



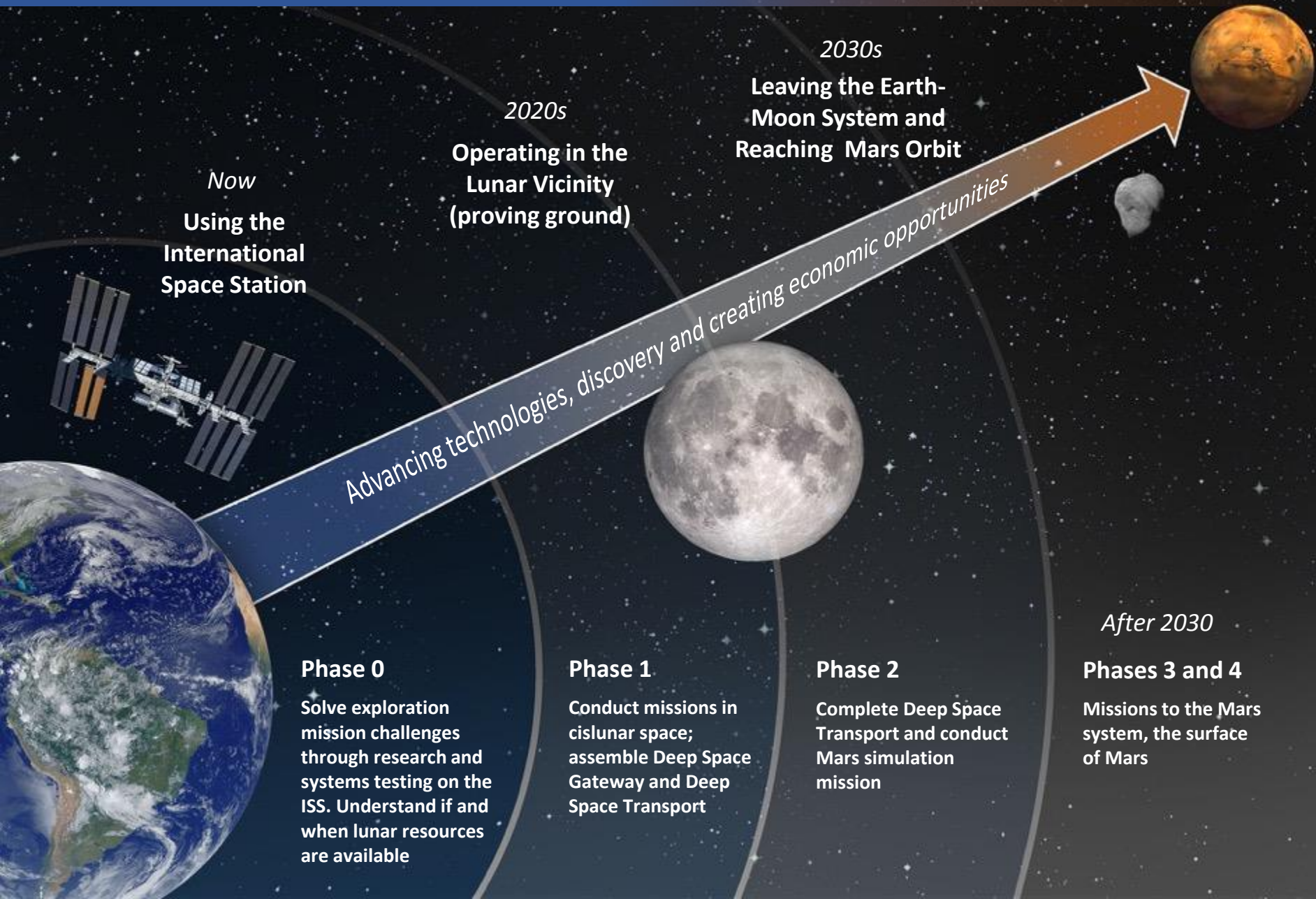
Challenges of Human Exploration of Mars

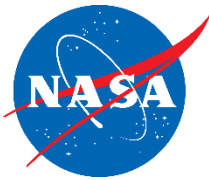
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Outline

- Vision
 - Achieving Earth Independence
- International Space Exploration Coordination Group
- Capabilities and Enablers
 - Spaceport Evolution
 - Legal Framework
 - Commercial Partnerships
- Challenges to getting to the Vision
- Video

Vision - Exploring Space In Partnership





NASA'S JOURNEY TO

MARS

SPACE PIONEERING:

**Achieving
Earth Independence**



Challenges of “Living on Mars”

- Transportation (to/from the surface)
- Radiation Protection
- Food
- Water
- Shelter
- Energy Production
- Oxygen Production
- Improved Communications

What does your Vision of “Living on Mars” look like?

Purpose

- Commercial
- Government
- Vacation
- Industry
- Species Survival
- Other?

Scale

- Outpost
- Community
- City
- Nation(s)

Learning Outcomes

Technical

- Challenge and risk analysis related to operations on Mars
- Government Deep space architecture elements
- Technical challenges and risks for 'Living on Mars'
- NASA operational plans to support Mars Missions
- Technical aspects of in-situ resource utilization related to operations on Mars

Gap Analysis

- Interdisciplinary team skills to quickly define a vision
- Identify gap between vision and current Technology Readiness Level (TRL)
- Identify One Key Development as critical to enabling vision



NASA plans

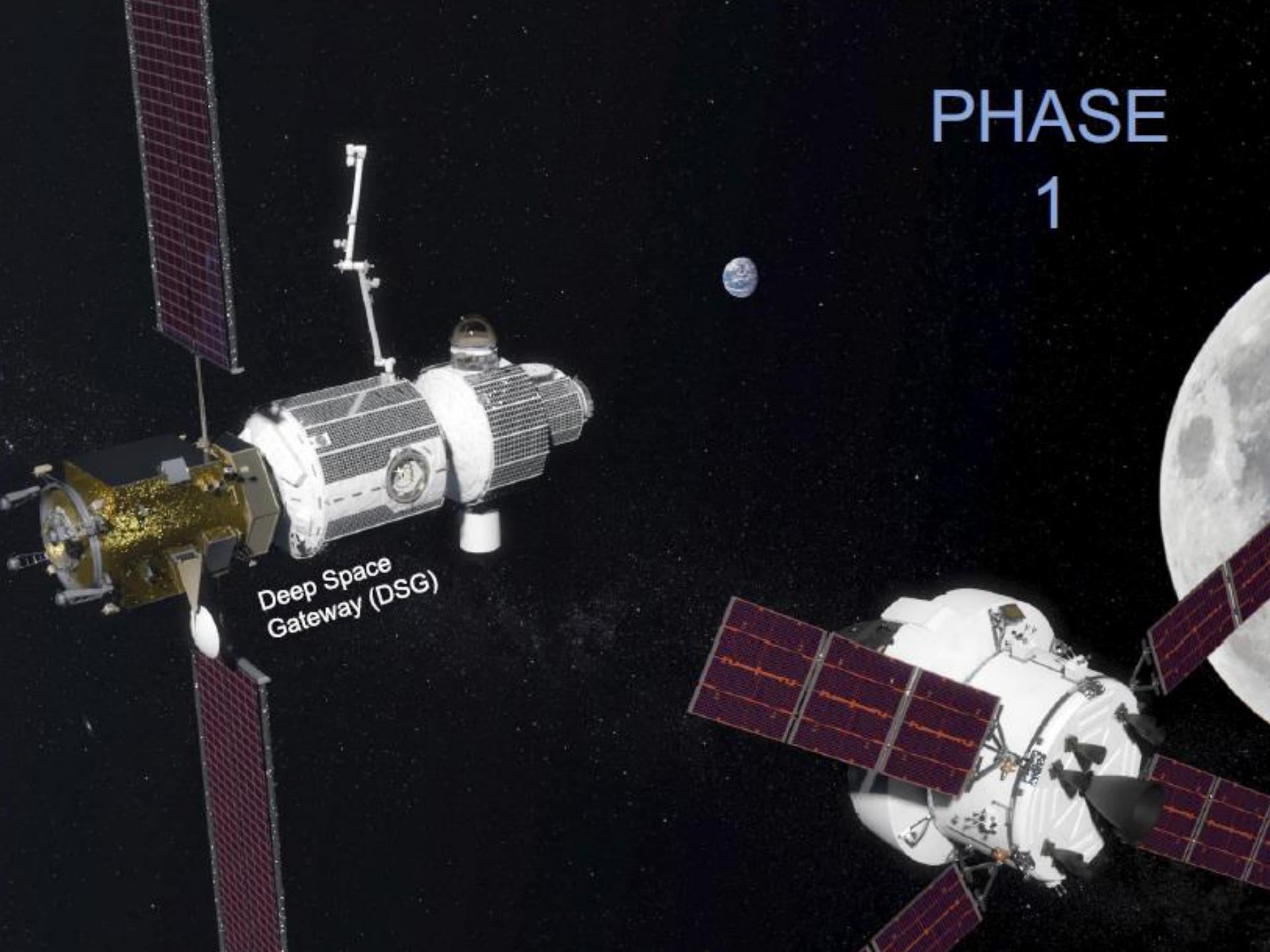
International Space Station



PHASE

1

Deep Space Gateway (DSG)



Deep Space Gateway Functionality

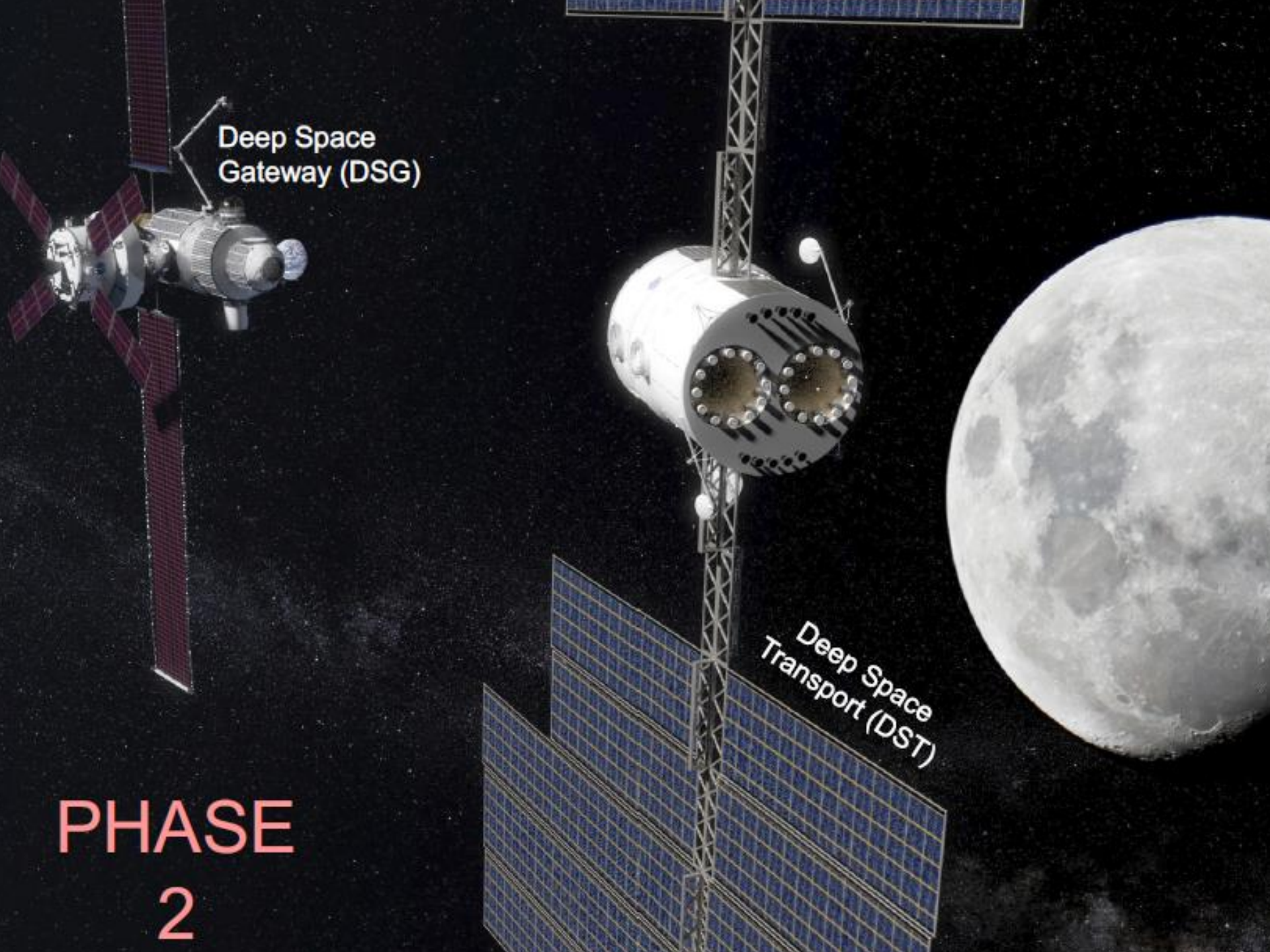


- **Assumptions**
 - Deep Space Gateway provides ability to support multiple NASA, U.S. commercial, and international partner objectives in Phase 1 and beyond
 - The Gateway is designed for deep space environments
 - Supports (with Orion docked) crew of 4 for total mission up to 42 days
 - Supports buildup of the Deep Space Transport
 - Open trade for compatibility for operations in Low Lunar Orbit
- **Emphasis on defining early Phase 1 elements**
 - Gateway Power Propulsion Bus
 - Gateway Habitat
 - Logistics Strategy
- **Future work to refine later elements; early feasibility trades complete**
 - Airlock
 - Deep Space Transport

Deep Space Gateway (DSG)

Deep Space Transport (DST)


PHASE
2





- **Assumptions**
 - Deep Space Transport provides habitation and transportation needs for transporting crew into deep space including supporting human Mars-class missions
 - The Transport system life will be designed for:
 - Reused for 3 Mars-class missions with resupply and minimal maintenance
 - Crew of 4 for 1,000 day-class missions in deep space
 - Launched on one SLS 1B cargo vehicle - resupply and minimal outfitting to be performed in cislunar space
- **Emphasis on supporting shakedown cruise by 2029**
 - Shakedown cruise to be performed in lunar vicinity
 - Utilizes deep space interfaces and common design standards
- **Future work trades**
 - Shakedown cruise objectives
 - Mars reference mission functional requirements

How are we leading future human exploration?

- 
- Maximizing utilization of the International Space Station
 - Actively promoting LEO commercialization
 - Resolving the human health and performance challenges
 - Expanding partnerships with commercial industry
 - Growing international partnerships
 - Building the critical *Deep Space Infrastructure*
 - Enabling the capabilities to explore multiple destinations



Buenos Aires 2017

International Space Exploration Coordination Group



International Space Exploration Coordination Group (ISECG)





International Space Exploration Coordination Group

Need: Coordinate multiple Space Agencies to achieve a shared vision of coordinated human and robotic space exploration focused on Solar System destinations where humans may one day live and work.

Benefits:

- Scientific Knowledge
- Sustained Human Presence
- Expand Economic Influence
- Global Partnership
- Inspiration & Education

Goals:

- Search for Life
- Extend Human Presence
- Develop Exploration Technologies and Capabilities
- Perform Science to Support Human Exploration
- Stimulate Economic Expansion
- Perform Space, Earth, and Applied Science
- Engage the Public in Exploration
- Enhance Earth Safety

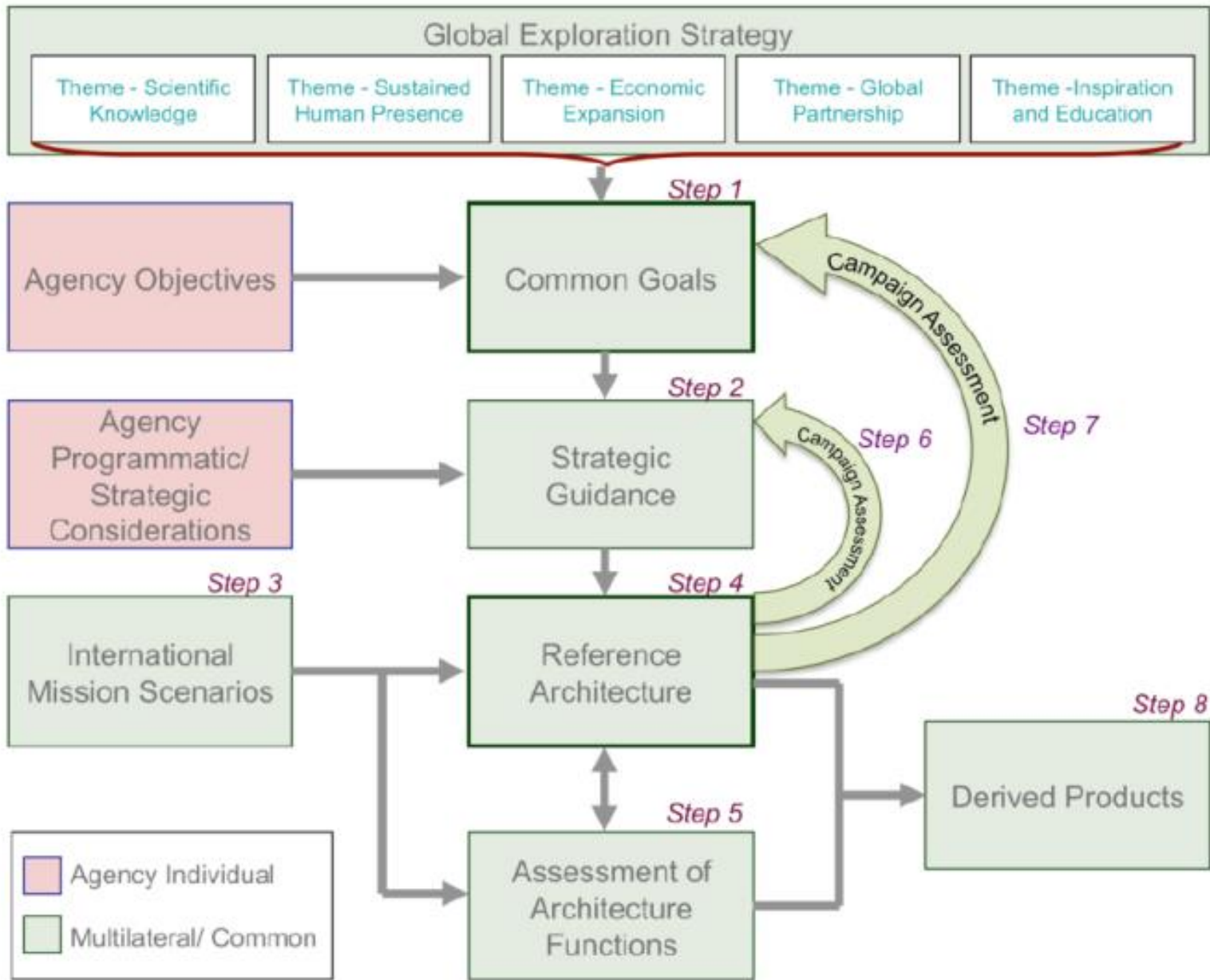


International Space Exploration Coordination Group

Objective: Destination specific Objectives were developed by ISECG, reference ISECG website

Mission: Develop Global Exploration Roadmap (GER) as a Reference Architecture

- GER 1.0 released Sept 2011
- GER 2.0 released August 2013
- GER 3.0 under development
- <https://www.globalspaceexploration.org/>





Low-Earth Orbit



International Space Station

Commercial or Government-Owned Platforms

Beyond Low-Earth Orbit

Test Missions

- Robotic Mission
- ▲ Human Mission
- Cargo Mission

Near-Earth Objects

Rosetta Hayabusa2 (Sample Return) OSIRIS-REx (Sample Return)

Asteroid Redirection

Apophis

Explore Near-Earth Asteroid

Lunar Vicinity

Moon

LADEE Luna 25 Luna 26 Chandrayaan-2 Luna 27 RESOLVE SELENE-2 Luna 28/29 (Sample Return) SELENE-3

Extended Duration Crew Missions

Human-Assisted Sample Return

Staging Post for Crew to Lunar Surface

Potential Commercial Opportunities

Humans to Lunar Surface

Potential Commercial Opportunities

Mars

MWEN ISRO Mars Orbiter Mission ExoMars 2016 InSight ExoMars 2018 Mars 2020 JAXA Mars Precursor

Human-Assisted Sample Return

Mars Sample Return Mission Opportunities

Human Scale EDL Test Mission Opportunities

Sustainable Human Missions to the Mars System

Multi-Destination Transportation Capabilities (Planned and Conceptual)

Icon indicates first use opportunity. Commercial/institutional launchers not shown.

Orion & SLS

Russian Piloted System

Advanced Electric Propulsion

Evolvible Deep Space Habitat

Orion & SLS (Upgrade)

Initial Cargo Delivery

Small Cargo Lander

Human Surface Mobility

Crewed Lunar Lander

Orion & SLS (Upgrade)



GER – Preparation for Boots on Mars

- The Global Exploration Roadmap outlines the following Human Exploration Preparatory Activities to extend our presence into the solar system:
 - Use of the ISS for Exploration
 - Robotic (precursor) Missions
 - Advanced Technology Development
 - Development of New Space Systems and Infrastructure
 - Analogue Activities
 - Managing Health and Human Performance Risks



Capabilities and Enablers

Spaceport Evolution at KSC

Timeframe	Theme
Pre-2012	Focused Support for NASA Programs
Near Term	Focused Support for Continuing NASA Programs with Emerging Commercial Integration; Economic Sustainability
Long Term	Continuing Support for NASA Programs with Balanced Commercial Integration
Future: Beyond 2032	Continued Support for NASA Programs; Fully Leverage All Assets and Land Area Resources; Optimized Diversified Commercial Integration

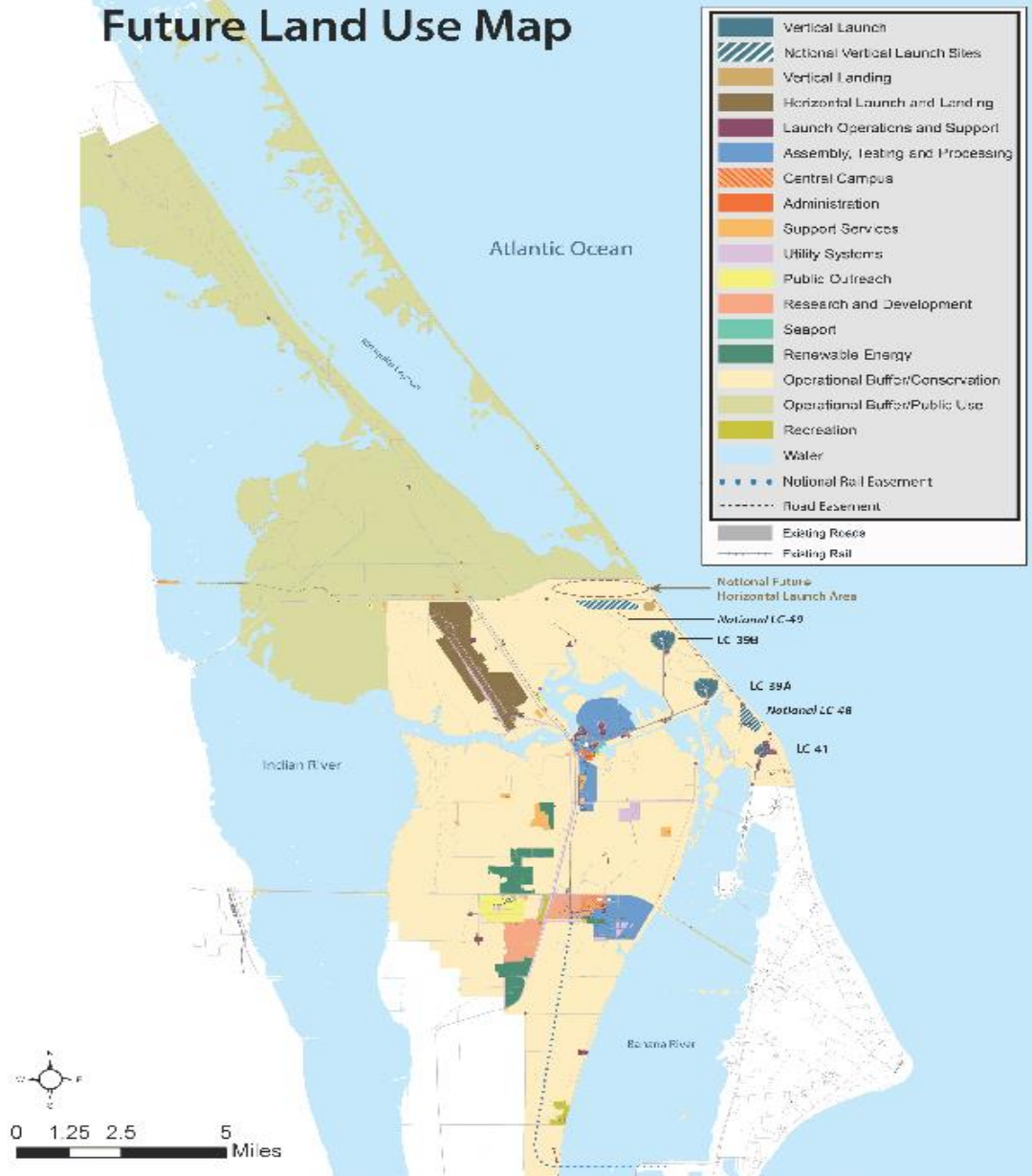
Spaceport models like Kennedy Space Center are changing toward airport-like operations that include government and commercial interests

Spaceports are getting planned by architects and city planners for these multiple interests

Includes:

- Administrative Areas
- Transportation
- Recreation
- Utilities
- Public Outreach
- Central Campus
- Horizontal and Vertical Launch and Landing Facilities
- Operational Buffers
- Notional Growth Areas Identified

Future Land Use Map



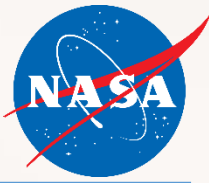
Legal Framework

- Fundamental principles – Concept of space as the province of all humankind, the freedom of exploration and use of outer space by all states without discrimination, and the principle of non-appropriation of outer space.
- The primary goals of space law are to ensure a rational, responsible approach to the exploration and use of outer space for the benefit and in the interests of all humankind.
- United Nations Office for Outer Space Affairs (NOOSA) Space Law
<http://www.unoosa.org/oosa/en/ourwork/spacelaw/index.html>
- Space Treaties & Principles
<http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html>

Legal Framework Utilization of Space Resources

- Recovery and Utilization of Space Resources – Scientific vs Commercial (Profit)
- 1967 OST (widely ratified) & 1979 Moon Agreement (poorly ratified)
- Differing views in OST Interpretation – Article 1 right to utilize resources for private commercial use consistent/not consistent for celestial bodies
- Further detailed information from UNOOSA, Legal Subcommittee 56th Session
April 2017, Legal Models Utilization of Space resources

<http://www.unoosa.org/oosa/en/ourwork/copuos/lsc/2017/symposium.html>



Space Resource Regulation

TITLE IV--SPACE RESOURCE EXPLORATION AND UTILIZATION

Space Resource Exploration and Utilization Act of 2015

(Sec. 402) The bill directs the President, acting through appropriate federal agencies, to:

- facilitate the commercial exploration for and commercial recovery of space resources by U.S. citizens;
- discourage government barriers to the development of economically viable, safe, and stable industries for the commercial exploration for and commercial recovery of space resources in manners consistent with U.S. international obligations; and
- promote the right of U.S. citizens to engage in commercial exploration for and commercial recovery of space resources free from harmful interference, in accordance with such obligations and subject to authorization and continuing supervision by the federal government.

A U.S. citizen engaged in commercial recovery of an asteroid resource or a space resource shall be entitled to any asteroid resource or space resource obtained, including to possess, own, transport, use, and sell it according to applicable law, including U.S. international obligations.

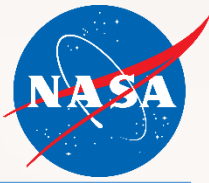
(Sec. 403) It is the sense of Congress that the United States does not, by enactment of this Act, assert sovereignty or sovereign or exclusive rights or jurisdiction over, or ownership of, any celestial body.

Commercial Engagement

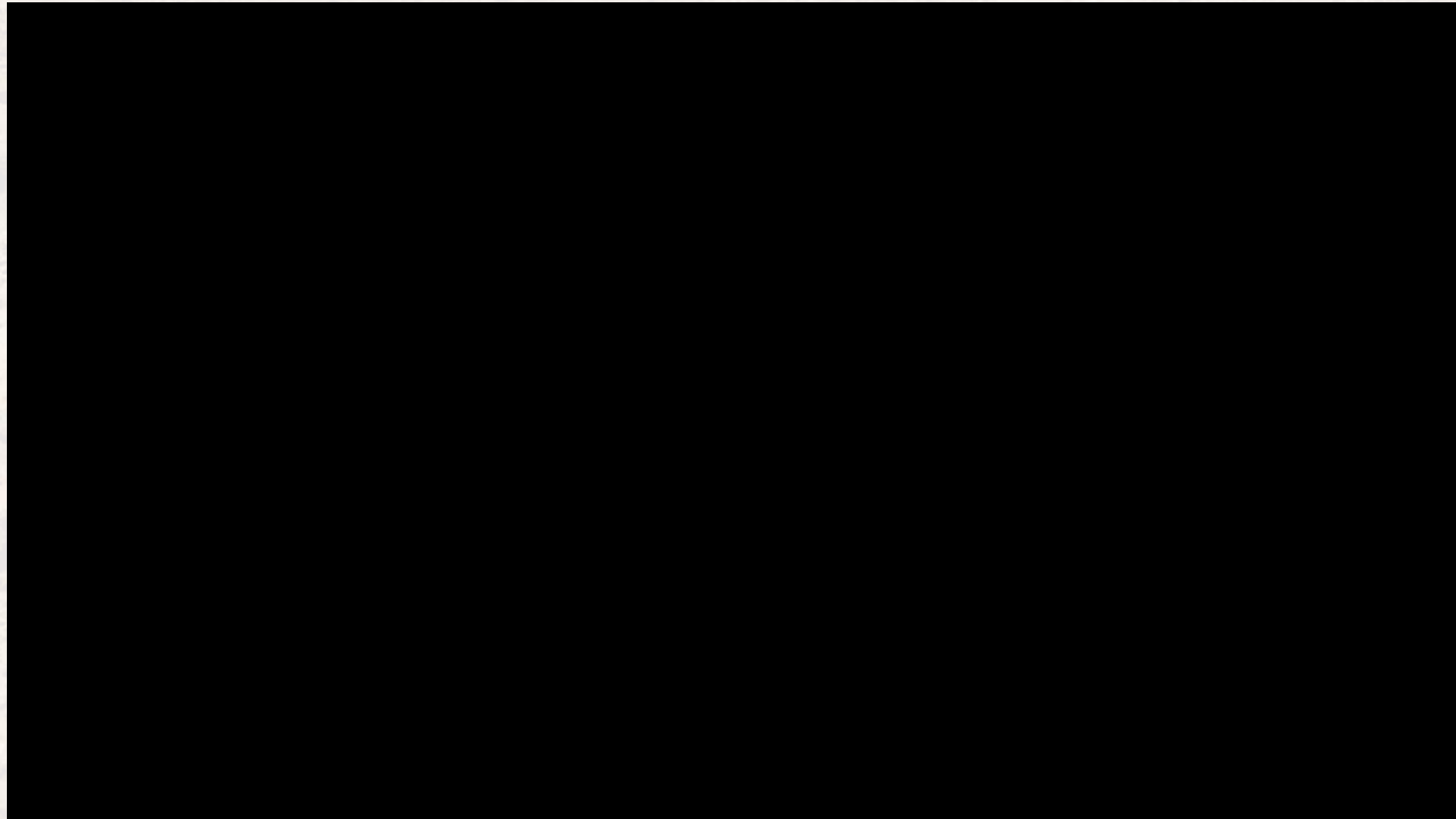
- NASA Next Space Technologies for Exploration Partnerships (STEP)
Habitat Systems – Phase 2
 - 6 commercial companies defining architectures for the Deep Space Gateway
 - Phase 3 Solicitation ~2019 for flight systems
- Commercial Partnerships facilitated through Space Act Agreements
<https://www.nasa.gov/open/space-act.html>
- Regulatory Barriers to commercial investment/participation

Biggest challenge to getting to the Vision?

- In-situ Resource Utilization (ISRU) – living off the land using available resources for fuel, life support, etc.
- Food Production - growing plants, fish, etc. and sustaining life using what you bring from Earth
- Human health – radiation damage during transit and at Mars and reduced gravity adaptation
- Cargo upmass and transportation to Mars – cost and availability for supplies from Earth
- Policy – legal and commercial barriers
- Many, many more...



Inspiration: Video – Mars Exploration Zones





Any Questions?

A wide-angle photograph of the Martian surface, showing a vast, rocky, and reddish-orange landscape under a hazy sky. The terrain is covered with numerous rocks of various sizes and shapes, extending to the horizon.

Notional SLS manifest for Deep Space Gateway and Deep Space Transport

Phase 1 Plan

Establishing deep-space leadership and preparing for Deep Space Transport development



		Deep Space Gateway Buildup				
EM-1	Europa Clipper	EM-2	EM-3	EM-4	EM-5	
2018 - 2025					2026	
<p>SLS Block 1 Crew: 0</p>	<p>SLS Block 1B Cargo Europa Clipper (subject to approval)</p>	<p>SLS Block 1B Crew: 4 CMP Capability: 8-9T 40kW Power/Prop Bus</p>	<p>SLS Block 1B Crew: 4 CMP Capability: 10mT Habitation</p>	<p>SLS Block 1B Crew: 4 CMP Capability: 10mT Logistics</p>	<p>SLS Block 1B Crew: 4 CPL Capability: 10mT Airlock</p>	
<p>Distant Retrograde Orbit (DRO) 26-40 days</p>	<p>Jupiter Direct</p>	<p>Multi-TLI Lunar Free Return 8-21 days</p>	<p>Near Rectilinear Halo Orbit (NRHO) 16-26 days</p>	<p>NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days</p>	<p>NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days</p>	
<p>Gateway (blue) Configuration (Orion in grey)</p>			<p>Cislunar Support Flight</p>	<p>Cislunar Support Flight</p>		

These essential Gateway elements can support multiple U.S. and international partner objectives in Phase 1 and beyond

Known Parameters:

- Gateway to architecture supports Phase 2 and beyond activities
- International and U.S. commercial development of elements and systems
- Gateway will translate uncrewed between cislunar orbits
- Ability to support science objectives in cislunar space

Open Opportunities:

- Order of logistics flights and logistics providers
- Use of logistics modules for available volume
- Ability to support lunar surface missions

(PLANNING REFERENCE) Phase 2 and Phase 3

Looking ahead to the shakedown cruise and the first crewed missions to Mars



Transport Delivery		Transport Shakedown		Mars Transit	
EM-6	EM-7	EM-8	EM-9	EM-10	EM-11
2027		2028 / 2029		2030+	
<p>SLS Block 1B Cargo P/L Capability: 41t TLI</p> <p>Deep Space Transport</p>	<p>SLS Block 1B Crew: 4 CMP Capability: 10t</p> <p>Logistics</p>	<p>SLS Block 1B Cargo P/L Capability: 41t TLI</p> <p>DST Logistics & Refueling</p>	<p>SLS Block 2 Crew: 4 CMP Capability: 13+t</p> <p>Logistics</p>	<p>SLS Block 2 Cargo P/L Capability: 45t TLI</p> <p>DST Logistics & Refueling</p>	<p>SLS Block 2 Crew: 4 CMP Capability: 13+t</p> <p>Logistics</p>
<p>DST checkout in NRHO 191-221 days</p> <p>Cislunar Support Flight</p>		<p>DSG: continued operations in cislunar space</p> <p>DST: shakedown in cislunar space with return to DSG in NRHO 300-400 days</p> <p>Cislunar Support Flight</p>		<p>DSG: continued operations in cislunar space</p> <p>DST: Mars transit and return to DSG in NRHO</p> <p>Cislunar Support Flight</p>	

Reusable Deep Space Transport supports repeated crewed missions to the Mars vicinity

- Known Parameters:**
- DST launch on one SLS cargo flight
 - DST shakedown cruise by 2029
 - DST supported by a mix of logistics flights for both shakedown and transit
 - Ability to support science objectives in cislunar space

- Open Opportunities:**
- Order of logistics flights and logistics providers
 - Shakedown cruise vehicle configuration and destination/s
 - Ability to support lunar surface missions