National Aeronautics and Space Administration

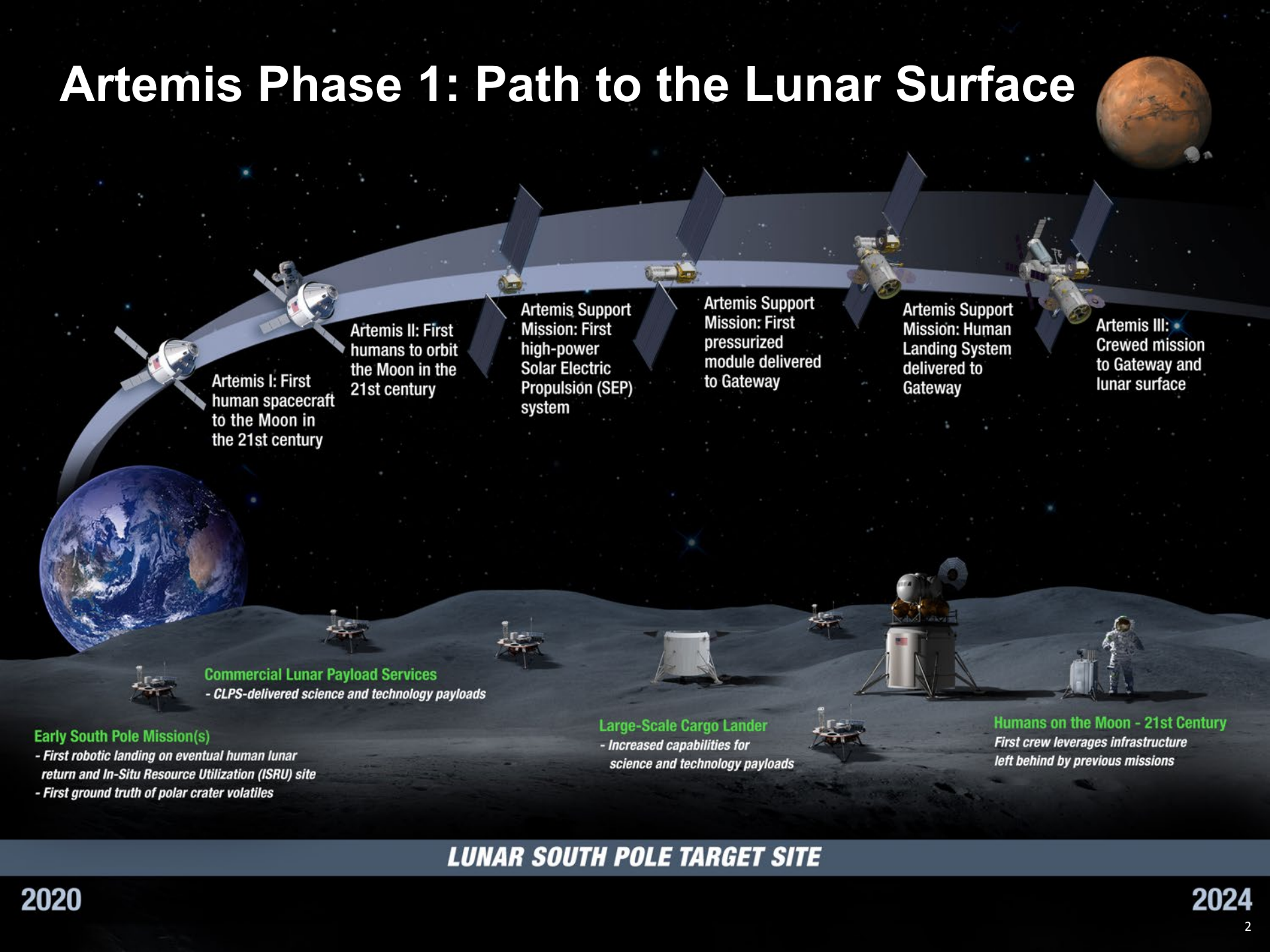
NASA

EXPLORESPACE TECH

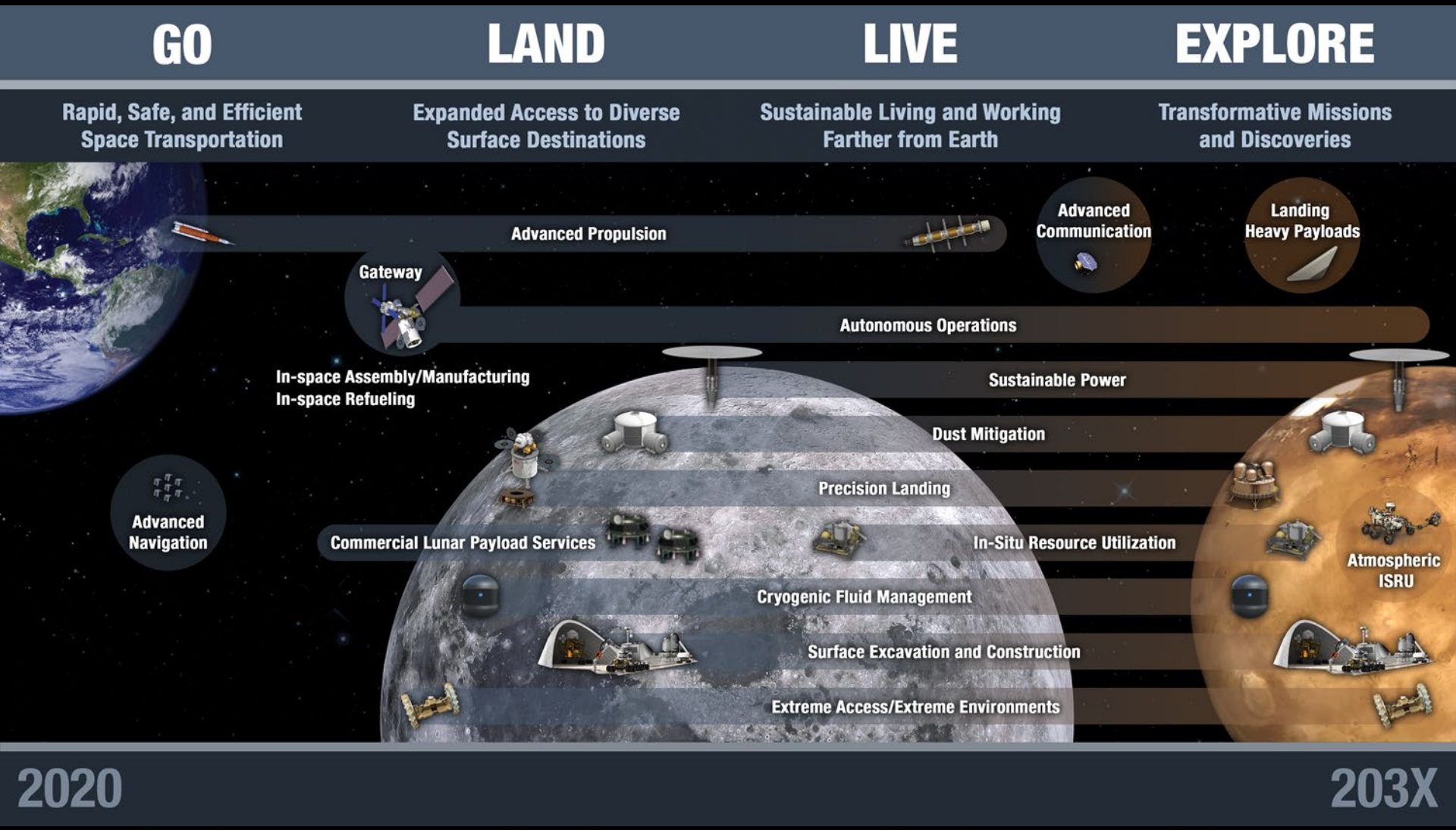
NASA Advisory Council
Technology, Innovation & Engineering Committee Meeting

Mr. James Reuter, Associate Administrator for NASA STMD | October 29, 2019

Artemis Phase 1: Path to the Lunar Surface



Technology Drives Exploration



Go

Rapid, Safe, & Efficient Space Transportation

Solar Electric Propulsion

Nuclear Thermal Propulsion Technologies

Thruster Advancement for Low-temperature Operations in Space

Cryogenic Fluid Management

Green Propellant Infusion Mission

Rapid Analysis and Manufacturing Propulsion Technology

- Reusable transportation between the Earth and Moon
- Reusable transportation between the Earth and Mars
- Rapid and efficient transportation through the solar system

Cryogenic Fluid Management

HLS Refueling Studies

NORTHROP GRUMMAN

Masten

SSL A MAXAR COMPANY

Dynetics

SPACEX

BOEING

LOCKHEED MARTIN

The Evolvable Cryogenics (eCryo) project

ULA United Launch Alliance

ULA H2/O2 Thruster development

Cryogenic Fluid Transfer Technology Demo Con-ops development with SpaceX

Lunar CFM Studies and Cryocooler Development with Lockheed Martin

AEROSPACE

Blue Origin: "Cryogenic Fluid Management-Enhanced Integrated Propulsion Testing for Robust Lander Services"

Creare

ASTROBOTIC

MOOG

PARAGON

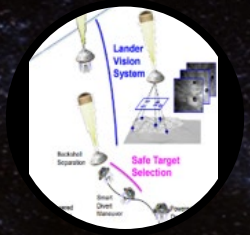
Cryocooler Development enabling zero boil-off with Creare

Paragon Space Development Corp.: Cryogenic Encapsulating Launch Shroud and Insulated Upper Stage (CELSIUS)

Land

Expanded Access to Diverse Surface Destinations

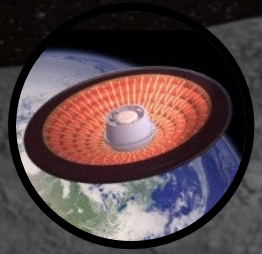
Navigation
Doppler LIDAR



Terrain Relative
Navigation

Mars EDL

- Routinely landing crew and cargo on the Moon
- Safely and efficiently returning large payloads to Earth
- Delivering robotic payloads to challenging new destinations
- Routinely landing crew and cargo on Mars

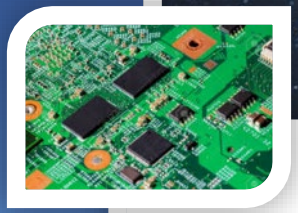


Low-Earth Orbit Flight
Test of an Inflatable
Decelerator

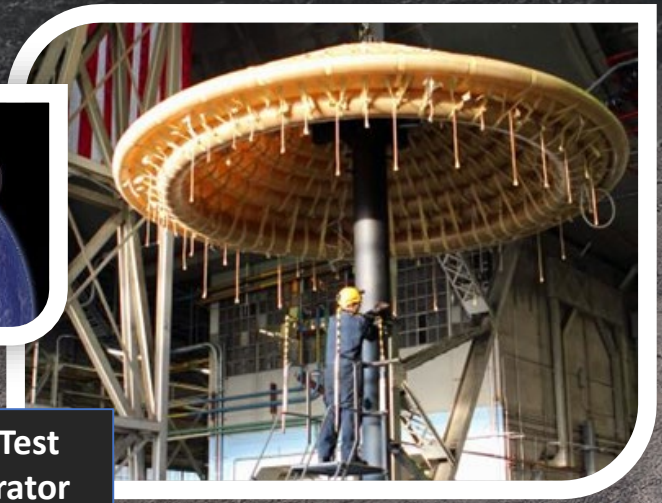
SPLICE

Exploration Technology in Entry, Descent & Landing

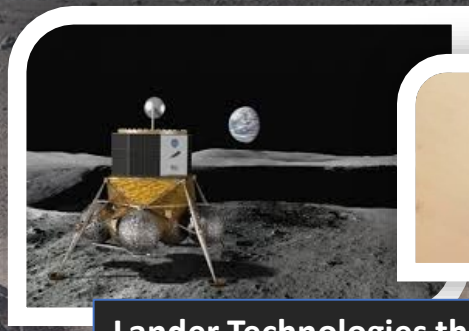
Mars Entry, Descent, and Landing Instrument (MEDLI 2) on Mars 2020



The Safe and Precise Landing Integrated Capabilities Evolution (SPLICE) project; includes high performance spaceflight computing



LeO-based Flight Test Inflatable Decelerator (LOFTID)



Lander Technologies through awards with Astrobotics and Blue Origins

Live

Sustainable Living and Working Farther from Earth

In Space Manufacturing

Regenerative Fuel Cells

Astrobee

Surface Power

Synthetic Biology

ISRU

- Routine crewed operations beyond low-Earth orbit
- Sustainable human presence on the Moon
- Producing propellant & consumables from local resources
- Sustainable human presence on Mars

Integrated Systems for Autonomous Adaptive Caretaking

Note: Mid TRL and High TRL Technology Development for Life Support and EVA suits are HEOMD Responsibility

Lunar Surface Innovation Initiative (LSII)

In Situ Resource Utilization

Collection, processing, storing and use of material found or manufactured on other astronomical objects

Surface Excavation/Construction

Enable affordable, autonomous manufacturing or construction

Lunar Dust Mitigation

Mitigate lunar dust hazards

Sustainable Power

Enable continuous power throughout lunar day and night

Extreme Environments

Enable systems to operate through out the full range of lunar surface conditions

Extreme Access

Access, navigate, and explore surface/subsurface areas

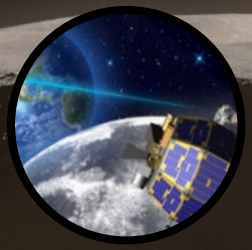
- Spurs the creation of novel technologies needed for lunar surface exploration.
- Accelerates technology readiness of key systems and components.
- Addresses technology development needs for lunar surface operations, including surface payloads.
- Implements development through a combination of unique in-house activities, competitive programs, and public-private partnerships.
- Coordinates with SMD and HEOMD to identify priorities.

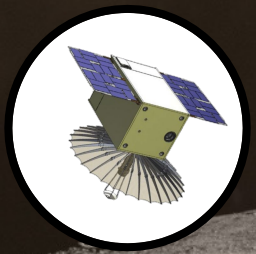
Explore

Transformative Missions and Discoveries

- Reach challenging sites and resources on the Moon
- Survive and operate through the lunar night
- Reach challenging sites and resources on Mars and beyond

Laser and Optical Communications



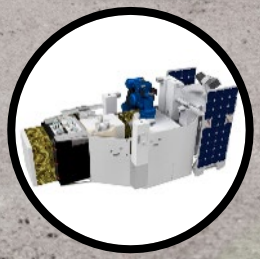


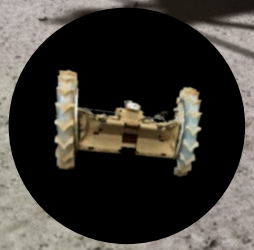
Small Spacecraft Demos

SPIDER

Bulk Metallic Glass Gears

Archinaut

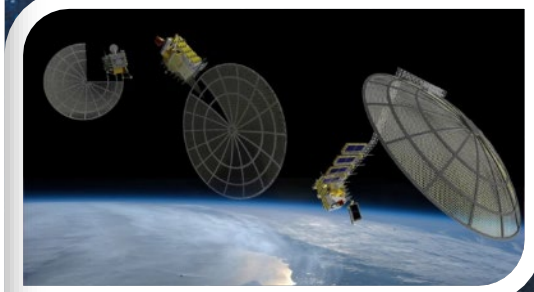




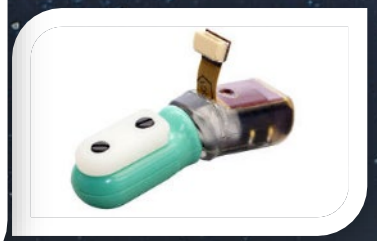
Surface Robotic Scouts

Atomic Clock

Exploration Technology for On-orbit Servicing, Assembly and Manufacturing

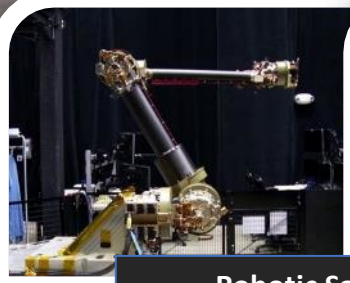


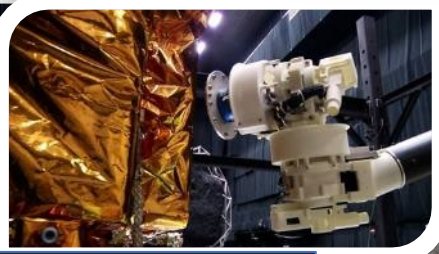
Made In Space validated additive manufacturing and robotic assembly with a future mission, Archinaut



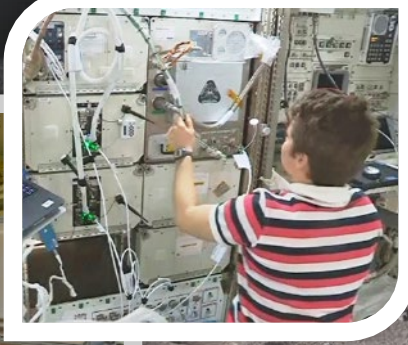
FabLab: Development of a first-generation, in-space, multi-material fabrication laboratory for space missions

Maxar SPIDER Robotic System successful ground demonstration for future mission



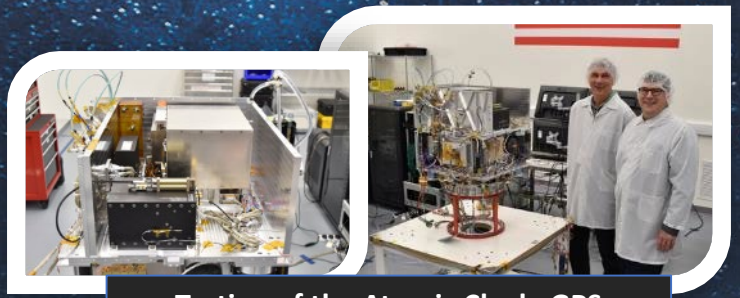


Robotic Satellite Servicing: Restore-L approaching CDR



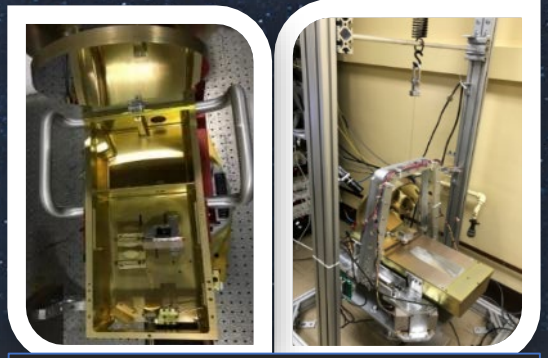
Refabricator is the first integrated 3D printer and recycler in space and currently aboard ISS

Exploration Technology in Deep Space Communications and Navigation



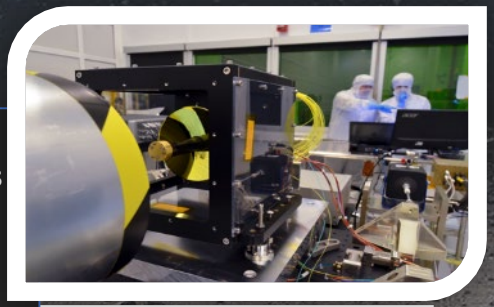
Testing of the Atomic Clock, GPS Receiver, and Ultra-Stable Oscillator which make up the Deep Space Atomic Clock Payload

Credits: General Atomics Electromagnetic Systems

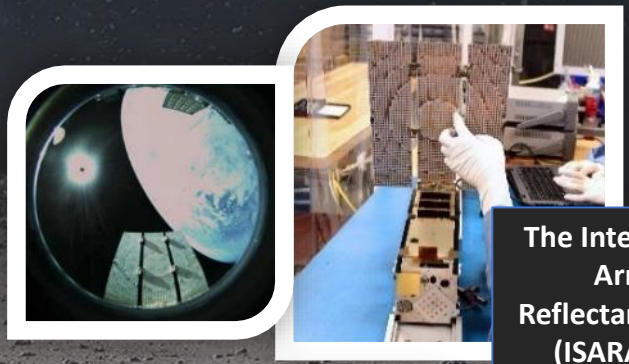


Deep Space Optical Communications project hardware being tested.

Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)



Laser Communications Relay Demonstration (LCRD) Project team integrating and testing flight hardware



The Integrated Solar Array and Reflectarray Antenna (ISARA) mission

Optical Communications and Sensor Demonstration (OCSD) spacecraft

CubeSat Laser Intersatellite CrosslinK (CLICK) project

Lunar and Mars Exploration FY 2019 Major Accomplishments

Launches and In-Space Demonstrations

- MarCO spacecraft used **ISARA** relay technology during the Mars InSight landing in November
- **Refabricator** launched to ISS in November
- **CubeSat Handling of Multisystem Precision Time Transfer (CHOMPTT)** launched in December
- **RRM3** launched to ISS in December
- **Astrobee** Honey Bee and Bumble Bee launched to ISS in April, Queen Bee in July
- **BioNutrients** experiment launched to ISS in April
- **ISARA to OCSD crosslink** demonstration in April
- **DSAC** launched on STP-2 in June
- **GPIM** launched on STP-2 in June
- **OCSD** demonstration concluded at the end of FY 2019
- Over 30 technology payloads on **commercial suborbital flight tests**

Deliveries

- **TRN** delivered to Mars2020 in November
- **MOXIE** delivered to Mars2020 in March
- **MEDLI2** 1st delivery to Mars2020 in May
- **EESP** hardware delivered to DART in September

Lunar and Mars Exploration FY 2019 Major Accomplishments

Major Project Milestones

- Advanced 3 TDM flight projects into Implementation Phase:
  - **LOFTID** KDP-C completed in June
  - **DSOC** KDP-C completed in June
  - **SEP** KDP-C completed in June
- Advancing 5 GCD projects into Implementation Phase:
  - **Distributed Spacecraft Autonomy** PDR in May
  - 2 **FabLab BAA** PDRs for ground demonstration by end of August
  - **Blue Origin Deorbit Descent & Landing** PDR in July
- **Lunar Ice Drill (PRIME)** drill tests completed in August
- **Autonomous Medical Operations** demonstration with US Army ISR in October
- **RAMPT** Composite Overwrap Hot Fire Test in March
- **PUFFER** ground demonstration completed in June
- **SPLICE Navigation Doppler Lidar** rocket sled test completed in June
- **Blue Origin BE-7 lunar lander engine** test in June
- **EESP** solar array demonstration in August
- 2 **SCOR** CDRs by end of FY 2019
- **TALOS** hot fire tests by end of FY 2019
- Key life cycle milestones for several small spacecraft missions, including **ACS3, CLICK, Starling, Lunar Flashlight, Pathfinder Technology Demonstrator (PTD) - 1 (HYDROS), PTD - 2 (HyperXACT)** and **PTD - 3 (TBIRD).**

Lunar and Mars Exploration FY 2019 Major Accomplishments

New Starts/Awards

- Initiated 10 **ISRU BAA** studies and demos
- **TALOS** and **Frontier Deep Space Engine** were baselined on Astrobotic Lunar Lander thrusters
- NASA internal CLPS payloads announced in February, including **SPLICE Navigation Doppler Lidar**
- 2 new **Space Tech Research Institutes** (**STRIs**) to advance SmartHabs awarded in April
- 11 new **NextStep Appendix E** awards for prototype efforts and refueling human lunar lander studies in May
- **CO_2 Conversion Challenge** made $250k in awards in May
- **3D Printed Habitat Challenge** made $700k in awards in May
- **Lunar Ice Drill** competition in June
- Initiated **Made In Space Archinaut** demo mission in July
- Initiated **Maxar SPIDER** demo to incorporate onto the Restore-L bus in June
- 2 new **NIAC Phase III** awards in June, including enabling lunar pit exploration
- 7 new **Early Career Initiative** (**ECI**) awards in July, including enabling surviving the lunar night and lunar ISRU
- 13 companies awarded 19 **ACO** partnerships in July
- Initiated **Applied Physics Lab LSII System Integration** task in August
- Initiated **LSII Technology Scouting** task for dust mitigation capabilities in August
- **25 Flight Opportunities Technology Flights** selections made October 2019
- **14 Tipping Point** selections were made September 2019

Tipping Point Technologies

- **Tipping Point:**
  - Increased focus on **collaboration** with the commercial space sector
  - Fixed price contracts with milestone payments
  - Requires a **minimum 25 percent contribution (10% for small businesses)** from corporation or customer
  - Leverage emerging marks and capabilities to meet NASA's strategic goals AND focus on **industry needs**
  - **Increase likelihood of infusion** into a commercial space application
  - Substantial benefit to both **commercial and government sectors**
- **Tipping Point Awards:**
  - **2016 – 9 Awards**
  - **2017 – 6 Awards**
  - **2018 – 6 Awards**
  - **2019 – 14 Awards**
- Next Opportunity – Utilizing Public-Private Partnerships to Advance Tipping Point Technologies released January 2020 (target)
- Space Tech Solicitations: https://go.usa.gov/xQRwV

NASA anticipates releasing Tipping Point with targeted topics every year

FY 2019 Tipping Point Technologies

Awardee	Title
Accion Systems	Increasing Commercial & Interplanetary Cubesat Accessibility with Lower SWaP Ion Electrospray Prop
Astrobotic Technology	CubeRover for Affordable, Modular, and Scalable Planetary Expl.
Blue Canyon Technologies	BCT X-NAV Autonomy Suite
Blue Origin	ISRU Propellant Liquefaction Plant Prototype
CU Aerospace	Dual Propulsion Experiment (DUPLEX) CubeSat
Intuitive Machines	Open Architecture Vision Processing for Space Nav
Exoterra Resource	Courier Solar Electric Propulsion Module
Infinity Fuel Cell and Hydrogen	Advanced Modular Power and Energy Systems
Luna Innovations	Embedded Structural Health Sensors for Inflatable Space Habitats
Oxeon Energy	Integrating Thermal Processing of Lunar Ice & Solid Oxide Electrolysis for Liquid H2 and O2 Production
Paragon Space Development Corp.	Shape Memory Alloys for Regulating TCS in Space
Skyre	Lunar Propellant Production Plant
SpaceX	Standardized Fluid Coupling Development for In-Space Cryogenic Propellant Transfer
TallannQuest	Flexible Radiation-Hardened Switching Power Controller

Announcement of Collaborative Opportunity (ACO)

- **Announcement of Collaborative Opportunity (ACO):**
  - Focus on industry-developed space technologies that can advance the commercial space sector and benefit future NASA missions
  - NASA provides technical expertise and test facilities, as well as hardware and software to aid industry partners in maturing technologies
  - Non-Reimbursable Space Act Agreements (no funds exchanged)

- **ACO Awards:**
  - **2015- 13 awards**
  - **2017- 10 awards**
  - **2019- 19 awards**

- **ACO2020:**
  - Release date: January 2020 (target)
  - 10+ awards are anticipated

- Space Tech Solicitations: https://go.usa.gov/xQRwV

NASA anticipates releasing ACO every year

FY2019 Announcement of Collaborative Opportunities (p 1 of 2)

Awardee	Title	Center
Advanced Space	Advancing Lunar Navigation Technologies to Enable Exploration and Commercial Development	GSFC
Aerogel Technologies	Mechanically Strong Polyimide Aerogels as Multifunctional Acoustic Insulation for Aerospace Applications	GRC
Aerojet Rocketdyne	Extensible Robotic Deposition Technology for Propulsion Systems	MSFC
Anasphere	Ground Testing of HIAD Hydrogen Gas Generator	MSFC
Bally Ribbon Mills	ADEPT/Spider Weave Thermal Testing	ARC
Blue Origin	Precision Safe Lunar Landing System Development	GSFC, JSC
Blue Origin	Primary Fuel Cell Power System for Lunar Landers	GRC, JSC
Blue Origin	Lunar Lander Advanced Nozzle Collaboration	LaRC, MSFC
Colorado Electronics	Qualification and Integration Tests of the Colorado Power Electronics Prototype Development Unit Power Processing Unit with NASA and Commercial Hall Thrusters	GRC
Lockheed Martin	Advanced Lightweight Powder Metallurgy for Hot Structures	LaRC

FY2019 Announcement of Collaborative Opportunities (p 2 of 2)

Awardee	Title	Center
Lockheed Martin	Integration of Autonomous Robotics for Plant-Based Systems in Deep Space	KSC
Maxar/Space Systems Loral	Advanced Packaging Methods for Next-Generation Reflectors	LaRC
Maxar/Space Systems Loral	Advancing Qualification Protocols of Ultra-lightweight 5-junction Solar Cells Applied to Flexible Solar Array Power Modules	GRC, MSFC
Sierra Nevada Corp	Dream Chaser Imaging During Atmosphere Re-entry	LaRC
Sierra Nevada Corp	Aeroheating and aerodynamic predictions correlation on the UPSTAR deployable decelerator	LaRC
SpaceX	Development of Large Vehicle Landing Surface Interaction and In-Situ Resource Risk Mitigation	KSC
SpaceX	Cryogenic Fluid Transfer Technology Demonstration: Technical Assessment and Concept of Operations Definition	GRC, MSFC
Spirit Aerosystems	Improved Durability for a Low-Cost Reusable Launch Vehicle Manufactured via Friction Stir Welding	MSFC
Vulcan Wireless	Resilience testing of Multi-Mode S-Band Transponder	GSFC

NextSTEP BAA Appendix D and Appendix E

- **Broad Agency Announcement (BAA):**
  - Appendix D: Proposals to advance In-situ Resource Utilization (ISRU)
    - Trade Studies, component, and subsystem development and testing in relevant environment
  - Appendix E: Proposals for prototype efforts and refueling human lunar lander studies
  - Fixed price contracts with milestone payments
  - Engage related terrestrial industries and leverage existing commercial capabilities
  - Increased focus on **collaboration** with the commercial sector
  - Requires a **minimum 20 percent contribution (10% for small businesses)** from corporation or customer
  - Substantial benefit to both **commercial and government sectors**

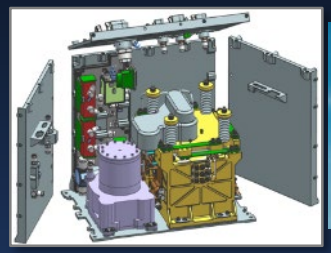
- **BAA Appendix D (2018-9): 9 Awards**
- **BAA Appendix E (STMD, 2019): 11 Awards**

NextSTEP Appendix D: ISRU BAA Awardees

Awardee	Title	Center
Blue Origin	Enhancing Lunar Exploration with ISRU Strategies	KSC
Collins Aerospace	Trade Study, Water Electrolysis	GRC
University of Illinois	Integrated Architecture Trade Studies on ISRU Technologies for Human Space Exploration	KSC
BlazeTech	Compact High Efficiency Self-Cleaning Dust Filter for Martian Air	KSC
Paragon	ISRU-derived Water Purification and Hydrogen Oxygen Production (IHOP)	JPL, JSC
Skyhaven	Hydrogen and Methane Separator for Martian ISRU Processing	GRC
Teledyne	Advanced Alkaline Electrolyzer to Support NASA ISRU Applications	GRC
Honeybee	RedWater: Extraction of Water from Mars' Ice Deposits	JPL, KSC
OxEon Energy	Production of O2 and Fuel from In-Situ Resources on Mars	JSC

FY 2019-2020 Plans

MOXIE
March 2019 delivery to Mars 2020 for **July 2020** Launch



Terrain Relative Navigation
November 2018
Delivery for integration on Mars 2020

Laser Comm Relay Demo
October 2019
Payload delivery for bus integration

Deep Space Optical Comm
June 2019 KDP-C for the flight terminal

MEDLI2
November 2019
Hardware Delivery for integration on Mars 2020 entry system

Astrobee
August 2019
Three free-fliers onboard ISS for demonstration

In Space Robotic Manufacturing and Assembly project
July 2019 Awarded Made in Space Archinaut mission to manufacture and assemble spacecraft components in LEO. Maxar award likely in Sept.

High Performance Spaceflight Computing (HPSC)
FY 2020
Completion of critical design

SPLICE
October 2019
Complete NDL environmental testing; 2020 flight test

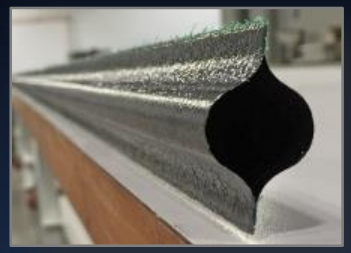
Refabricator Delivery and Installation aboard ISS February 2019
The first integrated recycler and 3D printer was successfully installed

Restore-L
April 2019
Spacecraft critical design review
February 2020
Mission CDR

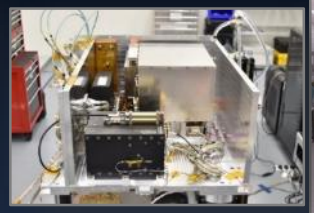
Flight Opportunities Campaigns

FY 2019-2020 Plans

eCryo
April 2020
SHIVER Testing Complete



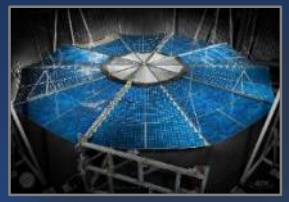
Deployable Composite Boom
November 2019
Manufactured boom and deployment system will be demonstrated early 2020



DSAC & GPIM
June 2019
Launched Aboard STP-2

LOFTID
June 2019
KDP-C
April 2020
CDR

Nuclear Thermal Propulsion
October 2019
Feasibility and risk assessment study of nuclear thermal propulsion



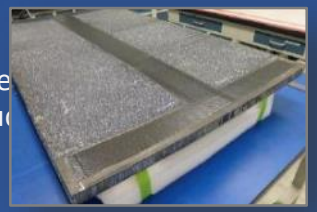
Extreme Environment Solar Power
July 2019
Developing solar cell concentrator technology for low-intensity, low-temperature space power applications. Hardware will be demonstrated for subsequent technology demonstration on SMD's future mission DART

New Space Technology Research Institutes
To advance space habitat designs using resilient and autonomous systems, NASA selected Habitats Optimized for Missions of Exploration (HOME)-Univ of Calif; and Resilient ExtraTerrestrial Habitats institute (RETHi)-Purdue Univ

SpaceCraft Oxygen Recovery (SCOR)
June 2020
Performance test results of two advanced oxygen recovery systems will be available in June 2020 for baseline comparison of capability

Solar Electric Propulsion
June 2019 KDP-C
FY19: Develop and test EDU/ETU/qualification hardware
FY20: Complete Critical Design Review, build qualification units and begin testing

Composite Technology for Exploration
September 2019
Complete testing of composite joint technology that will redu launch dry mass

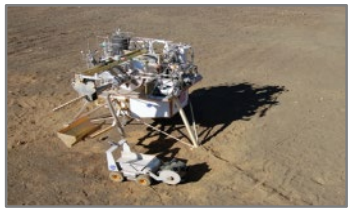


STMD by the Numbers (FY 2019)


NASA
EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION

Back-up

Mission and Guiding Principles



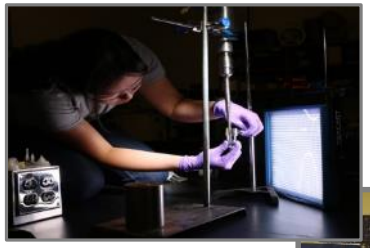
Space Technology develops critical technologies to enable:

- A sustainable Lunar surface presence,
- The future goal of sending humans to Mars, and
- Crosscutting and transformative technologies to enable future exploration, science and commercial missions.

We accomplish this mission by:

- Funding critical technology gaps
- Keeping NASA's space technology pipeline growing with emerging, innovative technologies that promise to drive the future of exploration, science and commercialization.

- ✓ Spark Innovation
- ✓ Engage The Brightest Minds
- ✓ Enable Exploration and Discovery
- ✓ Embrace Competition and Public-Private Partnerships
- ✓ Invest in America



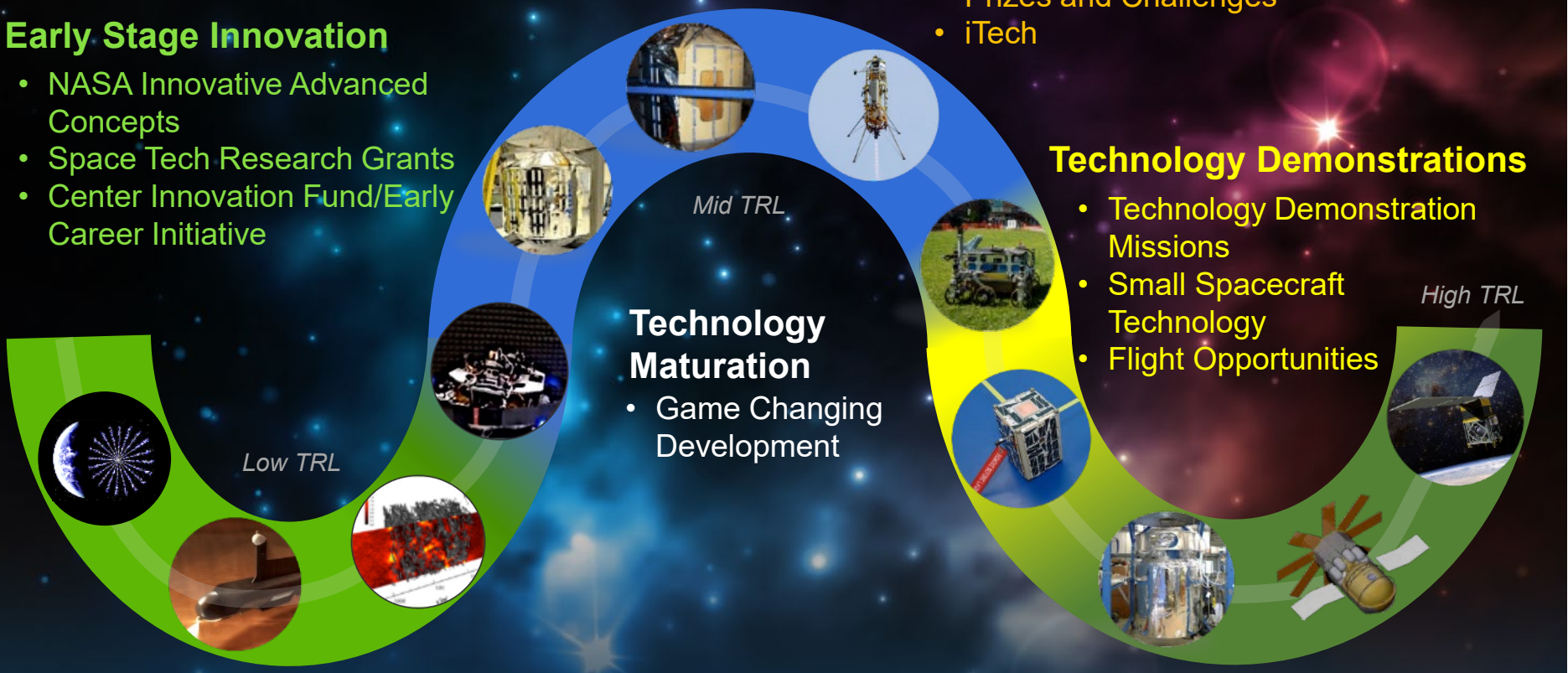
SBIR/STTR

Partnerships & Technology Transfer

- Technology Transfer
- Prizes and Challenges
- iTech

Early Stage Innovation

- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund/Early Career Initiative



Technology Maturation

- Game Changing Development

Technology Demonstrations

- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

TECHNOLOGY PIPELINE