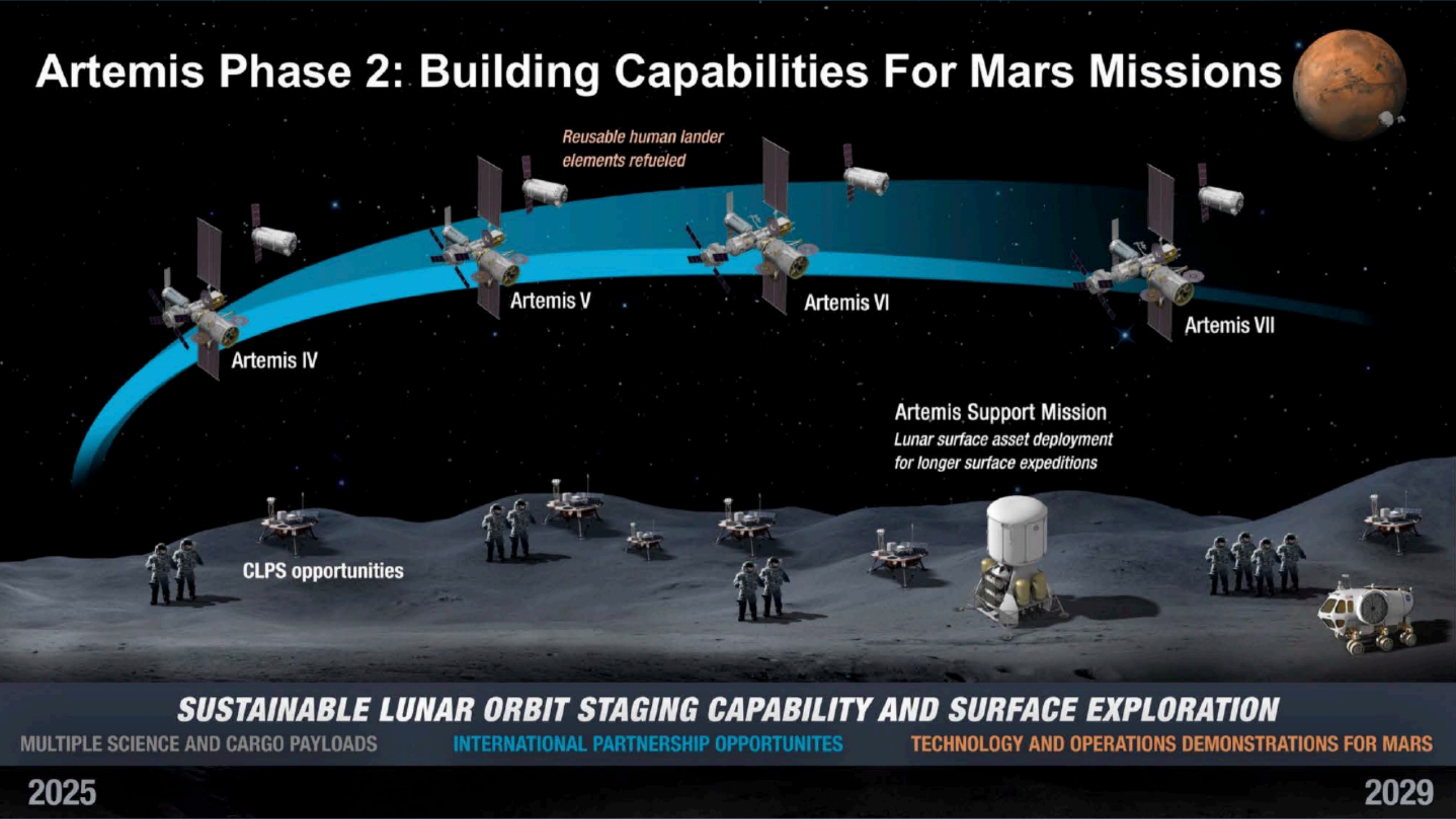
Building an Economical and Sustainable Lunar Infrastructure To Enable Human Lunar Missions

Dr. Allison Zuniga and Hemil Modi
NASA Ames Research Center, Moffett Field, CA
Aurelio Kaluthantrige and Heloise Vertadier
International Space University, Strasbourg, France

70th International Astronautical Congress, Washington, D.C.
21-25 October 2019

Artemis Phase 2: Building Capabilities For Mars Missions



SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

2025 2029

Artemis Phase 2: Building Capabilities For Mars Missions

Reusable human lander elements refueled

Artemis IV

Artemis V

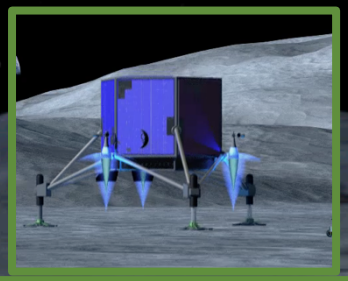
Artemis VI

Artemis VII

Artemis Support Mission

Lunar surface asset deployment for longer surface expeditions

CLPS opportunities



Lunar COTS Missions

- *Delivers infrastructure services*

SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

2025 2029

NASA COTS/CRS Return on Investment and Economic Impact

- NASA provided less than 50% of the total development cost to SpaceX and Orbital resulting in:
  - 10-to-1 reduction in total development costs
  - 3 to 1 reduction in operational costs

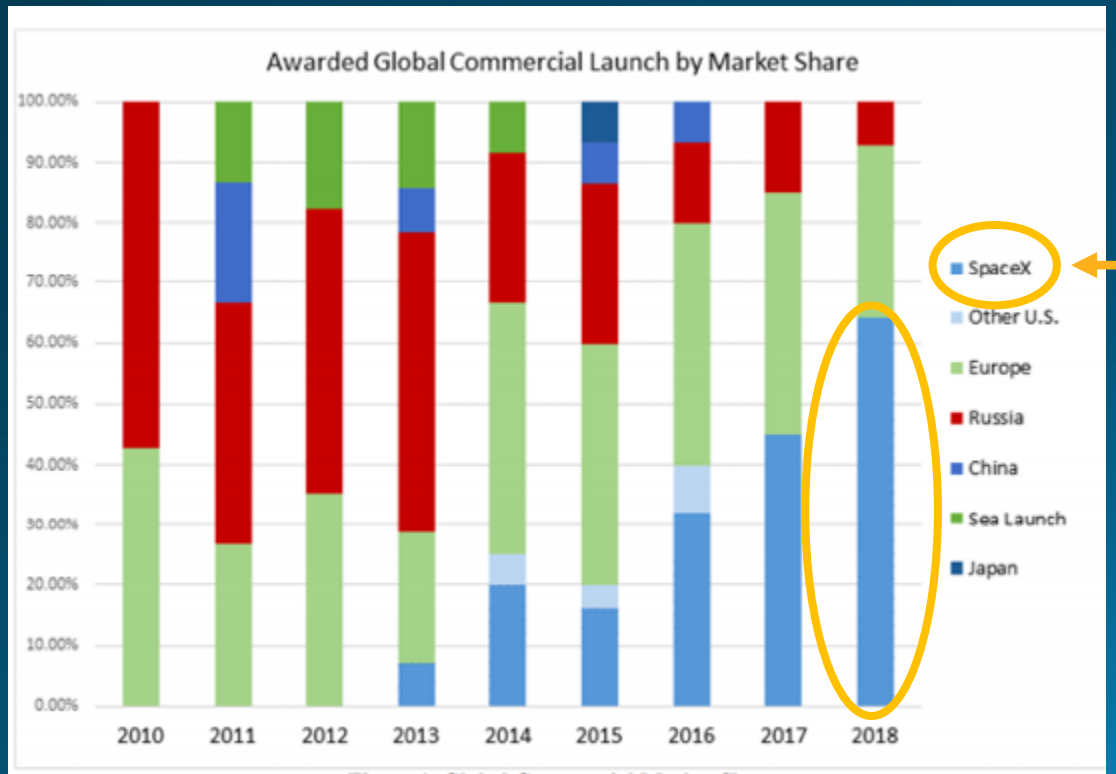


Figure 1: Global Commercial Market Share

Part of SpaceX testimony to US Senate Subcommittee on Space, Science, and Competitiveness. 7/13/17

NASA's COTS program enabled SpaceX to develop a competitive commercial launch business which has resulted in:

- US leadership in global commercial launches
- Significant growth in US space economy
- SpaceX development of new commercial space products (Falcon Heavy, Starship, etc)

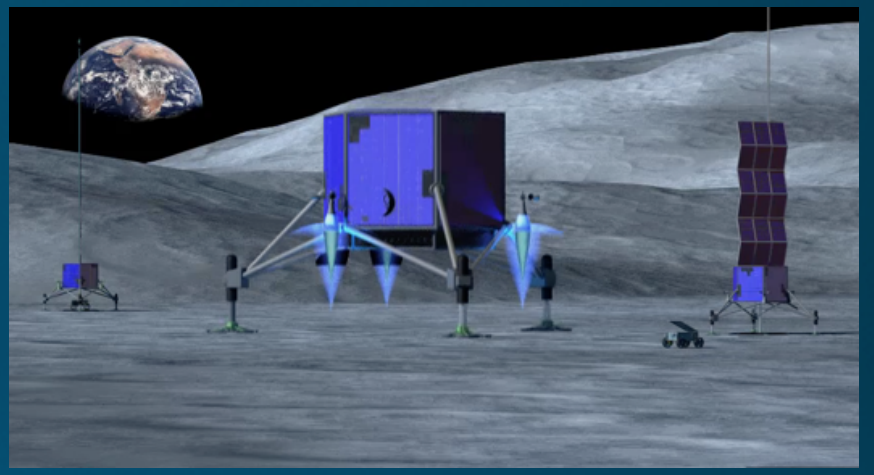
Leveraging Public-Private Partnerships

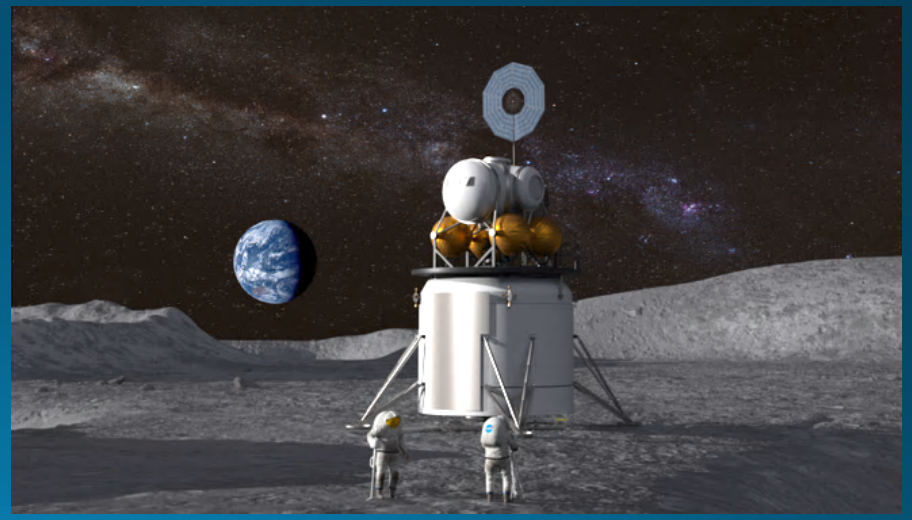
- NASA's COTS/CRS programs developed ISS cargo delivery services at significantly lower development and operational costs.
- NASA's Commercial Crew program partnered with industry since 2010 to develop crew capabilities and reduce risk.
- NASA's Lunar CATALYST initiative competitively selected partners in 2014 to develop commercial lunar cargo transportation capabilities and reduce risk
- NASA Commercial Lunar Payload Services (CLPS) program recently selected 9 companies to provide lunar cargo transportation services for small payloads.
- Lunar COTS is a concept study now focusing on the technical and economical feasibility of building lunar infrastructure to establish sustained human presence on the lunar surface by 2028.

Lunar COTS Enables Sustainable Human Missions

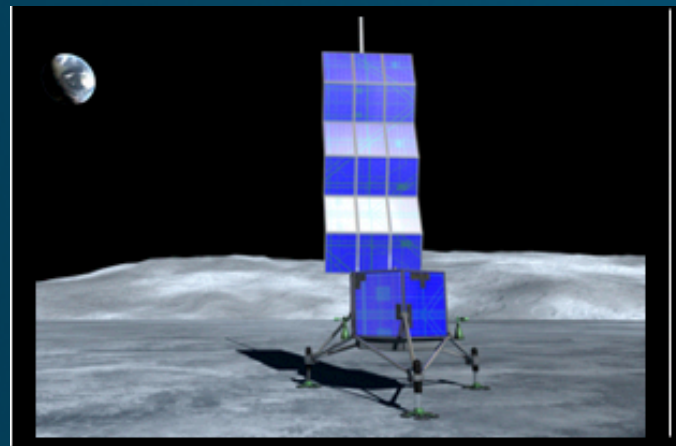
Lunar COTS was designed to enable NASA's goal of establishing a *sustainable human presence on the Moon* by 2028

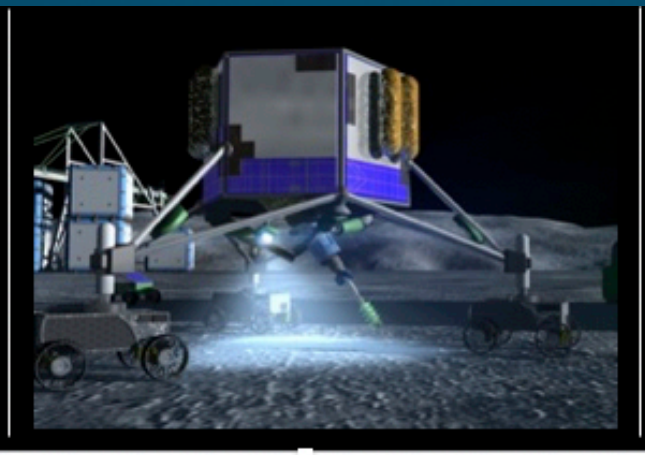
- Establish multi-purpose, reusable surface infrastructure services for sustainable and economical approach to human missions
- Apply the proven NASA COTS model to partner with industry for mutual benefit, accelerate development and reduce overall cost and risk
- Develop infrastructure to support sustained human presence at targeted areas near critical resources, such as, water, oxygen, etc
- Develop infrastructure to support commercial lunar mining and propellant production services
- Unlock private investment by serving as an anchor customer through long-term commitments

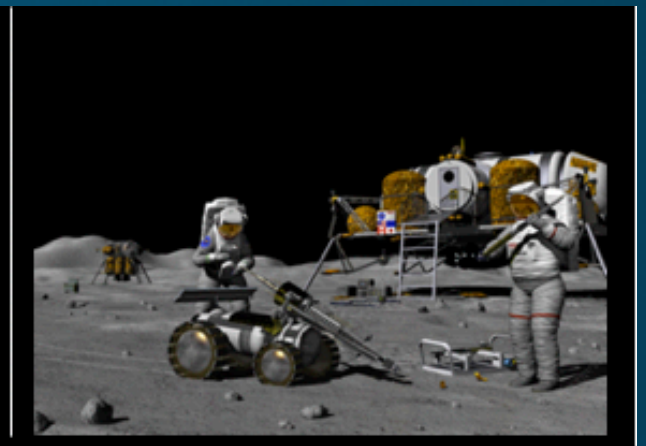




LCOTS Phased Development Approach



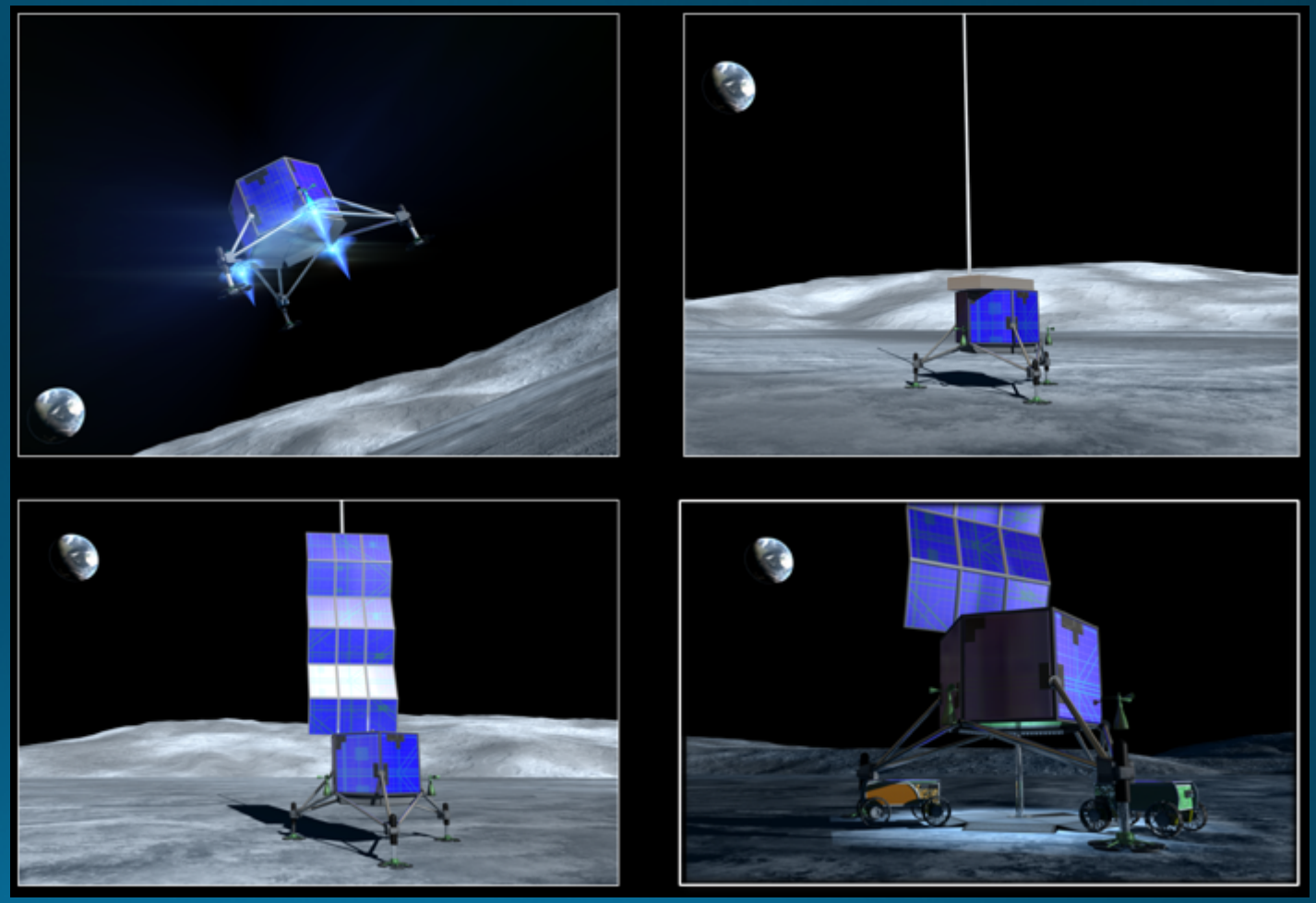




Phase 1: Small-Scale Demonstration Missions	Phase 2: Pilot-Scale Feasibility Missions	Phase 3: Human Return Missions
• Demonstrate commercial multi-purpose infrastructure services (e.g. Power-Towers) to support small-scale robotic missions • Obtain ground truth data of lunar resources • Provide best targets for future missions	• Demonstrate lunar mining capabilities including propellant production on a pilot-scale • Demonstrate commercial infrastructure capabilities to support human habitats on lunar surface • Evaluate technical feasibility and economic viability of scaling up production to full scale	• NASA may award long-term contracts for infrastructure services, such as, power, communications and habitats with life support systems. • NASA may also purchase yearly allotment of lunar-produced propellant for ascent stages and other vehicles.

PHASE 1: POWER-TOWER CONCEPT

- **Based on NASA Ames LADEE common bus with flight-proven solar panels and lithium-ion batteries**
- **Provides keep-alive power and thermal control for rovers to survive lunar nights**
- **Provides line-of-sight communication relay and high-bandwidth laser link to Earth**
- **Multiple Power Towers provide a Lunar Positioning System for precision landing**
- **Extends mission life from days to years** (from 6 to 8 years depending on battery life)
- **Extend traverse distances to hundreds of kilometers** (by addition of a mobility and suspension system)
- **Retires risk for development of human-scale infrastructure systems for long-term crewed missions**



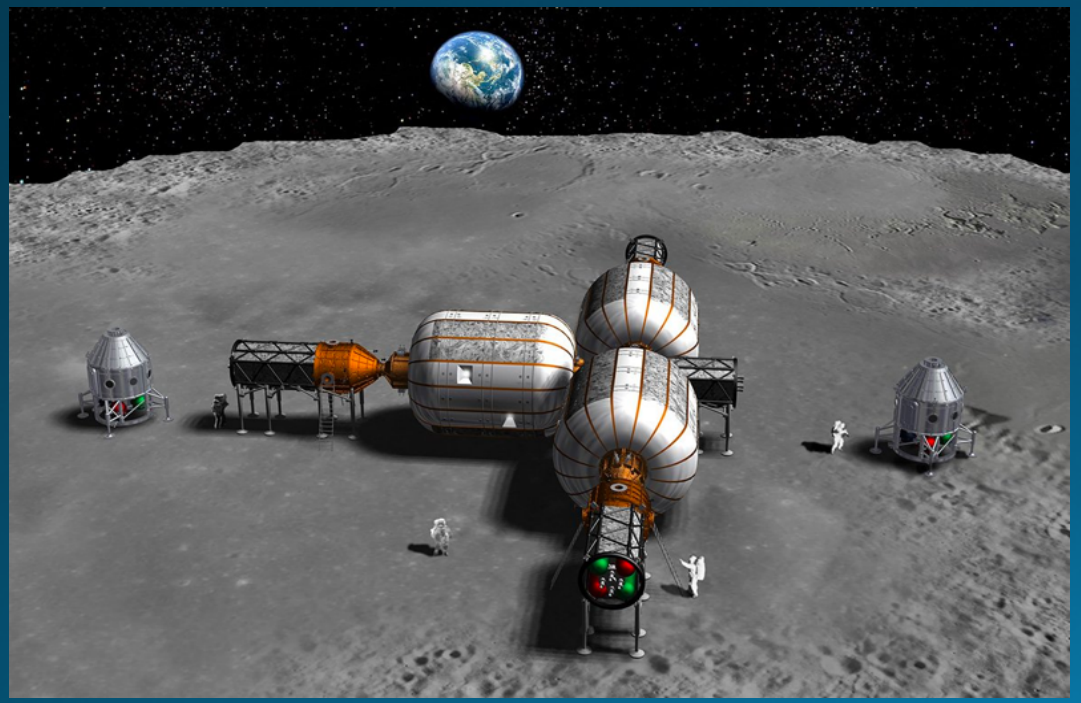
For more info: https://www.nasa.gov/ames/partnerships/spaceportal/LCOTS

PHASE 2: LUNAR SURFACE INFRASTRUCTURE DEVELOPMENT

Capability	Guidelines (based on ISS)	Challenge	Mitigation Strategy
Power	75-90 kW to sustain a crew of 6 for 30 days	- Survival of 14 days of darkness - Extreme temperatures from -180°C to 120°C near equator and down to -258°C in PSRs	- Select a site that has an extended period of illumination, such as, ”peaks of eternal light” at lunar poles - Use PV solar arrays combined with power beaming to permanently shadowed regions
Habitation Modules	Minimum acceptable net habitable volume for a crew of 6 is at least 150 m^3	- Provide a radiation and micrometeorite resilient structure - Equip with air locks that are able to remove the lunar dust particles upon entry	- Use an inflatable habitation system which provides greater volume, more durability and less mass than rigid modules - For more protection from harmful radiation, inflatables can be covered with regolith or placed within a lava tube or lunar cave
Life Support Systems	For crew of 6 and 30 day mission, life support resources needed: O_2: 151.2 kg Potable H_2O: 482.4 kg Other H_2O: 4671 kg	- A highly efficient ECLSS system can provide up to 90% efficiency - Need to resupply life support systems with O_2 and H_2O from Earth or surroundings	- Place habitats near lunar poles for ease of access to potential water-ice deposits for use in life-support systems - Send pre-cursor rover missions to potential sites to ensure accessibility of water-ice deposits

PHASE 2: LUNAR SURFACE INFRASTRUCTURE DEVELOPMENT

- For sustainable and economical sustained human presence, location of lunar outpost should be driven by cost, availability and accessibility of resources, environmental conditions, scientific interests and business potential
- A highly desirable location are the “peaks of eternal light” at the lunar poles that offer about 90% illumination, direct line-of-sight communications, proximity to water-ice deposits for use in life-support systems, and rocket propellant (liquid hydrogen and oxygen)



Habitation Modules Concept by Bigelow Aerospace

Capture Tent Concept by Colorado School of Mines

Examples of Promising Business Cases

- Propellant Production Business case shows a 9 to 16% return on investment over 15 years based on demand from ULA plus other commercial vehicles and potentially NASA

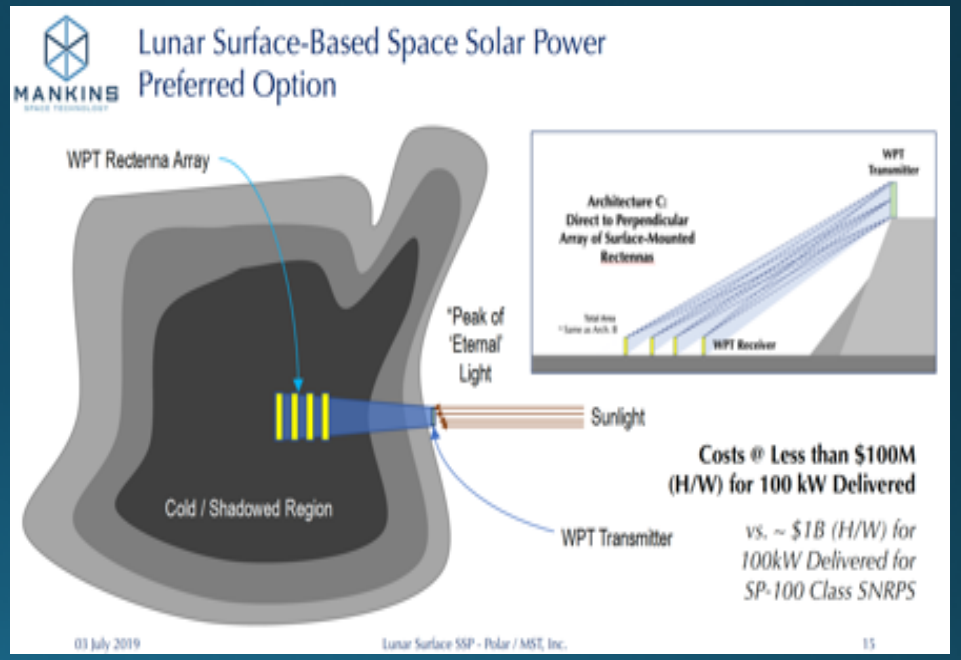
COLORADOSCHOOLOFMINES
EARTH • ENERGY • ENVIRONMENT

Business Case Analysis

Parameter	Commercial Only	Commercial + NASA
Propellant production rate	1100 mT/yr	1200 mT/yr
Price (on Moon)	$500/kg	$500/kg
HW Development & production cost	$1.5B	$1.6B
Transportation cost	$1.0B	$1.1B
Annual ops & maintenance cost	$87M/yr	$95M/yr
Annual revenue	$550M/yr	$600M/yr
NASA cost share	$0M	$800M
IRR	9%	16%

***Estimates provided by G. Sowers, Colorado School of Mines**
****Estimates based on Capture Tent Concept**

- Lunar Surface Base Power business case is based on a PV solar array system placed at "peak of eternal light" beaming power down to the permanently shadowed craters.
- Estimates show development costs of less than $100M, simple profit is approximately 30 to 1

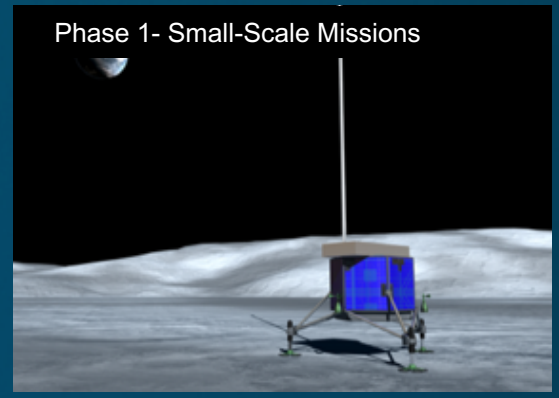


***Estimates provided by Mankins Space Technology**

By partnering with industry using LCOTS concept, we can jointly develop lunar commercial services that will benefit both NASA missions and business interests.

Summary

- Lunar COTS is a 3-Phase concept designed to develop infrastructure capabilities and services to enable a long-term, sustained human presence on the lunar surface
- LCOTS plans to use the COTS model to partner with industry for mutual benefit that should result in significant cost savings and risk reduction
- A high-level analysis of the infrastructure systems needed as well as the environmental challenges and mitigation strategies for a crew of 6 and 30-day mission was conducted.
- For an economical and sustainable human outpost, a highly desirable location is one of the “peaks of eternal light” in near proximity of permanently shadowed craters.
- Two business cases were highlighted as examples of potential partnerships where both NASA and industry can significantly benefit for economic gains and to enable a long-term, sustainable human presence.



THANK YOU!

For more info:
Dr. Allison Zuniga
NASA Ames -Space Portal Office
Email: allison.f.zuniga@nasa.gov
Voice: 650-604-2017

https://www.nasa.gov/ames/partnerships/spaceportal/LCOTS