National Aeronautics and Space Administration

Human Lunar Exploration

NASA Advisory Council Human Exploration & Operations Committee

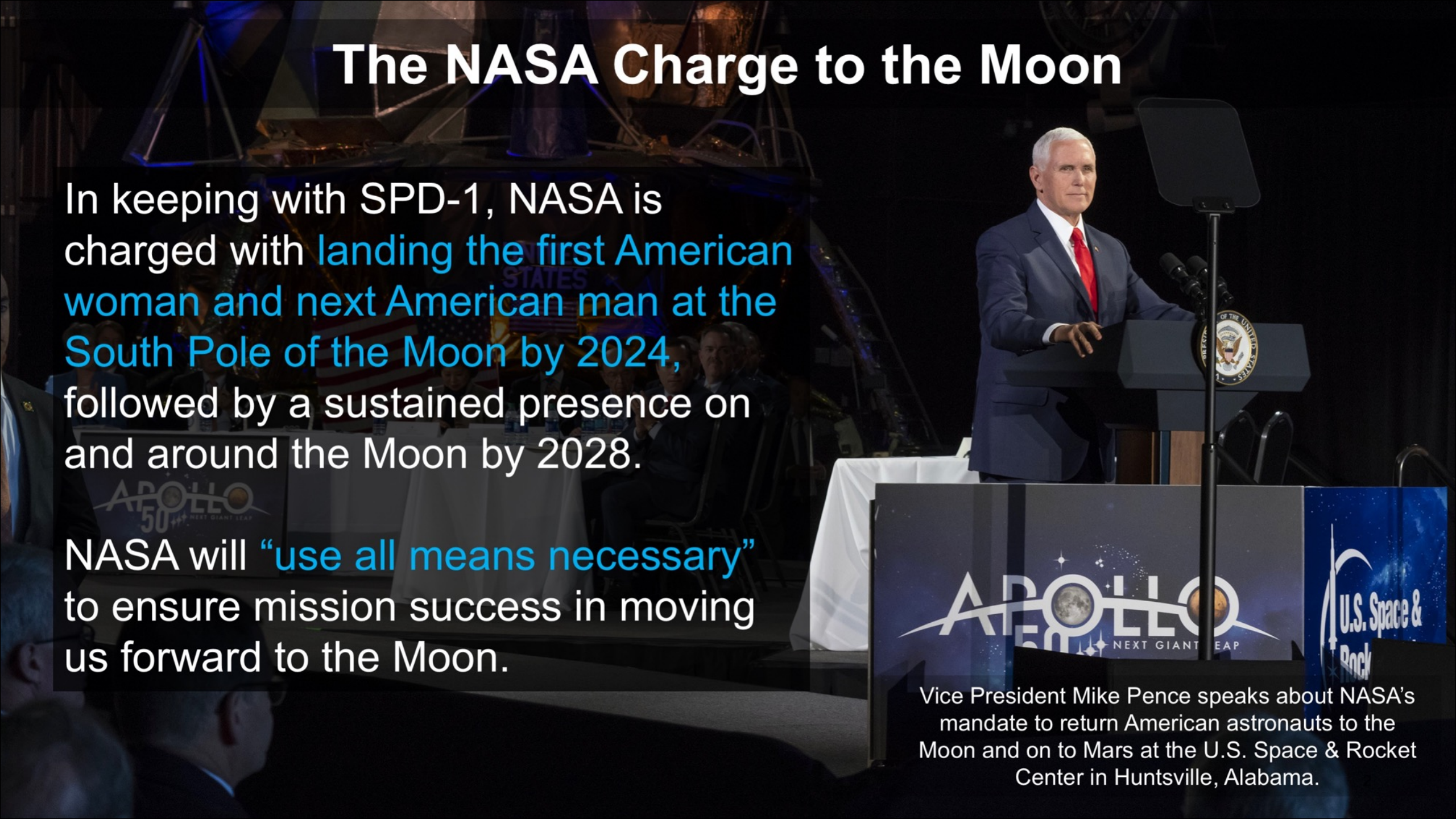
Marshall Smith
Director, Human Lunar Exploration Programs

May 28, 2019

The NASA Charge to the Moon

In keeping with SPD-1, NASA is charged with landing the first American woman and next American man at the South Pole of the Moon by 2024, followed by a sustained presence on and around the Moon by 2028.

NASA will "use all means necessary" to ensure mission success in moving us forward to the Moon.



Vice President Mike Pence speaks about NASA's mandate to return American astronauts to the Moon and on to Mars at the U.S. Space & Rocket Center in Huntsville, Alabama.

Why Go to the Moon?

Establishes American leadership and strategic presence

Proves technologies and capabilities for sending humans to Mars

Inspires a new generation and encourages careers in STEM

Leads civilization changing science and technology

Expands the U.S. global economic impact

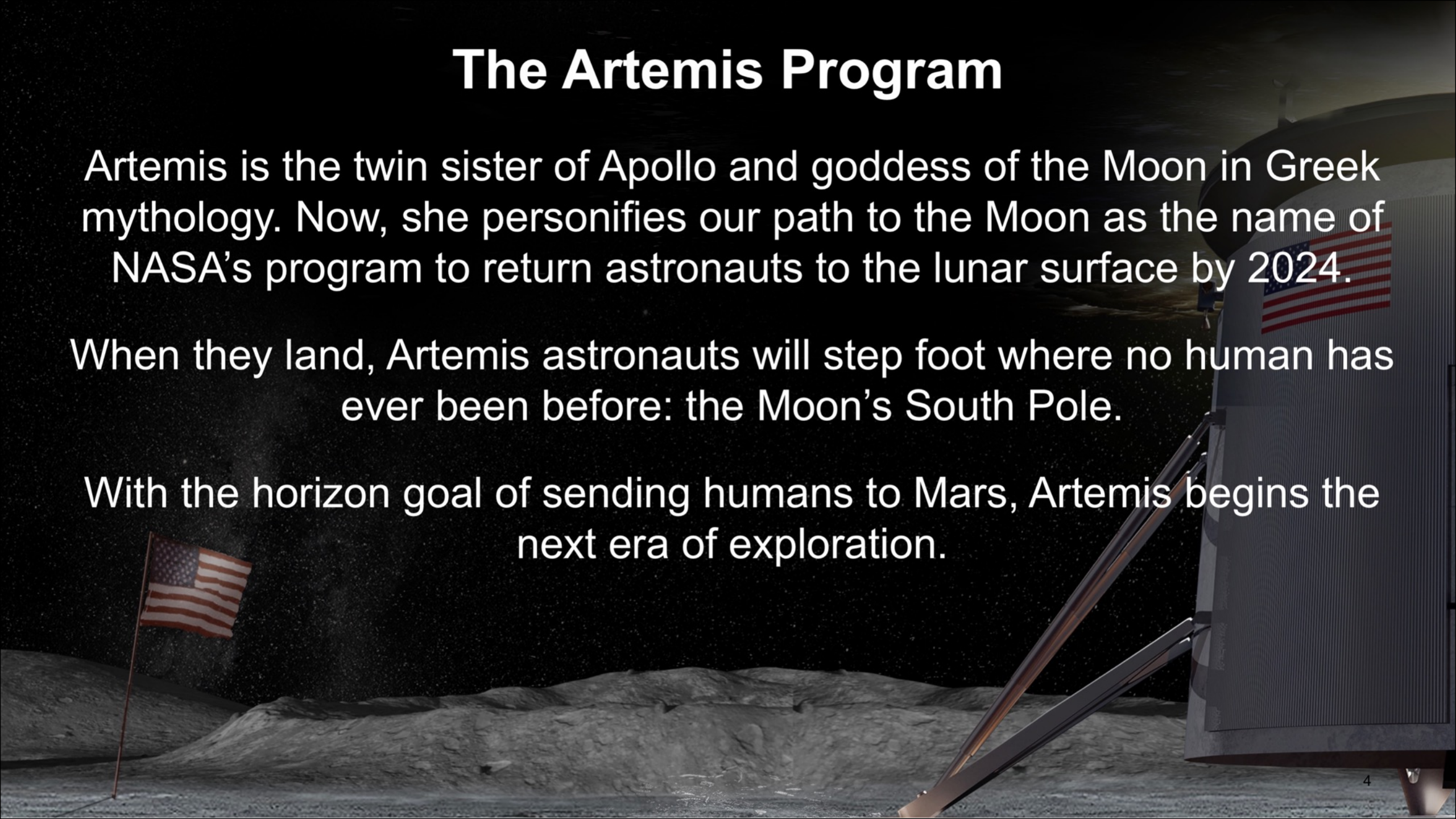
Broadens U.S. industry & international partnerships in deep space

The Artemis Program

Artemis is the twin sister of Apollo and goddess of the Moon in Greek mythology. Now, she personifies our path to the Moon as the name of NASA's program to return astronauts to the lunar surface by 2024.

When they land, Artemis astronauts will step foot where no human has ever been before: the Moon's South Pole.

With the horizon goal of sending humans to Mars, Artemis begins the next era of exploration.



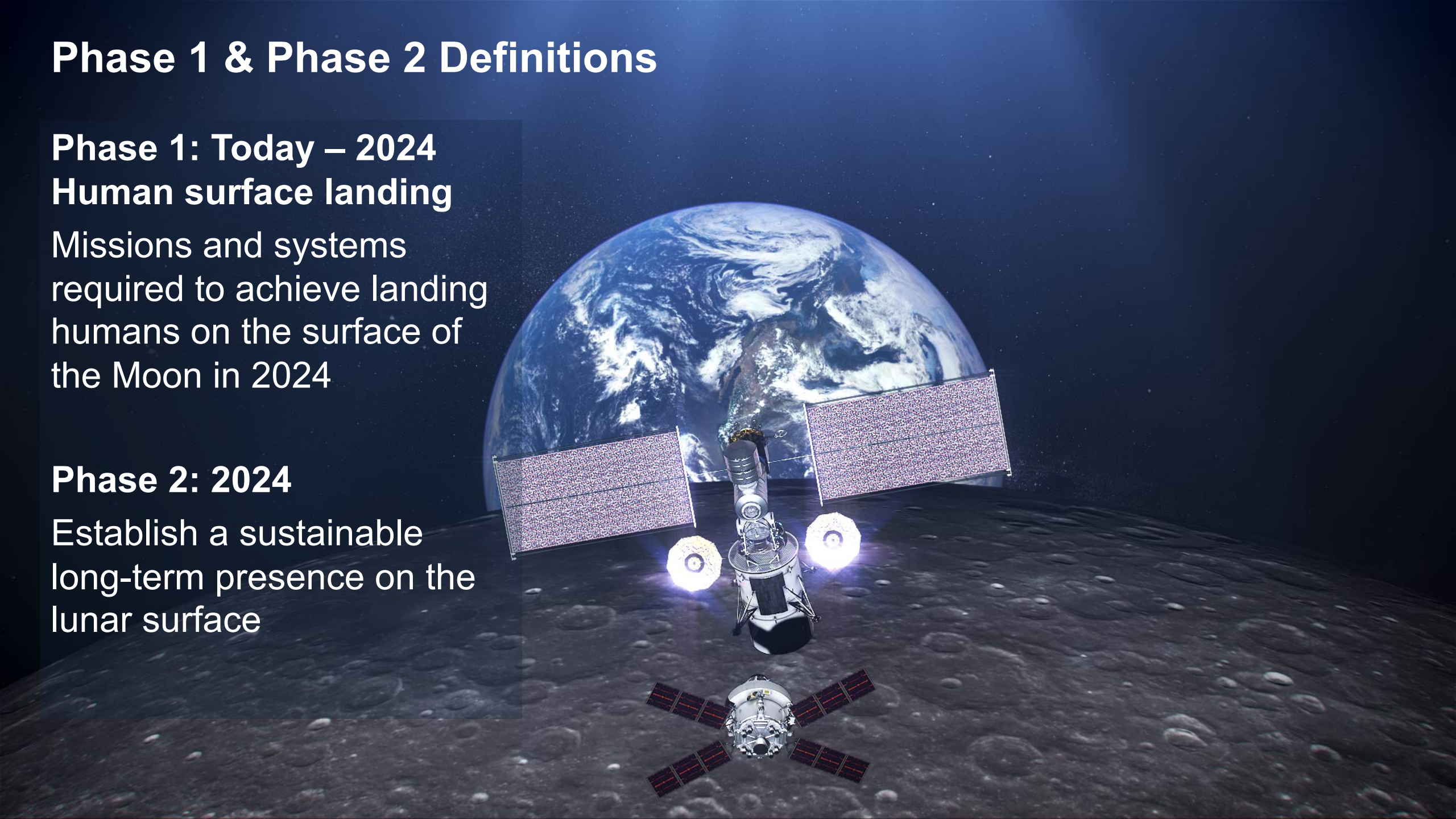
Phase 1 & Phase 2 Definitions

Phase 1: Today – 2024
Human surface landing

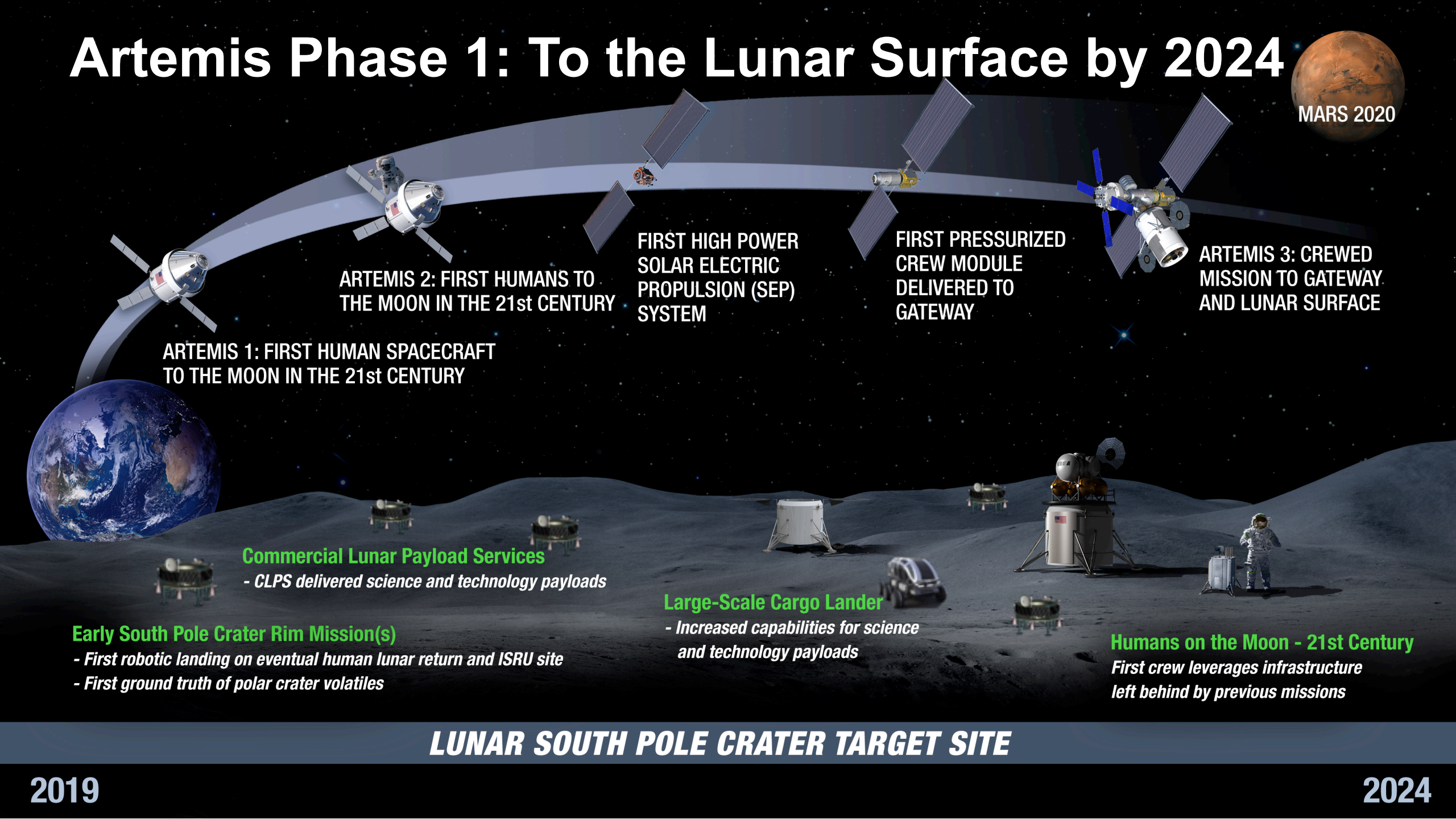
Missions and systems required to achieve landing humans on the surface of the Moon in 2024

Phase 2: 2024

Establish a sustainable long-term presence on the lunar surface



Artemis Phase 1: To the Lunar Surface by 2024



DEVELOPMENT BEGINS 2019

2024

Develop essential hardware and systems required for a 2024 landing

CREW

At least 2 on the South Pole

SUITS

Initial capability suit

EXPEDITION DURATION

Hours-Days (open trade)

ROCKETS

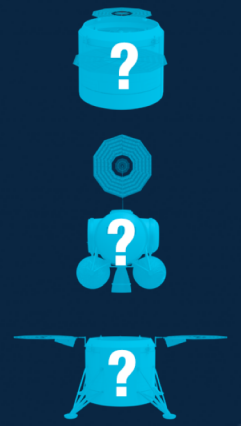
PARTNERS

Significant collaboration with U.S. industry

Potential opportunities for international partners

ACCESS

REUSABILITY



2028

Establish a sustainable human lunar presence with robust, reusable systems

CREW

Up to 4 on the Moon

SUITS

Sustained capability suit

EXPEDITION DURATION

Days-Weeks (open trade)

ROCKETS

PARTNERS

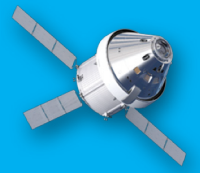
U.S. industry and international collaboration

ACCESS

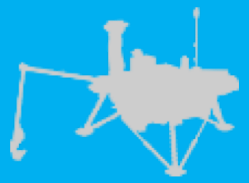
REUSABILITY

20190522

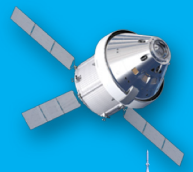
Phase 1: 2024 Lunar Campaign



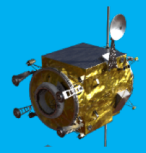
First human spacecraft to the Moon in the 21st Century



Commercial Lunar Payload Services deliveries starting in 2020

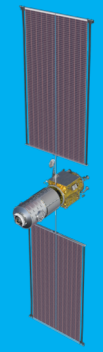


First humans to the Moon in the 21st Century



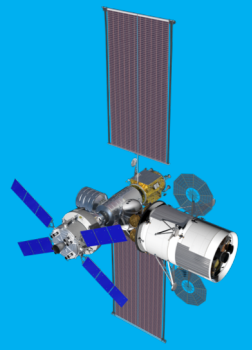
First high power solar electric propulsion system

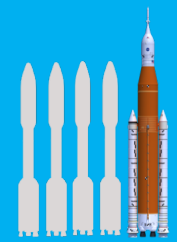
Descent Element Test/Rover



Gateway expanded with habitation capability

Crewed mission to the lunar surface





2020 | 2021 | 2022 | 2023 | 2024

South Pole Crater Rim Mission(s)

- *First* robotic landing on eventual human lunar return and ISRU site
- *First* ground truth of polar crater volatiles

Humans on the Moon – 21st century

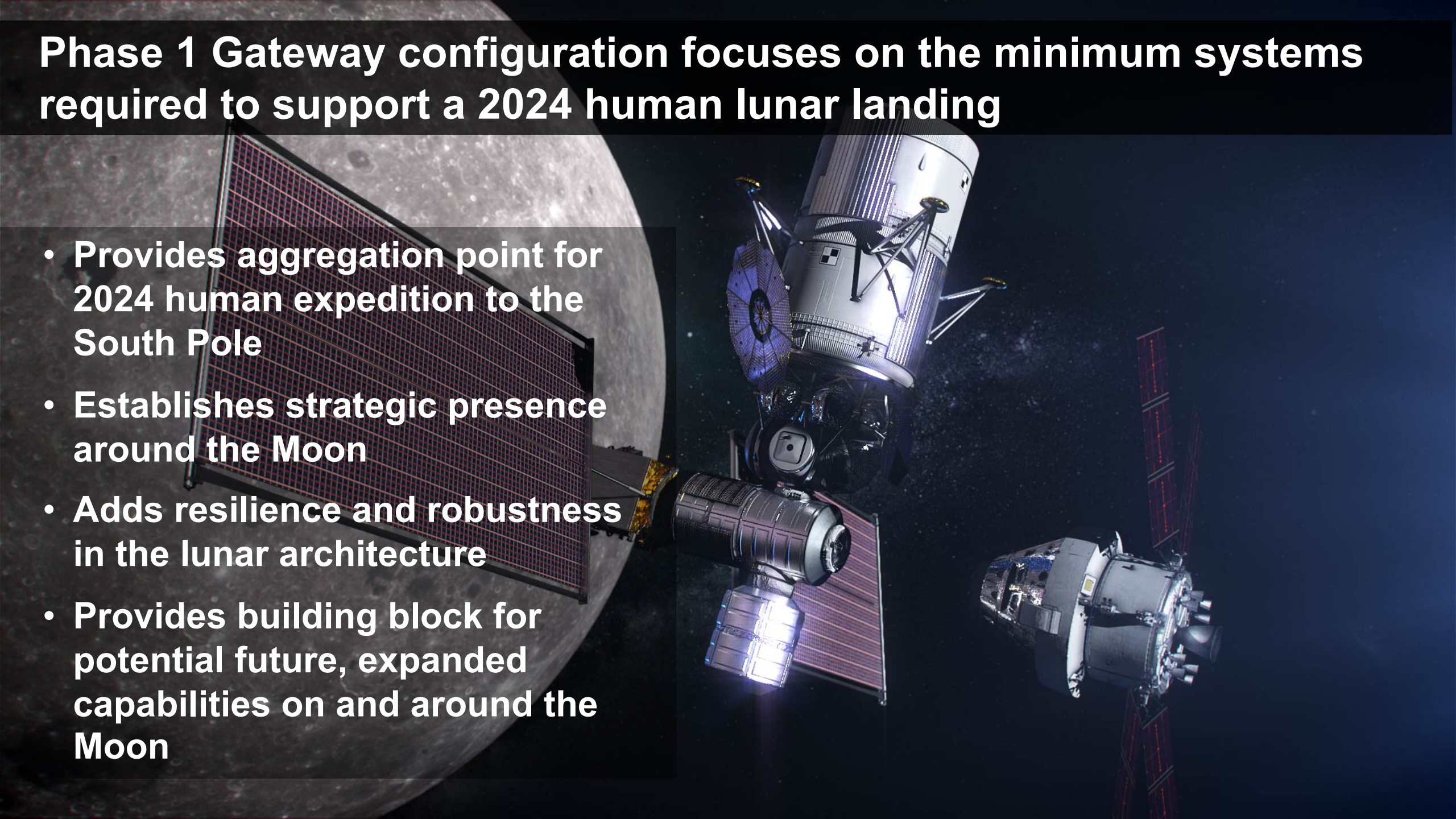
First crew leverages infrastructure left behind by previous missions

CLPS delivered science and technology payloads

Lunar South Pole Crater Target Site

20190425

Phase 1 Gateway configuration focuses on the minimum systems required to support a 2024 human lunar landing

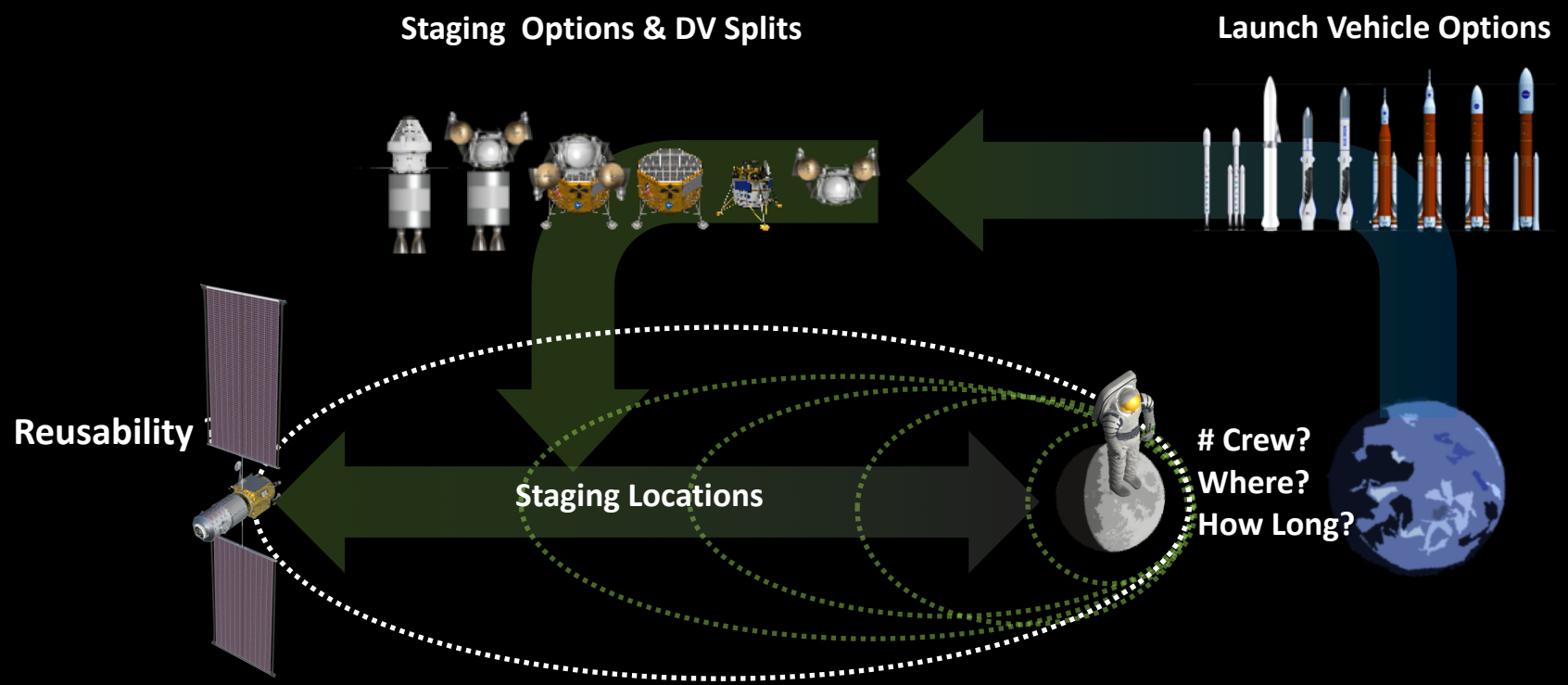


- Provides aggregation point for 2024 human expedition to the South Pole
- Establishes strategic presence around the Moon
- Adds resilience and robustness in the lunar architecture
- Provides building block for potential future, expanded capabilities on and around the Moon

LUNAR ARCHITECTURE UPDATES

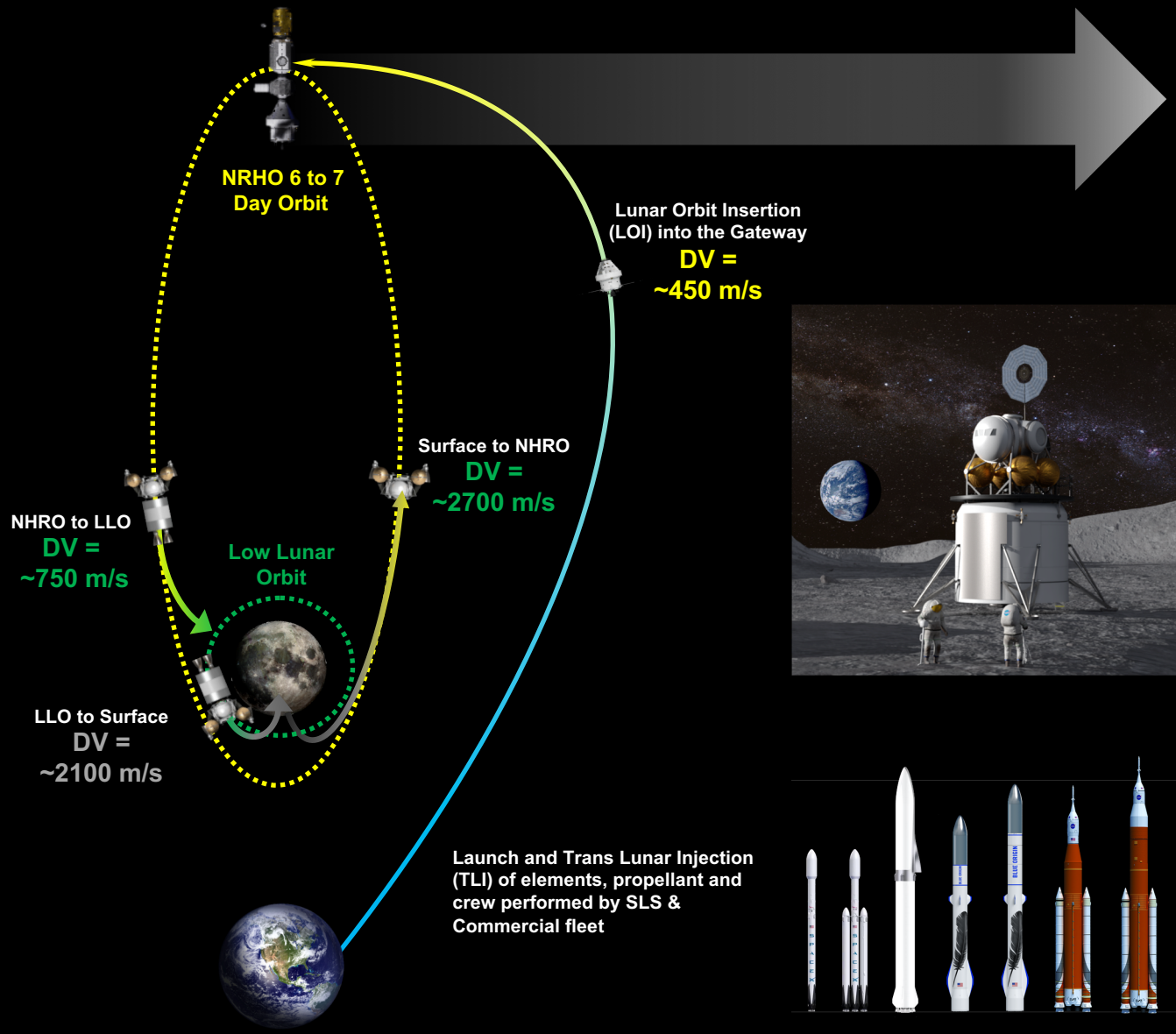
LRO: The phase and libration of the Moon for all of 2019 - Tuesday, May 28
https://svs.gsfc.nasa.gov/4442

Broad Trade Space for Sustainable Human Lunar Access



The architecture for returning humans to the lunar surface is a function of physics, available technology and weighted figures of merit

The Physics Driving Lunar Architecture Choices



Crewed lunar surface missions to polar regions require 6,390 m/s roundtrip through Gateway.

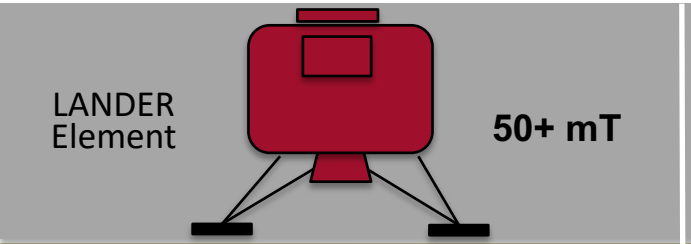
Delta-v for equivalent Direct to LLO mission is approximately 5% lower but requires slightly more mass for first mission. However, for subsequent missions, the Gateway approach significantly reduces mass and cost

Gateway approach allows for delta-v to be distributed across multiple elements reducing mass per launch

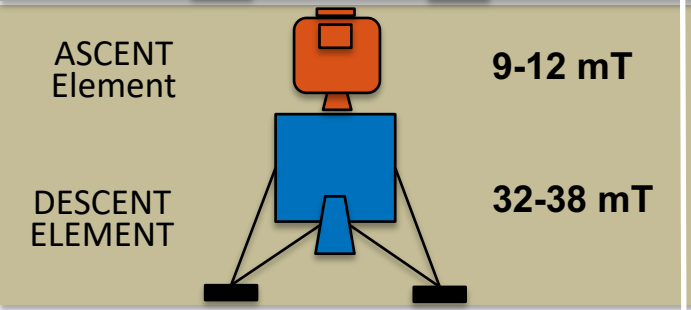
Commercial Launch Vehicles projected to be capable of sending around 15 mT to TLI

Key Takeaways from Initial Internal Architecture Approach Studies

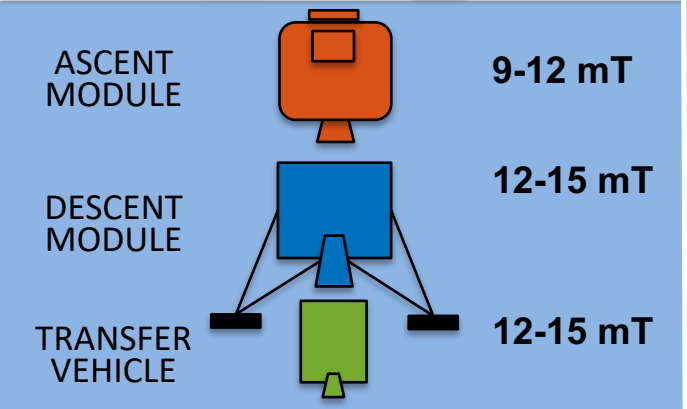
- **Several lander vehicle architecture options were assessed**
- **Single stage landers are not viable given desired requirements**
- **Still trading two and three stage options (and other hybrids)**



- **Direct single-stage human lander is not viable**
  - Does not fit on any launch vehicle, including SLS Block 2 Cargo



- **Two-stage options**
  - Ascent Element fits on commercial launch vehicles expected to be available
  - Maybe able to accommodate 2 stage options with different orbits
  - Descent Element may not fit on single commercial launch vehicle and requires SLS-class launch vehicle



- **Three-stage options**
  - Fits on commercial launch vehicles expected to be available
  - Single elements potentially can be co-manifested payload on SLS
  - Allows increased partnering opportunities
  - Maximizes reusability and flexibility
  - Small module commonality across habitable volumes

Lunar Science by 2024

Polar Landers and Rovers

- First direct measurement of polar volatiles, improving our understanding of their lateral and vertical distribution, as well as their physical state and chemical composition
- Information on the geology of the South-Pole Aitken basin, the largest impact in the solar system

Non-Polar Landers and Rovers

- Ability to explore scientifically valuable terrains not explored by Apollo.
  Examples include:
  - Land at a lunar swirl and make the first surface magnetic measurement
  - Visit young volcanic features such as Ina to understand volcanic evolution
- PI-led instruments - Discovery-class science such as geophysical network and visiting lunar volcanic region

Artemis 1 – Cube Satellite Program

- Over a dozen satellites will be launch as part of Artemis 1

Orbital Data

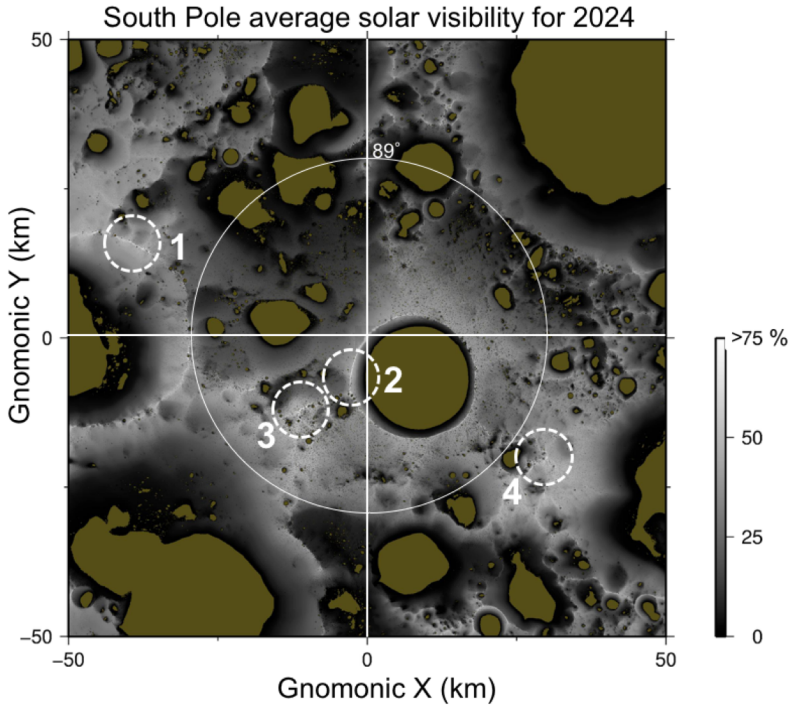
- Cubesats delivered by CLPS providers, or comm/relay spacecraft could acquire new scientifically valuable datasets
- Global mineral mapping (including resource identification), global elemental maps, improved volatile mapping

In-Situ Resource Initial Research

- What is the composition and ability to use lunar ice for sustainment and fuel

American Strategic Presence on the Moon –

High solar illumination areas within 2 degrees (<50 km) of the lunar south pole.



Four highly illuminated areas shown above:

1. De Gerlache Rim,
2. Shackleton Rim
3. Shackleton – De Gerlache Ridge
4. Plateau near Shackleton

High Priorities for Sustained Surface Activities

- **Long duration access to sunlight:** A confirmed resource providing power and minimal temperature variations
- **Direct to Earth communication:** Repeatable Earth line-of-sight communication for mission support
- **Surface roughness and slope:** Finding the safest locations for multiple landing systems, robotic and astronaut mobility
- **Permanently Shadowed Regions and Volatiles:** Learning to find and access water ice and other resources for sustainability

PROGRESS UPDATES

LRO - Tuesday, May 28
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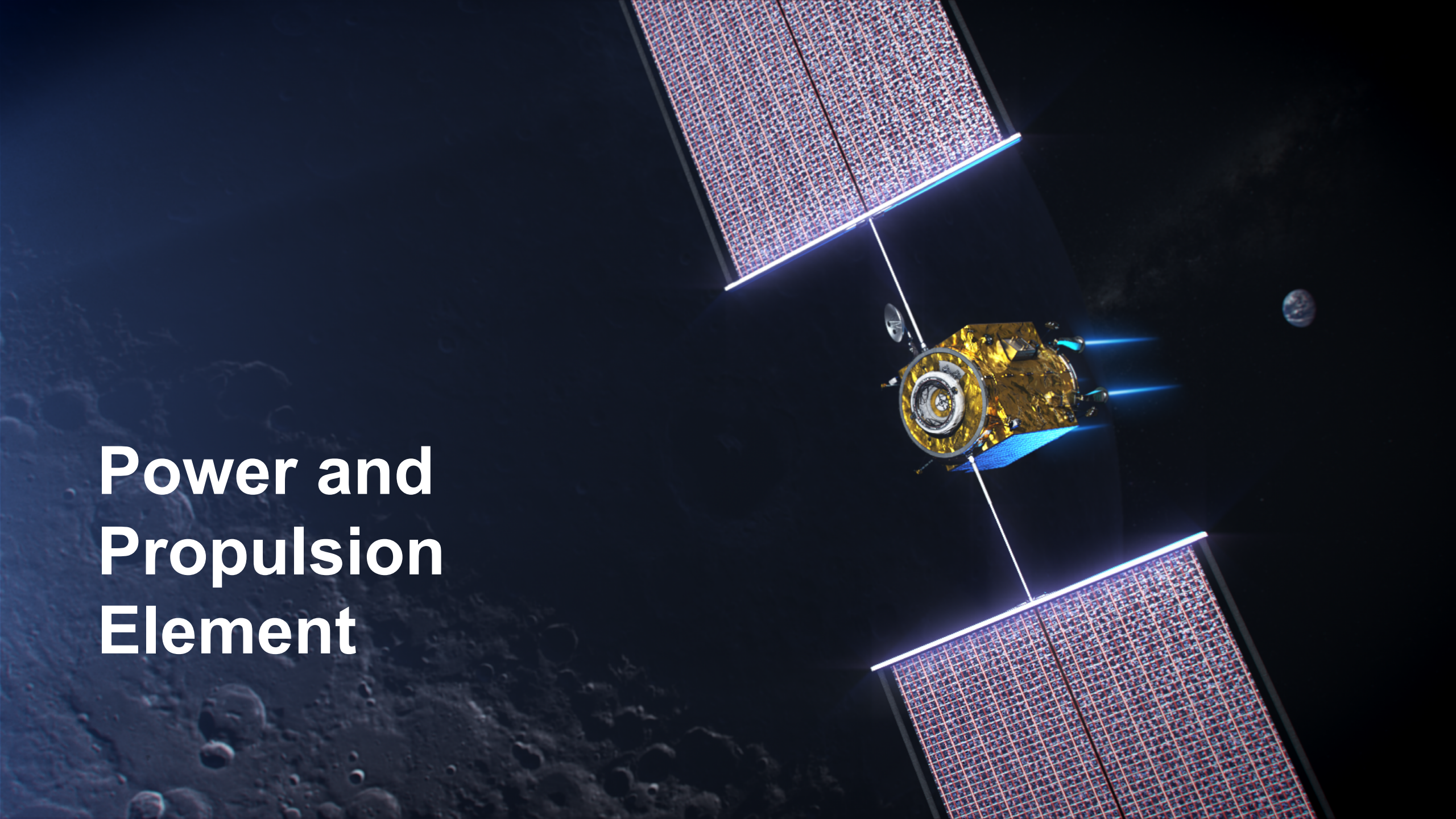
Power and Propulsion Element



PPE Milestones Completed & Upcoming Events

✓Final BAA released for Spaceflight Demonstration of a PPE	Sep 6, 2018
✓Participation in Gateway Formulation Sync Review (FSR) Kickoff	Sep 10-14, 2018
✓AIAA Space Forum panel participation*	Sep 18, 2018
✓International Astronautical Congress 2018 PPE status presentation*	Oct 1, 2018
✓PPE participation in Gateway/ESPRIT/PPE Virtual TIM with international partners	Oct 16, 2018
✓PPE Leadership Retreat, Plum Brook Station	Oct 24-25, 2018
✓Proposals to Final PPE Solicitation due	Nov 15, 2018
✓Participation in Gateway Formulation Sync Review (FSR) Kickoff	Feb 13, 2018
✓PPE partnership selection and contract award	May 23, 2019
• International Space Development Conference*	June 6-9, 2019
• AIAA Propulsion & Energy Forum*	Aug 19-22, 2019
• International Astronautical Congress*	Oct 21-25, 2019

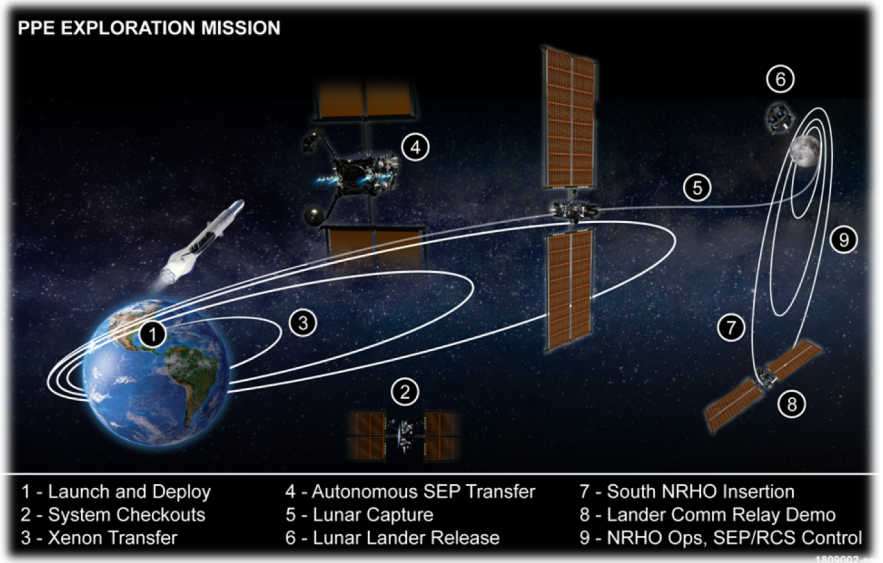
*External events


MAXAR
TECHNOLOGIES

Summary of Maxar's PPE approach

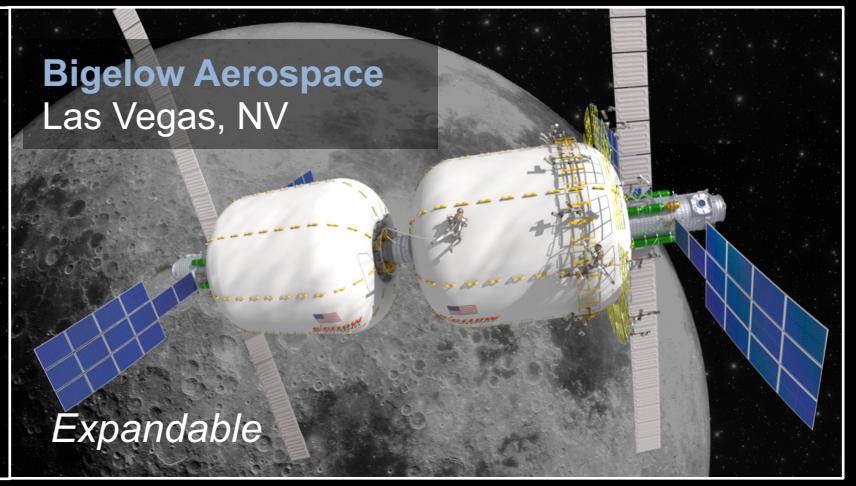
Leverage heritage reliability, proven development approach, and the scalable 1300-class platform as the basis for a PPE demonstration mission culminating with delivery of PPE to NASA in the target NRHO

- **Power – 60 kW+ provided by Roll Out Solar Array (ROSA) and Maxar's 1300 commercial power subsystem**
- **Propulsion – Leverage NASA development of 12.5 kW Electric Propulsion (EP), and internal Maxar advanced EP development, with Maxar expertise in system accommodation of EP elements**
- **Communications – Ka-band relay from Lunar vicinity to Earth, accommodations for future optical communications payloads**
- **Guidance Navigation and Control – Utilize proven approaches for station keeping, momentum management, and autonomous low thrust electric orbit transfer**
- **Gateway Interfaces – Support all interfaces with elements of Gateway including docked components, visiting vehicles, robotics, science payloads, Orion, and Human Landing System elements**
- **Payload Transfer – 1000kg for lunar lander or science instruments**



NextSTEP Habitat Prototype Testing

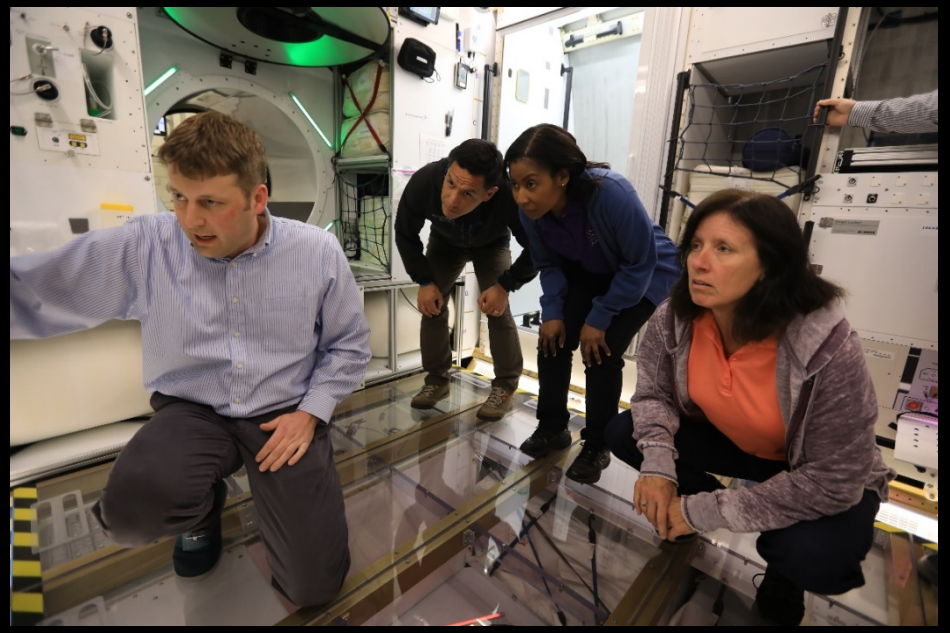
Five full-sized ground prototypes delivered for testing in 2019.

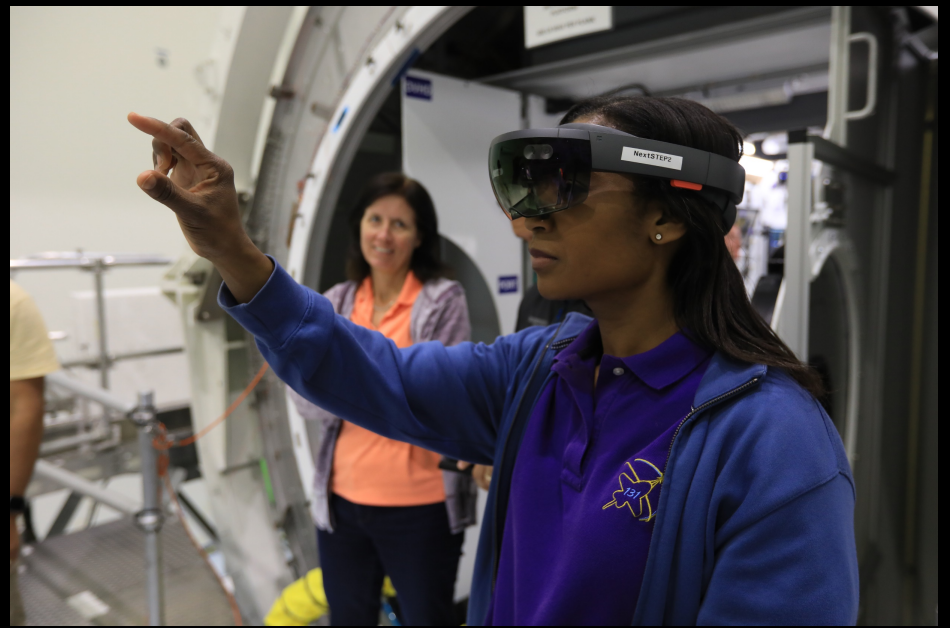


"Because of this prototyping exercise, we are 12-18 months farther along than we would normally be at this stage of concept development. Future programs should go through this approach along with requirements iteration with NASA."

"The NextSTEP approach has been really helpful. The mockup showed us we had more cargo space in our habitat than we originally believed based on the CAD models."

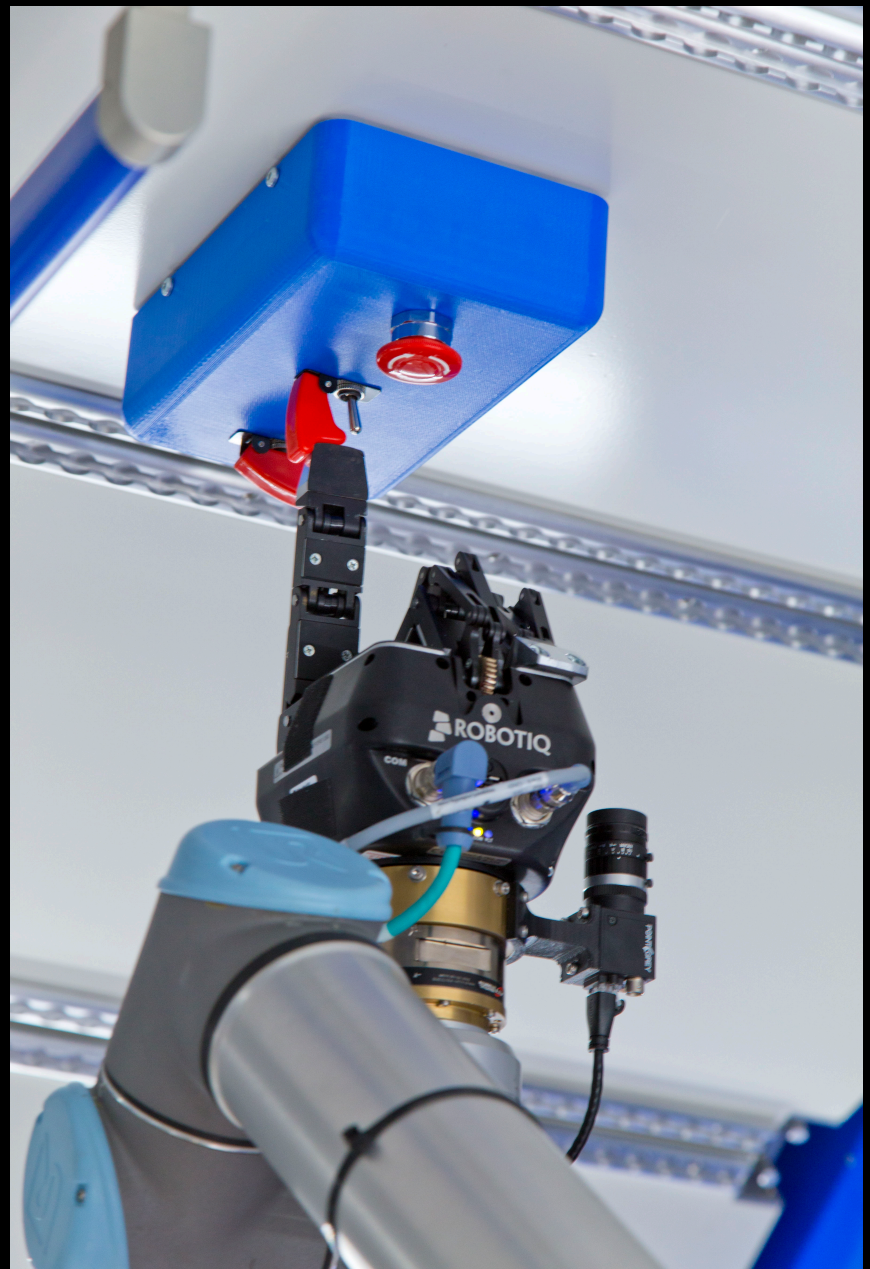
Lockheed Martin – Testing Complete at KSC

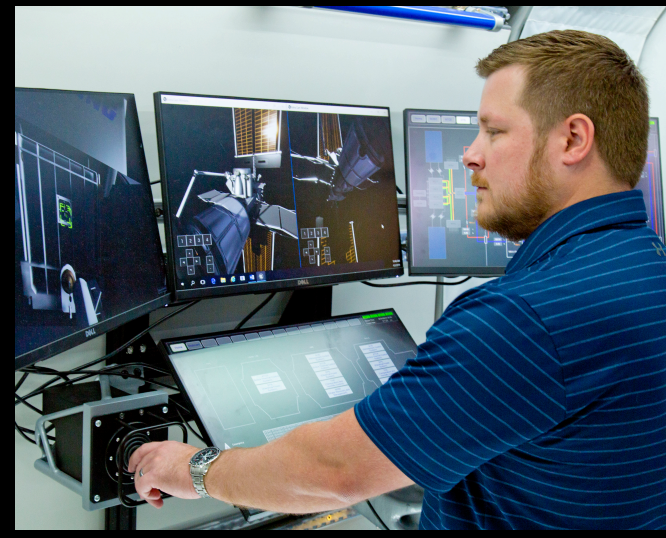




Northrop Grumman – Testing Complete at JSC

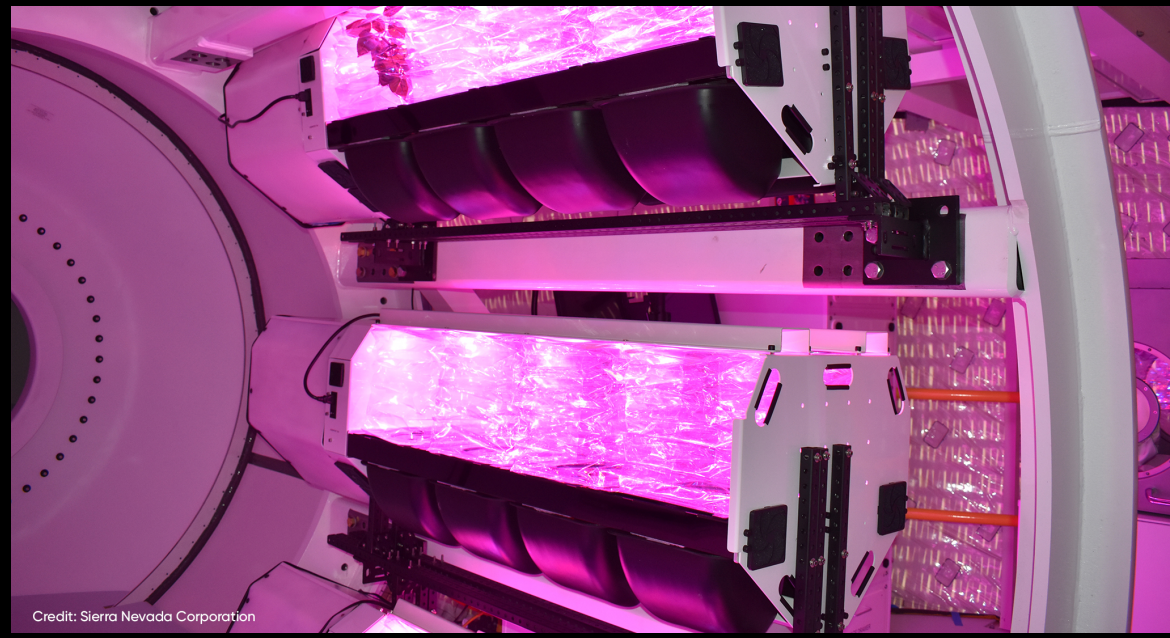
Boeing – Prototype Delivered to MSFC





Sierra Nevada Corporation – Prototype Delivered to JSC

Credit: Sierra Nevada Corporation


Credit: Sierra Nevada Corporation

Credit: Sierra Nevada Corporation

ACQUISITION STATUS

LRO - Tuesday, May 28
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System Summary

Phase 1 (Initial Capability by 2024)

- **Human Landing System (HLS)**
  - Initial mission including cargo launch
- **Gateway**
  - PPE (CLV)
  - Minimal Habitat (CLV) in 2023
  - Logistics/Tug (CLV) in 2024
- **Initial Capability Suit for 2024**
- **ESD**
  - Orion
  - SLS
  - EGS

Phase 2 (Sustaining Capability 2028)

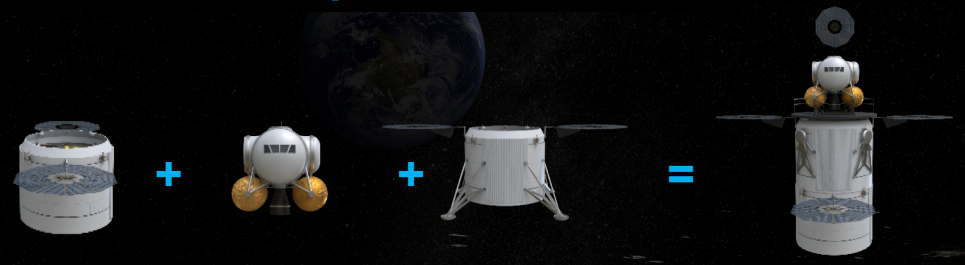
- **HLS Landing Services (2024 and beyond)**
- **Refueling**
- **Gateway**
  - Logistics (CLV)
  - International contributions as provided
- **Sustained Capability Suit**
- **Surface Logistics**
- **Surface Systems**
  - International contributions as provided
- **ESD**
  - Orion
  - SLS
  - EGS

Lunar Development Plans Summary

- **Integrated Human Landing System**
  - 11 companies selected for NextSTEP BAA Appendix E – Descent Element, Transfer Element, and Refueling studies and prototypes
  - Multiple industry systems will be developed to support a 2024 lunar landing demonstration mission via NextSTEP Appendix H
    - Launch options to be proposed by offerors
- **Gateway**
  - May 23, 2019, Selected Maxar Technologies to provide the Power and Propulsion Element
  - May 20, 2019 – released Logistics services RFP Synopsis for Gateway Logistics Services
  - Will leverage investments and work performed by NextSTEP-2 Appendix A contractors for the pressurized modules
- **Surface Suit**
  - Initial Capability Suit will mitigate schedule and mass risk in order meet 2024 mission timeline
  - Sustained Capability Suit will be available for Phase 2
- **Refueling Element**
  - Study phase for Refueling Elements already in work as part of NextSTEP Appendix E

Current Thoughts on Human Landing System

HLS Notional Transportation Elements



NextSTEP Appendix E: Human Lander System

- Issued: Feb 7
- Proposals submitted: March 25
- Selections: May
- Awards: July
- Phase A Risk Reduction Studies and prototypes for
  - Descent Element
  - Transfer Element
  - Refueling

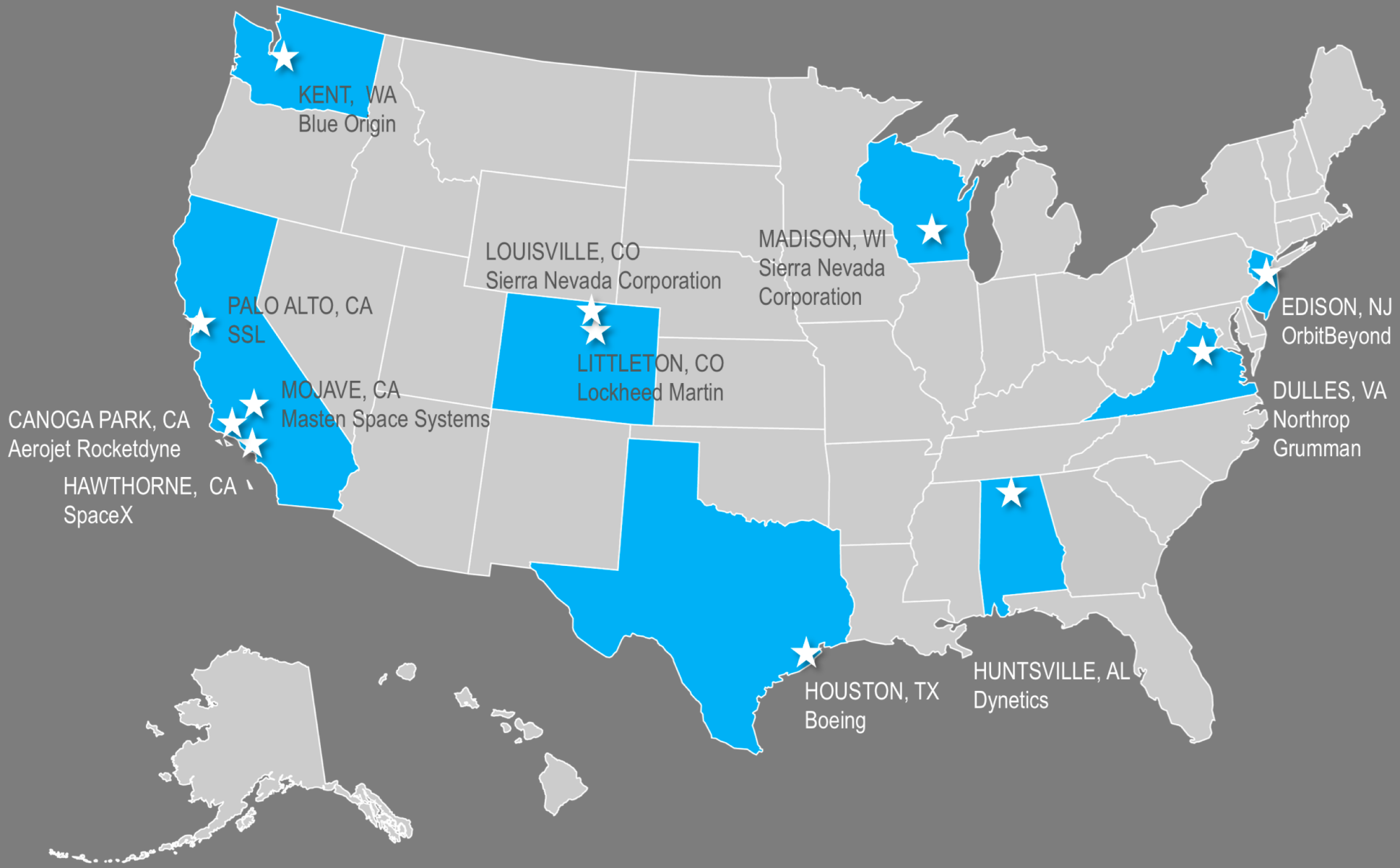
Studies expedited via Undefinitized Contract Awards

NextSTEP Appendix H: Human Lander System 2

- Synopsis Issued: April 8, for Ascent Element
- Synopsis updated: April 26, now for development, integration, and crewed demonstration of integrated landing system
- Final solicitation: NET July

LUNAR INDUSTRY SUPPLIERS: Human Landing System

8 States • 11 Contractors
17 Studies • 25 Prototypes



NextSTEP Appendix E Selections

Descent Element
- 7 Studies
- 17 Prototypes

Transfer Vehicle
- 5 Studies
- 3 Prototypes

Refueling Element
- 5 Studies
- 5 Prototypes

STAY CONNECTED

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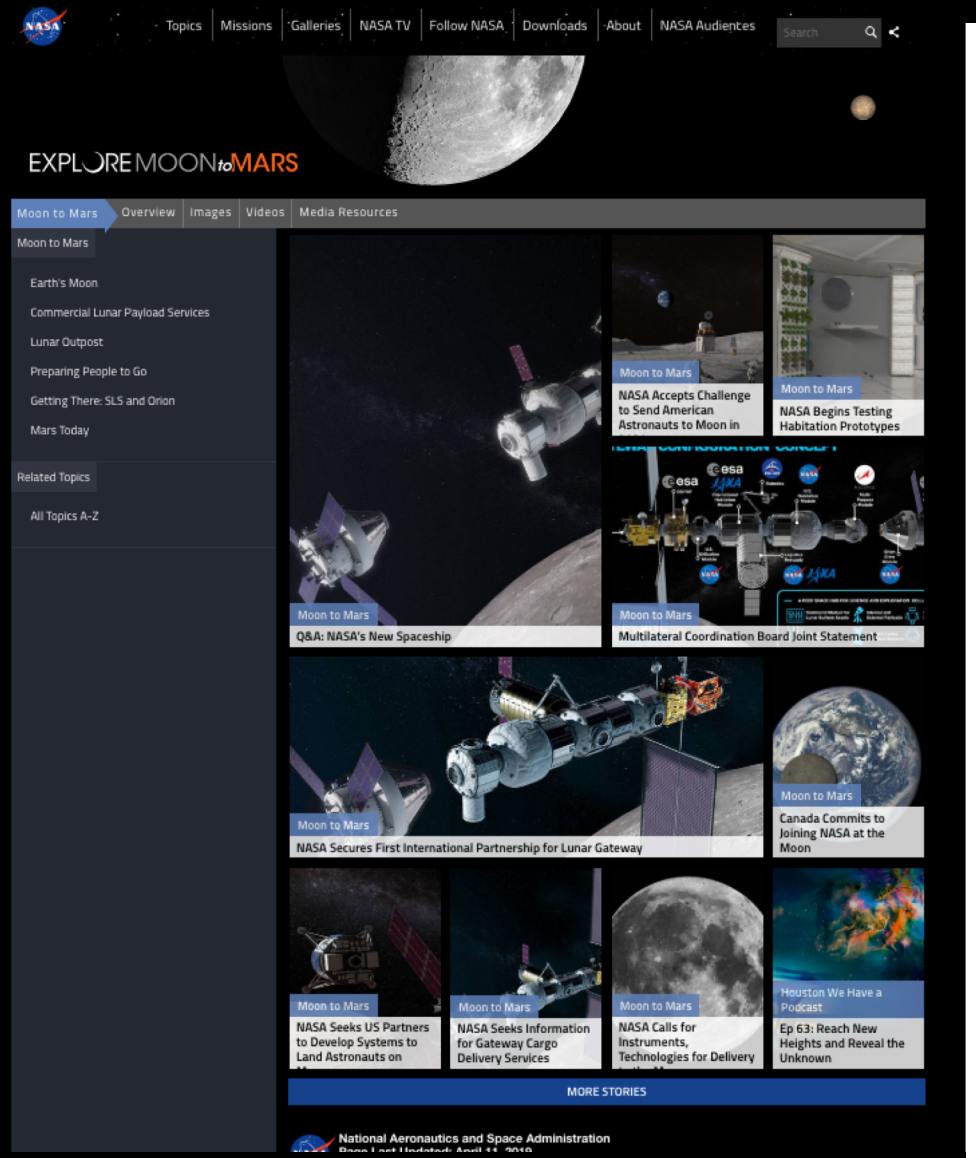
Stay Connected Between Committee Meetings



Sign up to get Moon to Mars updates from NASA: https://www.nasa.gov/specials/moon2mars/#five

- NASA Awards Artemis Contract for Lunar Gateway Power, Propulsion (May 23, 2019)
- NASA Taps 11 American Companies to Advance Human Lunar Landers (May 16, 2019)
- Sending American Astronauts to Moon in 2024: NASA Accepts Challenge (April 9, 2019)
- Sending American Astronauts to the Moon in 2024: NASA Accepts Challenge (April 2019)
- NASA Begins Testing Habitation Prototypes (March 27, 2019)
- Canada Commits to Joining NASA at the Moon (Feb. 2019)
- NASA Seeks U.S. Partners to Develop Reusable Systems to Land Astronauts on Moon (Feb 2019)
- NASA seeks information for Gateway Cargo Delivery Services (Oct. 2018)
- Q&A: NASA's New Spaceship (Nov. 2018)


EXPLORE
MOON to MARS
QUESTIONS?