategy (OTPS) Update
  - Dr. Bhavya Lal, Associate Administrator, OTPS
- Update on Moon to Mars Blueprint
  - Mr. Walt Engelund, Deputy AA for Programs, STMD

SPACE TECHNOLOGY PORTFOLIO

EARLY STAGE INNOVATION AND PARTNERSHIPS

- Early Stage Innovation
  - Space Tech Research Grants
  - Center Innovation Fund
  - Early Career Initiative
  - Prizes, Challenges & Crowdsourcing
  - NASA Innovation Advanced Concepts
- Technology Transfer

SBIR/STTR PROGRAMS

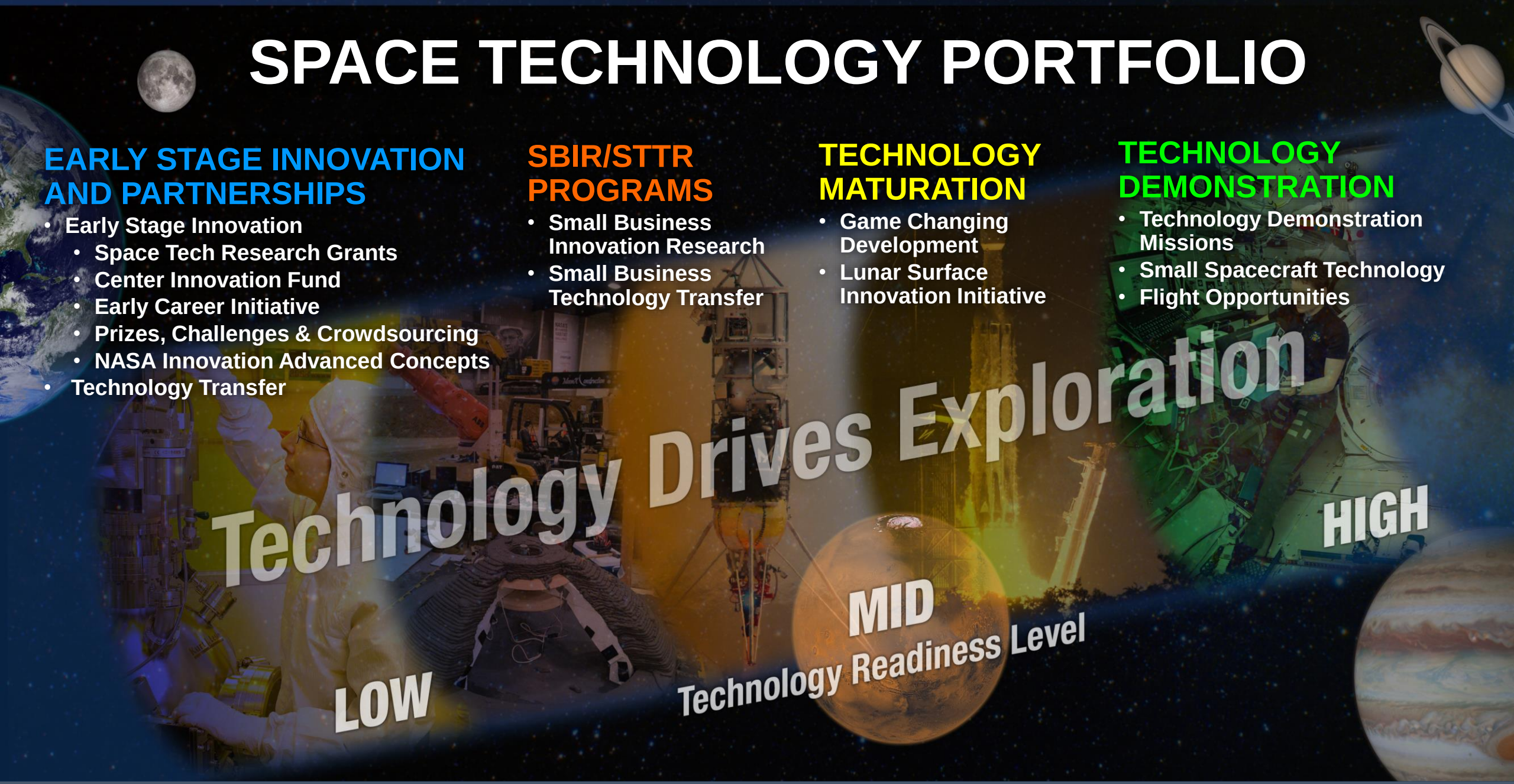
- Small Business Innovation Research
- Small Business Technology Transfer

TECHNOLOGY MATURATION

- Game Changing Development
- Lunar Surface Innovation Initiative

TECHNOLOGY DEMONSTRATION

- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities



Sustainable Exploration of Moon and Mars | Transformative Crosscutting Technologies | Economic Development and National Presence | Climate Change Technologies | Diversify and Inspire

STMD Strategic Framework

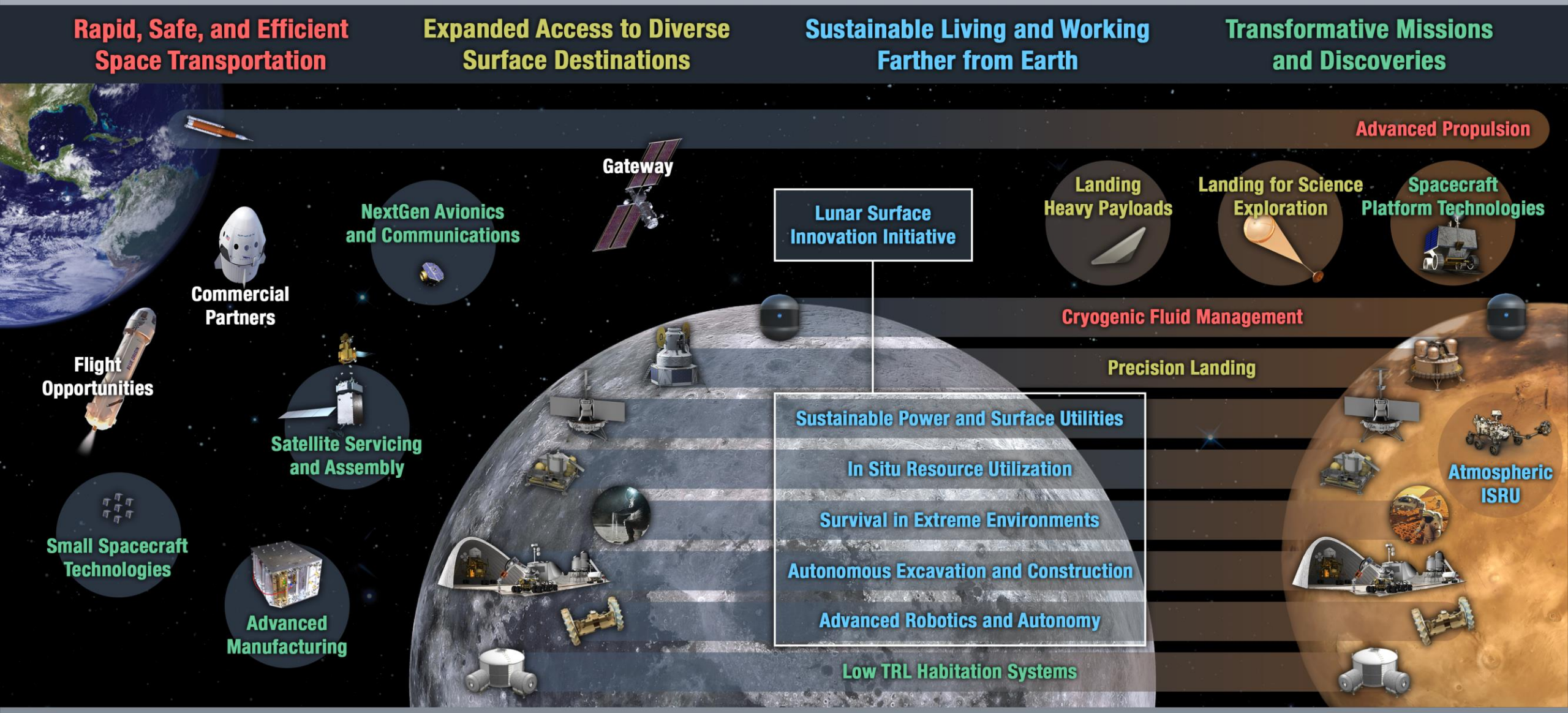
STMD rapidly develops, demonstrates, and transfers revolutionary, high pay-off space technologies, driven by diverse ideas

Lead	Thrusts	Outcomes	Primary Capabilities
Ensuring American global leadership in Space Technology • Advance US space technology innovation and competitiveness in a global context • Encourage technology driven economic growth with an emphasis on the expanding space economy • Inspire and develop a diverse and powerful US aerospace technology community	***Transforming Space Missions***		
	 **Go** Rapid, Safe, and Efficient Space Transportation	• Develop nuclear technologies enabling fast in-space transits. • Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications. • Develop advanced propulsion technologies that enable future science/exploration missions.	• Nuclear Systems • Cryogenic Fluid Management • Advanced Propulsion
	 **Land** Expanded Access to Diverse Surface Destinations	• Enable Lunar/Mars global access with ~20t payloads to support human missions. • Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies. • Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards.	• Entry, Descent, Landing, & Precision Landing

	 **Live**
	Sustainable Living and Working Farther from Earth
		• Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities
		  • Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations.
		  • Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar & Mars surface.
		  • Technologies that enable surviving the extreme lunar and Mars environments.
		  • Autonomous excavation, construction & outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in situ resources.
		• Enable long duration human exploration missions with Advanced Habitation System technologies. [Low TRL STMD; Mid-High TRL SOMD/ESDMD]
			• Advanced Power
			• In-Situ Resource Utilization
			• Advanced Thermal
			• Advanced Materials, Structures, & Construction
			• Advanced Habitation Systems

	 **Explore** Transformative Missions and Discoveries	• Develop next generation high performance computing, communications, and navigation. • Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions. • Develop technologies supporting emerging space industries including: Satellite Servicing & Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies. • Develop vehicle platform technologies supporting new discoveries. • Develop technologies for science instrumentation supporting new discoveries. [Low TRL STMD/Mid-High TRL SMD. SMD funds mission specific instrumentation (TRL 1-9)] • Develop transformative technologies that enable future NASA or commercial missions and discoveries	• Advanced Avionics Systems • Advanced Communications & Navigation • Advanced Robotics • Autonomous Systems • Satellite Servicing & Assembly • Advanced Manufacturing • Small Spacecraft • Rendezvous, Proximity Operations & Capture • Sensor & Instrumentation

Ensuring American Global Leadership in Space Technology



Technology Drives the Space Economy

Envisioned Future Priorities RFI Milestones

- **Completed:**
  - GO RFI – Closed on May 31
  - LIVE RFI – Closed on June 23

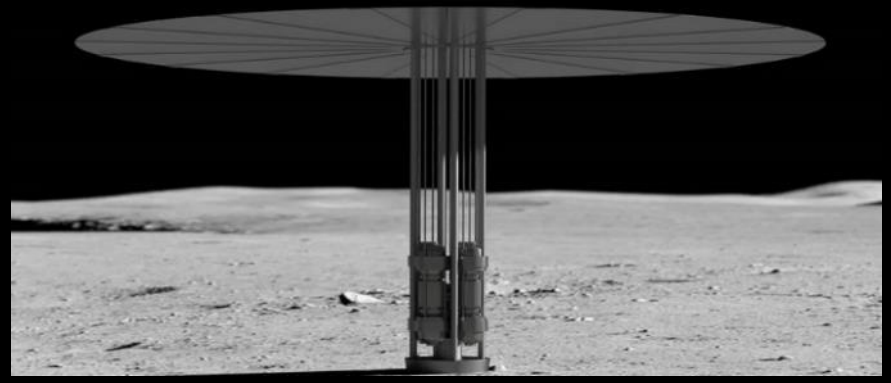
- **Upcoming:**
  - LAND and EXPLORE RFI – Opening on August 25, closing October 6
  - AIAA ASCEND – October 24-26
    - October 24
      - Luncheon lecture/fireside chat (60 minutes) on the State of NASA Space Technology; overview of the Strategic Framework
      - Afternoon Breakout Sessions with Principal Technologists and System Capability Leads; roundtable discussions on Envisioned Future Priorities
    - October 26
      - The Value of In-Space Servicing, Assembly, and Manufacturing (ISAM) for Space Sustainability panel
      - Technology at a Tipping Point: Cryogenic Fluid Management panel
      - Entry, Descent, and Landing Technologies for Human Missions to Mars panel

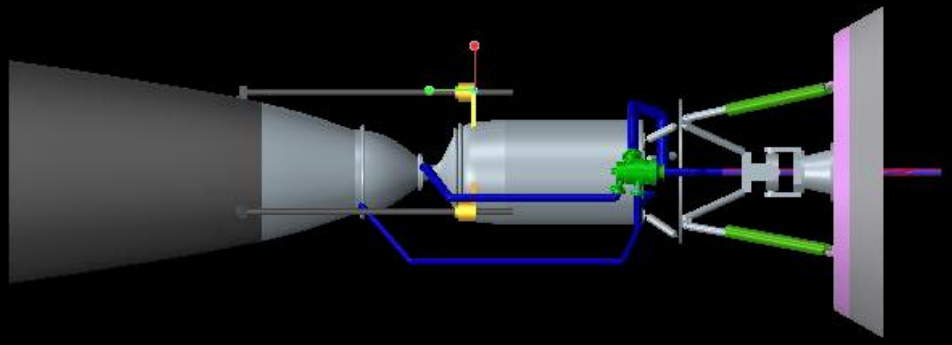
FY 2022 & FY 2023 Budget and Appropriations Status

FY 2022 STMD Appropriations	FY 2022				FY 2023		
	FY 2022 PBR	House Proposal	Senate Proposal	Enacted	FY 2023 PBR	House Proposal	Senate Proposal
OSAM-1 (Restore and SPIDER)	227	227	227	227	227	227	227
Nuclear Thermal Propulsion*	60	110	110	110	70	110	110
*NTP Flight**	*30*	*80*	*80*	*80*	*40*	*80*	
Reactor Development							*45*
Fuel Materials Development							*45*
NTP Foundational & Non-nuclear Systems Development	*30*	*10*	*30*	*30*	*30*	*30*	*20*
SBIR/STTR Statutory Requirements**	287	262	256	227	285	285	285
All other directions	146	177	148	148	190	204	193
Nuclear Electric Propulsion							
Regional Economic Development***							
Flight Opportunities							
Innovative Nanomaterials							
On-Surface Manufacturing Capabilities							
Additive Manufacturing Capabilities							
Moon-to-Mars Landing Demonstrations***							
Lunar Surface Power (FSP & VSAT)							
Large Orbital Debris Remediation							
Remaining STMD Programmatic Content	705	504	509	388	666	424	449
Total	**1,425**	**1,280**	**1,250**	**1,100**	**1,438**	**1,250**	**1,264**

*Includes CFM
**To be refined upon completion of OCFO extramural R&D calculation
***Activities across STMD portfolio

Space Nuclear Fission Technology Portfolio





Fission Surface Power

- Enable sustained, long-duration lunar operations
- Establish an evolvable system for the Moon and Mars

Space Nuclear Propulsion

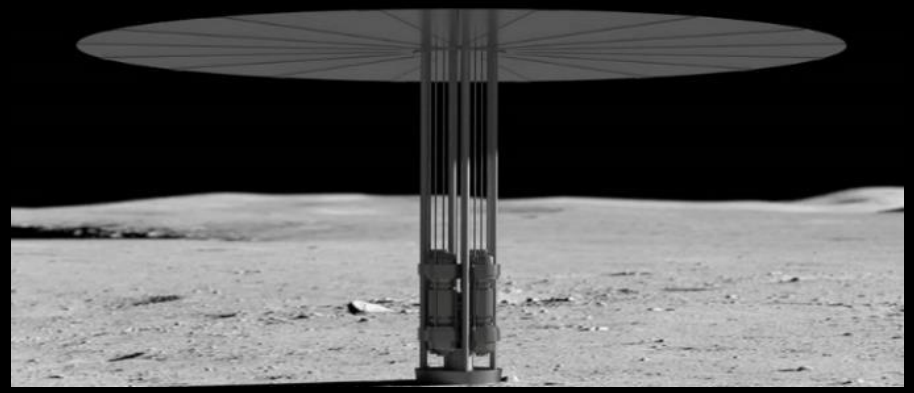
- Advance a fast transit, in-space, nuclear propulsion capability
- Evaluating nuclear thermal propulsion (NTP) and nuclear electric propulsion (NEP) options

NASA's priority remains surface fission power for lunar operations

Fission Surface Power Two Phase Acquisition Strategy

Phase 1

- Announced three $5M industry solicitation awards on June 21, 2022
  1. Lockheed Martin
     - Partnering with BWXT and Creare
  2. Westinghouse
     - Partnering with Aerojet Rocketdyne
  3. IX, a joint venture of Intuitive Machines and X-Energy
     - Partnering with Maxar and Boeing
- Managed by Idaho National Laboratory - estimating contracts finalized by late July with kickoffs in early August
- Objective: Each contract results in a system point design and assesses TRL
  - Estimate costs, schedule, and challenges for Phase 2
  - Identify critical subsystem technology development requirements



Power: 40 kWe with technology extensible to higher power
Mobility: Capable of being transported on a rover
Mass: less than 6,000 kg
Life: 10 years

Phase 1 will result in concept level point designs of a fully integrated system

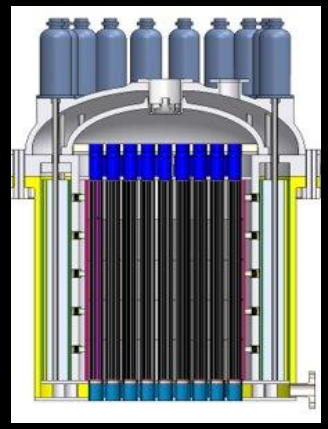
Nuclear Thermal Propulsion Industry Engagements

NASA selected three industry reactor preliminary design efforts in August 2021

- ✓ Preliminary design of a 12,500 lb, 900 sec Isp, HA-LEU powered reactor with a mass of less than 3500 kg
- ✓ Demonstrate design feasibility, manufacturability, and scalability

USNC partnered with Blue Origin, General Electric and Framatone are designing a beryllium moderator block reactor using cercer fuel

BWXT joined with Lockheed Martin, and Aerojet Rocketdyne are pursuing a metal hydride moderator block design with cercer fuel



General Atomics teamed with X-Energy and Aerojet Rocketdyne propose to design a carbide fueled reactor that builds on Project Rover

Phase 1 Design reviews to be held at MSFC by the end of FY 2022

Space Nuclear Propulsion Inter-agency Collaborations

Defense Advanced Research Projects Agency (DARPA)

- Continuing programmatic and technical support across NASA SNP Project and DARPA DRACO NTP flight demo project, including COR for GA contract and engine and turbomachinery support
  - Phase 2 collaborative support to comprise of testing, engineering, facilities, and regulations at all centers with desired capabilities via SAAs
- FY22 MOA is signed / FY23 MOA is in work

Air Force Research Laboratory (AFRL)

- Space Based Nuclear Electric Systems
- Collaboration with The Aerospace Corporation
- Nuclear Electric Propulsion engagement at MSFC/GRC
- Key focus areas:
  - Nuclear Electric Technology Assessment (existing and future)
  - Space Delivery Infrastructure Survey
  - Architecture Trade Space Analysis

Strategic Capabilities Office (SCO)

- Collaboration with DoE/INL for TRISO coated particle fuel facility to advance fabrication capabilities for high-performance nuclear fuels and provide logistics support for space-borne fission systems
- Current issue with funded facility only being usable for SiC CVD particles
- ZrC CVD changeover assessment in work by BWXT

Department of Energy (DoE) /Idaho National Laboratory (INL)

- INL leads SNP engagement with multiple DoE labs (i.e., LANL, ORNL, Y-12) for technical support in fuel/reactor development and programmatic involvement with nuclear industry contractors
  - Nuclear indemnification and assurance of regulatory compliance
- Continue to work the following areas of concern:
  - H2 Treat Loop Safety Review
  - TREAT Schedule
  - HALEU Supply

Space Nuclear Technology Key Takeaways

- NASA is working with other government agencies to establish a common technology development roadmap that leverage common priorities and resources
- NASA will continue to closely engage commercial capabilities and innovations for LEU reactor solutions
- NASA completed a series of technical interchange meetings with industry and OGA's to identify Nuclear Electric Propulsion technology solution sets and is using this information to establish an executable technology maturation plan
- NASA is modifying systems engineering procedures, safety standards, NEPA practices, and design handbooks to accommodate recent policies and directives related to the development and use of space nuclear power and propulsion systems

Space Technology Research Institutes

- Only U.S. universities may submit proposals
- Creative teaming arrangements are sought
  - Other universities (required) – 2+
  - Non-profits
  - Industry
- Co-Investigators are required
- Institute leadership or participation from Historically Black Colleges and Universities (HBCUs) or other Minority Serving Institutions (MSIs) is strongly encouraged; a DEIA plan is required
- 70% of the budget must go to U.S. universities

Award Information

- Expected duration: **5 years**
- Award amount up to **$3M per year** ($15M over 5 years)
- Award instrument: grants
- Institutes expected (and *empowered*) to implement their own review processes
- NASA oversight – annual reviews and brief quarterly status reports

Key Features

- **Empowered** university-led team
- Guiding Vision with ***resilient*** research strategy
- Specific research objectives with **credible expected outcomes** in next 5 years
- **Multidisciplinary** research program – synthesis of science, engineering and other disciples
- Innovative approaches for accelerated progress
- **Leveraging** SOA capabilities (likely created by OGA investments)
- Talented, **diverse**, cross-disciplinary, fully-integrated team; HBCU and MSI participation encouraged
- Student involvement in research
- Low to mid TRL
- **Publications** (many) and **open source** access to results
- ***Research products*** *tied to the research institute's Vision and research objectives.*

ACTIVE INSTITUTES

The Center for the Utilization of Biological Engineering in Space (CUBES)
University of California, Berkeley

The Institute for Ultra-Strong Composites by Computational Design (US-COMP)
Michigan Technological University

Habitats Optimized for Missions of Exploration (HOME)
University of California, Davis

Resilient ExtraTerrestrial Habitats research institute (RETHi)
Purdue University

Advanced Computational Center for Entry System Simulation (ACCESS)
University of Colorado Boulder

Joint Advanced Propulsion Institute (JANUS)
Georgia Institute of Technology

https://www.nasa.gov/directorates/spacetech/strg/stri

CUBES (2017)

The Center for the Utilization of Biological Engineering for Space

CUBES

Lead Institution:

University of California - Berkeley

- Dr. Adam Akin, PI

Collaborating Institutions:

Stanford University

University of California – Davis

Utah State University

University of Florida

5 years - $3M/year budget

Berkeley UNIVERSITY OF CALIFORNIA | Stanford University | UtahState University | UCDAVIS | UF UNIVERSITY of FLORIDA

https://cubes.space

CUBES - Biomanufacturing Systems for Space Exploration

Attributes:

- Scalable
- Programmable
- Precise (pure isomers)
- The only route of production in some cases (protein therapeutics)
- Low T^{o} and pressure
- Regenerable
- Obtain/Utilize *In Situ* Resources

Possible Biological Products:

- Food – plants and microbial products
- Vitamins, nutraceuticals
- Enzymes, flavors, preservatives
- Therapeutics/pharmaceuticals
- Polymers – plastics for parts, habitat construction, radiation protection
- Fuels – hydrocarbons, nitrogen-based
- Primary chemicals for 2^{o} products
- Adhesives/biocement - construction
- Specialized function biomolecules:
  - e.g., Carbonic anhydrase for CO_2 management
- Biosensors
- Probiotics

Engineering the organism and the environment

CUBES – Background and Current Status

- One of the two inaugural 5-Year STRIs (2017)
- **Currently at the end of year 5** – operating with a one year no-cost extension
- **Cumulative Personnel:**
  - 12 Principal Investigators (Dr. Adam Arkin – UC Berkeley - Lead PI)
  - ~10 Technical Staff/Scientists
  - ~15 Postdoctoral Scholars
  - ~35 Graduate Students
  - ~30 undergraduate Students
- **4 Research Divisions** – highly integrated staffing
- **~60 Peer-Reviewed Publications**
- Submitted **3 NASA BPS Decadal Survey White Papers**
- International technical advisory board with OGA, industry and academic members
- Conducts a regular **seminar series** for CUBES and NASA personnel participation

CUBES - Food and Pharmaceutical System Division Accomplishments

Optimizing plant production

- Worked with LED company to develop **very low mass plant lighting systems** using PV panels
- Studies led to a **revised definition of photosynthetic photons**: Demonstrated substantial increases in growth rates in lettuce with far-red wavelength addition
- Developed **wavelength recipes** for optimal growth – plant specific
- Engineering rice to **increase photosynthesis efficiency** via increased light penetration and planting density using truncated light antennae (TLA) method
- Developed Host-Mediated Microbiome Engineering system that resulted in first example of **increased plant health and water retention** (drought tolerance) without a cost to biomass production
- Demonstrated engraftment technique for **reliable probiotic establishment** with root system

CUBES - Food and Pharmaceutical System Division Accomplishments

Plant-based production of biopharmaceuticals

- Engineered lettuce to **produce a bone-regenerating therapeutic** (PTH-Fc fusion protein) for crew bone health using both transient and transgenic engineering techniques.
- Great Lakes and Romaine lettuce varieties were selected, and up to **65mg/kg fresh weight of PTH-Fc detected.**
- **Validating drug activity** using cell-based assays
- Demonstrated successful utilization of Viral Immunosorbent Nanoparticles (VINs) using tangential flow filtration for **protein purification in plants** to reduce needed purification resources

Pharmaceutical production in cyanobacteria

- **Novel engineering of *Spirulina*** for production of acetaminophen – potential breakthrough as a scalable photosynthetic drug production platform
- Developed **new engineering tools** for increased capability to engineer additional products

Early Career Initiative (ECI)

Overview:

- **ECI provides NASA early career civil servants with an opportunity to:**
  - Competitively propose two-year technology development projects
  - Engage with industry, academia, and other government agency partners
  - Gain management skills while leading a multidisciplinary project team
- **Proposals may be related to any NASA Taxonomy area**
  - Guided by but not restricted to the STMD Strategic Framework capability areas
  - Additional FY23 topic area identified for climate related technologies
- **2-year project life cycle, maximum $2.5M per project**
  - $1.25M/year per project, including partner funding costs
- **ECI will help ensure NASA remains a cutting-edge Agency** among the growing community of international and commercial space programs

ECI Knowledge Capture/Transfer

Supports Key Administration Goals

- **Expand** human knowledge through new scientific discoveries
- **Enhance** capabilities to catalyze current and future mission success
- **Catalyze** economic growth and drive innovation to meet national challenges
- **Extend** human presence to the Moon, Mars and Beyond
- **Invest** in and empower our workforce, shape the future, and foster agility

25 ECI projects funded to date

- 4 pilot projects awarded in FY15
- 21 projects awarded since FY18
- Projects listed in Backup Charts

Through FY21, ECI projects contributed:

- Over 80 Technical Papers/Publications
- 19 NASA New Technology Reports
- 3 US Patents, 5 Patent Applications
- 46 External Partnerships
- 3 ISS MISSE material exposure flights
- 2 suborbital flights, 1 pending LEO flight
- 2 NASA Early Career Achievement Medals
- Additional metrics will be collected at the end of FY22

ECI EXAMPLE

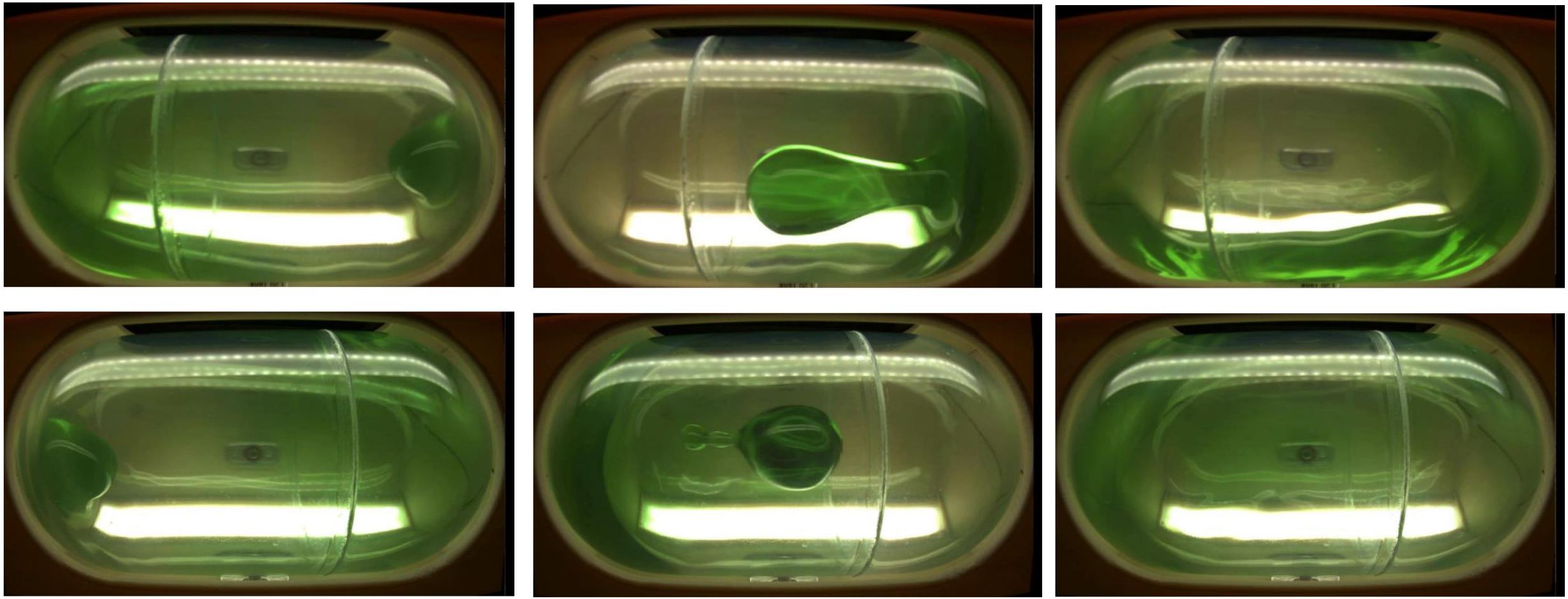
Problem Statement:

- Accurate and reliable micro-g mass gauging is essential for future space missions and operations
  - Identified by NASA as an enabling technology for deep-space exploration
    - Tier 1 technology gap (STMD-CFM-015)
  - Long-duration missions (e.g., cis-Lunar and Mars transit)
  - Orbital refueling
  - NEP and NTP
- Impacts
  - Performance characteristics
  - Propellant margin (uncertainty and settling burns), total burn time

Develop a new technology for micro-g cryogenic mass gauging based on whole-tank capacitive sensing

FLUIDS IN MICRO-G

FIT/NASA SPHERES-SLOSH Experiment
Storey et al. 2020 https://ntrs.nasa.gov/citations/20180001518



BENEFIT OF ECI - DEVELOP CAPABILITY AND TECHNOLOGY

- It's an excellent opportunity to
  - Develop NASA's early career workforce with accelerated experience
  - Develop transformative concepts into useable technology that will enable future space missions
- Helps establishes relationships and partnerships
  - The team is highly diverse and works closely together
  - Often need to seek additional resources within NASA
  - GRC and KSC work together in the development, along with the external partner
- Team members can (mostly) focus on what they enjoy
  - Gaining new skills in analysis, hands-on experimentation, programming, physics and engineering
- For me personally
  - The satisfaction of delving into a fascinating application of physics
  - Working with and learning from so many different people
  - Improving my capability to get things done with a diverse team using interpersonal, leadership, and project management skills

Skills + Knowledge + Experience = Capability

TI&E Observations August 2022

- The Committee is impressed by the progress and activity of launch service providers at NASA's Kennedy Space Center.
- The Committee visited Artemis-1 at the VAB and is excited for the launch NET Aug. 29. Space Tech funded the 3D-MAT compression pads developed by small business Bally Ribbon Mills in eastern Pennsylvania.
- The Committee noted that Space Tech's technology demonstrations and payloads (e.g. LCRD, CAPSTONE, DSOC, LOFTID) are being delivered on schedule.
- The Committee believes that the Early Career Initiative is a valuable retention tool and Space Tech should continue to invest in and consider expanding the program.
- The Committee has been impressed by the progress of the Space Tech Research Institutes over the last five years. The first two, US-COMP and CUBES, are nearing completion.
    - The Committee is interested to see the teams and the technologies transition beyond the 5-year period of performance.
- The Committee is impressed by the interagency collaboration within the nuclear portfolio.
- The Committee believes it is essential that the new Office of Technology, Policy and Strategy studies are coordinated and complementary to STMD and other mission directorates.

TI&E Findings: Space Nuclear Power and Propulsion

The TI&E Committee recognizes that Fission Surface Power (FSP) is the agency/Administration priority, however the Committee is concerned about the adequacy of funding to meet the 2030 lunar deployment plans.

- Phase II must start by Q1 2025 to meet the timeline.
- Currently funded at modest levels due to budget direction given in NTP.

NASA should substantially increase technology investments in nuclear thermal propulsion and nuclear electric propulsion and make a propulsion architecture selection based on the National Academy Study recommendation.

- Nuclear propulsion represents a critical transportation technology for future missions beyond LEO.
- NTP has funding and has substantial direction from Congress.
- NEP is funded at low levels but has collaboration potential from other agencies.

To fund both Nuclear Surface Power and Propulsion, requires substantial growth in STMD's future budget.

TI&E Committee Priorities for 2022-2023

- Technology transition/mission infusion, commercial involvement, and patent licensing of technologies that originate in STMD
- Continue monitoring progress of Lunar Surface Innovation Initiative; development of Cryogenic Fluid Management technologies
- Continue monitoring progress of the nuclear portfolio (surface power and propulsion) and progress toward propulsion architecture selection
- Follow evolution of the Office of Technology, Policy and Strategy within NASA; continue to receive briefings from the Office of the Chief Engineer
- Hear technology plans and needs from SOMD/ESDMD/SMD
- Continue following the progress of STMD's Early Stage Innovations & Partnerships portfolio including Space Technology Research Institutes selected in 2020 and the SBIR/STTR program including, new sequentials/follow-on funding opportunities
- Follow STMD's expansion of its focus on Diversity, Inclusion, Equity and Access initiatives, increasing outreach and engagement with new communities through the Early Stage portfolio

nasa.gov/calliefirst