Technology, Innovation & Engineering Committee Report
NASA Advisory Council Meeting

Mr. Michael Johns | Committee Chairman | March 1, 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 2020 Virtual Meetings & Presentations

- **March 19, 2020**
  - STMD update
  - Space tech on the ISS and Lunar Surface Innovation Initiative (LSII) update
  - Flight Opportunities and Small Spacecraft Technology Program updates
  - Office of Chief Engineer Update and Discussion of Processes to Evaluate Technology Implementation

- **September 1, 2020**
  - STMD update
  - Nuclear Technology Portfolio update
  - Science Mission Directorate Technology Portfolio update
  - TechPort Demonstration

TI&E Committee 2021 Virtual Meetings & Presentations

- **January 27, 2021**
  - STMD update
  - Office of the Chief Technologist update
  - Lunar Surface Innovation Initiative update
  - Office of the Chief Engineer update

- **December 14, 2021**
  - STMD Update
  - Office of Technology, Policy, and Strategy (OTPS) update
  - Exploration Systems Development Mission Directorate Intro
  - Perseverance Technology Demonstration and Cryogenics Fluid Management “Tipping Point” updates
  - “Space Nuclear Propulsion for Human Mars Exploration” Report Overview And NASA Nuclear Systems update
  - Early Stage Portfolio update

TI&E Committee Membership

- Mr. Michael Johns, Southern Research Institute – appointed Chair in Dec. 2021
- Ms. Lisa Callahan, Lockheed Martin Space – onboarded in Jan. 2022
- Dr. Mike Gazarik, Ball Aerospace – onboarded in July 2020
- Dr. Kathleen C. Howell, Purdue University
- Dr. Rebecca Kramer Bottiglio, Yale University – onboarded in July 2020
- Mr. Andrew Rush, Redwire – onboarded in Jan. 2022
- Dr. Bradford Tousley, Blue Canyon Technologies – onboarded in Jan. 2022
- Dr. Mitchell Walker, Georgia Institute of Technology – onboarded in July 2020
- Dr. Mary Ellen Weber, STELLAR Strategies, LLC

Background on TI&E Committee efforts

- TI&E has supported the need for a standalone Space Technology Program to ensure sufficient investment in future technologies since the committee's formulation in 2010. The agency stood up the Space Technology Mission Directorate in 2013.
  - Without a standalone entity distinct from current missions, budget pressures would likely have resulted in cutting back investment in future technologies as the path of least resistance to keeping current missions on track.
- While all of NASA has faced budgetary pressures over the years, STMD experienced a unique set of pressures.
  - All of the agency SBIR/STTR funding is managed out of STMD equaling ~20% of the total STMD budget
  - Congressional interest items in the STMD budget have increased and now equal ~25% annually
- STMD has done an outstanding job conveying the need for robust funding for future technology investment to its many stakeholders, including OMB/OSTP, Congress and other NASA mission directorates. This is evidenced by the growth of its overall budget since 2015.
- STMD has done an outstanding job managing its programs in a dynamic budget environment to ensure the projects overlap, interleave and contribute to its overall technology priorities.
- A robust and well-managed standalone STMD is essential for NASA's future. This is best evidenced by the many technologies that were initiated and matured within STMD that are essential for Artemis (e.g. SEP, cryotanks, EDL/precision landing, optical communications, etc.).

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

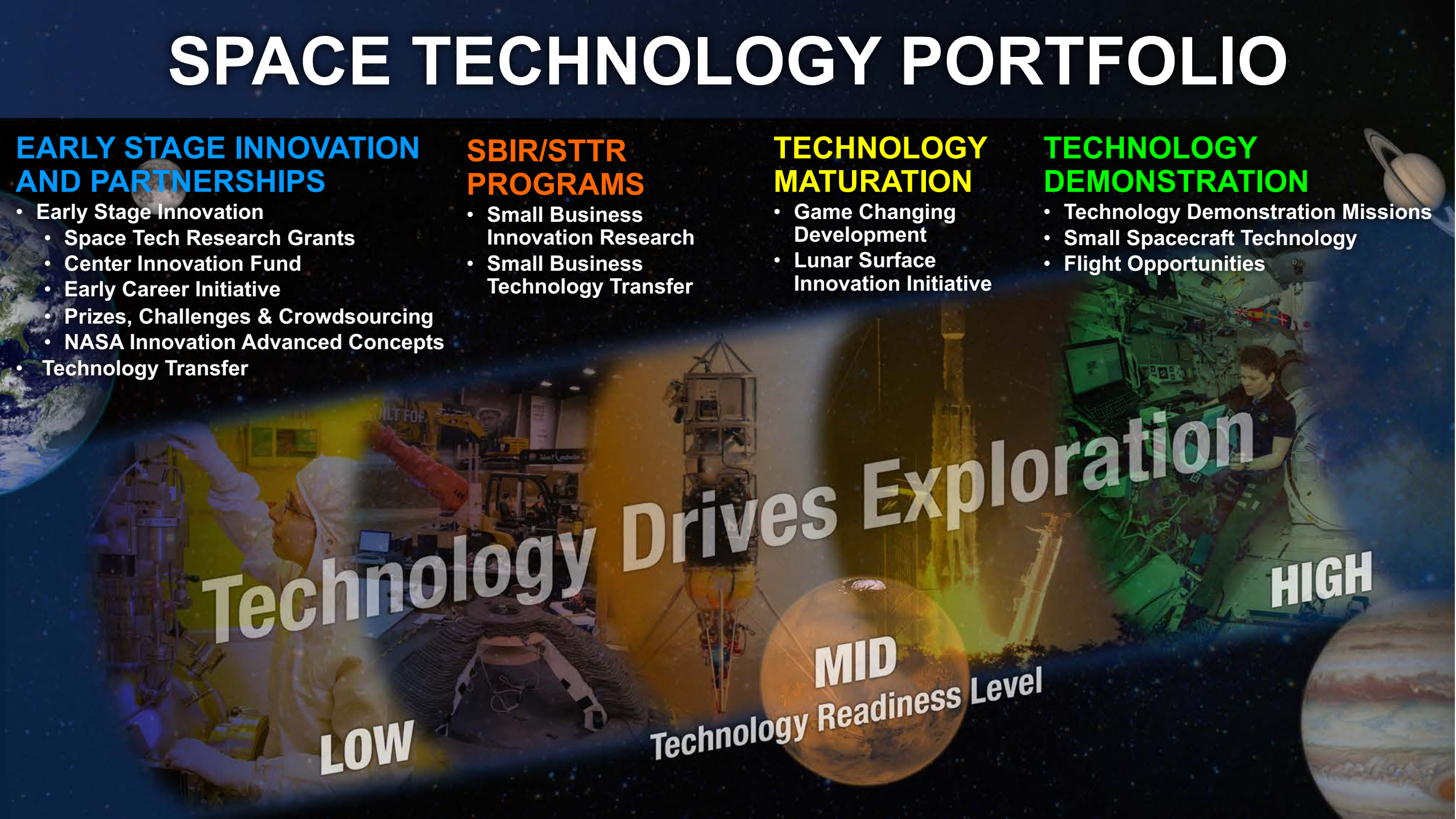
- Small Business Innovation Research
- Small Business Technology Transfer

TECHNOLOGY MATURATION

- Game Changing Development
- Lunar Surface Innovation Initiative

TECHNOLOGY DEMONSTRATION

- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities



STMD Strategic Framework

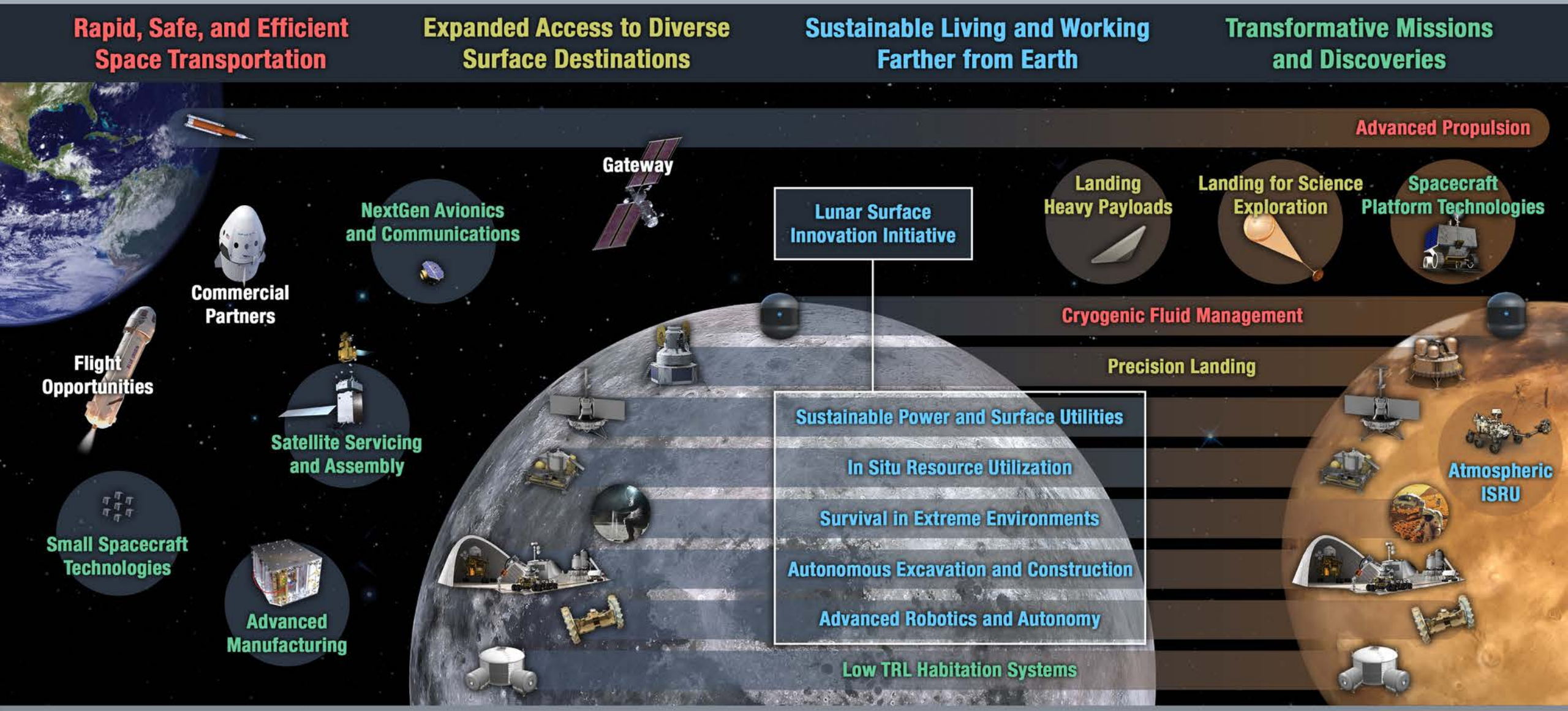
STMD rapidly develops, demonstrates, and transfers revolutionary, high pay-off space technologies, driven by diverse ideas

Lead	Thrusts	Outcomes
		Transforming Space Missions
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	**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.
	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.

	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]

	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

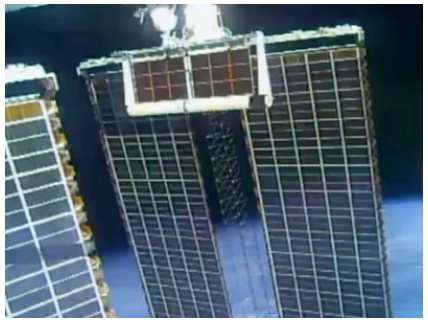
Ensuring American Global Leadership in Space Technology



Technology Drives Exploration

STMD FY 2022 Budget Summary ($M)	FY 2021 1,100.0	FY 2022 PBR 1,425.0	House $1,280.0 Senate $1,250.0	FY 2023 1,454.5	FY 2024 1,486.4	FY 2025 1,519.2	FY 2026 1,552.9
SBIR and STTR	**227.0**	**287.0**		**292.7**	**298.6**	**304.6**	**310.7**
Early Stage Innovation and Partnerships	**117.5**	**145.0**		**147.9**	**150.8**	**153.9**	**157.0**
Agency Technology and Innovation	**8.4**	**9.4**		**9.6**	**9.8**	**10.0**	**10.2**
Technology Transfer	**19.9**	**20.0**		**20.4**	**20.8**	**21.2**	**21.6**
Early Stage Innovation	**89.2**	**115.6**		**117.9**	**120.2**	**122.7**	**125.2**
Center Innovations Fund (CIF) / Early Career Initiative (ECI)	24.4	28.0		28.6	29.0	29.7	30.3
NASA Innovative Advanced Concepts (NIAC)	8.4	9.5		9.7	9.9	10.1	10.3
Space Technology Research Grants (STRG)	47.9	61.1		62.3	63.5	64.8	66.1
Prizes & Challenges (P&C)	8.6	17.0		17.3	17.7	18.0	18.4
Technology Maturation / Game Changing Development (GCD)	**227.1**	**491.2**		**501.0**	**511.1**	**521.3**	**531.7**
Rapid, Safe, & Efficient Space Transportation	11.0	44.0		33.8	26.6	12.0	12.0
Expanded Access to Diverse Surface Destinations	43.9	43.8		43.2	45.8	26.0	25.7
Sustainable Living and Working Farther from Earth	110.3	199.5		187.8	188.3	237.1	250.0
Transformative Missions and Discoveries	36.7	85.3		60.2	67.9	49.0	28.0
Industry and Commerce Innovation Opportunity	-	85.6		142.4	148.4	162.7	180.9
Tech Management & Integration	25.1	33.1		33.6	34.1	34.6	35.1
Technology Demonstration	**528.4**	**501.8**		**512.9**	**525.9**	**539.4**	**553.5**
Technology Demonstration Mission (TDM)	**461.2**	**430.6**		**440.3**	**451.9**	**463.9**	**476.5**
Cryogenic Fluid Management (CFM)	60.1	82.0		122.1	103.5	125.7	136.4
Space Nuclear Technologies (SNT)	57.9	34.0		34.1	87.2	186.7	258.3
Nuclear Fission Surface Power	*8.0*	*34.0*		*34.1*	*87.2*	*186.7*	*258.3*
Nuclear Thermal Propulsion	*49.9*		*110.0*				
OSAM-1 (Restore & SPIDER)	227.0	227.0	227.0	227.0	227.0	103.6	25.4
OSAM-2 (Archinaut)	17.7	16.1		16.5	-	-	-
Solar Electric Propulsion (SEP)	26.2	24.2		18.5	15.9	17.8	5.8
Low-Earth Orbit Flight Test of an Inflatable Dec (LOFTID)	20.4	13.0		2.4	-	-	-
Deep Space Optical Comm (DSOC)	16.4	6.2		2.0	0.1	-	-
LCRD, MOXIE, DSAC, TDM Management & Integration	35.6	28.1		17.8	18.2	30.1	50.6
Small Spacecraft Technology (SST)	**40.2**	**46.2**		**47.6**	**49.0**	**50.5**	**52.0**
Flight Opportunities (FO)	**27.0**	**25.0**		**25.0**	**25.0**	**25.0**	**25.0**

Impact Story: Roll-Out Solar Array (ROSA)



2009 First NASA SBIR Phase I

2014 20kW Ground Demo, GCD/ TDM

2019 STTR CCRPP

2021 ISS Solar Array Deployment

2021 Double Asteroid Redirection Test (DART) mission

Global Ecosystem

The U.S. Space Industry

The U.S. Government

NASA

STMD

Infusion into NASA Missions

Economic Growth, Commercialization & Spinoffs

NASA

The U.S. Government

2008 First SBIR from AFRL

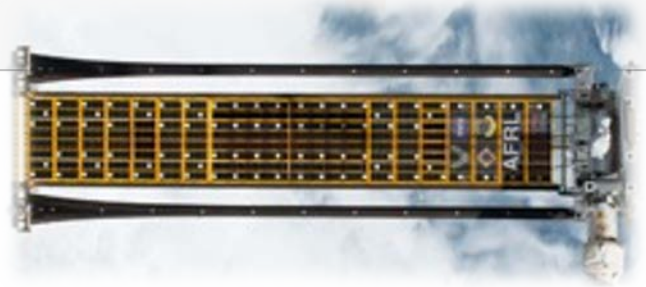
2017 AFRL ISS Demo

The U.S. Space Industry

2008 DSS Founded

Global Ecosystem

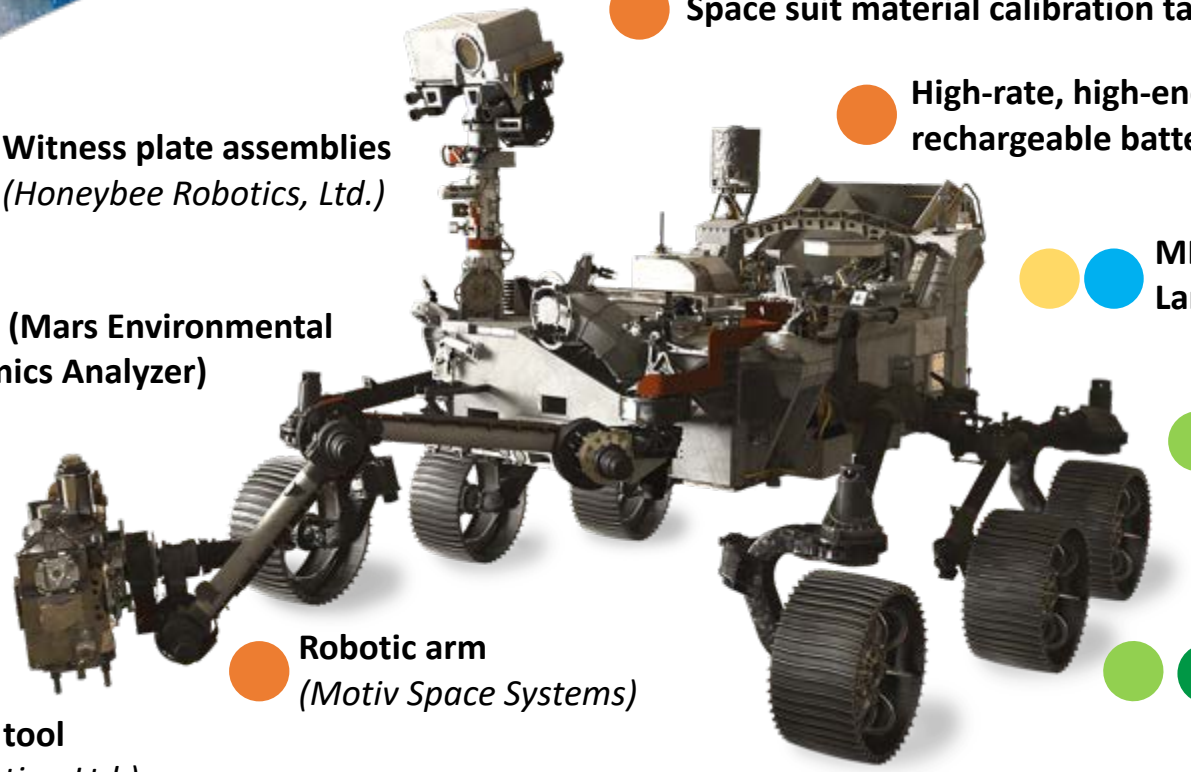
2012 SBIR Phase III for multi-mission space exploration vehicle wings



2021 Redwire acquisition of DSS; Planned Redwire Initial Public Offering (IPO)

Innovation Drives Technology….

Technology Drives Exploration

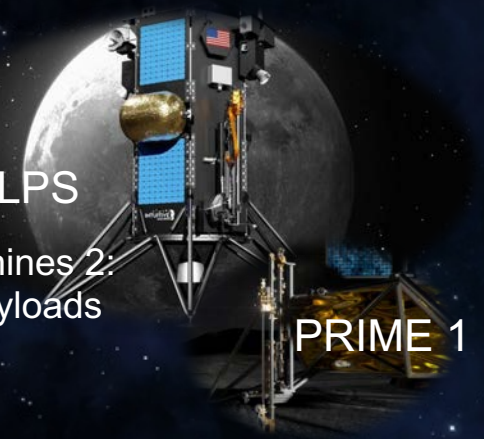


- **Laser for SHERLOC** *(Photon Systems, Inc.)*
- **Space suit material calibration target for SHERLOC** *(ENGI-MAT)*
- **High-rate, high-energy-density, lithium-ion rechargeable batteries** *(Yardney/Eagle Picher)*
- **Witness plate assemblies** *(Honeybee Robotics, Ltd.)*
- **MEDLI2 (Mars Entry, Descent and Landing Instrumentation 2)**
- **MEDA (Mars Environmental Dynamics Analyzer)**
- **TRN (Terrain Relative Navigation)**
- **Six-axis force-torque transducer** *(ATI Industrial Automation, Inc.)*
- **Robotic arm** *(Motiv Space Systems)*
- **Lander Vision System** *(JPL)*
- **Dust mitigation tool** *(Honeybee Robotics, Ltd.)*
- **MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment)**
- ***Scroll compressor*** *(Airsquared)*
- **Synthesizing Flight Software (FSW) Discrete Controllers from Formal Specifications** *(JPL)*

CIF STRG SBIR/STTR GCD TDM Flight Opportunities

These Mars Rover technologies are also useful here on Earth for everything from safer autonomous vehicles to helper robots in hospitals. To learn more, visit spinoff.nasa.gov.

Enabling Technologies for Future Science & Exploration Missions

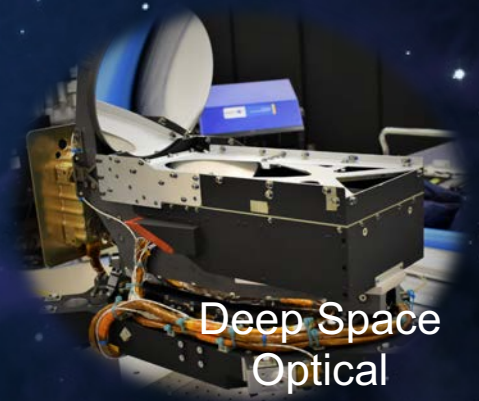


CLPS

Intuitive Machines 2: all STMD payloads

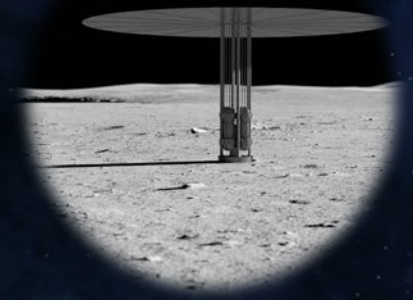
PRIME 1

EDL Technology



Deep Space Optical Communications

Fission Surface Power



Additive Manufacturing

Cryogenic Fluid Management

ISRU

Solar Electric Propulsion

CAPSTONE CubeSat

Laser Communications Relay Demonstration

Space Nuclear Technology Accomplishments

Fission Surface Power

- Established a HA-LEU government reference design to guide technology and design decisions
- Completed power conversion system and power transmission studies
- Released Phase I request for proposal to industry for industry-led designs
- Completed power conversion technology maturation SOW with planned release in summer 2022

Space Nuclear Propulsion

- Successfully fabricated and tested cermet fuel element feature design
- Awarded three Phase I industry design awards with kick-off in September 2021
- Completed critical design to integrate flowing hydrogen in the INL TREAT facility
- Completed ground site studies for potential modified open-air test of subscale engine

TI&E Observations March 2020 – December 2021

- The Committee is pleased to see the budget and activities of STMD continue to expand and support programs critical to the agency's future
- The Committee believes that sustained, early STMD investments in technologies such as SEP have enabled the rollout of Artemis and its target timeline
- The Committee finds that rapid expansion of the STMD purview and portfolio does present a challenge and a risk to the ability of STMD to manage its portfolio as effectively as it has been able to do to date.
- The Committee commends STMD on its planning thus far to ramp up personnel and to create flexibilities (e.g. a modification to SBIR to allow for larger awards such as Phase II sequentials), so that STMD can continue effective technology development critical to the agency's future.
- The Committee believes it is essential that the new Office of Technology, Policy and Strategy studies are coordinated and complementary to STMD moving forward.
- The Committee is pleased by the progress with the Lunar Surface Innovation Initiative and its ability to jump-start interest and investments in technologies to enable a sustainable lunar presence.

TI&E Space Nuclear Power and Propulsion Observations 2020-2021

Space nuclear power and propulsion can enable robust exploration of the Moon and Mars

- Fission surface power systems can provide abundant and continuous power in all environmental conditions in a less massive and more reliable implementation than solar power system
- Fission propulsion systems can enable the shortest total mission times to Mars and can enable the most challenging mission scenarios (such as opposition-class trajectories)

Key nuclear surface power investments are needed in the near term for a future flight demonstration to support lunar missions by the late 2020s.

- STMD is collaborating with DOE, DARPA and industry to design, fabricate, and test a fission power system that can enable human exploration of the Moon and Mars

Committee agrees with NAS Space Nuclear Propulsion Study recommendation that additional technology investments are needed before NTP/NEP downselect.

Key fission propulsion technologies need additional development and validation prior to undertaking a flight demonstration with extensibility to Mars transportation. Decision path likely needed by the mid-2020s.

- NTP technology maturation needs include fuel/element design and manufacturing; high-temperature reactor design; cryogenic propellant management; and test capabilities/facilities
- NEP technology maturation needs include fuel/element design and manufacturing; power conversion development; deployable radiators; high-power thrusters

STMD will mature technologies and demonstrate system capabilities to meet the power and propulsion needs for Artemis

TI&E Finding: Space Nuclear Power & Propulsion Systems and Commercial Space Engagement 2020-2021

The TI&E Committee believes that NASA/STMD should:

- Focus on the delivery of a nuclear surface power system for demonstration and use on the Moon by the late 2020s and for future human Mars missions
- Continue cryogenic fluid management technology development and demonstrations, completing by the late 2020s to align with needs of surface power and in-space propulsion
- Continue technology investments in NTP/NEP; complete the assessment of NTP/NEP and make a propulsion architecture selection when appropriate based on the National Academy Study recommendation
- Continue annual Tipping Point and Announcement of Collaborative Opportunities calls (vitally important for robust commercial space economy); this year's TPs will be funded Space Act agreements.

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