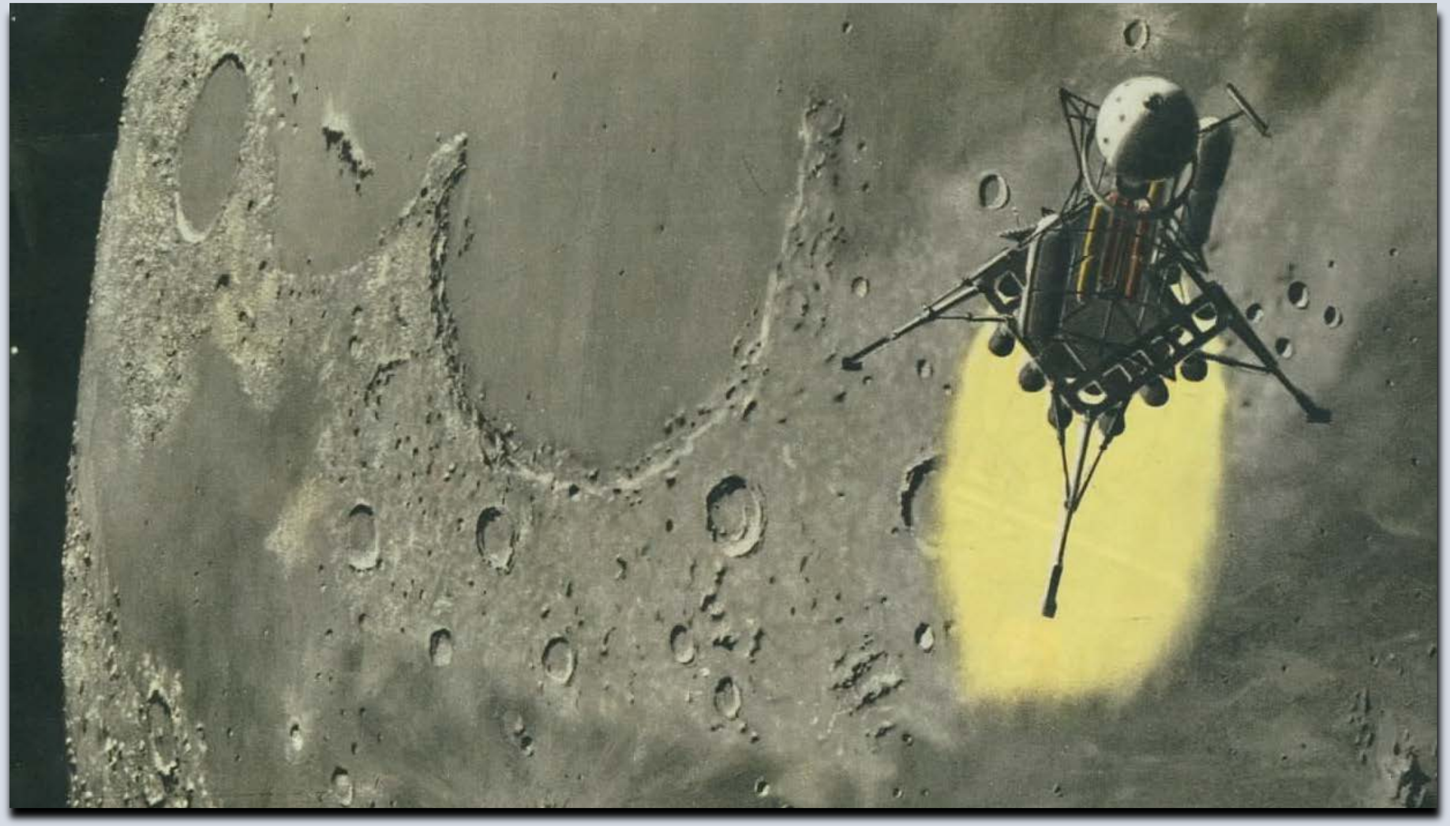


Human Exploration and Operations Committee

NASA Advisory Council

May 31, 2019

N. Wayne Hale, Jr.

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.

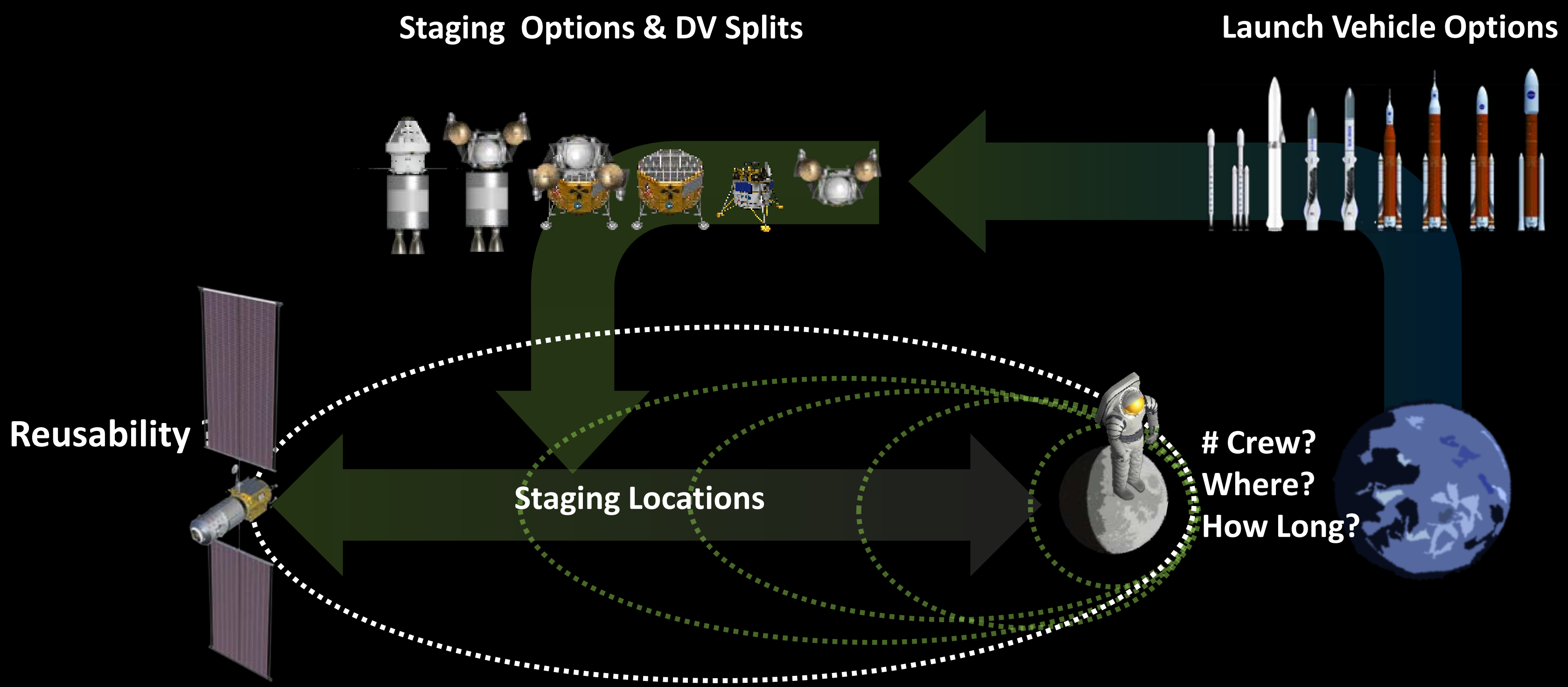
A Budget Increase Towards 2024

- The FY2020 budget amendment provides an ***increase*** of **$1.6 billion** above the president's initial **$21 billion** budget request with no money taken from existing NASA programs. This is the ***boost*** NASA needs.

  - ✔ $1 billion to accelerate development of human lunar transportation systems to take astronauts to the surface and back to Gateway*
  - ✔ $651 million towards the completion of SLS and Orion to support a 2024 landing.
  - $132 million for new technologies to help astronauts live and work on the lunar surface and in deep space.
  - $90 million for Science to increase robotic exploration at the lunar South Pole in advance of astronauts.

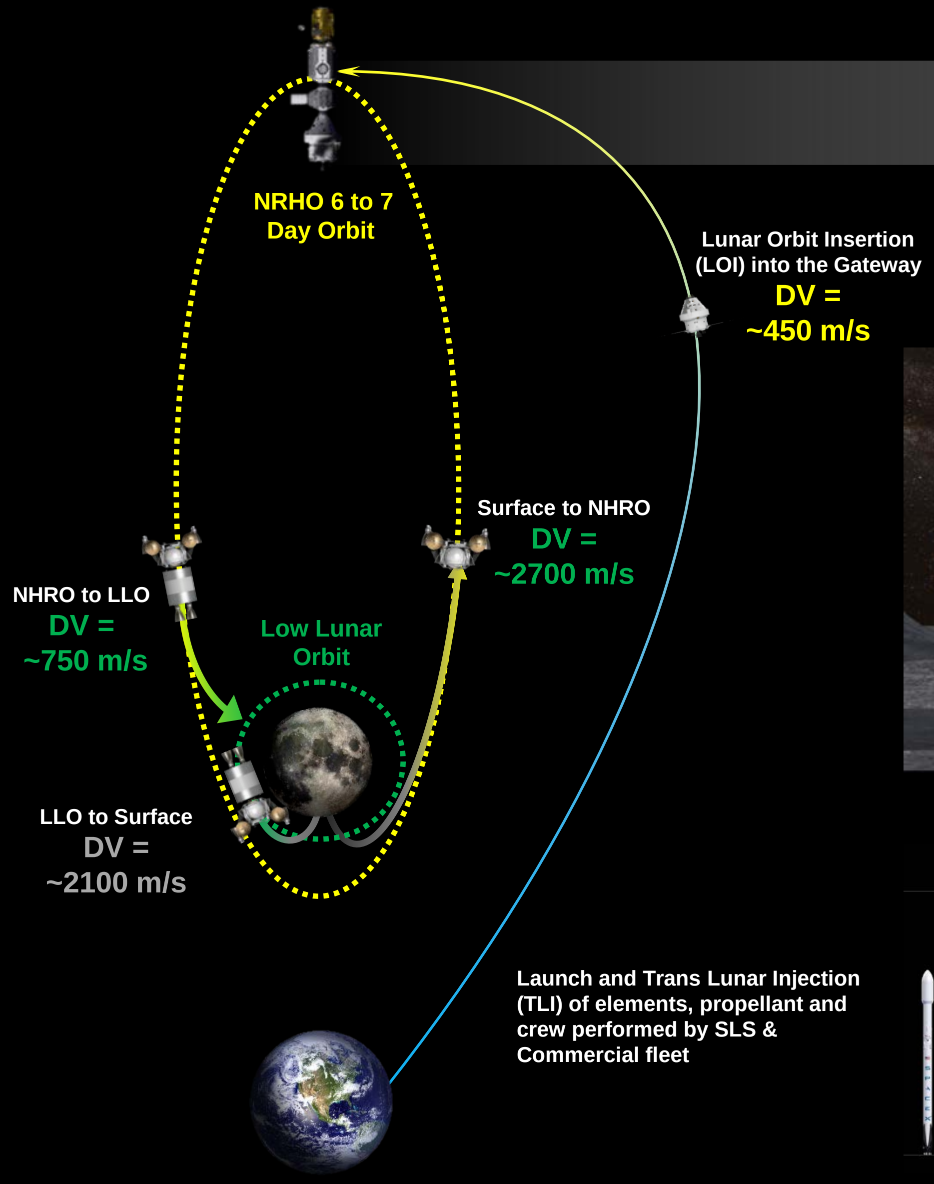
** Focusing Gateway on just the capabilities needed for Phase 1 allowed for a $321M scope reduction and shifts potential development and expanded capabilities for Gateway into Phase 2.*

Broad Trade Space for Sustainable Human Lunar Access



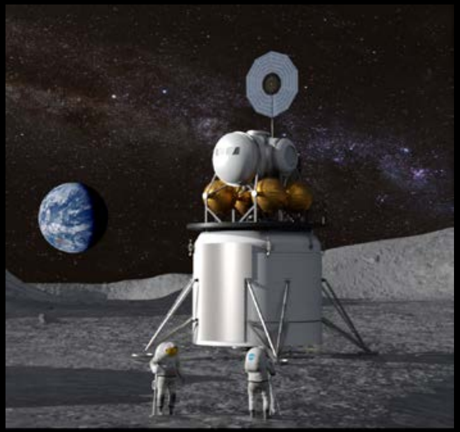
The architecture for returning humans to the lunar surface is a function of physics, available technology and weighted figures of merit

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

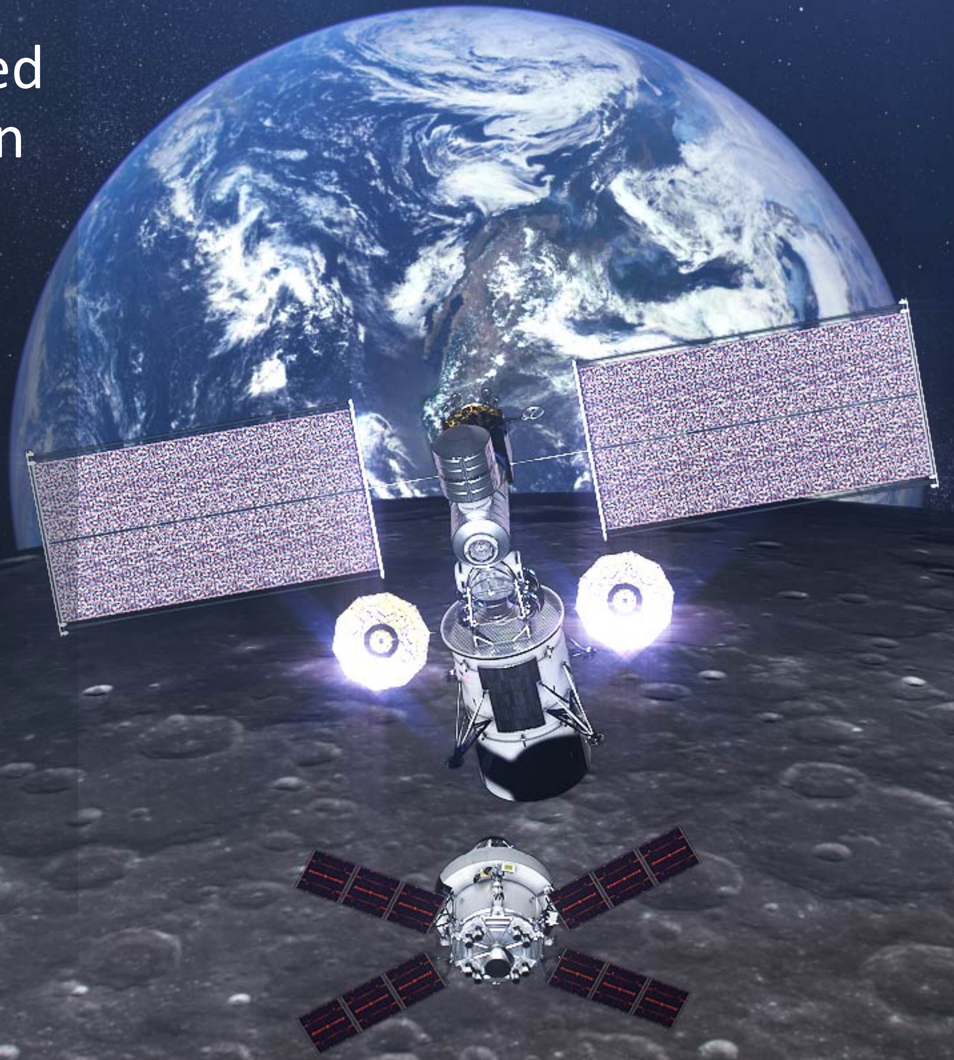
Phase 1 & Phase 2 Definitions

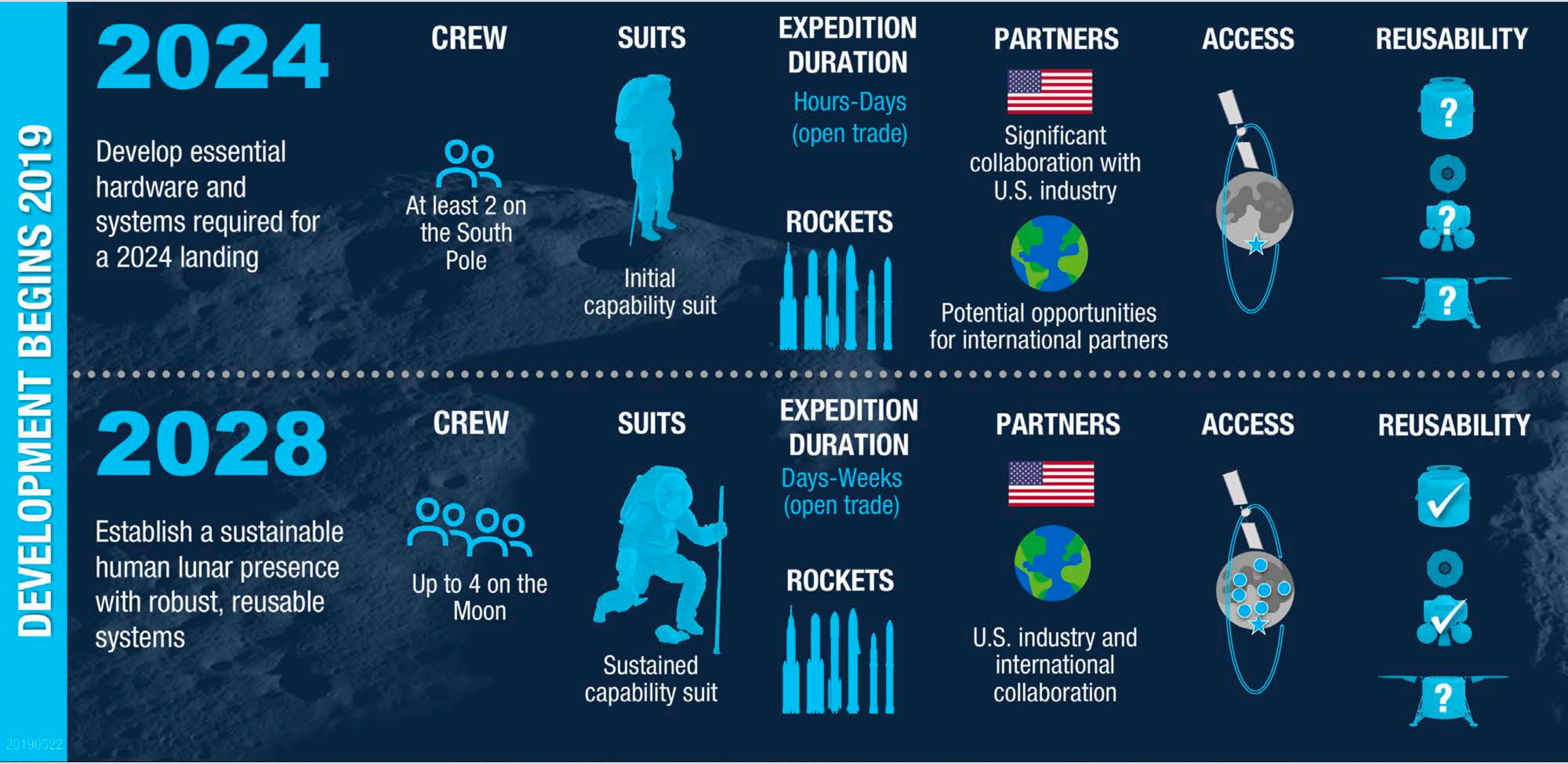
Phase 1: Today – 2024 Human surface landing

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

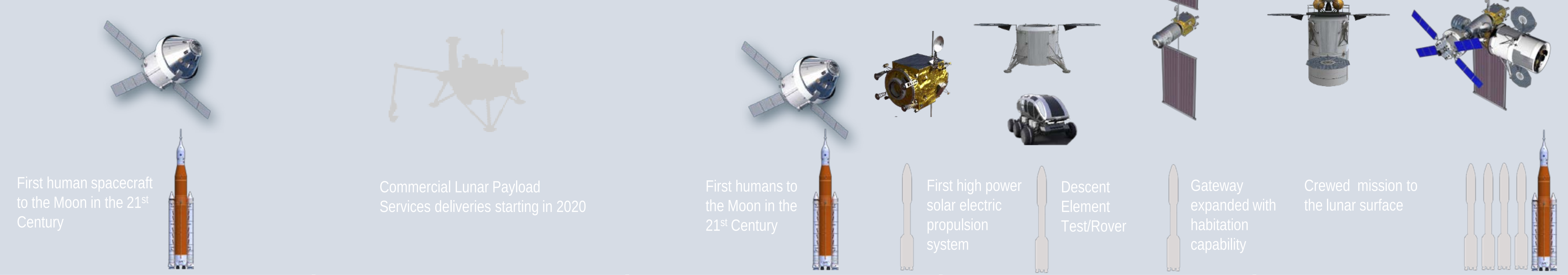
Phase 2: 2024

Establish a sustainable long-term presence on the lunar surface




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

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

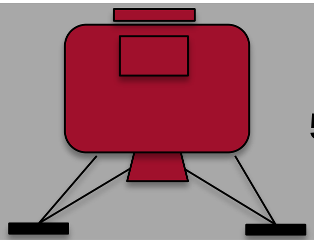
Studies expedited via Undefinitized Contract Awards

NextSTEP Appendix H: Human Lander System 2

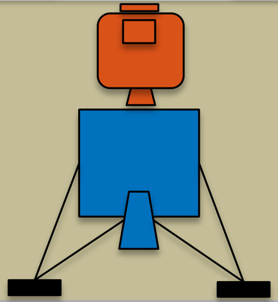
- Synopsis Issued: April 8, for Ascent Element
- Synopsis updated: April 26, now for development, integration, and crewed demonstration of integrated landing system
- Final solicitation: NET July

Key Takeaways from Initial Internal Architecture Approach Studies

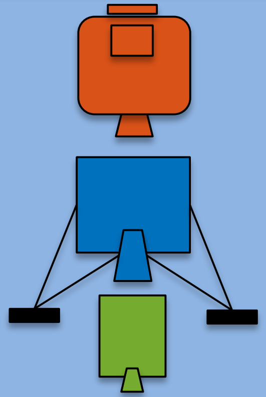
- **Several lander vehicle architecture options were assessed**
- **Single stage landers are not viable given desired requirements**
- **Still trading two and three stage options (and other hybrids)**



- **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

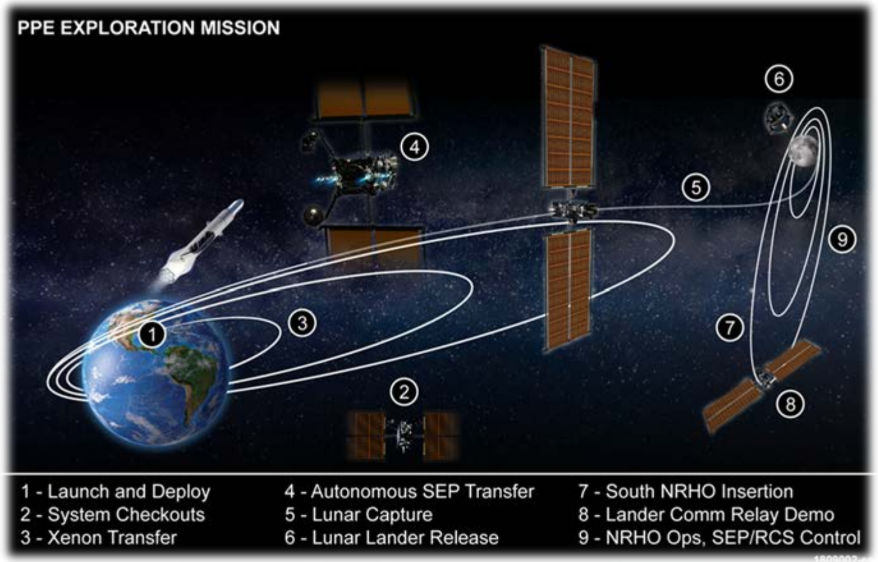


- **Three-stage options**
  - Fits on commercial launch vehicles expected to be available
  - Single elements potentially can be co-manifested payload on SLS
  - Allows increased partnering opportunities
  - Maximizes reusability and flexibility
  - Small module commonality across habitable volumes

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.

Lockheed Martin
Denver, CO

Refurbishes heritage hardware

Northrop Grumman
Dulles, VA

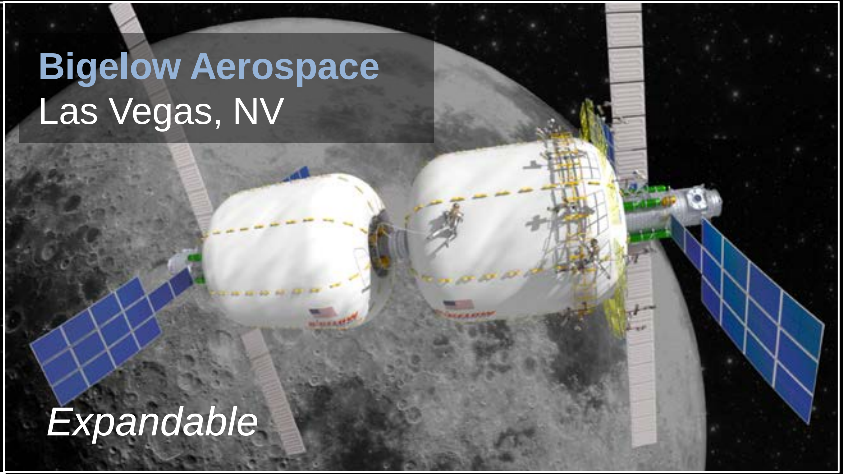
Builds on proven cargo spacecraft development

Boeing
Pasadena, TX

Leverages existing technologies

Sierra Nevada
Louisville, CO

Modular buildup



Bigelow Aerospace
Las Vegas, NV

Expandable

"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."

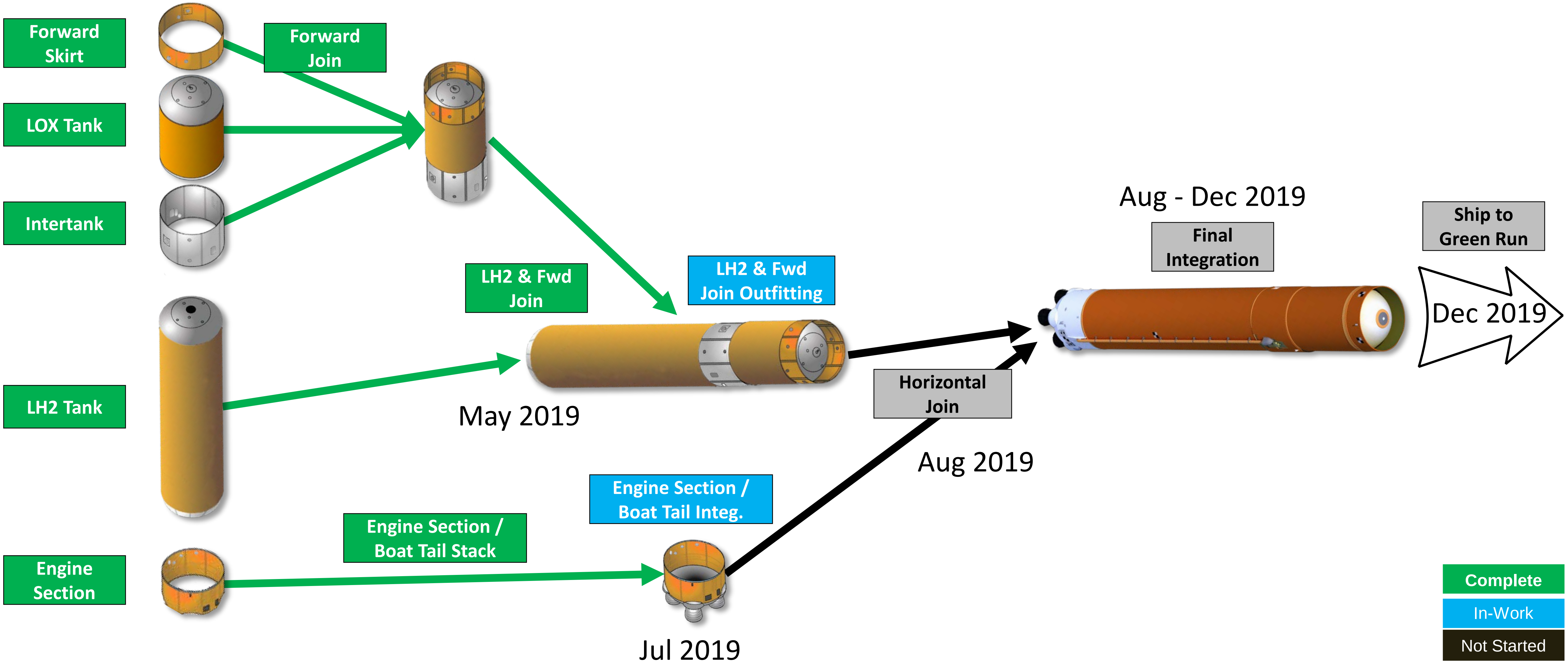
"The NextSTEP approach has been really helpful. The mockup showed us we had more cargo space in our habitat than we originally believed based on the CAD models."

ORION Status:
Artemis -1 spacecraft ready to assemble SM to CM and transport to Plumbrook for testing
Artemis-2 spacecraft started and will have complete ECLSS
Subsequent spacecraft – long lead items ordered, should not be a schedule impact

SLS Status:
Artemis-1 Core booster in work, engine section assembly nearing completion
Green run decision pending; schedule supports early 2021 launch (maybe late 2020)
Artemis-2 Core booster assembly started
Subsequent core booster long lead items ordered, should not be a schedule impact
Solid rocket segments for -1 and -2 complete
MLP-1 complete and in checkout
Ground systems and software on track with schedule

MLP-2 contract ready to be announced but funding in negotiation
EUS development on hold/slow rate with funding in negotiation for potential Artemis-3 use

Artemis 1 Stages (Boeing - MAF)



- Weld Confidence Articles
- All CS-1 VAC Complete
- FS Complete
- IT Complete
- LOX Tank Complete
- Forward Join
- LH2 Tank Complete
- ES Complete
- Aft Join
- Final Join

ISS Status:

- Continuing operations including increasing crew time devoted to utilization (research)
  - Crew rotations via Soyuz,
  - Cargo resupply via international partners and commercial vehicles (Cygnus and Dragon)
- ISS provisions for space flight participants in coming years

Commercial Crew Status:

- SpaceX uncrewed Demo-1 flight successful earlier this year
- Boeing Starliner uncrewed test flight scheduled for August
- Both providers attempting to fly crew test flights before the end of 2019
  - SpaceX schedule depends on resolving test anomalies
  - Both providers have abort tests and parachute tests plus other work to complete
- ISS program has established Soyuz seats through 2020 if commercial launches suffer delays

Increment 59

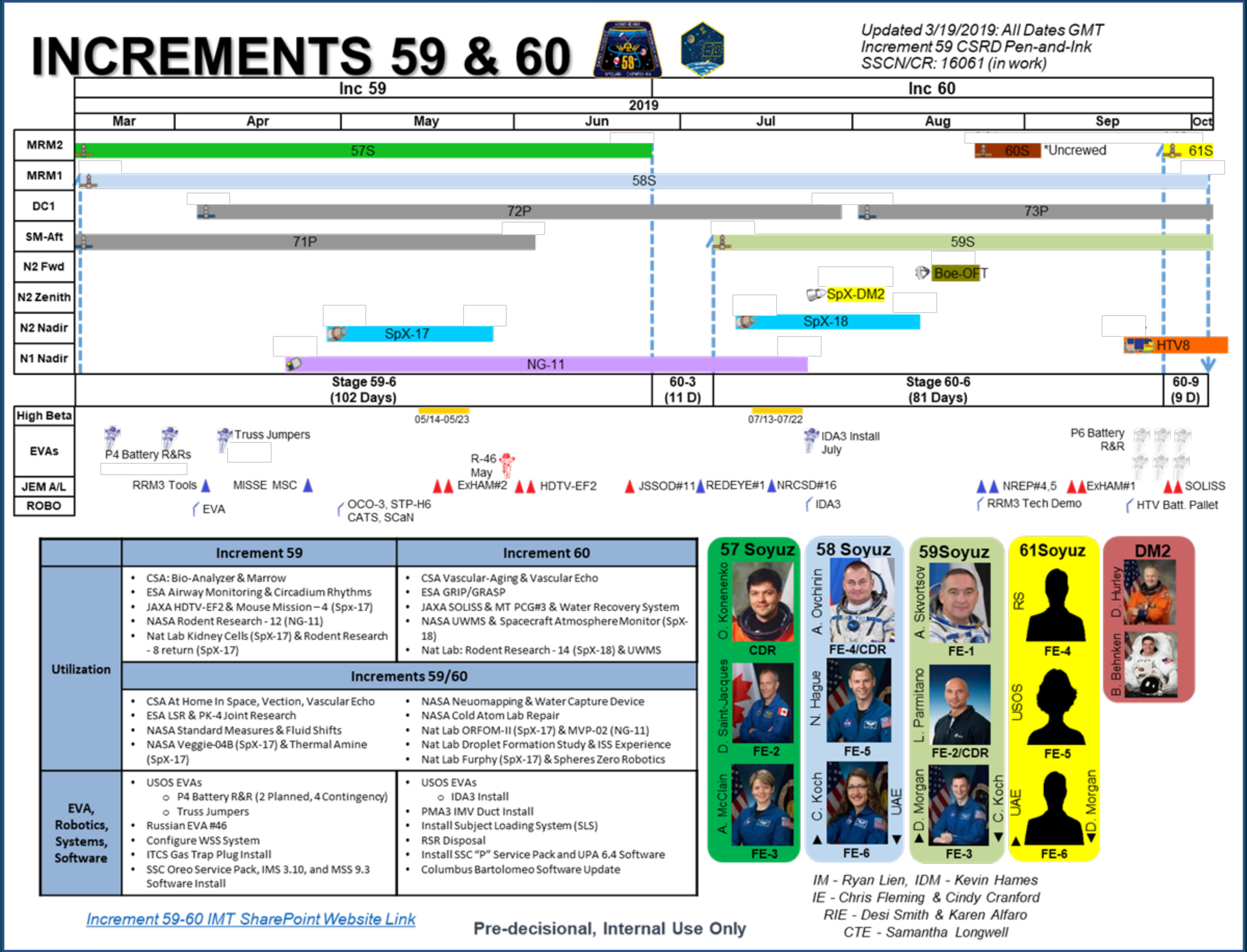
Increment 59: 102 days

Visiting vehicles:

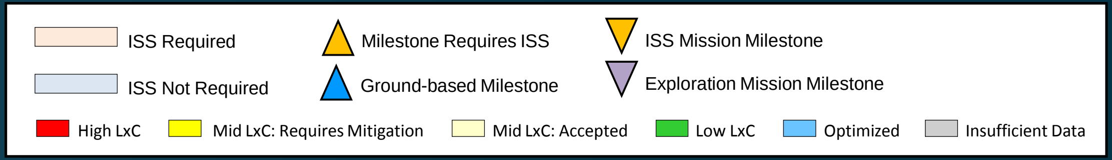
- 71P (11/18 – 6/4/19)
- 72P (4/4 -7/29)
- NG CRS-11 (4/19 -7/23)
- SpX CRS-17 (5/2-5/31)

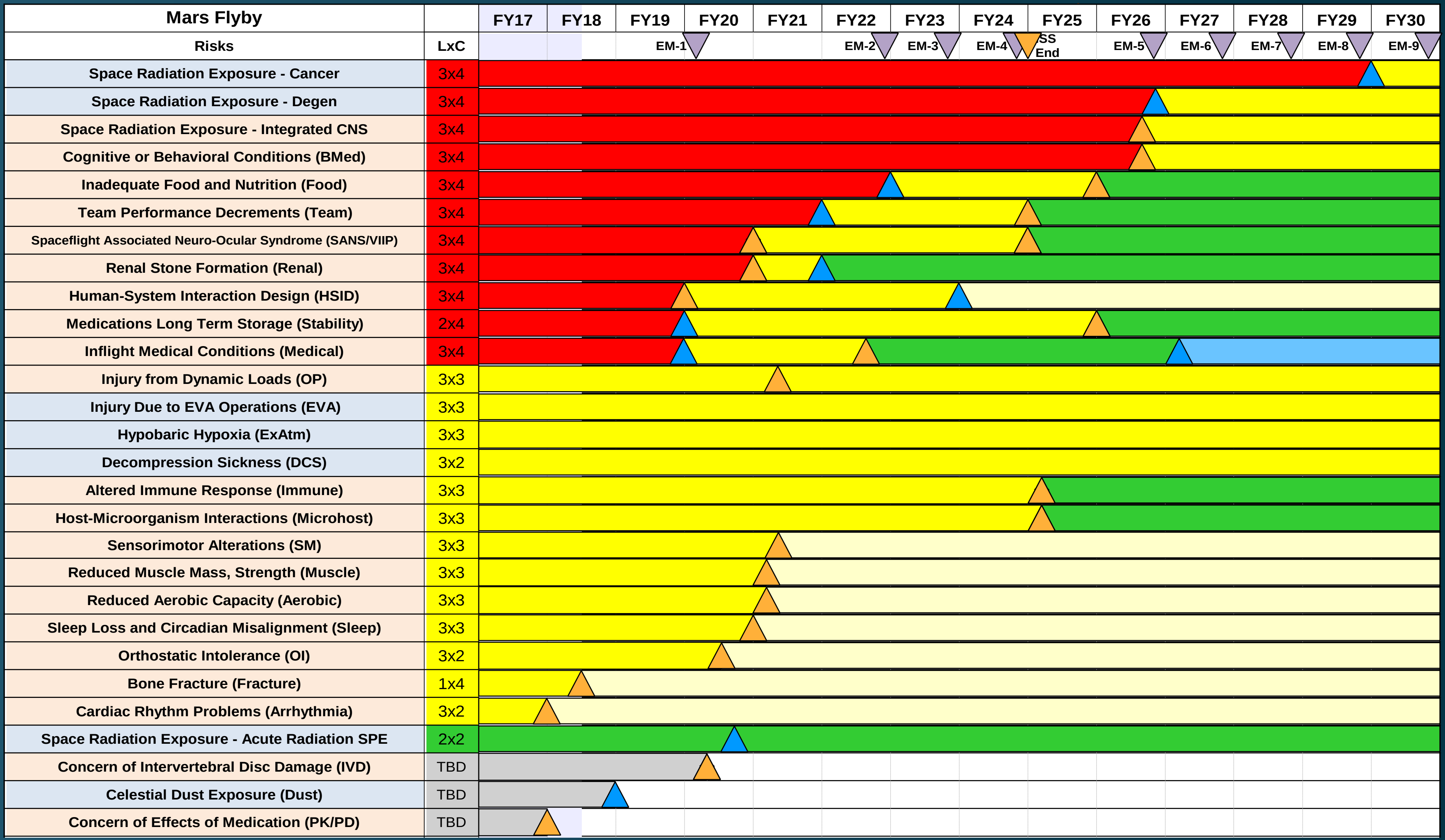
Science/Utilization:

- CSA: Bio-Analyzer & Marrow
- ESA Airway Monitoring & Circadium Rhythms
- JAXA HDTV-EF2 & Mouse Mission – 4 (Spx-17)
- NASA Rodent Research - 12 (NG-11)
- Nat Lab Kidney Cells (SpX-17) & Rodent Research – 8 return (SpX-17)
- CSA At Home In Space, Vection, Vascular Echo
- ESA LSR & PK-4 Joint Research
- NASA Standard Measures & Fluid Shifts
- NASA Veggie-04B (SpX-17) & Thermal Amine (SpX-17)
- NASA Neuromapping & Water Capture Device
- NASA Cold Atom Lab Repair
- Nat Lab ORFOM-II (SpX-17) & MVP-02 (NG-11)
- Nat Lab Droplet Formation Study & ISS Experience
- Nat Lab Furphy (SpX-17) & Spheres Zero Robotics



HRP Path to Risk Reduction

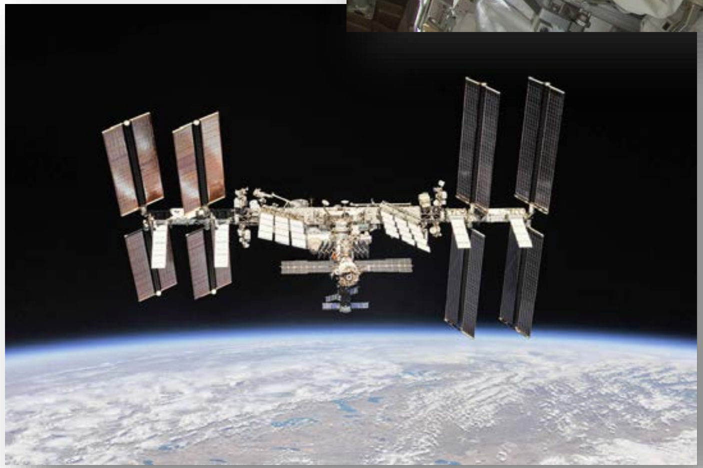




Enabling Commercial Space

- **CCP helps to facilitate Inter-Agency, Intergovernmental and International partnerships, agreements, and legislation with the strategic goal of enabling the commercial space industry**
  - **Inter-Agency Collaboration**
    - Department of Commerce (DOC)
    - Department of Defense (DoD)
    - Federal Aviation Administration (FAA)
    - Federal Communications Commission (FCC)
    - National Telecommunications and Information Administration (NTIA)
    - National Transportation and Safety Board (NTSB)
    - National Reconnaissance Office (NRO)
  - **Legislation and Regulation**
    - "Government Astronaut" classification
    - Mission licensing to include launch, re-entry, launch site and operator
    - Public health and safety protections
    - Jurisdiction and authority during phases of flight
    - Independent investigation authority
    - Update to executive order for contingency operations
  - **Spectrum Usage**
    - Ensure secure communication pathway availability
  - **Liability and Insurance**
    - Cross waivers
    - Financial responsibility
    - Third-party indemnification
    - Government property

ISS Crew EVA

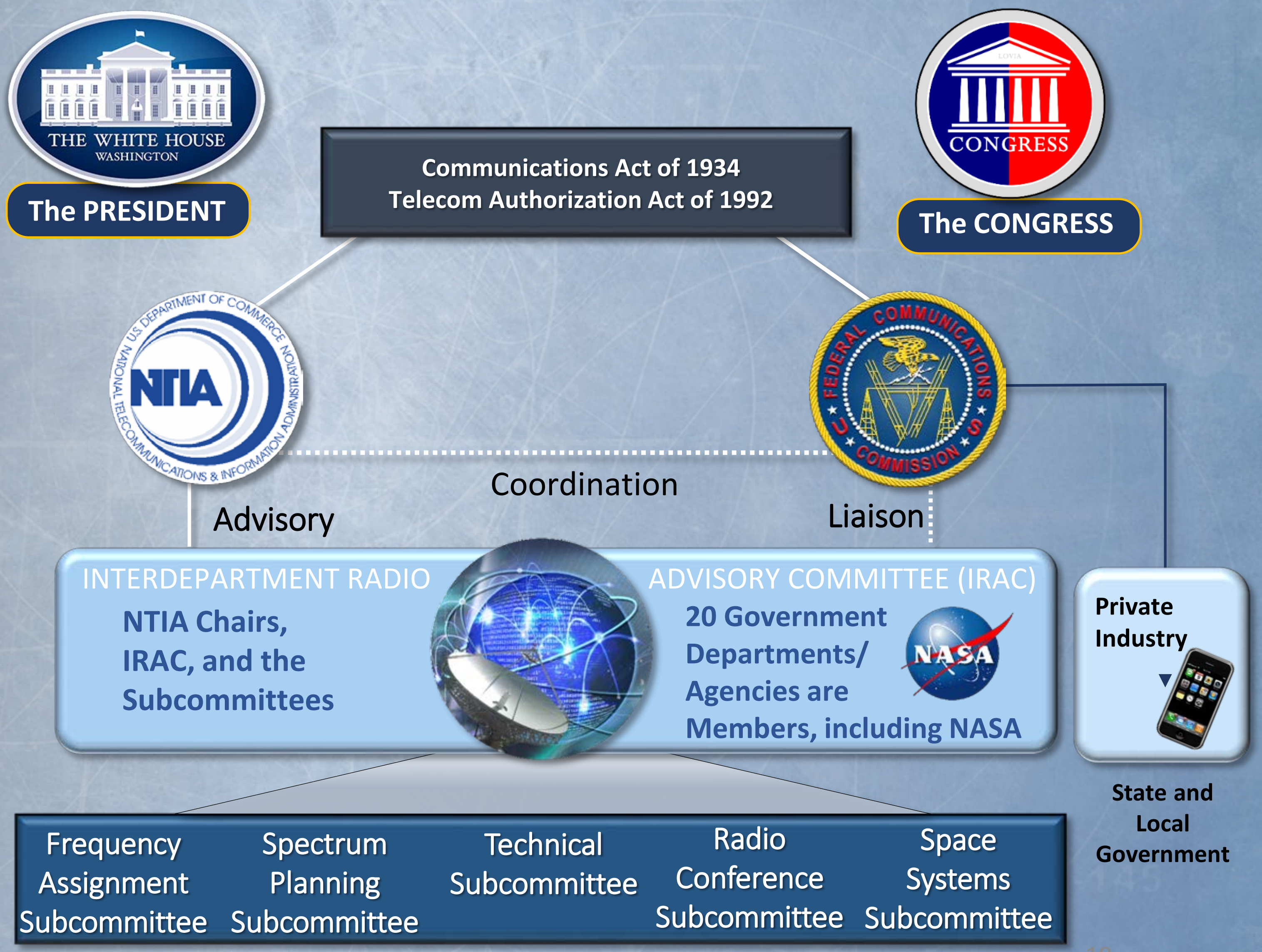


International Space Station

Ensure Efficient Use of Spectrum through Regulatory Oversight

- Streamline processes and reduce regulatory impediments enhancing availability of spectrum for access by NASA’s mission
- Partner with the Department of State, NTIA, and FCC to define and defend US positions on spectrum issues, specifically activities leading up to and including the WRC
- Continue building spectrum-related relationships with other space-faring Nations
- Execute National Space Council’s Space Policy Directives regarding spectrum
- Maximize NASA’s influence to evolve a forward-looking, balanced, flexible, sustainable approach to spectrum management in support of the 2018 Presidential Memorandum

National Spectrum Management Process



Short Title of Recommendation:

Lunar Plans

Recommendation:

The HEO Committee recommends that the current planning for human spaceflight to the moon continue along the lines of the recent planning study to include long term sustainability features including reusability, refueling, and in situ resource utilization at a ‘gateway’ or reusable aggregation point.

Major Reasons for the Recommendation:

NASA has been doing trade studies on how to return to the moon for decades and the recent acceleration study included the results from all previous trade studies. To ensure the long-term viability of human spaceflight, efficient and affordable measures must be taken to reduce costs and enhance flexibility. Having a rally point or aggregation node with human shelter capability appears to be the best way to minimize long term costs and provide flexibility. The HEO committee concludes that a dash to the moon without including infrastructure for the longer term would not lead to a sustainable program of deep space human exploration. Near term focus on rapid lunar missions should not distract from the long-term objectives.

Consequences of No Action on the Recommendation:

A higher cost program with limited scope and decreased long term viability would most likely result from a different approach. The intent of SPD-1 would not be met.

Short Title of Recommendation:

Continue utilization of the ISS until other commercial platforms in LEO are available

Recommendation:

Continued utilization of the ISS with increasing support for commercial LEO activities is recommended for continuity of human presence in space. Plans should be made to continue ISS operations past 2024 while at the same time maximizing the prospect of having follow on LEO platforms available through the private sector.

Major Reasons for the Recommendation:

NASA will require services in LEO to resolve issues with life science concerns as well as to continue to practice operational skills. This platform provides a facility to do outstanding scientific research, commercial product development, small satellite deployment, and a myriad of other useful activities. The ISS is a major infrastructure element which can continue to provide a platform to do this work. The goal of enabling commercial services platforms and activities in LEO should continue to be a focal point. NASA should take all reasonable steps to encourage and enable commercial activities while continuing to use the ISS until suitable replacement platforms are commercially operated and available for NASA service contracts. This likely will take more time than the current envisioned decrease in US government funding of ISS in late 2024.

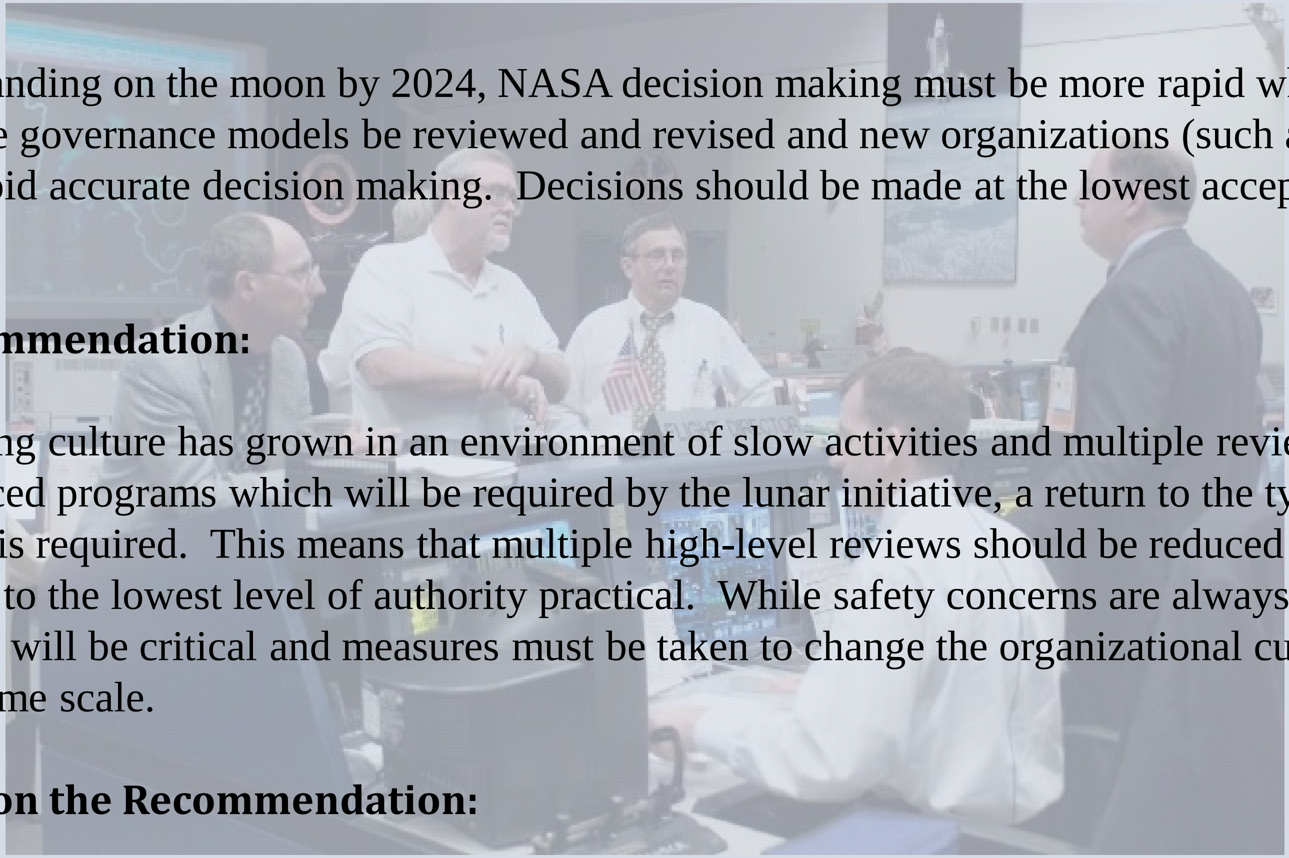
Consequences of No Action on the Recommendation:

US government major decrease of funding for the ISS following 2024 without follow on commercial human platforms available will mean that NASA will be unable to resolve critical life science issues for long duration spaceflight and will lose the capability to practice routine operational activities in LEO. The ISS is a significant investment and early termination would be a waste of taxpayer investment.

Short Title of Recommendation:

Streamline NASA decision making

Recommendation:



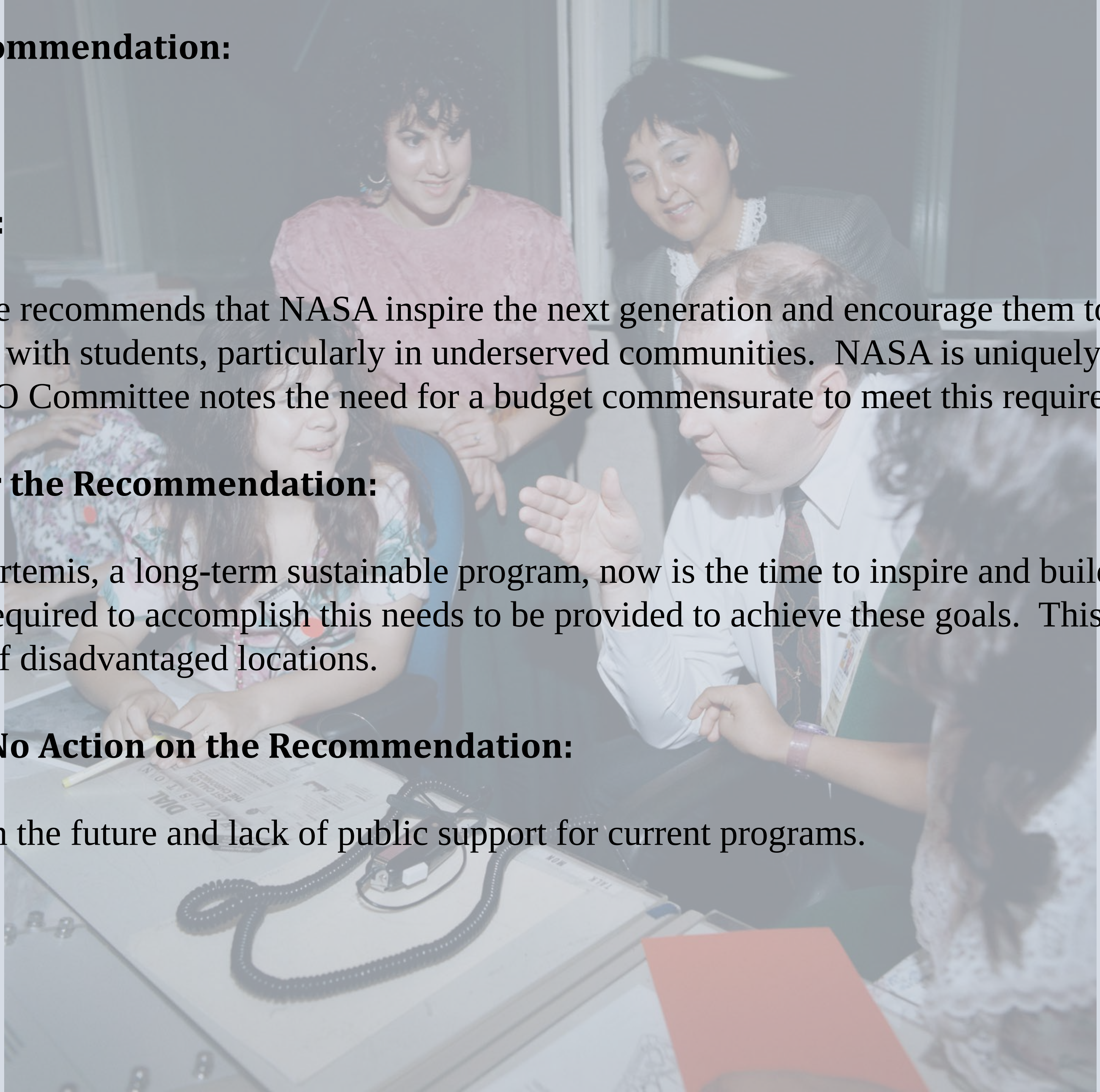
To achieve the goal of human landing on the moon by 2024, NASA decision making must be more rapid while still making appropriate decisions. It is recommended that the governance models be reviewed and revised and new organizations (such as the lunar lander program) be organized in such a way to ensure rapid accurate decision making. Decisions should be made at the lowest acceptable level and multiple reviews and ‘analysis paralysis’ must be avoided.

Major Reasons for the Recommendation:

Currently NASA decision making culture has grown in an environment of slow activities and multiple reviews at a very high level. To ensure the success of large scale and fast paced programs which will be required by the lunar initiative, a return to the type of decision making that was the hallmark of the agency in the 1960’s is required. This means that multiple high-level reviews should be reduced to the minimum possible and decision making should be delegated to the lowest level of authority practical. While safety concerns are always a top consideration, the necessity to make rapid and appropriate decisions will be critical and measures must be taken to change the organizational culture as well as the documented processes to accommodate the new time scale.

Consequences of No Action on the Recommendation:

Current programmatic decision-making processes and culture in NASA are not appropriate to the new accelerated lunar program. Without significant change in decision making processes, the new programs will not accomplish the goals required and certainly not within the time frame which has been established.



Short Title of Recommendation:

STEM activities

Recommendation:

The HEO Committee recommends that NASA inspire the next generation and encourage them to pursue STEM careers through direct interaction with students, particularly in underserved communities. NASA is uniquely positioned to inspire the next generation. The HEO Committee notes the need for a budget commensurate to meet this requirement.

Major Reasons for the Recommendation:

As NASA pursues Artemis, a long-term sustainable program, now is the time to inspire and build this next generation workforce. The budget required to accomplish this needs to be provided to achieve these goals. This would be helpful to the economic improvement of disadvantaged locations.

Consequences of No Action on the Recommendation:

Lack of workforce in the future and lack of public support for current programs.

Short Title of Finding:

Commendation for streamlining commercial spaceflight requirements and regulations

Finding:

NASA's Commercial Crew Program office and the Space Communications and Navigation office have done yeoman's work to help commercial programs cut through interagency bureaucracy. These organizations are commended for this work. The commercialization of activities in low earth orbit is a goal of the US government yet the multiple interagency bureaucracy surrounding space activities is very difficult to navigate. NASA should continue to help commercial space efforts by providing guidance and advocacy in the streamlining of the complex bureaucracy surrounding space activities. NASA should continue to provide leadership to coordinate responsibilities across the US Government.