Astromaterials Research and Exploration Science
Johnson Space Center

National Aeronautics and
Space Administration

Raising the TRL of your Lunar Payload
ISDC 2026

Anastasia Ford
Surface Science and Technology Specialist in JSC ARES Division Exploration Science Office
Previous: Test Engineer/Technology and Architecture Lead in JSC Propulsion and Power Division

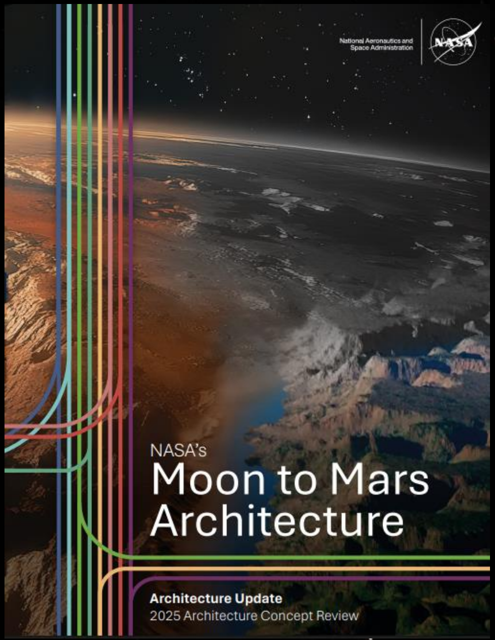
With contributions by:
Jeremiah McNatt, Principal Technologist of Power for STMD at GRC
CLPS Office

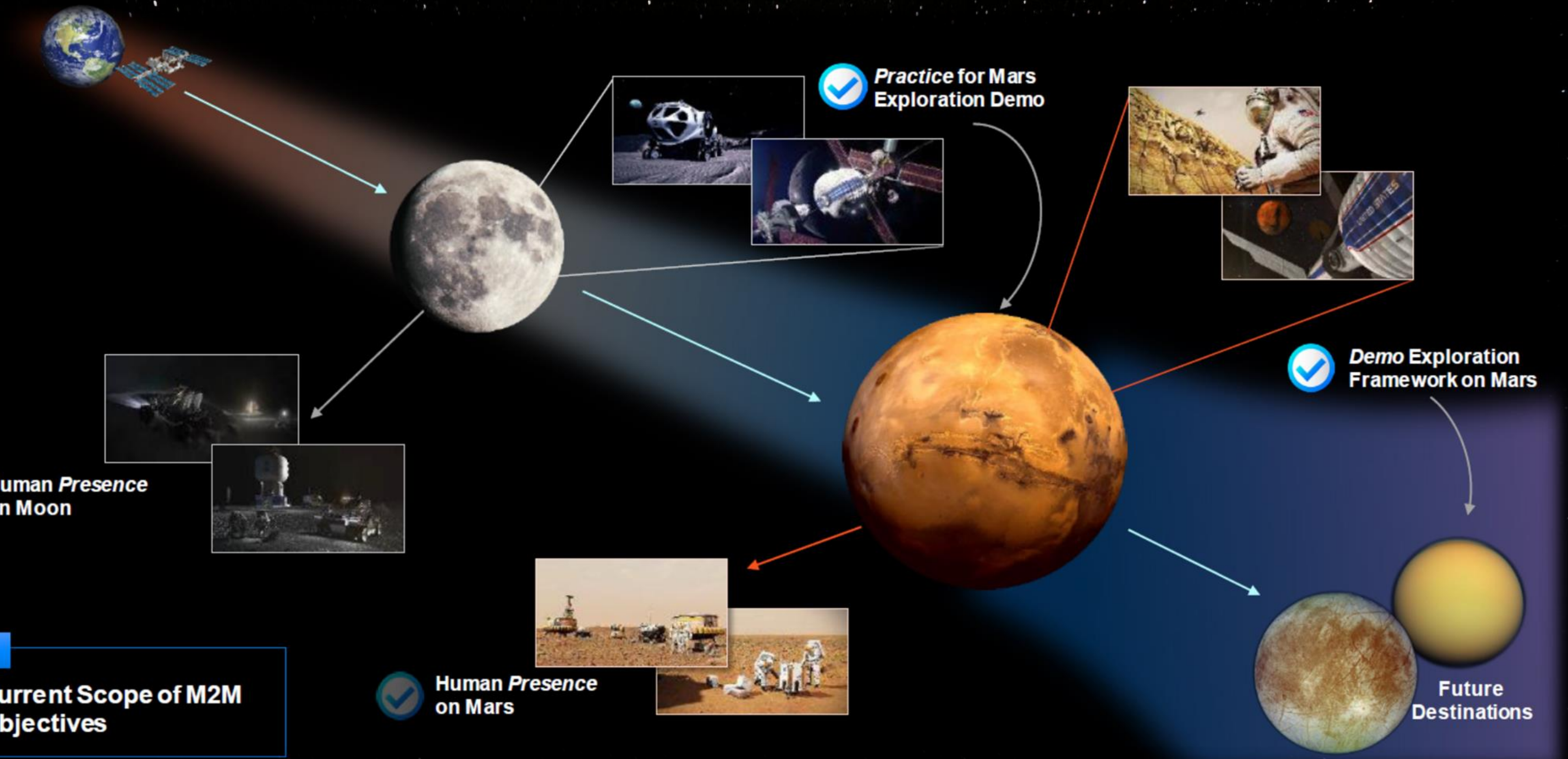
Note: Due to the rapid evolution of program schedules and mission plans, this presentation may include information that is no longer current.

Artificial Intelligence (AI) Usage Disclosure

This presentation was created with assistance from Copilot for editing the document for grammar and composing some of the sentences. The content has been reviewed and edited by Anastasia Ford.

Big Picture: Moon to Mars





KEY

Current Scope of M2M Objectives

McNatt, J. *Lunar Surface Power: Needs, Challenges, and Technologies* [PowerPoint slides]. NASA Space Technology Mission Directorate. (2026, February 10). Virtual presentation delivered to the Ohio Federal Research Network (OFRN) Opportunity Days.

Architecture Segments

Future Segments

Human Lunar Return	Foundational Exploration	Sustained Lunar Evolution	Humans to Mars
Initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization on and around the Moon.	Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization and Mars forward precursor missions.	Enabling capabilities, systems, and operations to support regional and global utilization, economic opportunity, and a steady cadence of human presence on and around the Moon.	Initial capabilities, systems, and operations necessary to establish human presence and initial utilization on Mars and continued exploration.

McNatt, J. *Lunar Surface Power: Needs, Challenges, and Technologies* [PowerPoint slides]. NASA Space Technology Mission Directorate. (2026, February 10). Virtual presentation delivered to the Ohio Federal Research Network (OFRN) Opportunity Days.

Enabling Key Moon-to-Mars Lunar Infrastructure Objectives

LI-1^{L} / MI-1^{M}: Develop an incremental **lunar power** generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels.

LI-2^{L} / MI-2^{M}: Develop a lunar surface, orbital, and Moon-to-Earth **communications** architecture capable of scaling to support long term science, exploration, and industrial needs.

LI-3^{L} / MI-3^{M}: Develop a **lunar position, navigation and timing** architecture capable of scaling to support long term science, exploration, and industrial needs.

LI-4^{L}: Demonstrate **advanced manufacturing and autonomous construction** capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-5^{L}: Demonstrate **precision landing** capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-6^{L}: Demonstrate local, regional, and global **surface** transportation and **mobility** capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-7^{L} / MI-4^{M}: Demonstrate industrial scale **ISRU** capabilities in support of continuous human lunar presence and a robust lunar economy.

LI-8^{L}: Demonstrate technologies supporting cislunar orbital/surface depots, **construction and manufacturing** maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.

LI-9^{L}: Develop **environmental monitoring**, situational awareness, and early warning capabilities to support a resilient, continuous human/robotic lunar presence.

McNatt, J. *Lunar Surface Power: Needs, Challenges, and Technologies* [PowerPoint slides]. NASA Space Technology Mission Directorate. (2026, February 10). Virtual presentation delivered to the Ohio Federal Research Network (OFRN) Opportunity Days.

The Benefits and Challenges of Illumination

An abundant resource to produce power in space but scarce and/or limited on at the surface

Lunar Equatorial Illumination Limits

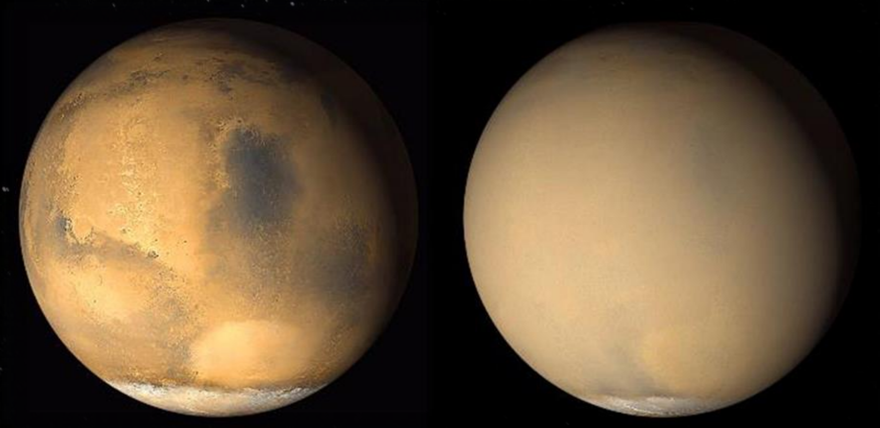
- Cyclical periods of 14 days illuminated, 14 days (*340 hours*) dark
- Consistent

Lunar Polar Illumination Limits

- High illumination sites exist but with intermittent (up to 3-day) periods of continuous darkness
- Highly dependent on location/elevation

Mars Surface Illumination Limits

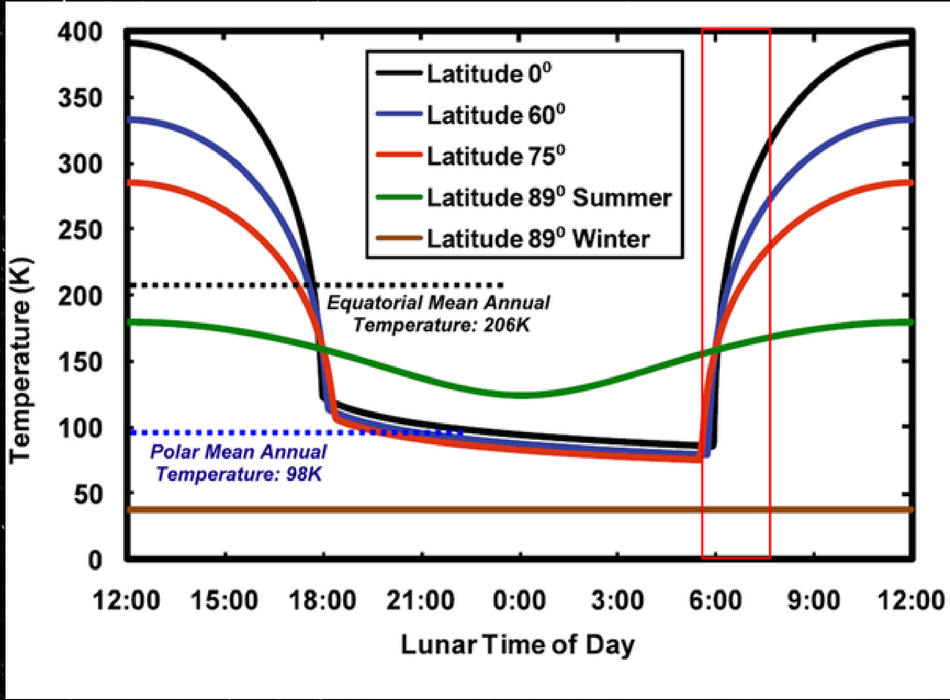
- Global and Local dust storms decrease illumination as much as 95% in extreme cases



McNatt, J. *Lunar Surface Power: Needs, Challenges, and Technologies* [PowerPoint slides]. NASA Space Technology Mission Directorate. (2026, February 10). Virtual presentation delivered to the Ohio Federal Research Network (OFRN) Opportunity Days.

The Moon also has Unique Thermal Conditions

- Temperatures near the Moon's equator can spike to 250°F (121°C / 390 K) in daylight, then plummet after nightfall to -274°F (-170°C / 100 K).
- In deep craters near the Moon's poles, permanent shadows keep the surface even colder — NASA's Lunar Reconnaissance Orbiter has measured temperatures lower than -410°F (-246°C / 30K).



McNatt, J. *Lunar Surface Power: Needs, Challenges, and Technologies* [PowerPoint slides]. NASA Space Technology Mission Directorate. (2026, February 10). Virtual presentation delivered to the Ohio Federal Research Network (OFRN) Opportunity Days.

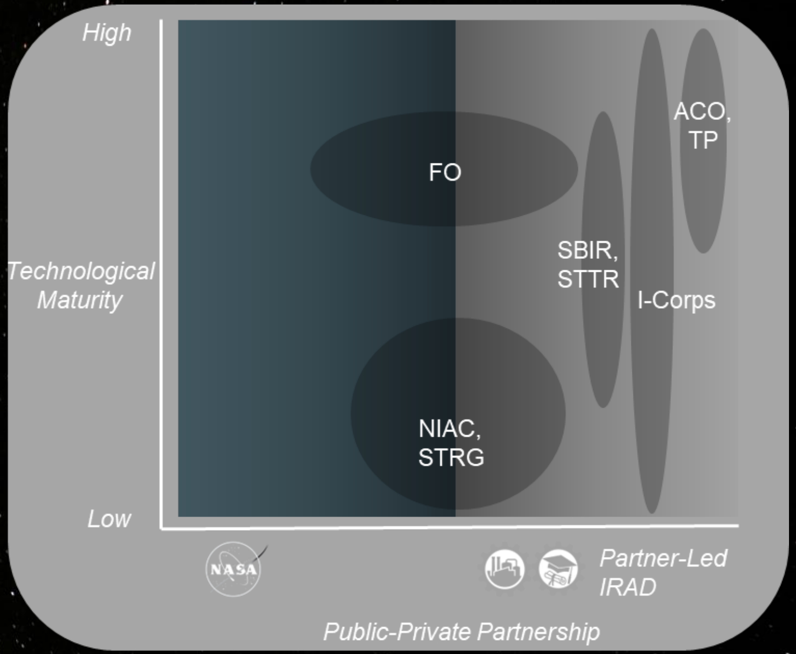
NASA's Innovation Pipeline

NASA's STMD advances U.S. leadership by delivering strong economic returns and strengthening domestic industry through its unique, collaborative role across the full technology development lifecycle.

Near-Term, Partner-led Research and Development: Industry or Academic Institution led research and development, leveraging NASA's facilities, expertise accessed through procurement and mutual agreements mechanisms to accelerate progress, offset and reduce costs. These efforts are designed to advance TRL and enable near-term mission infusion.

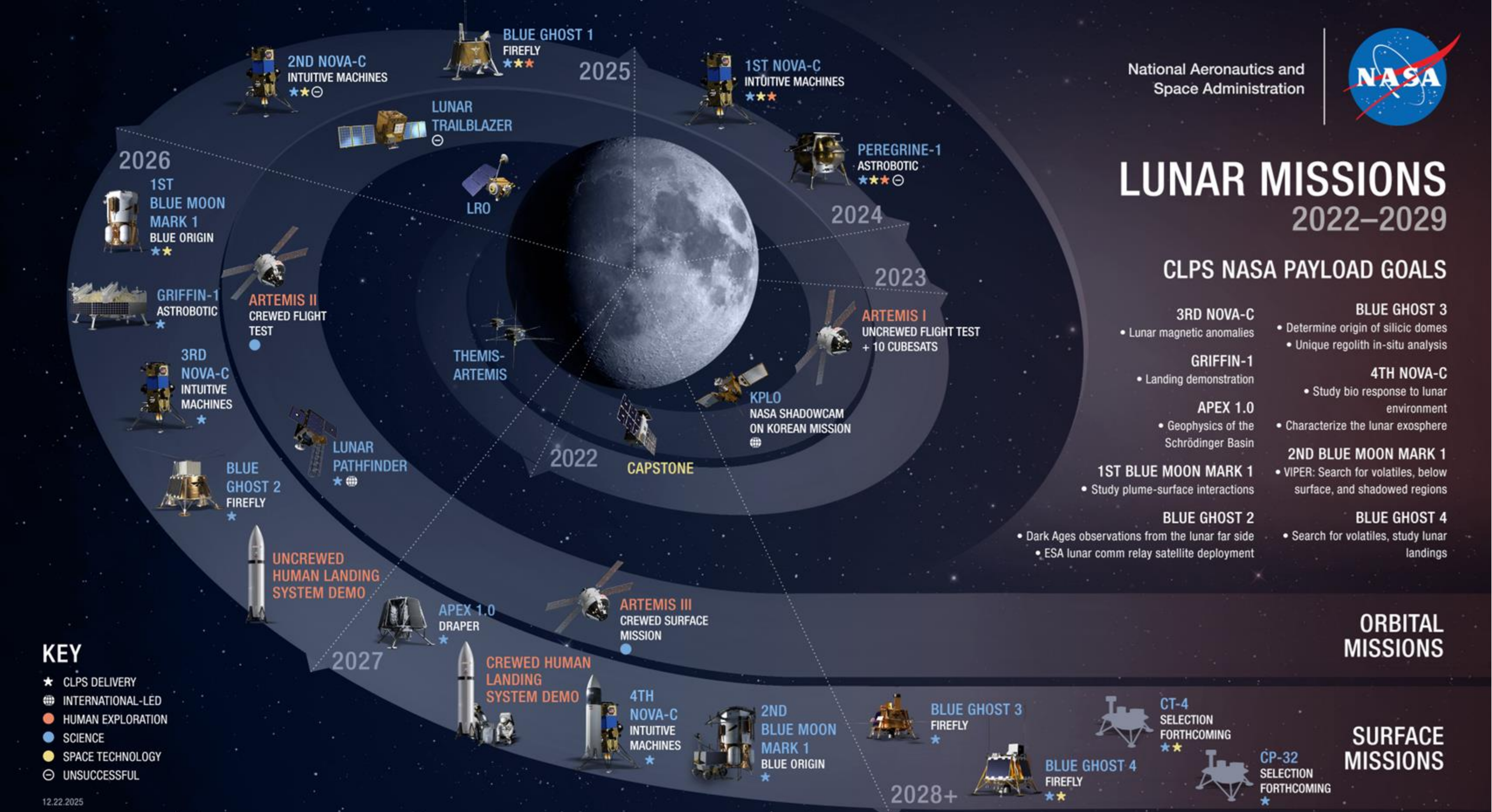
NASA uses a variety of specialized programs —each utilizing tailored procurement and agreement mechanisms to support innovation at specific stages of technology maturity. These programs include:

- NASA Innovative Advanced Concepts (NIAC)
- Space Technology Research Grants (STRG)
- Small Business Innovative Research (SBIR)
- Small Business Technology Transfer (STTR)
- Flight Opportunities (FO)
- Announcement of Collaborative Opportunity (ACO)
- Tipping Points (TP)

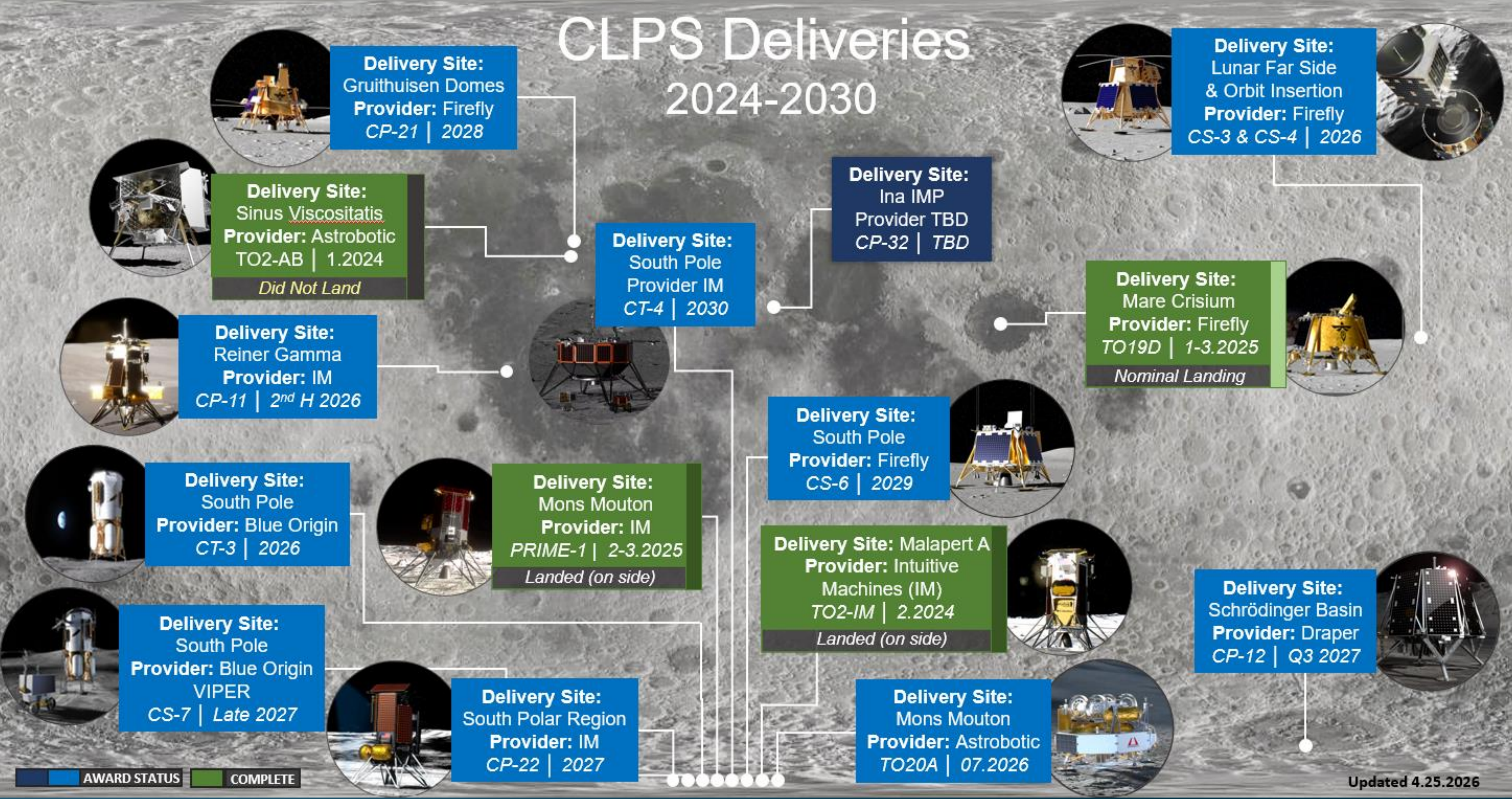


Through these mechanisms, NASA brings a powerful combination of institutional assets to its partnerships—*including world-class technical expertise and access to specialized facilities across its Centers*—enabling the development of transformative technologies with both space and terrestrial applications.

McNatt, J. *Lunar Surface Power: Needs, Challenges, and Technologies* [PowerPoint slides]. NASA Space Technology Mission Directorate. (2026, February 10). Virtual presentation delivered to the Ohio Federal Research Network (OFRN) Opportunity Days.

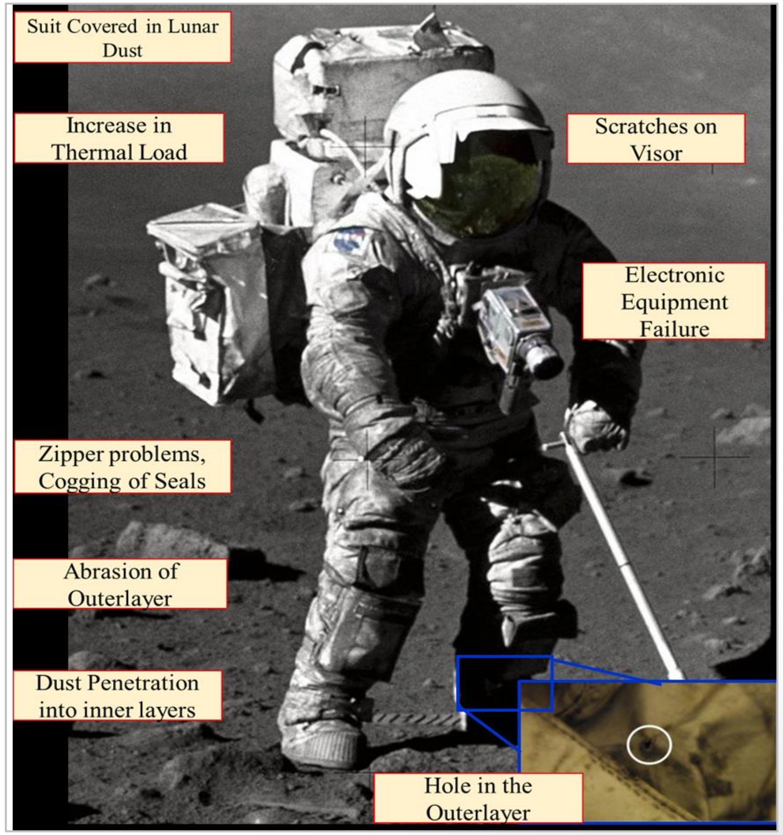


NASA CLPS Program Office. (2025, December 22). Lunar missions 2022–2029 [Diagram].



CLPS Program Office (2026, April 25). CLPS Deliveries landing sites diagram 2024–2030 [Image].

Dust is Difficult



Lunar dust effects on spacesuits and operations during Apollo[1]

Mission	#EVAs[1]	EVA Hours[1] (HH:MM)
Apollo 11	1	2:32
Apollo 12	2	7:45
Apollo 14	2	9:22
Apollo 15	1*+3	18:34
Apollo 16	3	20:14
Apollo 17	3	22:03
Total Apollo	14+1*	79.5hr
Artemis IV+	4	32:00
Artemis VI+		24hr/week

* Apollo15: 33-min Stand-up EVA out top hatch of LEM, before 3 EVAs

Dust is difficult!

Excerpts of few remarks on Lunar dust from Apollo astronauts during Apollo missions[2]

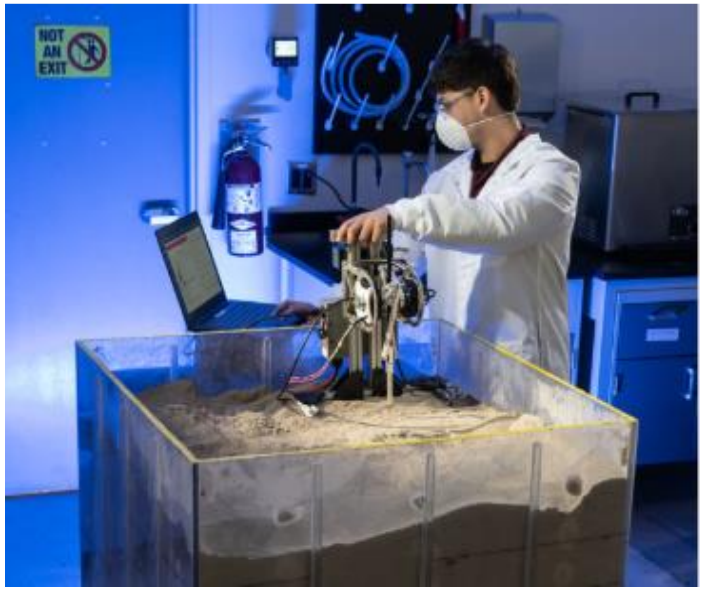
- **Apollo 17-Cernan**: *"Dust - I think probably one of the most aggravating, restricting facets of lunar surface exploration is the dust and its adherence to everything no matter what kind of material, whether it be skin, suit material, metal, no matter what it be and it's restrictive friction-like action to everything it gets on"….."I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust."*
- **Apollo 16 -Young** *"Dust is the number one concern in returning to the moon"*

References:

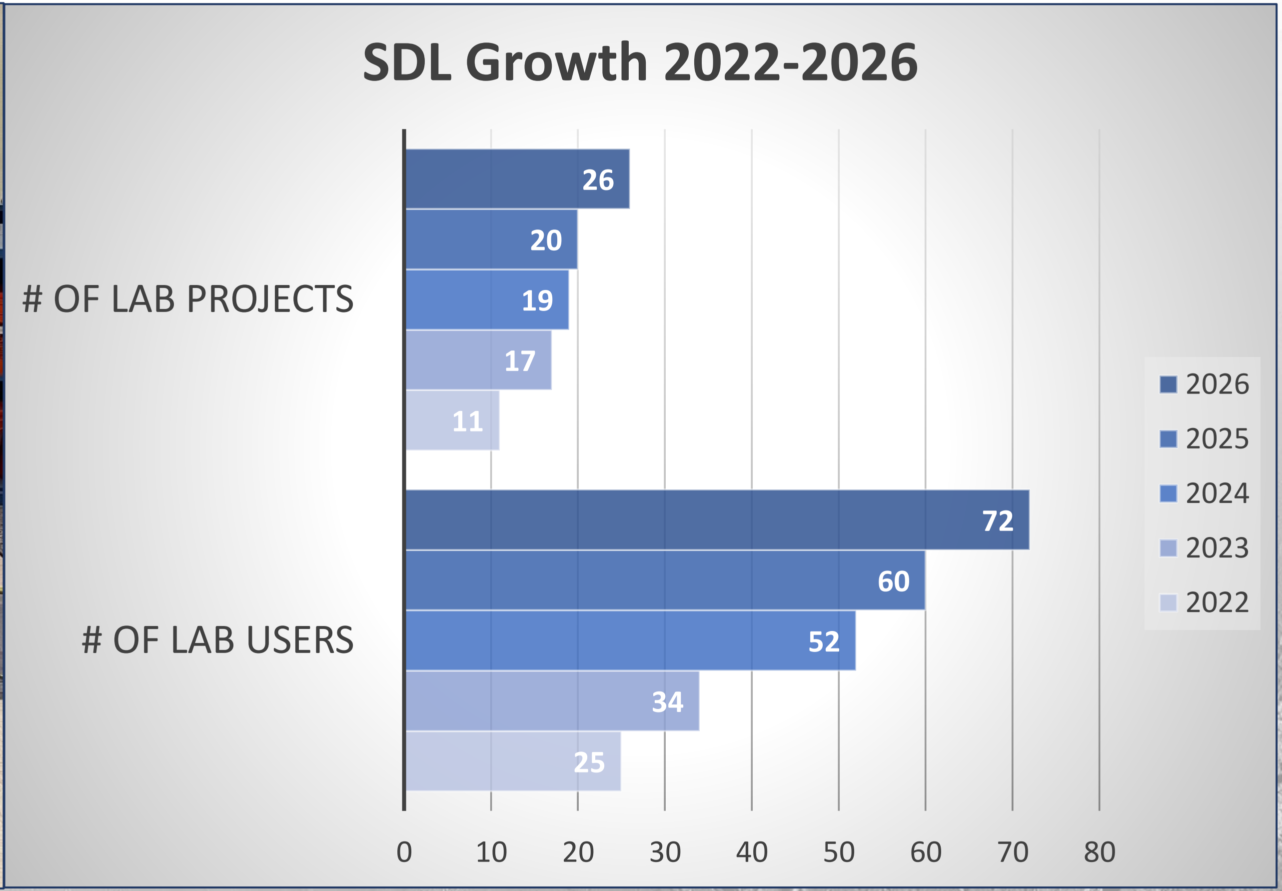
1. Kavya K. Manyapu, Leora Peltz, Pablo De Leon, Self-cleaning spacesuits for future planetary missions using carbon nanotube technology, Acta Astronautica, Volume 157, 2019, Pages 134-144, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2018.12.019.
2. Gaier, J.R. (2005) The Effects of Lunar Dust on EVA Systems during the Apollo Missions, NASA/TM-2005-213610, NASA Glenn Research Center, Cleveland, Ohio. - References - Scientific Research Publishing. https://ntrs.nasa.gov/api/citations/20050160460/downloads/20050160460.pdf

Simulant Development Lab (SDL) at JSC

- The **SDL** is a **multifunction collaborative lab space** that supports the **development**, **curation**, **analysis**, **testing**, and **distribution** of **planetary simulants** (Lunar, Martian, Asteroidal) and granular materials.
- The SDL provides a dynamic working space where **science** (*characterization of physical simulant properties*) and **engineering** (*tools, gloves and suit materials, dust mitigation, robotic prototypes*) **experiments can be conducted using testbeds of simulants**.
- The lab currently houses over ***35 metric tons of simulant material***.
- Additionally, the SDL is furnished with a wide scope of **equipment and tools** used to **process simulants** (*including bulk simulant and feedstock materials such as rocks*) along with a key selection of **analytical instruments** which are used to **characterize** these materials.



Simulant Development Lab (SDL) at JSC is growing



Advanced Concepts for Exploration (ACE) Lab

What is JSC-ARES XI4's Advanced Concepts for Exploration (ACE) Laboratory?

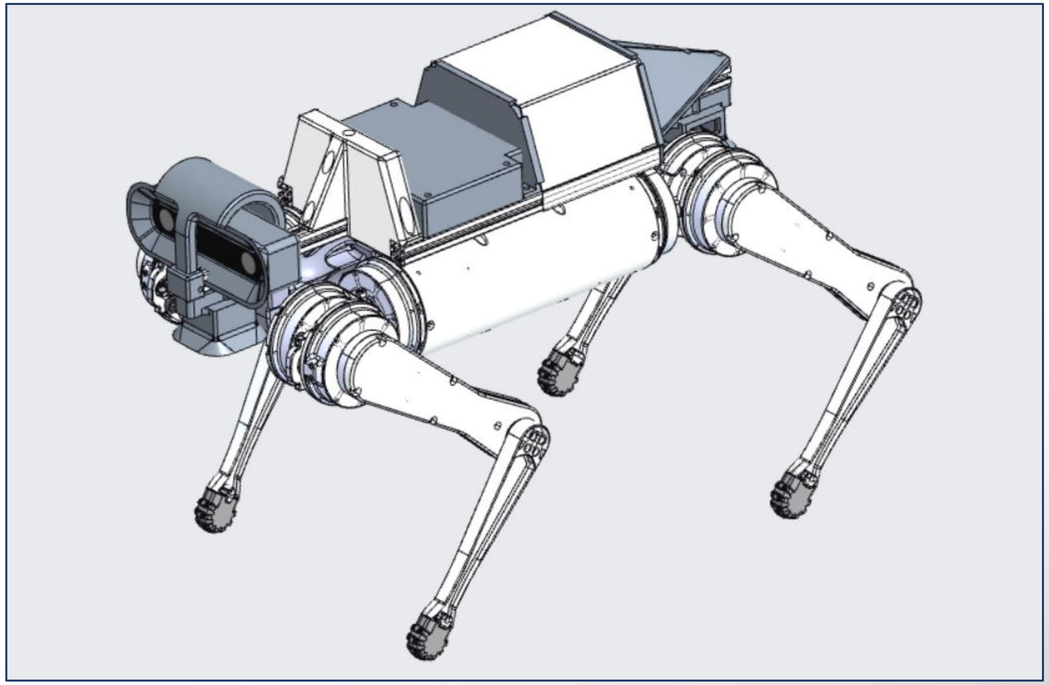
- Hardware makerspace supporting early- to mid-TRL prototyping for human and robotic off-planet exploration
- Provides open-benchtop workspace plus a wide array of tools and equipment
- Functions as a collaborative nexus bridging science and engineering teams

Tools/equipment available:
- High-vacuum chamber
- Soldering station with electronic/circuit components
- Motherboards/breadboards, with plenty of electric wire
- New, state-of-the-art 3D printer
- Computer stations (raspberry pi desktop, NVIDIA Jetson's)
- Rechargeable batteries, power banks & power supplies, multimeters and oscilloscopes
- Plenty of hand and power tools
- 80/20 structural beams and hardware for test setups
- Misc. sensors: stereocameras, an IMU, & Pi cameras.

ACE Lab Project: LASSIE

Legged Autonomous Surface Science In Analogue Environments

LASSIE payload prototype designed in/around ACE lab:

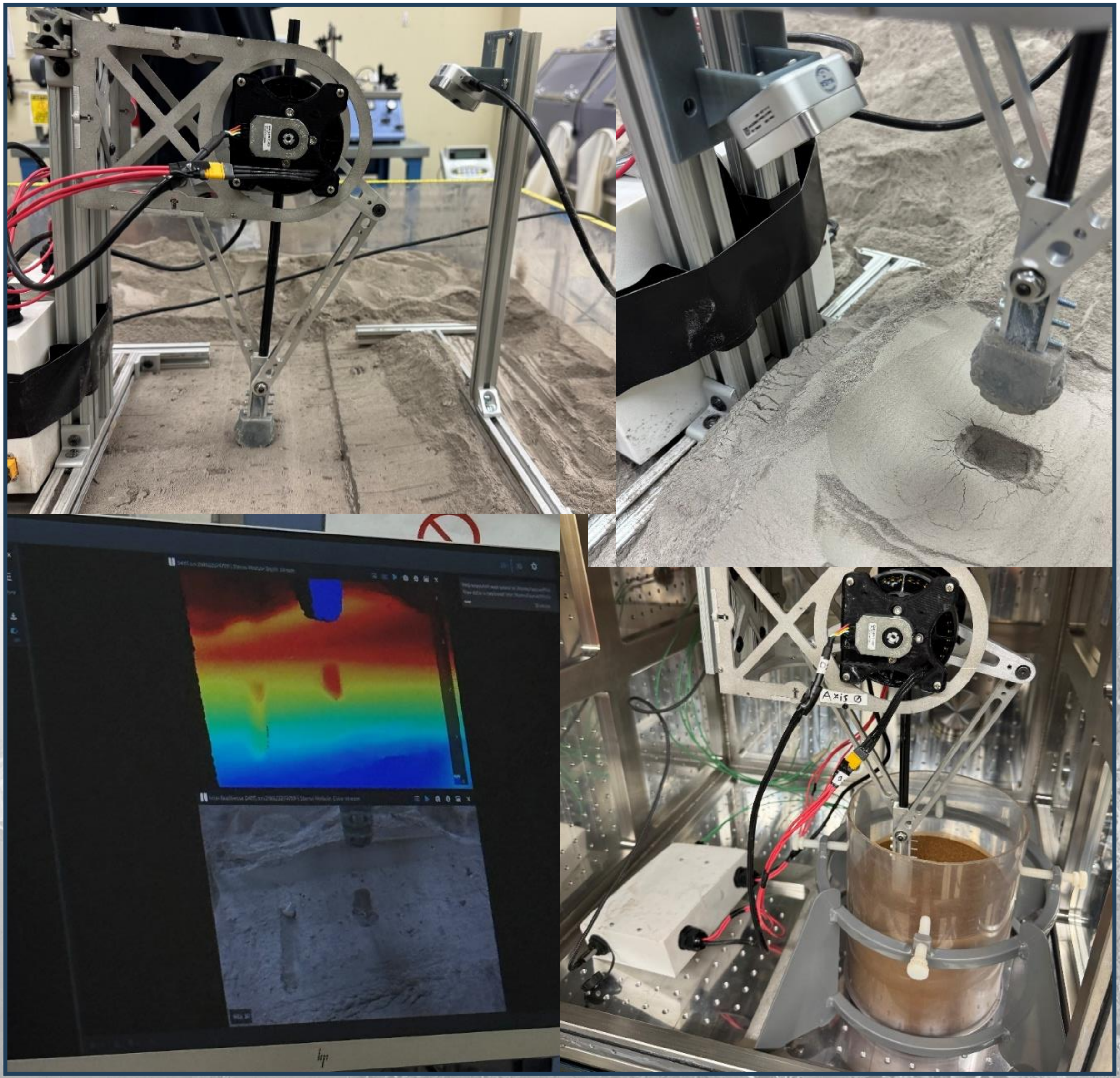


LASSIE field deployment in White Sands NP, New Mexico (Aug 2025):

ACE Lab Projects

Current/past projects:

- LASSIE-M(ars): ACTIVE
  - Multi-disciplinary robotic quadruped project aimed at evaluating the effectiveness of legged robots for exploration science.
- Project Newton: ACTIVE
  - Assessing the capabilities of a COTS wheeled robot for “Risk-Bounded, Goal-Driven AI for Human Planetary Exploration.”
- EC5 Advanced Suit Team - EXCON Suits: ACTIVE
  - These suits are mockup space suits based on xEMU hardware architecture and are used to simulate the movement restrictions of a space suit while performing comms testing and training.
- Wizard LiDAR staff
  - Rechargeable, battery powered mobile tool with a variety of uses for lunar surface exploration.
- HERMES Strata-1 ISS Payload
  - Flown hardware that investigated asteroid regolith dynamics over a one-year trip aboard the ISS.
- Lunar Superconducting Magnetic Energy Storage (LSMES) for Artemis project
  - Assessment of high temp superconductors (HTS) for applications within the moon’s permanently shadowed regions (PSR’s).



ARES Hypervelocity Impact & Orbital Debris Office

NASA mission-focused organization supporting flight programs with orbital debris models, risk assessments, and guidance to meet orbital debris mitigation and micrometeoroid orbit debris (MMOD) protection requirements with minimal mass and cost.

- **HVIT** Hyper Velocity Impact Technology capabilities:
  - **Risk Assessment:** Bumped-code used to calculate probability-of-no-penetration values, identify MMOD risk drivers, guide risk mitigation design solutions, and support mass-reduction trades. (ITAR; releasable via NASA SUA with active U.S. Gov contracts.)
  - **Shield Development:** Designs and evaluates advanced spacecraft shielding for meteoroid and debris protection.
  - **Hypervelocity Impact Testing:** Performs real-world impact tests to validate shield performance and derive failure-prediction equations.
- **ODPO** Orbital Debris Program Office provides:
  - **Measurements**: Actively collects data to support orbital debris environment definition models via ground-based sensors (radar and optical), impact data from returned spacecraft surfaces, develops in-situ sensors (i.e., Multilayer Acoustic Conductive-grid Sensor: MACS), and utilizes ground-based laboratory experiments and characterization to support size/breakup/environment models
  - **Models** on the environment flux, evolution, and analysis of on-orbit breakups to evaluate risk to NASA spacecraft
  - **Mitigation/Policy**: Develops and updates USG and NASA debris mitigation requirements/standards and is designated by Office of Safety and Mission Assurance (OSMA) to evaluate compliance to these requirements for all NASA flight Programs/Projects
  - **Reentry risk assessment:** NASA mission orbital debris assessment reports and end of mission plans
  - **Inter-agency and International coordination**: Supports and represents JSC, NASA and US Government in all aspects of orbital debris environment measurement, modeling, assessments and mitigation, publication of the Orbital Debris Quarterly News (ODQN) https://orbitaldebris.jsc.nasa.gov/quarterly-news/

Additional ARES Labs Capabilities

Coordinated Analysis

- Electron Microprobe - Cameca SX-100
- Electron Microprobe - JEOL 8530F
- Focused Ion Beam
- Fourier Transform Infrared
- Laser Microprobe
- NanoSIMS 50L
- Optical Microscopy
- Raman Microprobe
- Scanning Electron Microscopes
- Transmission Electron Microscopes
- Next Generation Sample Preparation

Geo-Cosmochemistry

- Isotope Chemistry
- Isotope Preparation
- ICP-MS | LA-ICP-MS

Geo-Cosmochemistry continued

- MC-ICP-MS | LA-MC-ICP-MS
- Light Element Analysis
- Thermal Ionization Mass Spectrometry

Mission Enabling

- Analytical Geochemistry
- General Chemistry
- M3EGA
- Spectroscopy & Magnetics
- Soil Chemistry & Mineralogy
- X-Ray Diffraction

Organic Geochemistry

- Soluble Organics in Astromaterials

Process Simulation

- Experimental Impact
- Experimental Petrology

ESTA – Energy Systems Test Area at JSC

ESTA Dust Containment and Preparation Room

- Enclosed 750 ft^2 room sealed and equipped with HEPA fan filtration unit for dust containment and negative pressure maintenance.
- Particulate monitoring and audible alarm to ensure air quality is maintained.
- Provides room for regolith bin loading and preparation.
- Provides room for test article preparation and pre-conditioning prior to transfer to the 15’ chamber.
- Houses desktop ambient dust box and small vacuum bell jar.

3ft Dusty TVAC Chamber

- Description
  - Dust tolerant 3’ TVAC chamber capable of testing components and technologies in lunar simulant
- Specifications
  - Dimensions: 36” x 36” x 36”
  - Vacuum: 1×10^{-6} torr
    - Throttleable roughing pump-down with Pfeiffer turbopump for high vacuum
    - 1×10^{-6} torr within 1-hour, empty chamber
  - Atmosphere: Air or GN_2 Repressurization
  - Thermal Range: -185°C to +150°C Thermal shroud temperatures
  - Shroud walls independently controlled for zone temperature conditioning if needed

15ft Dusty TVAC Chamber

15ft Dusty TVAC Chamber

- Description
  - 15ft Φ Spherical Chamber with ~78in Φ clear entry
  - Dust tolerant chamber capable of testing systems or subsystems with lunar simulant
- Environment Capability
  - Vacuum: $1x10^{-6}$ torr (ultimate),
    - Pumping, rotary piston pumps, roots blowers & two 36in diameter diffusion pumps
  - Atmosphere: Air or GN_2 Repressurization
  - Thermal Range: -196°C to +120°C Thermal shroud temperatures
  - High channel count data feedthroughs
  - High power feedthroughs available
  - Max platform load: 4,000 lb
  - Test article operation on 48” x 96” regolith bed in chamber with surface interactions with regolith to depths down to ~6 ft
- Previous tests: used for fuel cell, electric APU during Shuttle, Cryogenic propellant storage, Apollo lunar rover tire

Thank You!

McNatt, J. *Lunar Surface Power: Needs, Challenges, and Technologies* [PowerPoint slides]. NASA Space Technology Mission Directorate. (2026, February 10). Virtual presentation delivered to the Ohio Federal Research Network (OFRN) Opportunity Days.