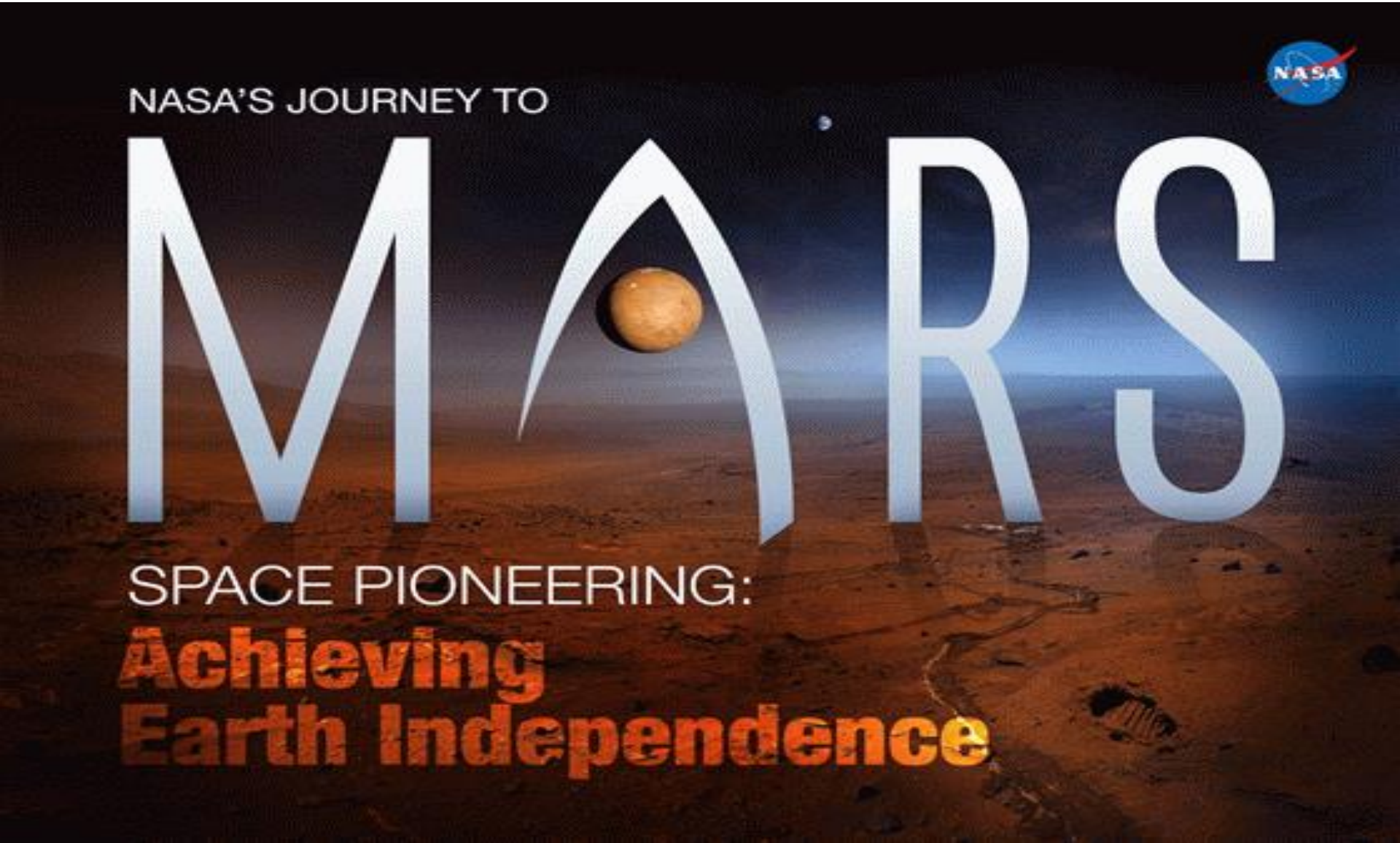
Boots on Mars: Earth Independent Human Exploration of Mars

Josephine Burnett/NASA Kennedy Space Center

Kim Ellis/Earth Space Technology Pty Ltd

Tracy Gill/NASA Kennedy Space Center


NASA
NASA'S JOURNEY TO
MARS
SPACE PIONEERING:
Achieving
Earth Independence

Outline

- Vision (Josie)
- NASA plans (Josie)
- International Space Exploration Coordination Group (Tracy)
- Capabilities and Enablers
  - Spaceport Evolution (Tracy)
  - Legal Framework (Kim)
  - Commercial Partnerships (Kim)
- Barriers and Challenges (Tracy)
- Team Activity Kickoff (Kim)

Learning Outcomes

Technical

- Challenge and risk analysis related to operations on Mars
- Government Deep space architecture elements
- Technical challenges and risks for ‘Boots 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

The Year is 2030

NASA's long term effort of 'pioneering space' for current and future generations is now approaching the 'Earth Independent Phase' of Operations.

Following the technical briefing your team will;

1. Develop a vision for future "Pioneering on Mars"
2. Identify the single greatest challenge to achieving that vision
3. Draft a Request for Proposals (RFP) response which supplies a solution to the greatest challenge that your team identifies
4. Present the vision, challenge and solution to the RFP evaluation team.

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

Purpose

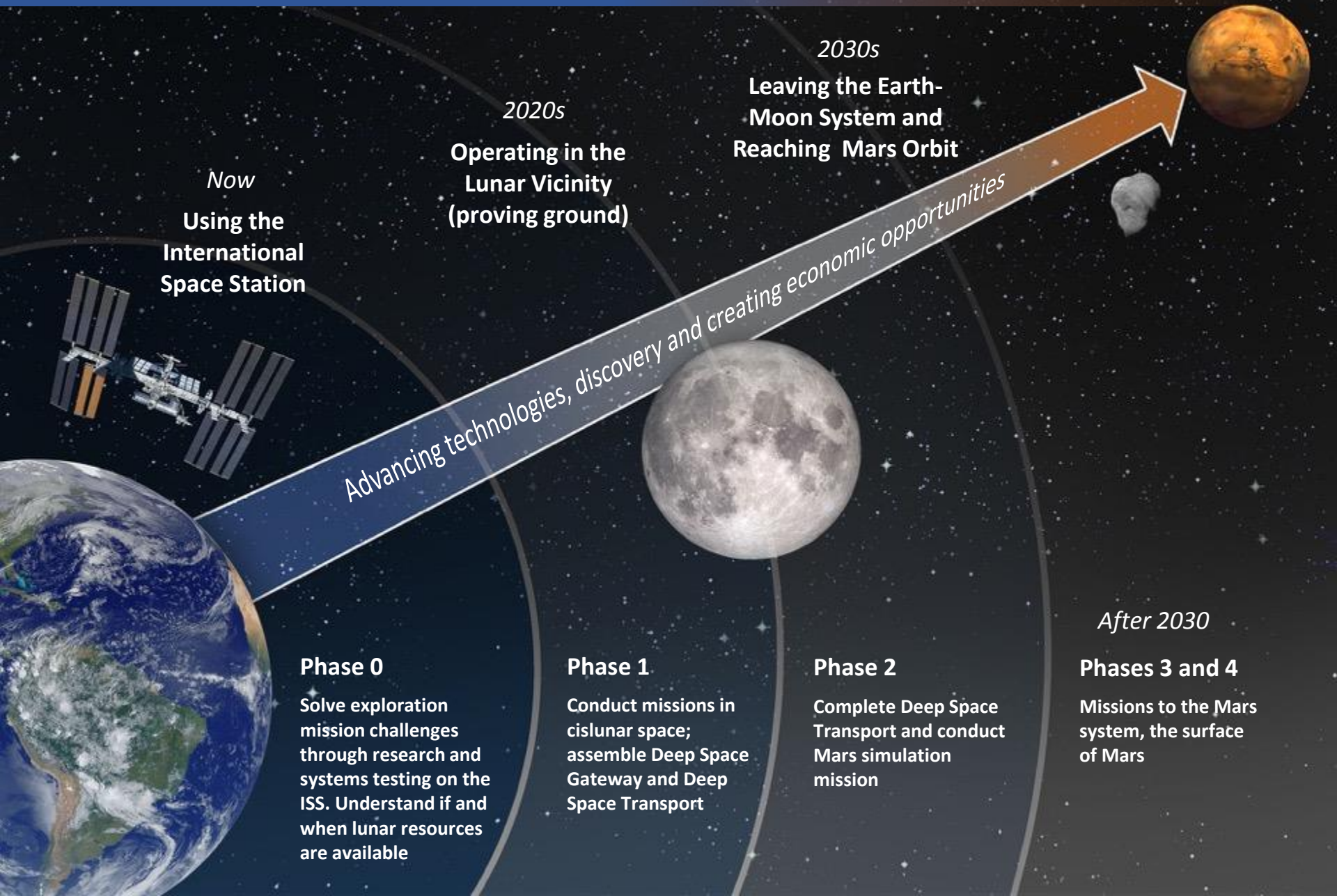
- Commercial
- Government
- Vacation
- Industry
- Species Survival
- Other?

Scale

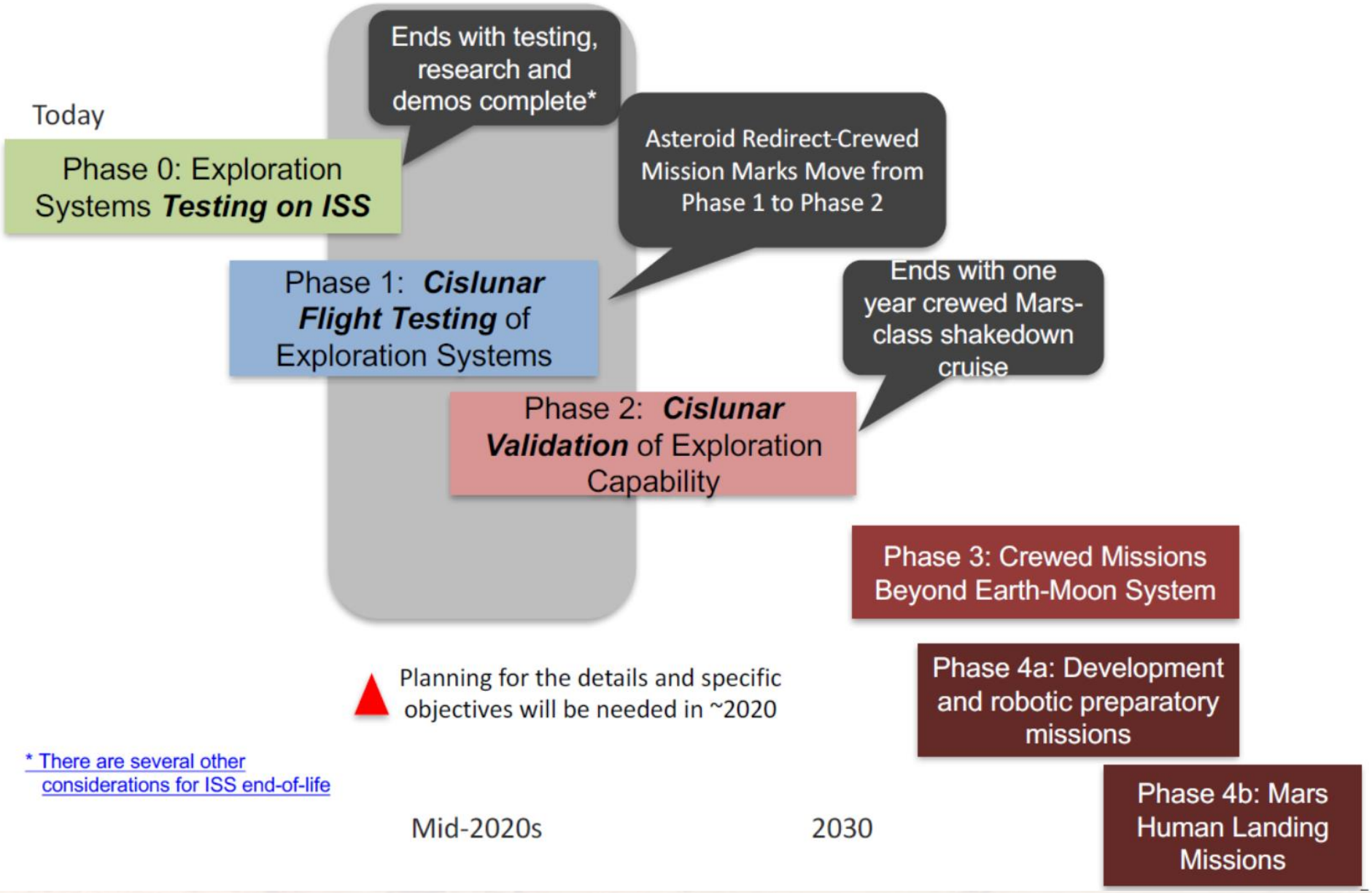
- Outpost
- Community
- City
- Nation(s)

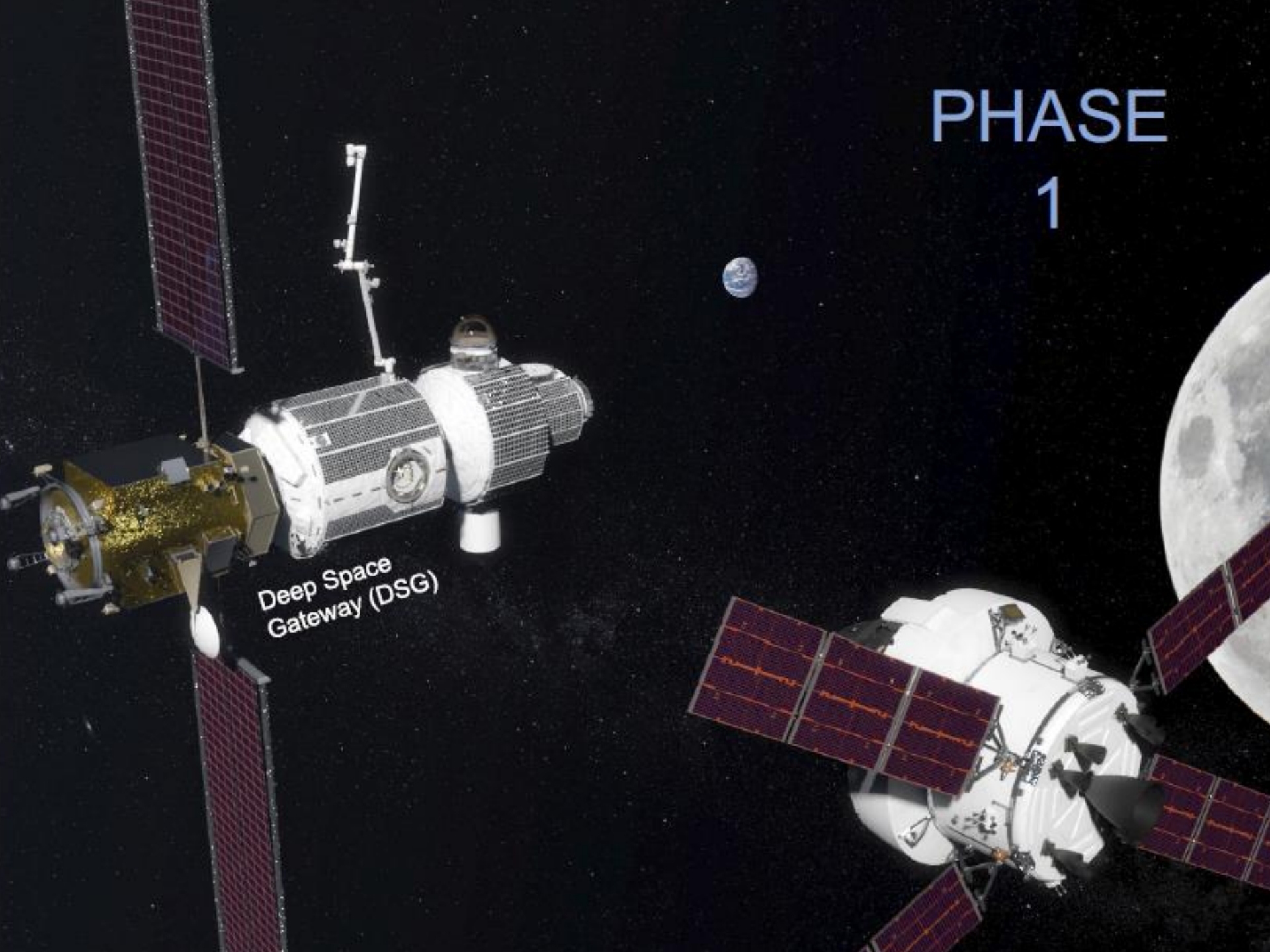
NASA plans

Exploring Space In Partnership



Human Space Exploration Phases From ISS to the Surface of Mars
as of November 2016



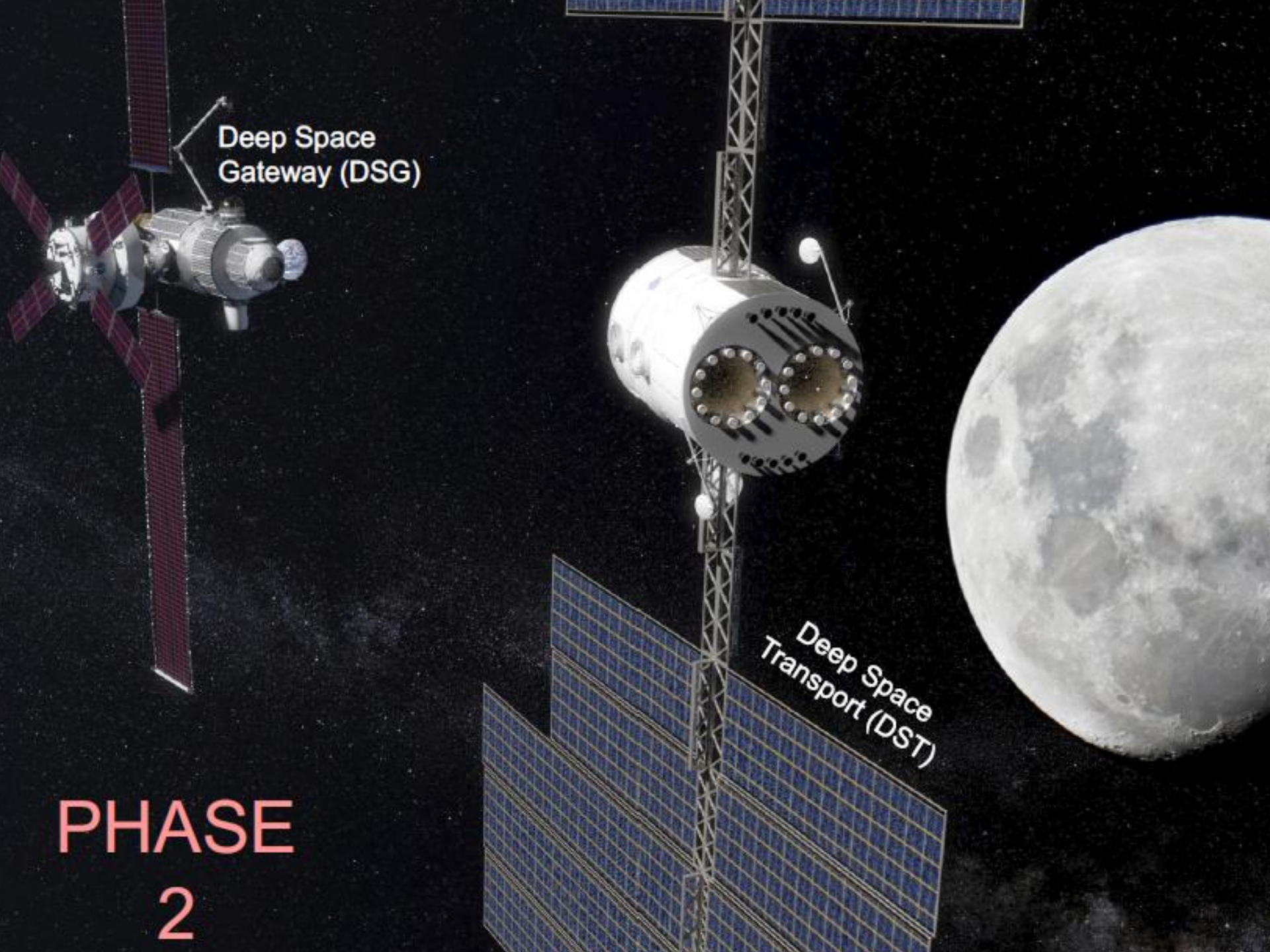

PHASE
1
Deep Space
Gateway (DSG)

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

Deep Space Transport Functionality

- **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

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:

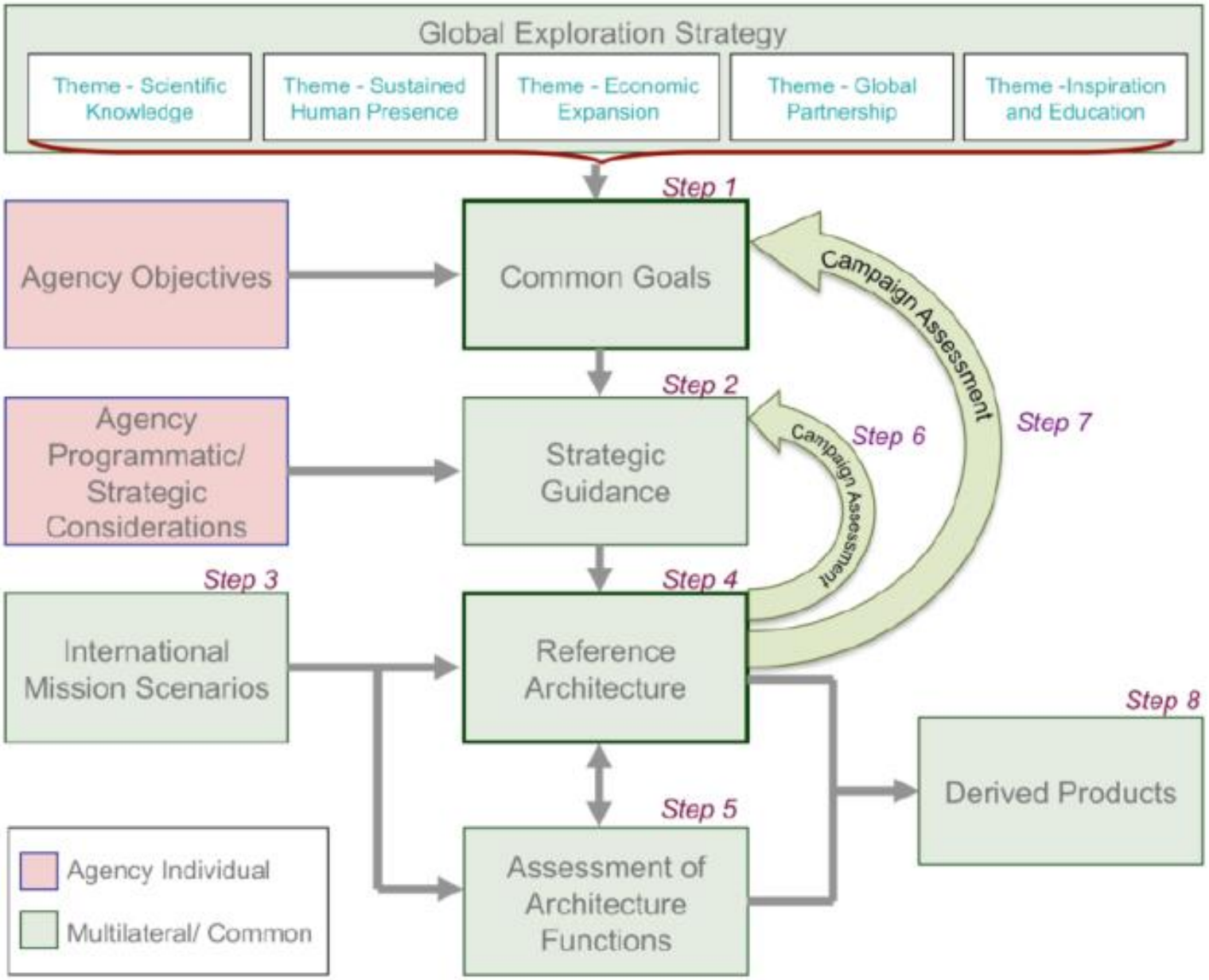
- Search for Life
- Extend Human Presence
- Develop Exploration Technologies and Capabilities
- Perform Science to Support Human Exploration
- Stimulate Economic Expansion
- Perform Space, Earth, and Applied Science
- Engage the Public in Exploration
- Enhance Earth Safety

International Space Exploration Coordination Group

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

Mission: Develop the Global Exploration Roadmap 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/


Global Exploration Strategy
Theme - Scientific Knowledge
Theme - Sustained Human Presence
Theme - Economic Expansion
Theme - Global Partnership
Theme -Inspiration and Education
Step 1
Agency Objectives
Common Goals
Campaign Assessment
Step 7
Step 2
Agency Programmatic/ Strategic Considerations
Strategic Guidance
Step 6
Campaign Assessment
Step 3
Step 4
International Mission Scenarios
Reference Architecture
Step 8
Derived Products
Step 5
Assessment of Architecture Functions
Agency Individual
Multilateral/ Common

INTERNATIONAL ISECG Mission Scenario

2020 2030

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

Extended Duration Crew Missions
Staging Post for Crew to Lunar Surface
Potential Commercial Opportunities

Moon

LADEE
Luna 25
Chandrayaan-2
Luna 26
Luna 27
RESOLVE
SELENE-2
Luna 28/29 (Sample Return)
SELENE-3
Human-Assisted Sample Return
Humans to Lunar Surface
Potential Commercial Opportunities

Mars

Human-Assisted Sample Return
MAVEN
ISRO Mars Orbiter Mission
ExoMars 2016
InSight
ExoMars 2018
Mars 2020
JAXA Mars Precursor
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)

Orion & SLS
Russian Piloted System
Advanced Electric Propulsion
Evolvable Deep Space Habitat
Orion & SLS (Upgrade)
Initial Cargo Delivery
Small Cargo Lander
Human Surface Mobility
Crewed Lunar Lander
Orion & SLS (Upgrade)

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

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

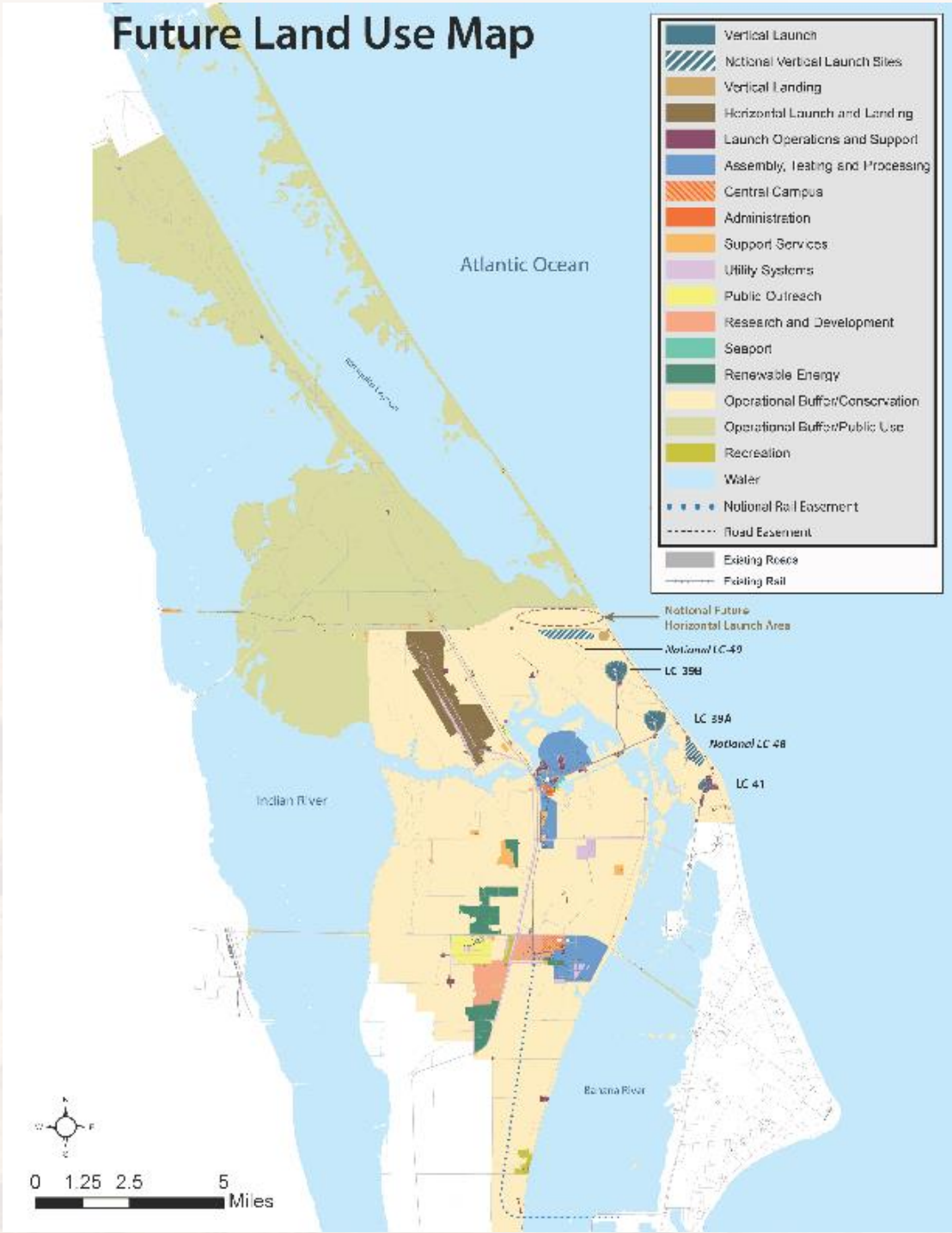
Spaceport Evolution at KSC

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 which includes government and commercial interests

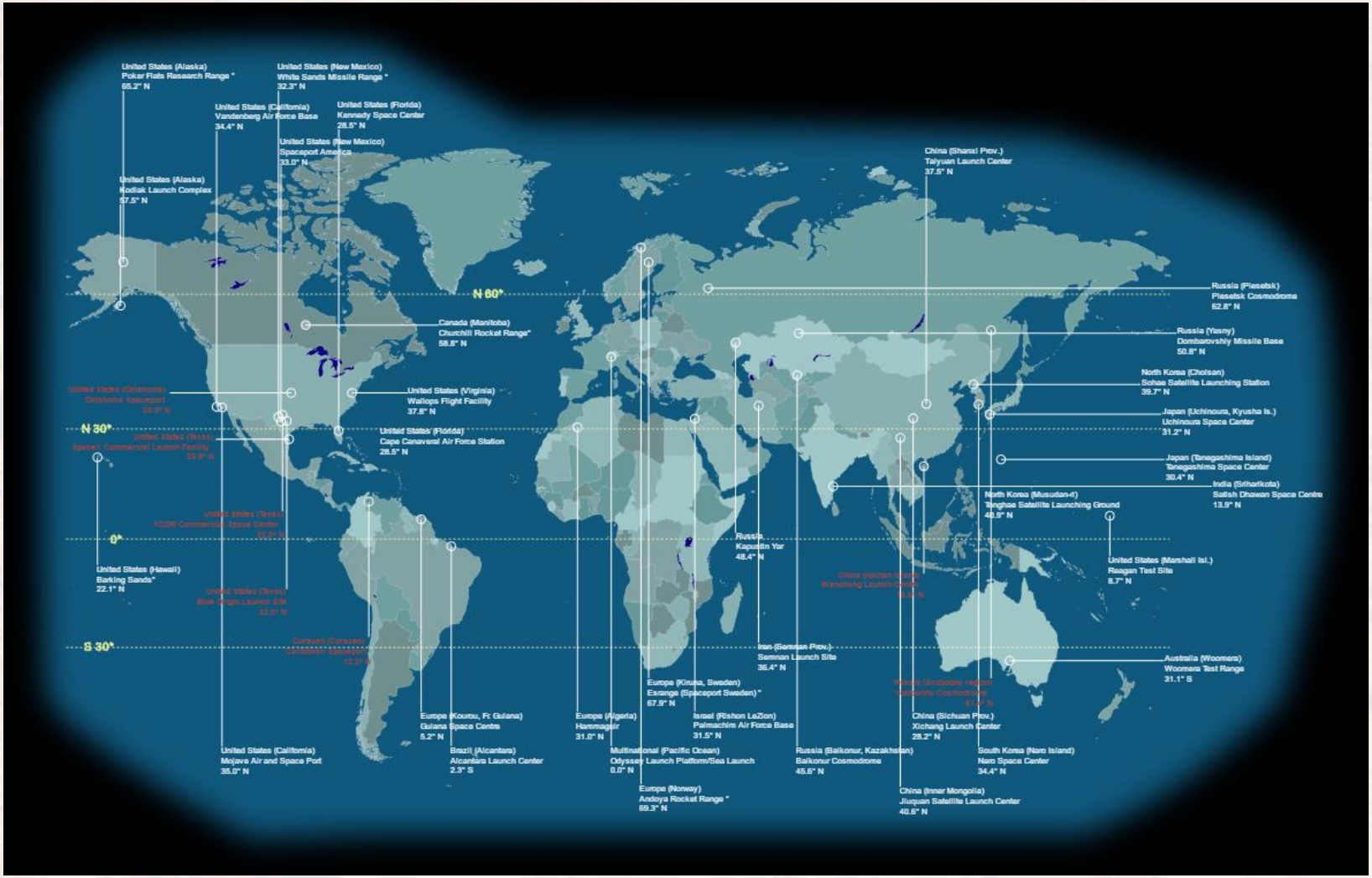
Spaceports are getting planned by architects and city planners for these multiple interests
Includes:

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



Adobe Acrobat Document

Launch Sites around the World



These planning lessons apply not only at KSC but at spaceports all over the world. And they will apply to destination spaceports as well

Notional image of spaceports around the world from https://integratedspaceanalytics.com/cms/portal/spaceports

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.
- UNOOSA 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

Identify and present the biggest challenge to getting to the Vision?

These are some of the types of things your team may see as challenges:

- 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

Team Activity Kickoff

- Restate what is asked of the team for defining the vision and identifying the greatest challenge, the timeframe they have, and the format for the outbrief – see slide after the video

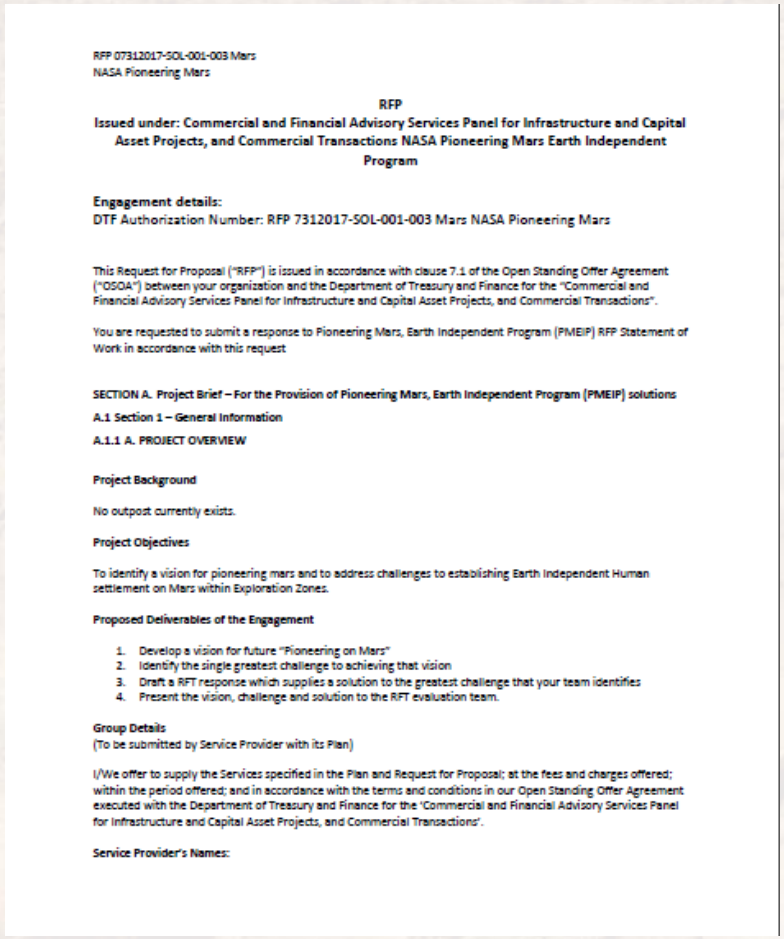
The Year is 2030

NASA's long term effort of 'pioneering space' for current and future generations is now approaching the 'Earth Independent Phase' of Operations.

Following the technical briefing your team will;

1. Develop a vision for future "Pioneering on Mars"
2. Identify the single greatest challenge to achieving that vision
3. Draft a Request for Proposals (RFP) response which supplies a solution to the greatest challenge that your team identifies
4. Present the vision, challenge and solution to the RFP evaluation team.

RFP & Statement of Work



RFP 07312017-SOL-001-003 Mars
NASA Pioneering Mars

RFP
Issued under: Commercial and Financial Advisory Services Panel for Infrastructure and Capital Asset Projects, and Commercial Transactions NASA Pioneering Mars Earth Independent Program

Engagement details:
DTF Authorization Number: RFP 7312017-SOL-001-003 Mars NASA Pioneering Mars

This Request for Proposal ("RFP") is issued in accordance with clause 7.1 of the Open Standing Offer Agreement ("OSOA") between your organization and the Department of Treasury and Finance for the "Commercial and Financial Advisory Services Panel for Infrastructure and Capital Asset Projects, and Commercial Transactions".

You are requested to submit a response to Pioneering Mars, Earth Independent Program (PMEIP) RFP Statement of Work in accordance with this request

SECTION A. Project Brief – For the Provision of Pioneering Mars, Earth Independent Program (PMEIP) solutions

A.1 Section 1 – General Information

A.1.1 A. PROJECT OVERVIEW

Project Background

No outpost currently exists.

Project Objectives

To identify a vision for pioneering mars and to address challenges to establishing Earth Independent Human settlement on Mars within Exploration Zones.

Proposed Deliverables of the Engagement

1. Develop a vision for future "Pioneering on Mars"
2. Identify the single greatest challenge to achieving that vision
3. Draft a RFT response which supplies a solution to the greatest challenge that your team identifies
4. Present the vision, challenge and solution to the RFT evaluation team.

Group Details
(To be submitted by Service Provider with its Plan)

I/We offer to supply the Services specified in the Plan and Request for Proposal; at the fees and charges offered; within the period offered; and in accordance with the terms and conditions in our Open Standing Offer Agreement executed with the Department of Treasury and Finance for the 'Commercial and Financial Advisory Services Panel for Infrastructure and Capital Asset Projects, and Commercial Transactions'.

Service Provider's Names:

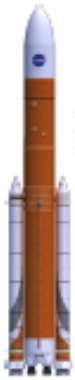
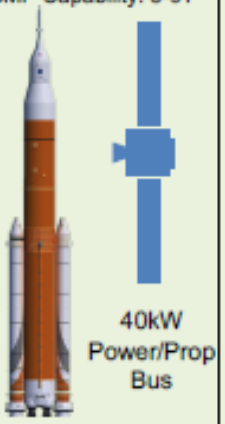
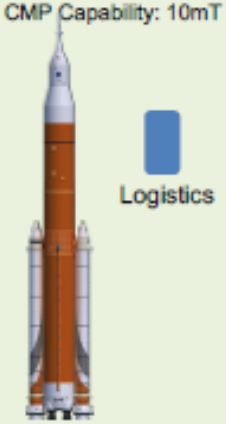
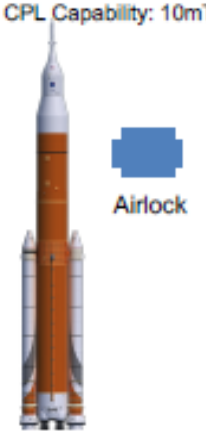
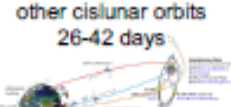
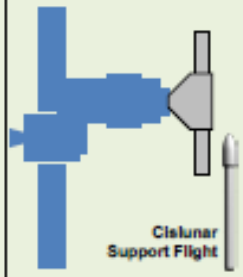
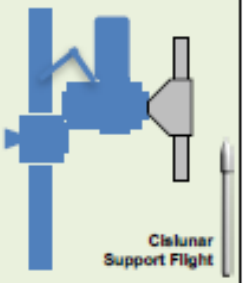
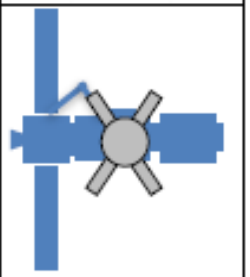
Adobe Acrobat Document

Backup

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

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

Known Parameters:

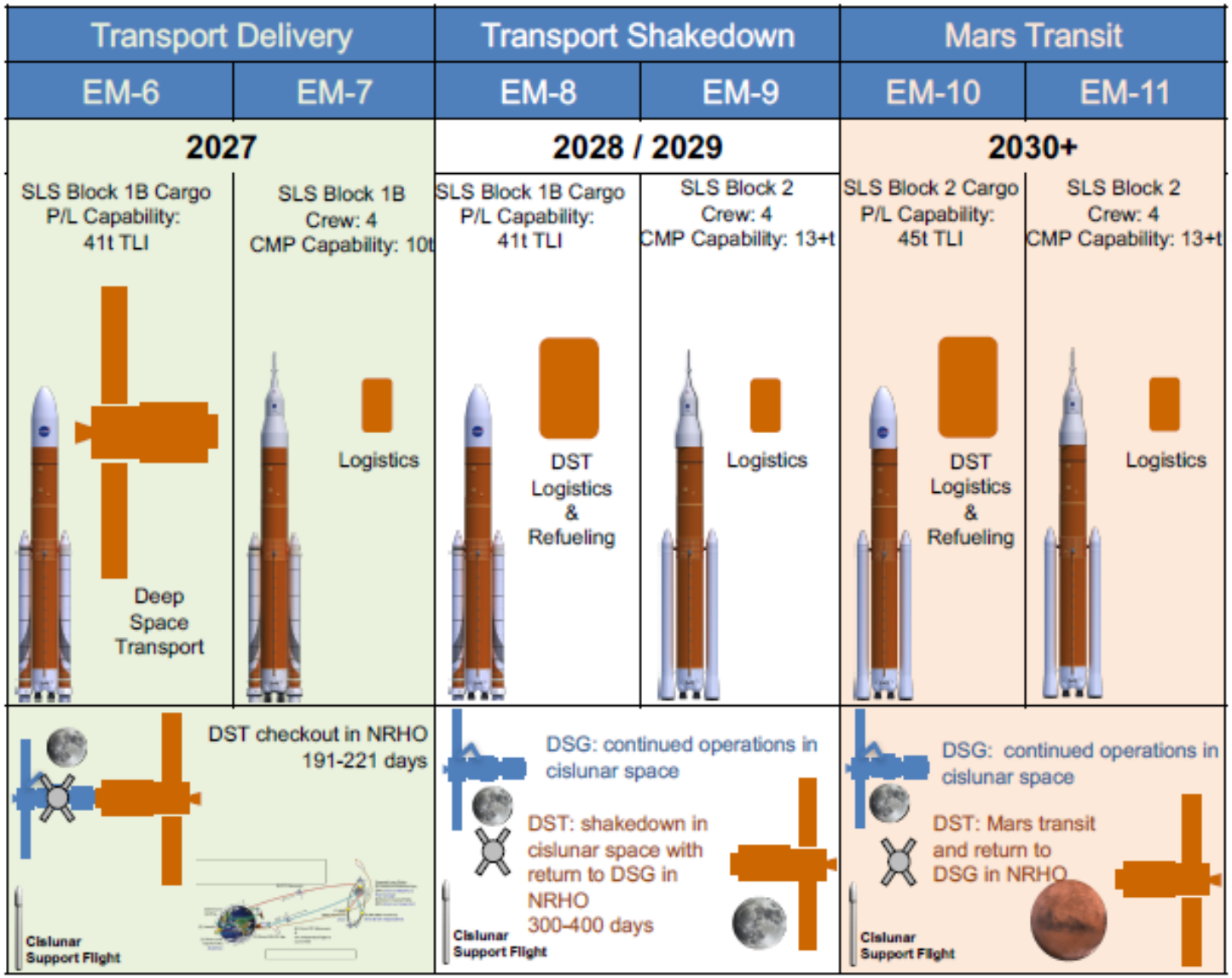
- Gateway to architecture supports Phase 2 and beyond activities
- International and U.S. commercial development of elements and systems
- Gateway will translate uncrewed between cislunar orbits
- Ability to support science objectives in cislunar space

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



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

GER backup

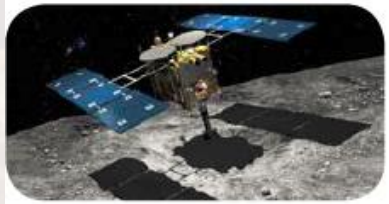
INTERNATIONAL SPACE UNIVERSITY

Detail on GER Goals and Objectives

Common Goals and Objectives

The Global Exploration Roadmap is driven by a set of goals and supporting objectives that reflect commonality while respecting each individual agency's priorities. They demonstrate the rich potential for exploration of each of the target destinations, delivering benefits to people on Earth. The definitions listed below remain largely unchanged and demonstrate the synergy between science and human exploration goals and objectives.

ISS Commander Chris Hadfield communicates the significance of research activities on board the station.



Manufacturing has begun on the JAXA's Hayabusa2 flight article that is scheduled to launch in 2014.

Robo-Ops is an example of how planetary surface exploration challenges engage the minds of students around the world.

ESA's Mars Express image of the Reull Vallis region of Mars, showing a river-like structure that stretches for almost 1,500 km and is believed to have been formed long ago by running water.

Develop Exploration Technologies and Capabilities
Develop the knowledge, capabilities, and infrastructure required to live and work at destinations beyond low-Earth orbit through development and testing of advanced technologies, reliable systems, and efficient operations concepts in an off-Earth environment.

Engage the Public in Exploration
Provide opportunities for the public to engage interactively in space exploration.

Enhance Earth Safety
Enhance the safety of planet Earth by contributing to collaborative pursuit of planetary defense and orbital debris management mechanisms.

Extend Human Presence
Explore a variety of destinations beyond low-Earth orbit with a focus on continually increasing the number of individuals that can be supported at these destinations, the duration of time that individuals can remain at these destinations, and the level of self-sufficiency.

Perform Science to Enable Human Exploration
Reduce the risks and increase the productivity of future missions in our solar system, characterizing the effect of the space environment on human health and exploration systems.

Perform Space, Earth, and Applied Science
Engage in science investigations of, and from, solar system destinations and conduct applied research in the unique environment at solar system destinations.

Search for Life
Determine if life is or was present outside of Earth and understand the environments that support or supported it.

Stimulate Economic Expansion
Support or encourage provision of technology, systems, hardware, and services from commercial entities and create new markets based on space activities that will return economic, technological, and quality-of-life benefits to all humankind.

References

- Progress in Defining the Deep Space Gateway and Transport Plan https://www.nasa.gov/sites/default/files/atoms/files/nss_chart_v23.pdf
- Exploration Architecture Planning https://www.nasa.gov/sites/default/files/atoms/files/march_2017_nac_charts_architecturejmf_rev_3.pdf
- International Space Exploration Coordination Group https://www.globalspaceexploration.org/documents
- KSC Master Plan https://masterplan.ksc.nasa.gov/HTMLAssets/NASAKSCExecSummNew.pdf
- KSC Future Use Plan https://masterplan.ksc.nasa.gov/-/media/Master%20Plan/Future%20Land%20Use%20Map%20Stretched_Final.ashx