

# Human Space Exploration Framework Summary



## ◆ Context and approach for human space exploration

- Key guiding principles
- Figures of Merit

## ◆ Capability-Driven Framework

## ◆ Technology

## ◆ Partnerships

## ◆ Affordability & Cost Analysis

## ◆ Summary

- Key takeaways
- Forward work



- ◆ **Human spaceflight (HSF) programs are complex and can occur on decadal timescales, yet funding is annual and political cycles occur on 2, 4, and 6-year intervals.**
- ◆ **Since 1969, 24 blue-ribbon panels have (re)assessed HSF strategy, and exploration concepts and technologies and national priorities have continued to evolve.**
- ◆ **Planning and program implementation teams established in February 2010, after the FY11 President's Budget Request and the NASA Authorization Act of 2010, needed integrated guidance.**

**NASA uses an ongoing, integrated HSF architecture decision-support function to develop and evaluate viable architecture candidates, inform near-term strategy and budget decisions, and provide analysis continuity over time.**



- ◆ **2009: Review of U.S. HSF Plans Committee [Augustine Committee]**
- ◆ **2010: National Space Policy (28 June 2010)**
- ◆ **2010: NASA Human Exploration Framework Team (HEFT)**
  - Phase 1 (Apr-Aug 2010)
  - Phase 2 (Sep-Dec 2010)
- ◆ **2010: NASA Authorization Act**
  - Long-term goal: “To expand permanent human presence beyond low Earth orbit and to do so, where practical, in a manner involving international partners.”
- ◆ **2011: NASA Human Space Exploration Architecture Planning (ongoing)**



*Review of U.S. Human Space Flight Plans Committee (Augustine Committee) defined “Flexible Path” as:*

*“Steadily advancing...human exploration of space beyond Earth orbit...successively distant or challenging destinations...”*

## Destination options include:

- ◆ Low Earth orbit (LEO) and the International Space Station (ISS)
- ◆ High Earth Orbit (HEO), Geosynchronous Orbit (GEO)
- ◆ Cis-lunar space (Lagrange/Libration points, e.g., L1, L2), lunar orbit, and the surface of the moon
- ◆ Near-Earth asteroids (NEAs), near-Earth objects (NEOs)
- ◆ The moons of Mars (Phobos, Deimos), Mars orbit, surface of Mars

Can multiple paths get us where we want to go?



Can the program keep its basic shape despite unforeseen events?



Can milestones stretch out without the program breaking?



# What is the Human Exploration Framework Team (HEFT)?



- ◆ HEFT provides *decision support* to NASA senior leadership for planning human spaceflight exploration beyond LEO
  
- ◆ *Decision support* informs potential decisions
  - Objective, consistent, credible, and transparent analyses
  
- ◆ **Multi-layered team tapped from throughout NASA**
  - From Strategic Management Council to technical subject matter experts
  - From all centers and headquarters
  
- ◆ **Analysis scope includes all architecture aspects: technical, programmatic, and fiscal**
  - Destinations, operations, elements, performance, technologies, safety, risk, schedule, cost, partnerships, and stakeholder priorities
  
- ◆ HEFT prepares *architecture decision packages* for NASA senior leadership
  - Objective sensitivity analyses, inclusive trade studies, integrated conditional choices
  - Draft multi-destination architectures that are affordable and implement stakeholder priorities
  - Neither “point solution” architectures, decision recommendations, nor decisions



- ◆ **Make affordability a fundamental requirement** that obligates NASA to identify all content/milestones in budget, all content/milestones exceeding the available budget, and all content/milestones that could be gained through budget increases in a prioritized structure. Create and refine a culture of value, fiscal prudence, and prioritization.
- ◆ **Reward value-conscious performance, prudent risk assumption, and bold innovation, and incentivize the executive leadership team** to further create a “can-do” culture of excellence and a team of scientists, engineers, pioneers, explorers, and shrewd mission implementers.
- ◆ **Employ an executive leadership team to seek consensus that is fully empowered,** capable and willing to make decisions in the absence of consensus. Build a culture of empowerment, accountability, and responsibility.
- ◆ **Build on and apply design knowledge** captured through previously planned programs. Also **seek out innovative new processes,** techniques, or world-class best practices to improve the safety, cost, schedule, or performance of existing and planned programs, thereby enhancing their sustainability.
- ◆ **Leverage existing NASA infrastructure** and assets, as appropriate, following a requirements-based need and affordability assessment.

# Human Space Exploration Guiding Principles



- ◆ **Conduct a routine cadence of missions to exciting solar system destinations including the Moon and NEAs with Mars' surface as a horizon destination for human exploration**
- ◆ **Build capabilities that will enable future exploration missions and support the expansion of human activity throughout the inner Solar System**
- ◆ **Inspire through numerous "firsts"**
- ◆ **Fit within projected NASA HSF budget (affordability and sustainability)**
- ◆ **Use and leverage the International Space Station**
- ◆ **Balance high-payoff technology infusion with mission architectures and timeline**
- ◆ **Develop evolutionary family of systems and leverage commonality as appropriate**
- ◆ **Combine use of human and robotic systems**
- ◆ **Exploit synergies between Science and HSF Exploration objectives**
- ◆ **Leverage non-NASA capabilities (e.g., launches, systems, facilities)**
- ◆ **Minimize NASA-unique supply chain and new facility starts**
- ◆ **Pursue "lean" development and operations "best practices"**



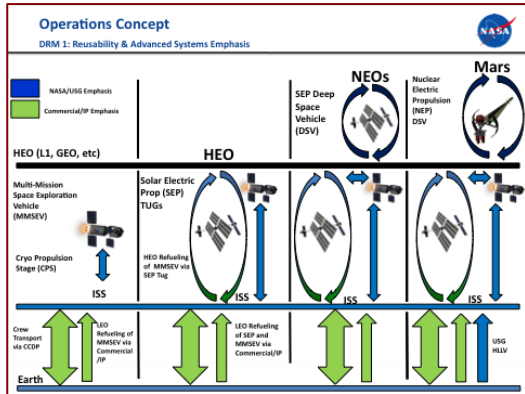
# What Has HEFT Done?



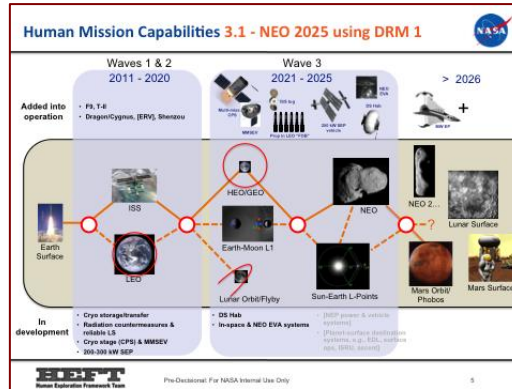
- ◆ **HEFT was chartered in April 2010. The first phase concluded in early September 2010, and the second phase concluded in December 2010.**
- ◆ **HEFT established and exercised a consistent method for asking questions, comparing architecture alternatives, integrating findings and fostering cross-agency discussions.**
- ◆ **HEFT examined a broad trade space of program strategies and technical approaches in an effort to meet priorities from the White House, Congress, and other stakeholders.**
- ◆ **HEFT explored new affordability options and applied a refined cost analysis approach to do relative comparison of alternatives in order to hone and narrow the trade space.**
- ◆ **A smaller HEFT-like effort will continue for the foreseeable future since the HSF technical and programmatic environment will continue to evolve over time.**

**NASA HSF architecture must provide the flexibility to accommodate technical, programmatic, economic and political dynamics while enabling a safe, affordable and sustainable human space exploration program.**

# HEFT Architecture Analysis Cycle Approach (Iterative)



Technical Design Reference Mission

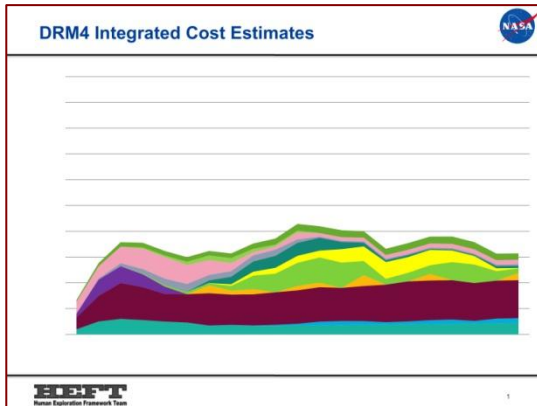


Investment strategy

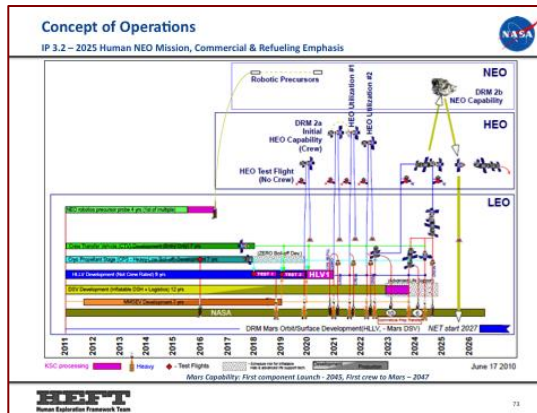
**Capabilities Catalogue**  
In-Space Crew Elements

Capability	Description	Required Technology
MMSEV Multi-Mission Space Exploration Vehicle	The MMSEV is configured as a multi-use habitation system. The MMSEV must provide procedural support and support for orbital habitation for a minimum of 90-day mission and provide an emergency approach at deep space destination. It has the capability to support crew through two sorties and from a crew control guiding system for sample collection and guidance attach to access these samples without EVA.	<ul style="list-style-type: none"> <li>• IEC (G2/G202)</li> <li>• ICA (Growth, suits, etc)</li> <li>• Radiation Protection</li> <li>• Cold Power: 20kW</li> </ul>
DSH Deep Space Habitat	The DSH provides habitation for crew members while in transit to and from NEO. The habitat has conversion adaptors in order to dock with the MMSEV and the propulsion unit. The MMSEV will supply the main EVA operations for the DSH.	<ul style="list-style-type: none"> <li>• Inflatable structures</li> <li>• Power system</li> <li>• Airlocks &amp; software</li> <li>• Thermal solutions</li> <li>• Advanced medical care</li> <li>• Biomedical countermeasures</li> <li>• Environmental monitoring &amp; control</li> <li>• Closed loop ECLSS (95-98% air and water)</li> <li>• Fire prevention, detection, &amp; suppression</li> <li>• Radiation protection</li> </ul>
LM Logistics Module	Similar to an ISS MPLM. Provides storage for DSV.	

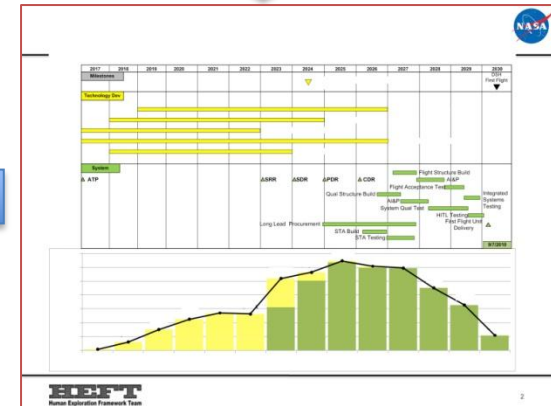
Element catalog



Non-optimized cost rollup through 2025



Integrated program schedule & flight manifest



Schedule and cost to develop and operate each element

Also addressed tech investment priorities & stakeholder concerns, objectives & constraints



- ◆ **No single solution achieved all of the objectives**
  - There is no “magic architectural bullet”
  - Lean system development approaches will be essential
- ◆ **Compromise is key to forward progress and sustainability**
  - Satisfying all major stakeholders, while desirable, is not feasible
- ◆ **A 15-year analysis horizon is too short**
  - Understanding the impacts of a series of exploration missions and the potential value of system reusability requires a longer view
- ◆ **New technologies are required for sustainable human exploration beyond LEO**
  - Key technology investments are applicable to multiple destinations
  - “Technology priority” investment strategy highlighted key technology investment need
- ◆ **Human-rated heavy-lift launch and an exploration-class crew vehicle are desired for human exploration beyond LEO**
  - Initial analysis shows a 100t-class evolvable to about 130t human-rated launch vehicle is best option of those studied (based upon performance, reliability, risk, and cost, but not operations affordability)
  - Needed for planet-surface-class missions and all but nearest deep-space missions
  - Current designs, however, may not be affordable in present fiscal conditions, based on existing cost models, historical data, and traditional acquisition approaches. Affordability initiatives are necessary to enable these and other content needed for exploration
  - Exploration-class heavy lift and crew launch systems dominate the program content and cost profile for years
  - An exploration crew vehicle requires additional capabilities as compared to a LEO-class crew vehicle
  - Staging for deep space missions is best done in HEO at the Earth-Moon Lagrange (L1) point
- ◆ **Some major choices and elements can be delayed or re-phased**
  - Examples: the type of Mars-class propulsion and whether lunar surface operations should precede Mars
  - A flexible path strategy preserves options for future stakeholders

# Early Findings Drove Analysis of Key Issues



## ◆ Launch vehicle options

- Analysis areas included: implications for readiness date, cost risk, alignment with national propulsion objectives, potential development of partnerships, and use of existing NASA expertise, alternatives to Expendable Launch Vehicles (ELVs) alone and propellant depots
- Assessed key trade for heavy lift between affordable DDT&E\* vs. affordable annual cost
- Evaluated cost uncertainty, complexity, and launch rate for commercial propellant launch

## ◆ Crew vehicle options

- Assessed: system options for ascent/descent capsule and destination operations vehicle
- Addressed implications of Orion derivatives and commercial crew launch for exploration
- Analyzed development pace of radiation mitigation, reliable Environmental Control Life and Support System (ECLSS), and deep space habitat system

## ◆ Advanced Propulsion: electric propulsion trip time

- Electric propulsion is key for achieving affordable missions to an asteroid or similar long-range destinations, however there are important considerations for number of units needed vs. time to first asteroid mission
- Electric propulsion can't be used for crew transit through the Van Allen radiation belts and there are also issues associated with long-duration spacecraft operations within the belts

## ◆ Cost profile

- Complete accounting of all elements and reconciliation of assumptions
- Conservative projection of available budget
- Getting through the “budget keyhole” constrained by near-term budget liens

**Affordability is essential; sustainability and flexibility are key drivers for investment in pursuit of inspirational objectives that return true value to the nation and improve life on Earth.**



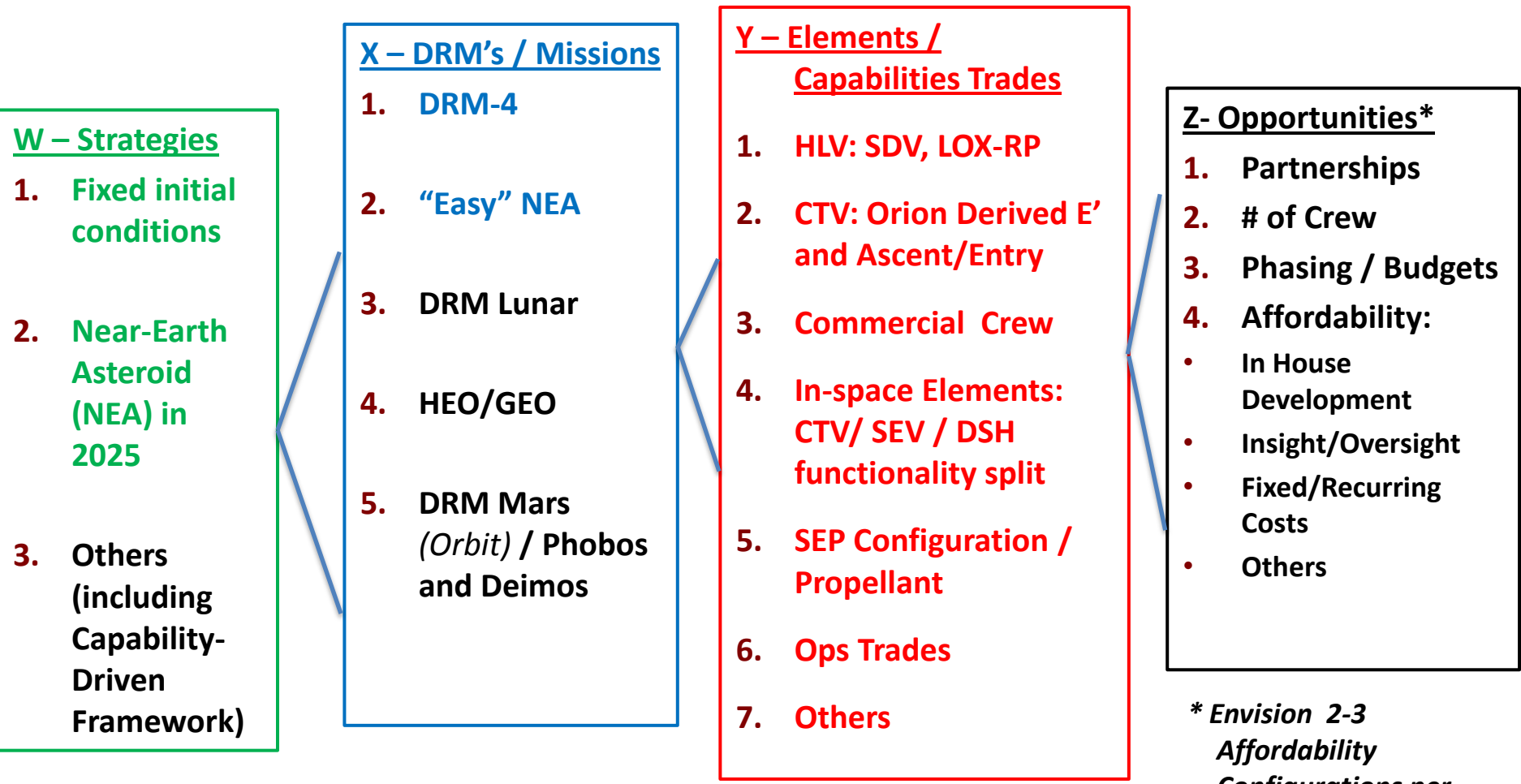
- ◆ **Leverage HEFT’s “analysis engine” to conduct and validate key trades**
  - Elements: heavy-lift launch vehicle (HLLV) options, crew vehicles, in-space systems, ground-based elements
  - Locations: cis-lunar staging; cis-lunar, trans-lunar, and real asteroid targets
  - Alternative providers: critical-path partnerships with other domestic and international agencies, balanced reliance on commercial launches of propellant, in-space elements, and exploration crew
  - Sensitivity analyses to understand impact of varying key assumptions
- ◆ **Use decision trees used to lay out the option space and to drive which branch to analyze; iterate process and identify most fruitful branches**
- ◆ **Define multiple architecture alternatives that “work” based upon key Figures of Merit (mission and stakeholder drivers)**
  - Based on coherent, implementable assumptions and concepts of operation
  - Options that fit the budget and meet stakeholder objectives on acceptable schedules
  - Refine concepts of operations that address the spectrum of operations, including destination operations, aborts, and contingencies





- ◆ **Advanced in-space propulsion (e.g., solar electric propulsion {SEP}) is a big enabler: Reduces launch mass by 50% (factor of 2) and mass growth sensitivity by 60%**
- ◆ **A balance of ELVs and HLLVs is optimal for varying mission needs**
- ◆ **Shuttle-derived HLLV option (100t-class evolvable to ~130t for deep space, full capability missions) meets more current FOMS than other options, although out-year affordability is still a fundamental challenge for long term exploration. Alternative design analysis continues to be part of NASA's strategy, coupled with an assessment of possible affordability initiatives.**
- ◆ **HLLV and crew vehicle should be a human-rated system**
- ◆ **ELV-only solution not optimal given all factors**
- ◆ **Staging at HEO or Earth-Moon L1 for deep space missions better than LEO**
- ◆ **Crew Transportation Vehicle (CTV) full ascent and entry capability is needed**
- ◆ **Additional capability, such as the MMSEV needed for EVA and robotics capability**
- ◆ **High reliability ECLSS is desired over fully closed loop ECLSS except for Mars missions**
- ◆ **In-Situ Resource Utilization (ISRU) is an enabler, particularly for surface missions**
- ◆ **Modularity and commonality aid key affordability FOM**

# General Decision Tree Analysis Approach (Notional)



*W : X : Y : Z – Filtered to control number of cases*

*\* Envision 2-3 Affordability Configurations per Element*






• HLV=Heavy Lift Vehicle  
 • SDV=Shuttle-Derived Vehicle  
 • LOX-RP= Liquid Oxygen-Rocket Propellant (Kerosene)

• CTV=Crew Transportation Vehicle  
 • SEV=Space Exploration Vehicle  
 • DSH=Deep Space Habitat  
 • SEP=Solar Electric Propulsion

# Figures of Merit (FOMs) Areas



- ◆ FOMs are quantitative or qualitative expressions representing the value of a given system. FOMs ensure that each architecture or trade space option is evaluated with the same parameters and they go hand-in-hand with ground rules & assumptions, and help to mature decision options.

FOM Area	Top-Level (Proxy) FOMs
 <p>Affordability</p>	<ul style="list-style-type: none"> <li>• DDT&amp;E cost</li> <li>• Annual recurring cost</li> <li>• Annual savings from affordability strategies</li> <li>• Cost risk</li> </ul>
 <p>Sustainability</p>	<ul style="list-style-type: none"> <li>• Number of key events in the architecture/manifest</li> <li>• Assumed element production &amp; flight rates (min/max)</li> <li>• Number of partner launch opportunities</li> <li>• Number and scope of partner element opportunities</li> <li>• Destinations accessible (with no added DDT&amp;E)</li> <li>• HSF capability sustainment?</li> </ul>
 <p>Safety &amp; Mission Success</p>	<ul style="list-style-type: none"> <li>• Mission probability of loss of crew (LOC)</li> <li>• Mission probability of loss of mission (LOM)</li> </ul>
 <p>Schedule</p>	<ul style="list-style-type: none"> <li>• Crewed U.S. access to LEO and ISS capability date</li> <li>• First beyond LEO mission date</li> <li>• First NEA mission date</li> </ul>
 <p>Benefits</p>	<ul style="list-style-type: none"> <li>• Number of destinations visited by type</li> <li>• Percentage of NEA population accessible</li> <li>• Mass delivered /returned</li> <li>• Crewed days beyond LEO</li> <li>• Percentage of Mars technologies demonstrated</li> <li>• Alternate destinations accessible (with added DDT&amp;E)</li> </ul>

Inspiration for current and future generations remains an important intangible FOM.

# Strategies and Design Reference Missions (DRMs)



◆ **Four different strategies were developed in the HEFT Phase 2 Architecture Analysis Cycle.**

- Strategies 1, 1' and 2: Built an integrated manifest with the respective element schedule and cost data
- Strategy 3: Capability Driven Framework not manifested in HEFT 2 [Early Forward Work in Jan 2011]

Strategy	Description	DRM	Simple Result Description
<b>1 – Fixed Initial Conditions: Mission to a NEA when Affordable</b>	A fixed cost and initial milestone-constrained assessment, consistent with the NASA 2010 Authorization for the DRM 4B ( <i>NEA mission</i> ) only. Manifest changed to incorporate HLLV test flight. Utilized updated design & cost estimates, that include some lean development options	4B	Over-constrained. Does not meet all schedule, budget, and performance requirements. Results heavily dependent upon budget availability and phasing.
<b>1 Prime – Affordability Centric</b>	Same as Strategy 1. Combines Expendable Launch Vehicles flights into an HLLV flight. Utilized updated design and cost estimates that include some lean development options	4B	Small improvement, but still didn't close on budget in out-years. Key insights into necessary affordability measures.
<b>2 – NEA by 2025</b>	Deadline and cost-constrained assessment to reach a NEA by 2025 utilizing a “minimal” set of systems/elements and an “easy” target	5B	Not prudent: Sprint with minimum capability mission to asteroid too costly for sustained benefit/ROI.
<b>3 – Capability-Driven Framework</b>	Journey, not destination. Builds capabilities that enable many potential paths w/DRMs to GEO, L1/2, Lunar, NEA< Mars Orbits/Moons	Multiple	Departure from long-standing destination-focused approach – <b>Best path given constraints.</b>

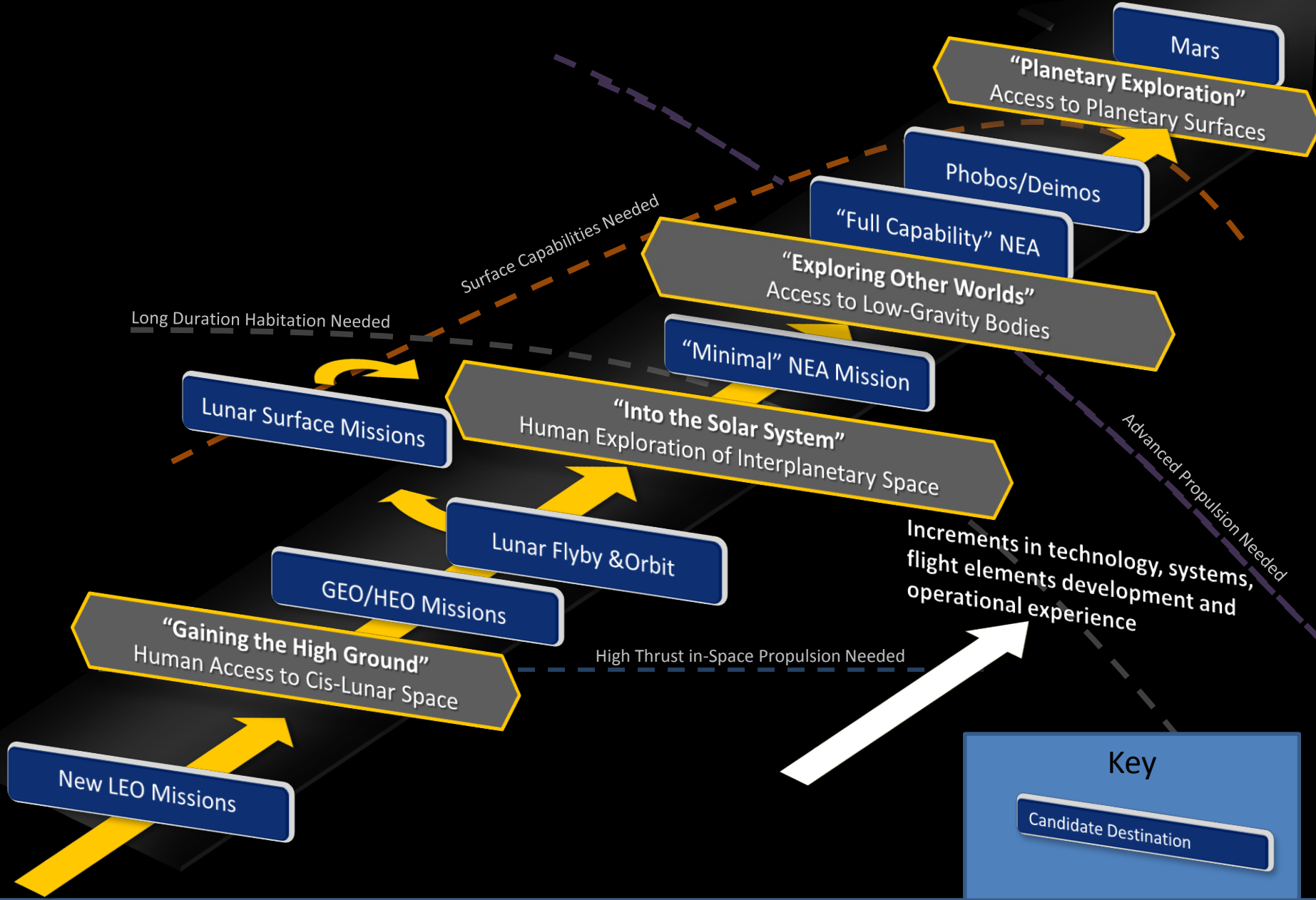


- ◆ **Objective: Facilitates a capability-driven approach to human exploration rather than one based on a specific destination and schedule**
- ◆ **Evolving capabilities would be based on:**
  - Previously demonstrated capabilities and operational experience
  - New technologies, systems and flight elements development
  - Concept of minimizing destination-specific developments
- ◆ **Multiple possible destinations/missions would be enabled by each discrete level of capability**
- ◆ **Would allow reprioritization of destination/missions by policy-makers without wholesale abandonment of then-existing exploration architecture**

**A Capability-Driven Framework enables multiple destinations and provides increased flexibility, greater cost effectiveness, and sustainability.**



# Notional Incremental Expansion of Human Space Exploration Capabilities



# Capability-Driven Framework Approach



- ◆ **Establish “Mission Space” defined by multiple possible destinations**
  - Define Design Reference Missions to drive out required functions and capabilities
- ◆ **Utilize common elements across all DRMs**
  - Size element functionality and performance to support entire mission space
  - Common element and DRM analyses still in work, appears feasible
- ◆ **Assess key contingencies and abort scenarios to drive out and allocate any additional key capabilities to element(s)**
  - Iterate element sizing and functionality to ensure key contingency and abort scenarios are addressed
- ◆ **Establish key driving requirements for common elements**
  - Establish technology needs for each element
- ◆ **Identify key decision points for element/capability phasing**
  - Decision trees/paths for transportation architecture and destination architecture
- ◆ **Assess various manifest scenarios for costing and other constraint analysis**
  - Select various strategies for acquisition approach and affordability
- ◆ **Actively seek international and commercial involvement where possible**

**Costing not completed, additional work required to complete integration of Capability-Driven Framework assessment**

# Example DRM Mission Space to Common Element Mapping



DRM TITLE	MINIMUM ELEMENTS									
	Commercial LV	SLS - HLLV	MPCV	CPS	REM/SEV	EVA Suit	Lunar Lander & Elements	DSH	SEP	Mars Elements
LEO missions	R	B	B			R				
HEO/GEO vicinity without pre-deploy		D	D	D	D	R				
HEO/GEO vicinity with pre-deploy	R	R	R	R	D	R				
Lunar vicinity missions		R	R	R		R				
Low lunar orbital mission		R	R	R		R				
Lunar surface mission		R	R	D		D	D			
Minimum capability NEA		R	R*	D	D	R		R		
Full capability NEA		D	D*	D	D	D		D	D	
Martian moons: Phobos/Deimos		R	R*	R		D		R	R	
Mars landing		D	R*	R		D		R	D	D

\* MPCV entry velocity could be driven by these missions for certain targets, if selected.

<b>D</b>	<b>Driving Case</b>
<b>R</b>	<b>Required Elements</b>
<b>B</b>	<b>Back-Up Capability</b>

D/R/B Element allocations based on Authorization Act and other conditions. Different constraint basis would result in different element allocations/options.

**Driving:** There is something in this DRM that is "driving" the performance requirement of the element.  
*Example : Entry speeds for MPCV driven by NEO DRM.*

**Required:** This element must be present to accomplish this DRM.  
*Example : SEV required for Full Capability NEO, but not for other DRMs*

Flexible mission space analysis validates that several fundamental building blocks, including the SLS and MPCV, are needed to support multiple destinations.

- LV=Launch Vehicle
- SLS=Space Launch System
- MPCV=Multi-person Crew Vehicle
- CPS=Cryogenic Propulsion Stage

- REM=Robotics & EVA Module
- EVA=Extravehicular Activity
- DSH=Deep Space Hab
- SEP=Solar Electric Propulsion

# INCREMENTAL EXPANSION OF HUMAN EXPLORATION CAPABILITIES

Capabilities required at each destination are determined by the mission and packaged into elements. Capability-Driven Framework approach seeks to package these capabilities into a logical progression of common elements to minimize DDT&E and embrace incremental development.

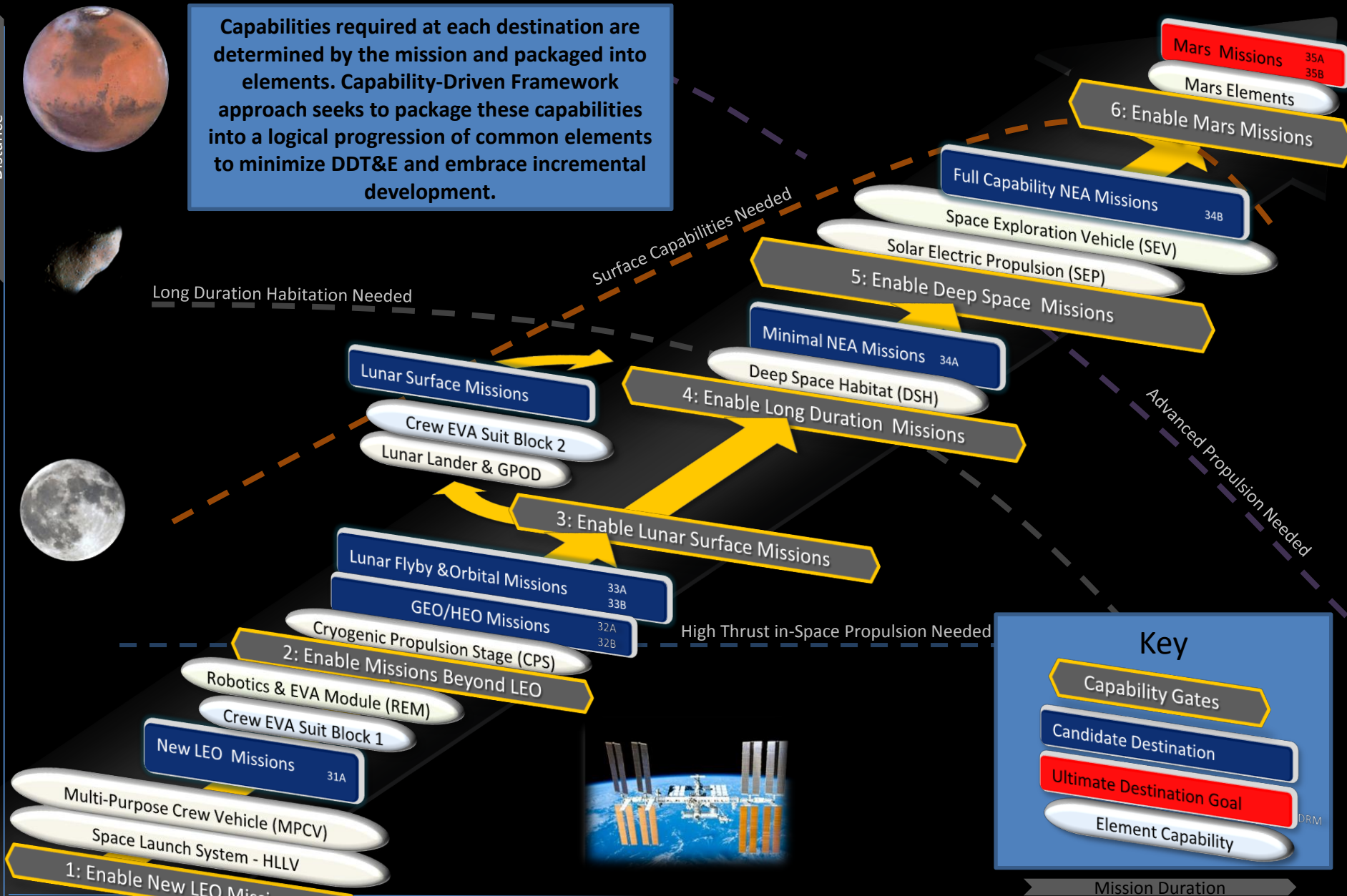
Distance

Long Duration Habitation Needed

Surface Capabilities Needed

Advanced Propulsion Needed

High Thrust in-Space Propulsion Needed

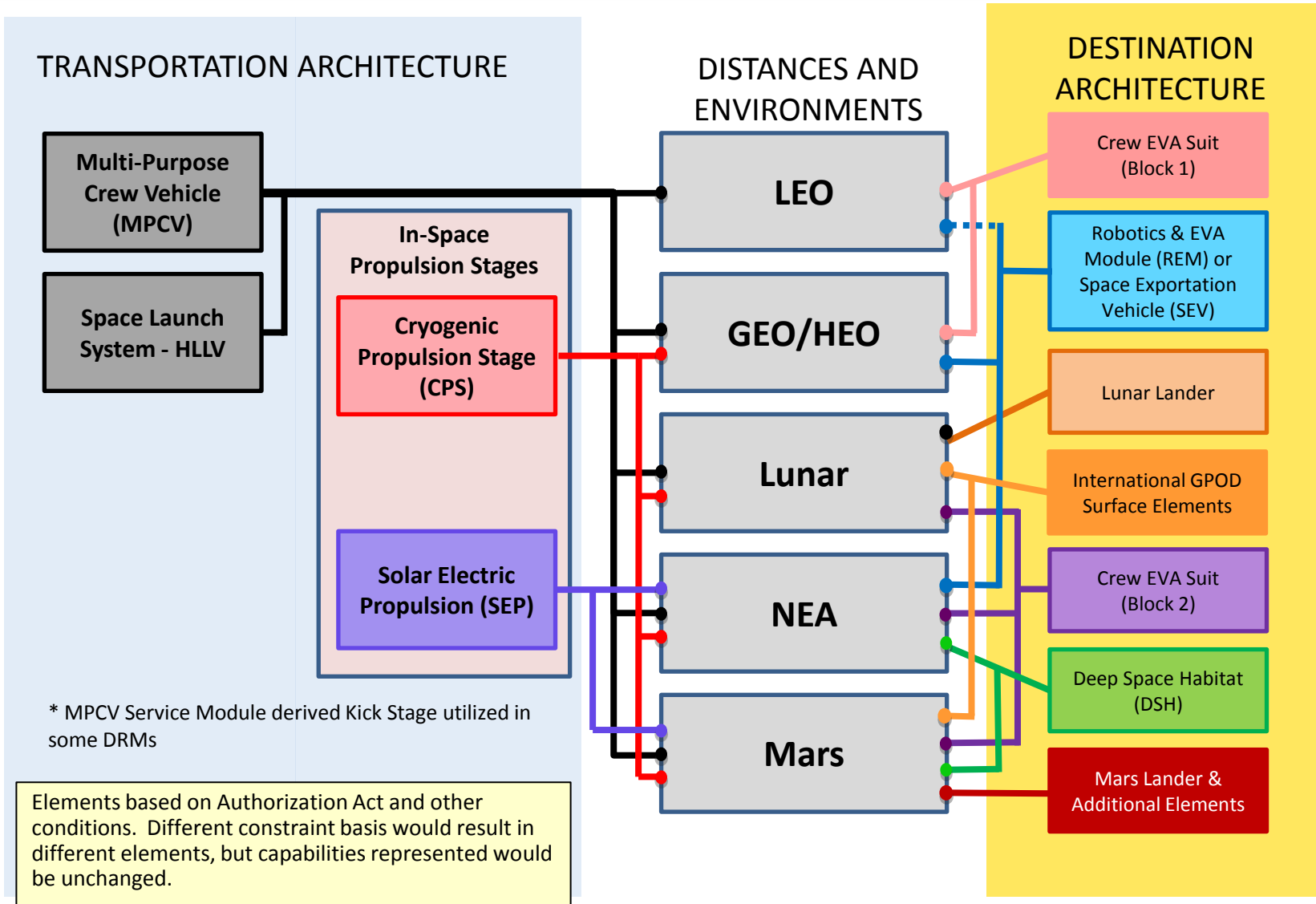


### Key

- Capability Gates
- Candidate Destination
- Ultimate Destination Goal
- Element Capability



# Transportation and Destination Architectures for Flexible Path

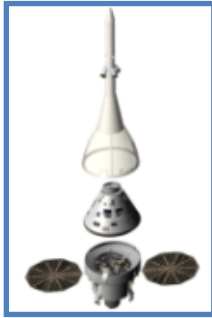




# Notional Architecture Elements



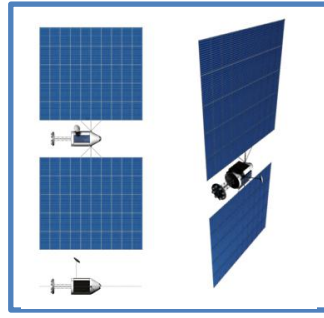
Space Launch System (SLS)-HLLV



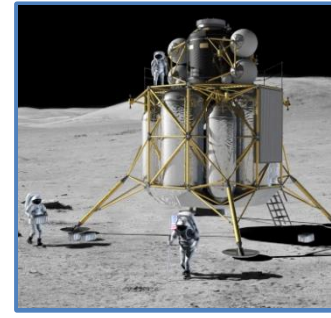
Multi-purpose Crew Vehicle (MPCV)



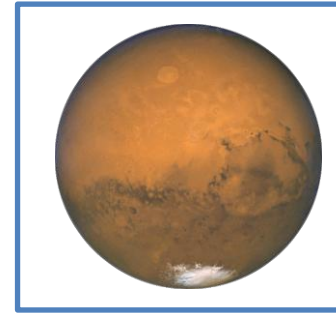
Cryogenic Propulsion Stage (CPS)



Solar Electric Propulsion (SEP)



Lander

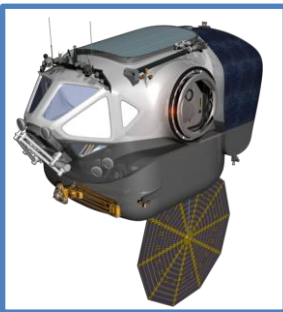


Mars Elements

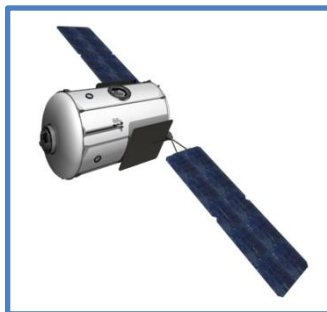
Graphics are Notional Only – Design and Analysis On-going



EVA Suit



Multi-Mission Space Exploration Vehicle (MMSEV)



Deep Space Habitat (DSH)



Robotics & EVA Module (REM)



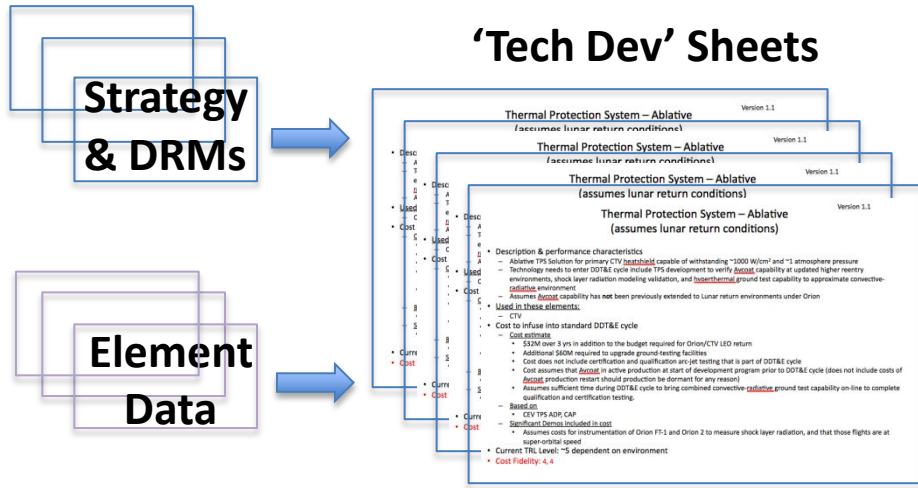
Kick Stage



NEA Science Package



## 'Tech Dev' Summary Spreadsheet (per Strategy/DRM)



Initial Look: Technology Applicability by Destination

Destination	AS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	OS (14)	
LO2/LHD reduced boiloff (Hydrome (PFD) Cycle)																		
LO2/LHD reduced boiloff (Other CPS) development																		
LO2/LHD zero boiloff development																		
Subsea Ops Propulsion																		
Energy Storage																		
Electronics for Life Support (part of Energy Storage)																		
Fire Protection, Detection & Suppression (No EMI)																		
Environmental Monitoring and Control																		
High Reliability Life Support Systems																		
Class-1000, High Reliability, Life Support Systems																		
Proximity Communications																		
In-Space Timing and Navigation for Autonomy																		
High Data Rate Forward Link (Orb & High)																		
Hybrid AV Control Terminal (Comm)																		
Collocated Health																		
Collocated Biologic Countermeasures Hardware																		
Human Factors and Habitability																		
Long Duration Habitat																		
Biomedical Support Systems																		
Space Radiation Protection - Detailed Gamma Rays (OCR)																		
Space Radiation Protection - Neutron Proton Source (OCR)																		
Space Radiation Shielding - OCR & SFR																		
Vehicle Autonomy																		
Mission Control Autonomy																		
Common Avionics																		
Advanced Software Development/Tools																		
Thermal Management (Available Heat Sink)																		
High Reliability for Long Duration, Deep Space Missions																		
Lightweight Structures and Materials (MLU)																		
Lightweight Structures and Materials (In-Space Repair)																		

Legend: Not applicable (White), Probably required (Yellow), Required Technology (Green), Use Only (Dark Green)

HEFT Human Exploration Framework Team

**Subject Matter Expert POCs**

### Cost Fidelity

Cost Fidelity Matrix

How well is the plan defined in the project plan?	1	2	3	4	5	6
How well is the plan defined in the project plan?	5	4	3	2	1	0
How well is the plan defined in the project plan?	4	3	2	1	0	0
How well is the plan defined in the project plan?	3	2	1	0	0	0
How well is the plan defined in the project plan?	2	1	0	0	0	0
How well is the plan defined in the project plan?	1	0	0	0	0	0
How well is the plan defined in the project plan?	0	0	0	0	0	0
How well is the plan defined in the project plan?	0	0	0	0	0	0
How well is the plan defined in the project plan?	0	0	0	0	0	0
How well is the plan defined in the project plan?	0	0	0	0	0	0

Legend: High Fidelity (Green), Medium (Yellow), Low Fidelity (Red)

**Tech Dev Data for Cost Team:**

- Cost, Schedule, Phasing
- Applicable Elements (per Strat/DRM)

# Technology Applicability to Destination Overview (1)



	LEO (31A)	Adv. LEO (31B)	Cis-Lunar (32A,B & 33A,B)	Lunar Surface - Sortie (33C)	Lunar Surface - GPOD (33X)	Min NEA (34A)	Full NEA (34B)	Mars Orbit	Mars Moons (35A)	Mars Surface (35B)
LO2/LH2 reduced boiloff flight demo			Yellow	Green	Green	Green	Green	Green	Green	Green
LO2/LH2 reduced boiloff & other CPS tech development			Yellow	Green	Green	Green	Green	Green	Green	Green
LO2/LH2 Zero boiloff tech development					Yellow	Yellow	Yellow	Light Green	Light Green	Light Green
In-Space Cryo Prop Transfer										
Energy Storage	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Electrolysis for Life Support (part of Energy Storage)										
Fire Prevention, Detection & Suppression (for 8 psi)		Yellow	Yellow	Green	Green	Green	Green	Green	Green	Green
Environmental Monitoring and Control		Yellow	Yellow		Green	Green	Green	Green	Green	Green
High Reliability Life Support Systems					Green	Green	Green	Green	Green	Green
Closed-Loop, High Reliability, Life Support Systems					Light Green	Yellow	Yellow	Light Green	Light Green	Light Green
Proximity Communications			Light Green	Green	Green	Green	Green	Light Green	Light Green	Light Green
In-Space Timing and Navigation for Autonomy			Light Green	Green	Green	Green	Green	Light Green	Light Green	Light Green
High Data Rate Forward Link (Ground & Flight)			Yellow	Yellow	Yellow	Green	Green	Green	Green	Green
Hybrid RF/Optical Terminal (Communications)										
Behavioral Health					Green	Green	Green	Green	Green	Green
Optimized Exercise Countermeasures Hardware					Green	Green	Green	Green	Green	Green
Human Factors and Habitability	Light Green	Light Green	Green	Green	Green	Green	Green	Green	Green	Green
Long Duration Medical			Yellow	Green	Green	Green	Green	Green	Green	Green
Biomedical countermeasures					Green	Green	Green	Green	Green	Green
Space Radiation Protection – Galactic Cosmic Rays (GCR)					Green	Green	Green	Green	Green	Green
Space Radiation Protection – Solar Proton Events (SPE)	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Space Radiation Shielding – GCR & SPE			Green	Green	Green	Green	Green	Green	Green	Green
Vehicle Systems Mgmt		Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green
Crew Autonomy										
Mission Control Autonomy		Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green
Common Avionics	Yellow	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green
Advanced Software Development/Tools					Green	Yellow	Yellow	Green	Green	Green
Thermal Management (e.g., Fusible Heat Sinks)					Green	Green	Green	Green	Green	Green
Mechanisms for Long Duration, Deep Space Missions					Green	Green	Green	Green	Green	Green
Lightweight Structures and Materials (HLLV)					Yellow	Yellow	Yellow	Green	Green	Green
Lightweight Structures and Materials (In-Space Elements)					Yellow	Yellow	Yellow	Green	Green	Green

Not applicable	Probably required
May be required	Required technology

# Technology Applicability to Destination Overview (2)



	LEO (31A)	Adv. LEO (31B)	Cis-Lunar (32A,B & 33A,B)	Lunar Surface - Sortie (33C)	Lunar Surface - GPOD (33X)	Min NEA (34A)	Full NEA (34B)	Mars Orbit	Mars Moons (35A)	Mars Surface (35B)
Robots Working Side-by-Side with Suited Crew		Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green
Telerobotic control of robotic systems with time delay										
Surface Mobility				Light Green	Light Green					
Suitport		Yellow	Yellow	Light Green	Light Green		Light Green		Light Green	Light Green
Deep Space Suit (Block 1)		Green	Green			Light Green	Light Green	Yellow	Light Green	
Surface Space Suit (Block 2)				Light Green	Light Green					Light Green
NEA Surface Ops (related to EVA)							Light Green		Light Green	
Environment Mitigation (e.g., dust)				Light Green	Light Green	Light Green	Light Green		Light Green	Light Green
Autonomously Deployable very large Solar Arrays							Light Green	Light Green	Light Green	Light Green
SEP demo				Light Green			Light Green	Light Green	Light Green	Light Green
Solar Electric Propulsion (SEP) Stage		Not applicable	Probably required	Light Green			Light Green	Light Green	Light Green	Light Green
Fission Power for Nuclear Electric Propulsion (NEP)		May be required	Required technology	Light Green				Light Green	Light Green	Light Green
Nuclear Thermal Propulsion (NTP) Engine		Yellow	Required technology	Light Green				Light Green	Light Green	Light Green
Fission Power for Surface Missions					Yellow					Light Green
Inflatable Habitat Flight Demo (flight demo launch)								Light Green	Light Green	Light Green
Inflatable Habitat Tech Development (including demo)								Light Green	Light Green	Light Green
In-Situ Resource Utilization (ISRU)					Light Green					Light Green
TPS -- low speed (<11.5 km/sec; Avcoat)			Green	Green	Green	Green	Green	Green	Green	Green
Thermal Protection System (TPS) -- high speed						Yellow	Yellow	Light Green	Light Green	Light Green
NEA Auto Rendezvous, Prox Ops, and Terrain Relative Nav				Light Green	Light Green	Light Green	Light Green		Light Green	Light Green
Precision Landing				Light Green	Light Green					Light Green
Entry, Decent, and Landing (EDL)						Yellow	Yellow	Light Green	Light Green	Light Green
Supportability and Logistics								Yellow	Yellow	Light Green
LOX/Methane RCS					Yellow					Light Green
LOX/Methane Propulsion Stage - Pressure Fed				Yellow	Yellow					Light Green
LOX/Methane Propulsion Stage - Pump Fed				Yellow	Yellow					Light Green
In-Space Chemical (Non-Toxic Reaction Control System)						Yellow	Yellow		Yellow	
HLLV Oxygen-Rich Staged Combustion Engine	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow



- ◆ **The Capability-Driven Framework (CDF) offers an opportunity for a more complete look at technology needs over a longer span of time. It has the inherent benefit of not stranding technologies that result from only considering a single destination.**
  
- ◆ **Technology investment:**
  - Total amount will depend on the set of DRMs that are chosen
  - We will attempt to follow the structure that the DRM team has been using to build the decision framework
  - Many of the DRMs represent new discussion and so will require more work to understand what kind of technology advancement is required
  
- ◆ **Some technologies are likely to be required to enable the full set of DRMs in CDF (i.e., environment [e.g., dust] mitigation, supportability & logistics, communication technologies)**



- ◆ **More forward work is required for the HEFT Technology Team to align with other technology investments**
  - Need Crossflow with DoD/DARPA technology investments (tied to NASA strategies)
- ◆ **Total cost for exploration-focused technology development investments are \$0.5-1B per year -- a relatively small portion of the total life cycle costs**
- ◆ **Majority of needed technologies can be matured in 3 to 8 years; some key Mars technologies require longer lead time**
- ◆ **Wide range of areas require technology maturation, but most specific technology needs require less than \$500M to mature**
- ◆ **Some technologies are likely required to enable the full set of DRMs in the Capability-Driven Framework**
- ◆ **DRMs that only consider one mission/destination create an incomplete picture of agency technology needs**
- ◆ **Exploration (ETDD & HRP) programs are well aligned with HEFT direction**

# Capabilities, Technology and Partnerships



## ◆ DRM-Element matrices represent sets of functional capabilities and technologies packaged into specific elements

- There are many examples of potential common capabilities or technologies that apply across multiple elements
- Detailed capability identification enables discussion on several topics

Example DRM Mission Space to Common Element Mapping

DRM TITLE	Component/OP	MINI/NASA SUBSYSTEMS												
		SIS/IMV	IMV	CRM	IMV/IMV	IMV/IMV	IMV/IMV	IMV/IMV	IMV/IMV	IMV/IMV	IMV/IMV			
ISD Mission		X	X	X	X									
ISD Ops (Vehicle Without Propulsion)		X	X	X	X	X								
ISD Ops (Vehicle With Propulsion)		X	X	X	X	X	X							
Surface-based Mission		X	X	X	X	X	X							
Orbiter-based Mission		X	X	X	X	X	X	X						
Surface-based Mission		X	X	X	X	X	X	X						
Orbiter-based Mission		X	X	X	X	X	X	X	X					
Full Capability ISD - DRM/IS		X	X	X	X	X	X	X	X					
Full Capability ISD - DRM/IS		X	X	X	X	X	X	X	X					
Full Capability ISD - DRM/IS		X	X	X	X	X	X	X	X					
Full Capability ISD - DRM/IS		X	X	X	X	X	X	X	X					

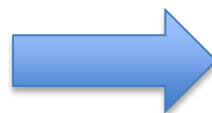
Legend:   
X Required Core   
X Required Demands

DRM Element allocations based on Authorization Act and other conditions. Different conditions based on different element in conditions and options.

\* MPCV Body (Vehicle) could be driven by other means for certain targets (if enabled).

Flexible Mission space analysis validates SLS and MPCV fundamental building blocks as sound basis to support multiple destinations.

ESPT - Sensitive But Unclassified (SBU); NASA Internal Use Only



Initial Look: Technology Applicability by Destination

	ASU	ISD	ORION	SLS	MPCV	ISL	ORION	SLS	MPCV	ISL	ORION	SLS	MPCV	ISL	ORION	SLS	MPCV	ISL	
Destination																			
ISD Mission																			
ISD Ops (Vehicle Without Propulsion)																			
ISD Ops (Vehicle With Propulsion)																			
Surface-based Mission																			
Orbiter-based Mission																			
Surface-based Mission																			
Orbiter-based Mission																			
Full Capability ISD - DRM/IS																			
Full Capability ISD - DRM/IS																			
Full Capability ISD - DRM/IS																			
Full Capability ISD - DRM/IS																			

Legend:   
■ Not required   
■ Potentially required   
■ Required Technology

ESPT - Sensitive But Unclassified (SBU); NASA Internal Use Only

## ◆ DRM-Element matrices being extended to additional detail to identify specific capabilities and technologies to drive out technology roadmap, potential common capabilities and partnership opportunities





## ◆ Definition:

- A partnership is an agreement between NASA and one or more entities that provides tangible benefit and shares cost, equity, and/or risk between all parties.
  - For international partners this should be done on a no-exchange of funds basis

## ◆ National Space Policy mandates that NASA:

- “Expand international cooperation”
- “Energize competitive domestic industries”
- “Strengthen inter-agency partnerships”

## ◆ Potential benefits to NASA and/or the Nation

- Economic incentive (expansion, prosperity, innovation)
- Enhancement through foreign technology and ideas
- Enabling new domestic industries
- Promotion of foreign policy interests
- Affordability
  - Able to achieve missions that would otherwise be unaffordable
- Sustainability
- Schedule acceleration
- Ensuring domestic space industrial base viability
- Avoiding domestic capital investments which are significant and sustained
- Multiple users – spreads cost base



## ◆ Partnerships = International, Interagency, Commercial

## ◆ The Capability-Driven Framework enables on-ramps for:

- Partnerships that **Expand** the architecture
  - Characterized by adding elements and functional capabilities to the architecture that would not be otherwise funded for development, thus enabling missions that otherwise would not be possible
- Partnerships that **Enable** the architecture
  - Characterized by partners that develop elements that enable missions sooner than could otherwise be accomplished
- Partnerships that **Enhance** the architecture
  - Characterized by partners developing technologies or systems that enhance the existing or planned element capabilities within the architecture

# International, Interagency, and Commercial Partnerships



- ◆ **Interagency** partnership opportunities: DoD/IC, FAA, DOE, NSF, DHS, NIST
- ◆ **DoD/IC promising potential partnership areas:** In-space propulsion (Solar Electric Propulsion), range modernization, Technologies, Industrial base, Landing, recovery, and medical operations support, communications
- ◆ **Commercial** partnerships: “Traditional,” Entrepreneurial, and “Non-Traditional”
- ◆ **Key Areas of Potential Interest:** Cargo and crew transportation, in-space habitation, communications, in-situ resource utilization, propellant transfer, storage, and re-supply

• DoD=Department of Defense  
• IC=Intelligence Community  
• FAA=Federal Aviation Administration  
• DOE=Department of Energy

• NSF=National Science Foundation  
• DHS=Department of Homeland Security  
• NIST=National Institute for Standards and Technology

# Affordability - Most Significant Challenge Moving Forward



- ◆ **Affordability: The ability of NASA to safely execute missions within the available funding constraints (long term and short term).**
  - Program/Project Management, Risk Management Culture, Systems Engineering, Workforce/Infrastructure, Acquisition Approaches
- ◆ **Opportunities to address affordability in program/project formulation and planning**
  - Levy lean development approaches and “design-to-cost” targets on implementing programs
  - Identify and negotiate international partner contributions
  - Identify and pursue domestic partnerships
- ◆ **Traditional development**
  - Balance large traditional contracting practices with fixed-price or cost challenges coupled with in-house development
  - Use the existing workforce, infrastructure, and contracts where possible; address insight/oversight, fixed-costs, cost analysis and cost estimation
- ◆ **Adopt alternative development approaches**
  - Leverage civil servant workforce to do leading-edge development work
  - Attempt to minimize use of NASA-unique infrastructure, seeking instead to share infrastructure costs where feasible.
  - Specifically, take advantage of existing resources to initiate the development and help reduce upfront costs on the following elements: Multi-Mission Space Exploration Vehicle, Solar Electric Propulsion Freighter, Cryo Propulsion Stage, Deep Space Habitat

**In order to close on affordability and shorten the development cycle, NASA must change its traditional approach to human space systems acquisition and development.**



## ◆ **Affordability meetings with industry**

- Received input from NASA contractors on how to reduce costs, maintain quality/performance, and improve our affordability

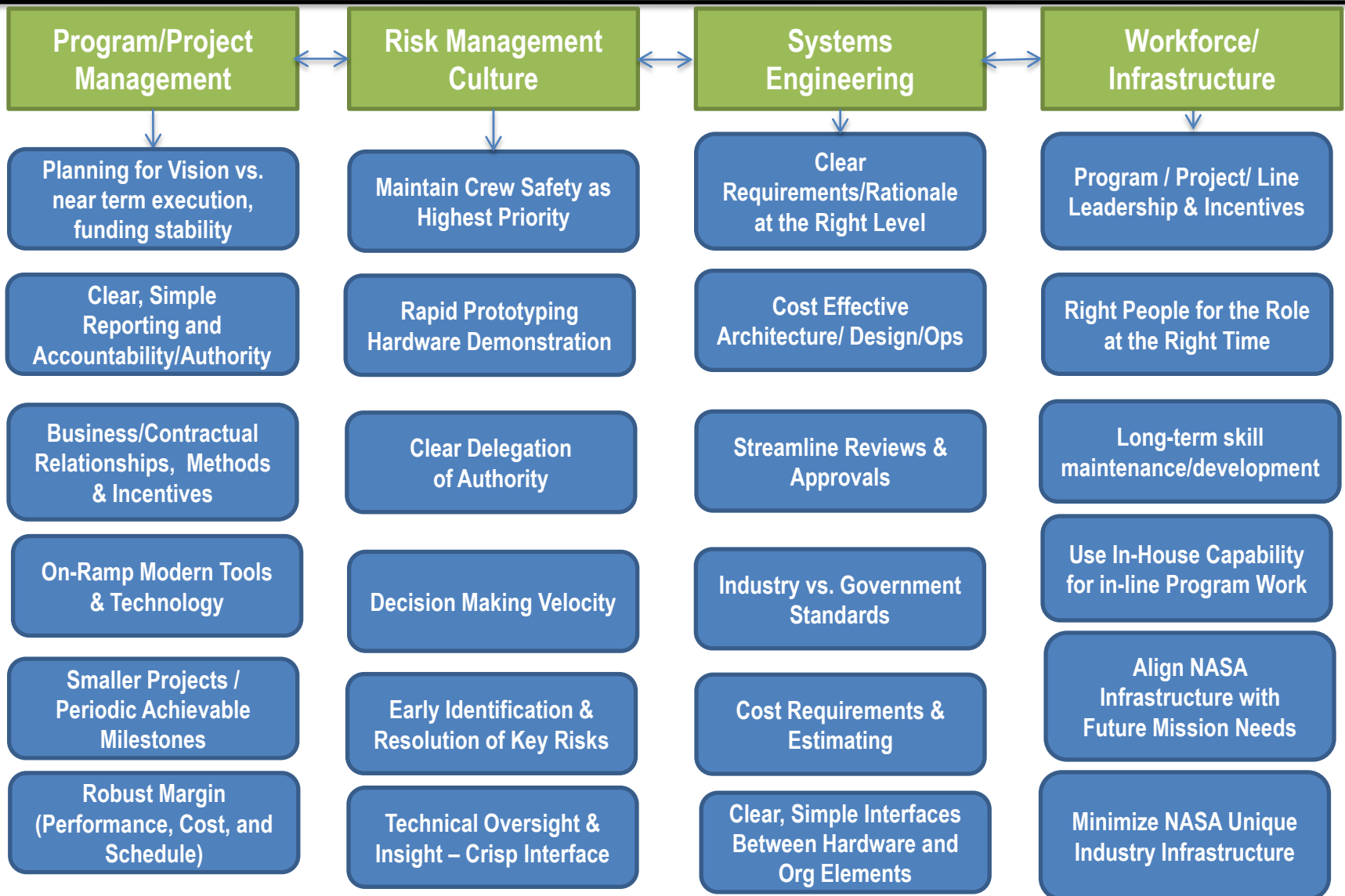
## ◆ **Affordability practices summit (Federal Government only)**

- Explored concepts and processes that will increase program affordability

## ◆ **Near-term strategies for affordability “Blue Sky” meetings in D.C.**

- Brainstormed concepts to enable affordable, near-term missions; topics include utilizing ISS to support exploration, and concepts for near-term flight demonstrations

# Elements of Affordability





## ◆ HEFT Affordability Team requested industry input

- Approaches for more cost-effective development and operation of human spaceflight missions
- Priority must be maintaining safety
- Opportunity to provide input advertised openly through NASA Acquisition Internet Service (NAIS)

## ◆ Submissions were received and if requested, meetings were held with industry to discuss their input

## ◆ Submissions were received from:

- ATK, Ball, Blue Origin, Dynetics, SpaceX, Hamilton Sundstrand, Honeywell, Georgia Tech, Paragon, L3 Communications, Space Partnership International, Valador, Lockheed Martin, KT Engineering, Boeing, Pratt and Whitney Rocketdyne, Orbitec, Northrop Grumman, United Launch Alliance, Florida Turbine Technologies, Johns Hopkins University Applied Physics Lab, RAND, Space Partnership, and United Space Alliance





## ◆ Key tenets and recurring themes identified in industry submissions:

- Systems engineering is more than requirements tracking and documents
- Model, test and fly early and often
- Use small lean projects with highly competent empowered personnel
- Push decision authority to the lowest level. Trust them to implement and don't second guess (over-manage)
- Maintain aggressive schedules
- Manage cost and schedule as well as technical performance (maybe even more so)
- Keep it simple
- Dramatically minimize fixed costs (the key driver of mission cost)
- Oversight/Insight model has to change

**Focused, Realistic and Stable Requirements + Capable, Connected and Incentivized  
Lean Teams + Short Schedules = Low cost**

# Key Cost and Budget Analysis Overview



- ◆ **Innovative cost analysis approach enables significant insight into programmatic issues, thereby allowing us to address issues and develop solutions**
- ◆ **Authorization Act-driven HSF architecture does not yet close on budget and schedule**
  - The “big four” elements (SLS, MPCV, Commercial/Crew, Technology) comprise the majority of the budget
- ◆ **To close on affordability, the agency consensus is to:**
  - Embrace the Capability-Driven Framework with a “go-as-you-pay” approach
  - Maintain the “big four” and set challenging cost targets to fit within the available budget
    - Requires forward analysis with a resolved budget
  - Pursue agency transformation and aggressively implement applicable affordability practices
  - Vigorously pursue partnerships as part of the solution
  - Leverage innovative “NASAworks,” lean development, and other infrastructure/workforce efficiency measures in order to further improve our affordability posture

**A Capability-Driven Framework allows NASA to increment or decrement prioritized investments based upon direction and available budget.**



- ◆ **The Capability-Driven Framework:**
  - Is the most viable approach given the cost, technical and political constraints
  - Provides a foundation for the agency's needed technology investments
  - Enables common elements to support multiple destinations
  - Provides flexibility, greater cost-effectiveness and easy integration of partnerships
- ◆ **NASA-wide transformational change is required to significantly improve affordability and meet budget constraints**
- ◆ **Beyond LEO destinations require:**
  - Development of a HLLV and MPCV as the key core elements
  - An investment in advanced space propulsion and long-duration habitation (including high-reliability ECLSS and radiation protection)
  - Robotic precursors for human near-Earth asteroid mission
- ◆ **Authorization Act-driven HSF architecture still presents a fundamental forward challenge to close on budget and schedule**
- ◆ **Partnerships are imperative to enabling our exploration goals**
- ◆ **Compelling, overarching mission goals are necessary to justify high-risk human spaceflight exploration beyond LEO**



## ◆ **Continue Development of Capability Driven Framework**

- Continue launch and crew vehicle architecture trades (SLS, MPCV, CCDev\*)
- Continue iteration and refinement of DRM definition and analysis
  - Develop more detailed destination capability descriptions for each DRM
- Initiate integrated capability-driven approach for multi-destination elements
  - Incremental approach for developing element; utilize modular approach to avoid redundant capability development; fewer elements = lower cost
  - Map technology developments based on destination and element

## ◆ **Continue assessment of affordability options**

- Affordability strategies can be applied to possible multiple architecture implementations; for example, use of civil servants for early development could be applied to many possible common elements

## ◆ **Continue engagement with Partnership, Technology, Operations, Elements and other HEFT teams to refine approach and define scenarios for further assessment**

## ◆ **Identify and prioritize key technology and capability investment areas for NASAworks and other lean development approaches**

## ◆ **Hone Concept of Operations, to include key objectives and refine abort/contingency planning**



- ◆ **The Capability-Driven Framework is the NASA approach to meeting the nation's goals and objectives for HSF Exploration in a dynamic policy and budget environment**
- ◆ **NASA has a short-, mid-, and long-term human and robotic spaceflight exploration plan consistent with law and policy**
- ◆ **Affordability, technology development, and partnerships are enablers**
- ◆ **Important forward work has begun, much remains**
- ◆ **Investments in HSF exploration will be leveraged across the government, industry, and public sectors for National benefit**
- ◆ **Significant global, interagency, and commercial cooperation opportunities exist and NASA will continue to engage**

**Capability-Driven Framework shows that bold, smart, affordable, and sustainable opportunities exist -- We must implement them now!**