Technical and Programmatic Prospects for Human Space Exploration 2015-2030

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NATIONAL RESEARCH COUNCIL
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PATHWAYS TO EXPLORATION
Rationales and Approaches for a U.S. Program of Human Space Exploration

- U.S. National Research Council report, June 2014
- Requested by Congress in 2010 NASA Authorization Act
- Support establishment of a sustainable U.S. human spaceflight program
- Includes a technical and affordability assessment

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Human Mission to the Mars Surface

- Mars is the horizon destination for human space exploration
- Getting there will require overcoming unprecedented technical risk, fiscal risk, and programmatic challenges
- Progress will be measured in decades with costs measured in hundreds of billions of dollars and significant risk to human life

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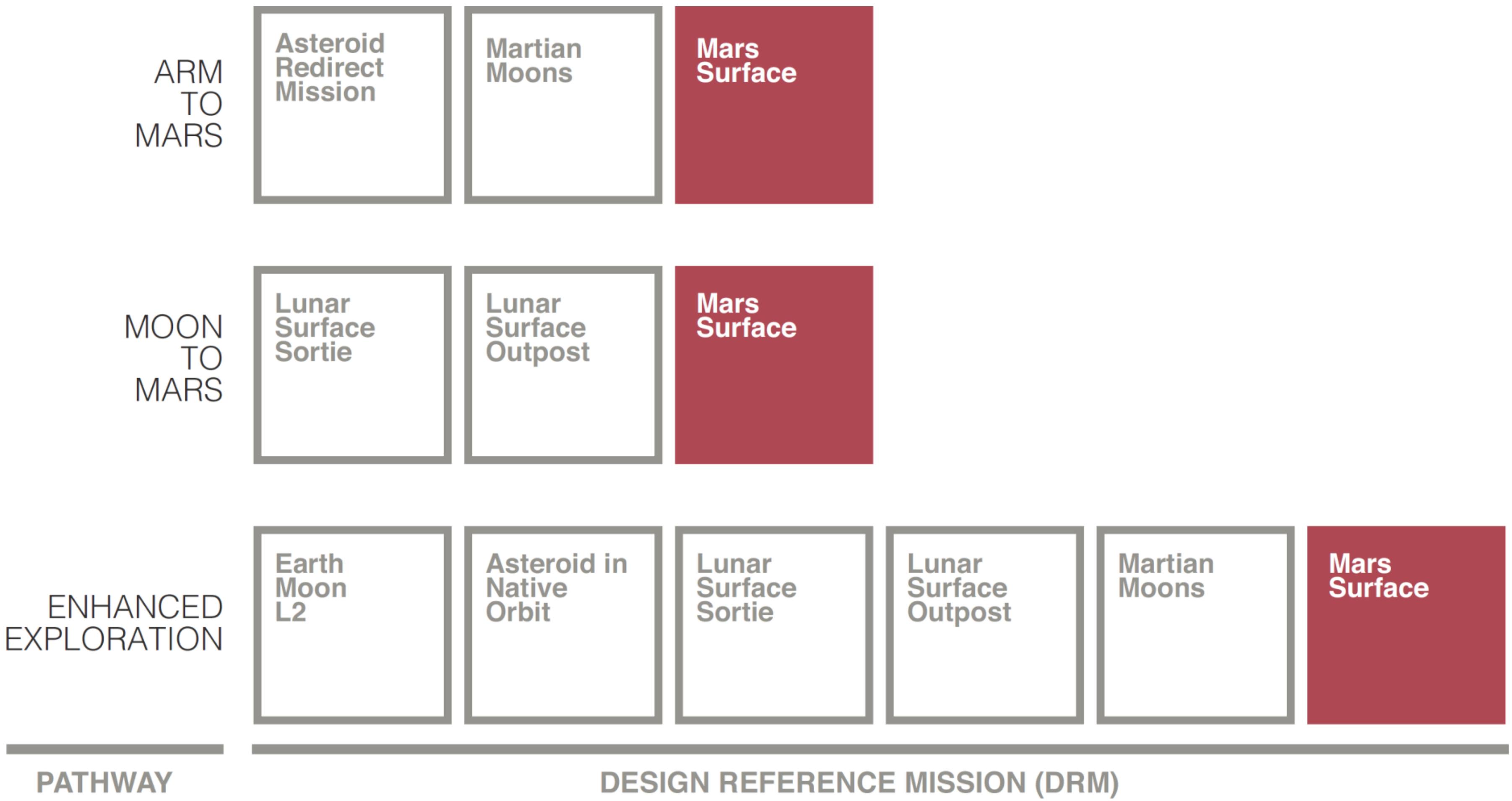
Approaches to Human Spaceflight

- Capability based
- Flexible path
- Pathway based
  - specific sequence of missions
  - increasing difficulty and complexity
  - targets specific exploration goals
  - facilitates continuity of development of required systems

Three Notional Pathways



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11 Primary Mission Elements

- Advanced extravehicular activity (EVA)
- Advanced in-space propulsion
- Aeroassist system
- Crew command and service module (Orion)
- Deep space habitation
- Heavy-lift launch vehicles
- Mars ascent vehicle
- Pressurized surface mobility
- Long-duration surface habitat
- Surface nuclear power
- Tele-robotic rovers

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3 Transitional Mission Elements

- Lunar orbital outpost (lunar DRMs)
- Lunar module (lunar DRMs)
- Cryogenic in-space propulsion system (lunar DRMs)

5 Dead-end Mission Elements

- Asteroid retrieval vehicle (ARM)
- Large storable stage (lunar DRMs)
- Multi-year deep space habitat (Mars Moons DRM)
- Mars orbit transfer vehicle (Mars Moons DRM)
- Space exploration vehicle (Mars Moons and asteroid in its native orbit DRMs)


ARM TO MARS
MOON TO MARS
ENHANCED EXPLORATION
ARM
MARTIAN MOONS
MARS SURFACE
LUNAR SORTIE
LUNAR OUTPOST
MARS SURFACE
EARTH-MOON L2
ASTEROID IN NATIVE ORBIT
LUNAR SORTIE
LUNAR OUTPOST
MARTIAN MOONS
MARS SURFACE
PRIMARY MISSION ELEMENT
TRANSITIONAL MISSION ELEMENT
DEAD-END MISSION ELEMENT
CUMULATIVE NUMBER OF ELEMENTS

Capability Assessment Parameters and Criteria

DIFFICULTY OF MAKING NEEDED ADVANCES

	HIGH	MEDIUM	LOW
TECHNICAL CHALLENGES	Technical solution currently unknown or unattainable with current technology	Solution is known but not well understood	Solution is well understood with current or previous relevant research
CAPABILITY GAP	No relevant systems exist or have existed at the appropriate scale	Systems exist or have existed that are scalable to mission needs	Systems exist that are translatable or are easily scalable to mission needs
REGULATORY CHALLENGES	Current regulations impose significant restrictions and will be difficult to change	Current regulations impose a challenge	No regulatory issues
COST & SCHEDULE CHALLENGES	Development to operational capability is on the order of previous large, national programs (Shuttle Orbiter)	On the order of Apollo Heat Shield or Orion ECLSS	< 5 years development with < 50 person team

10 High-Priority Capabilities

Mars EDL

Radiation Safety

In-Space Propulsion and Power

- Fission Power
- Cryogenic Propulsion
- NEP
- NTP
- SEP

Heavy Lift Launch Vehicles

- SLS
- Falcon Heavy

Planetary Ascent Propulsion

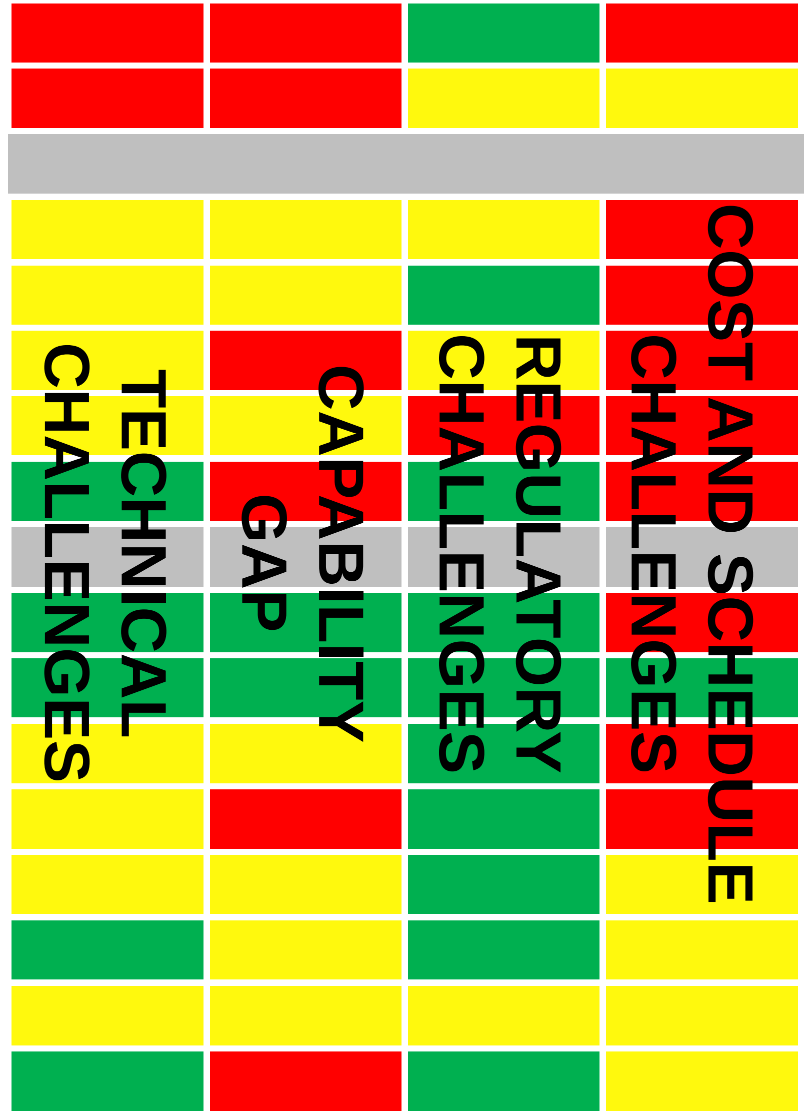
ECLSS

Habitats

EVA Suits

Crew Health

ISRU (Mars atmosphere)



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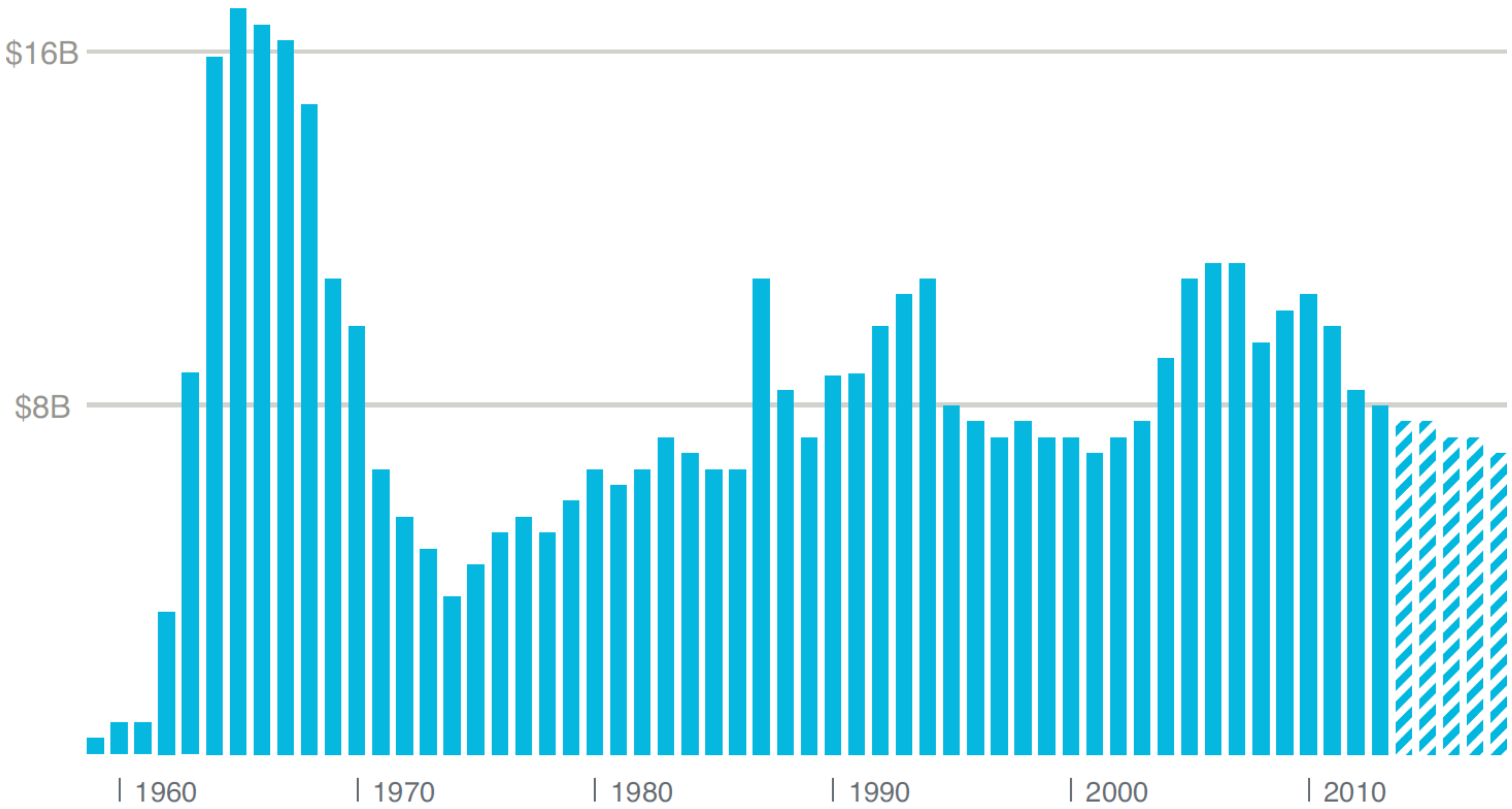
Funding of NASA HSF programs, FY 2013 dollars



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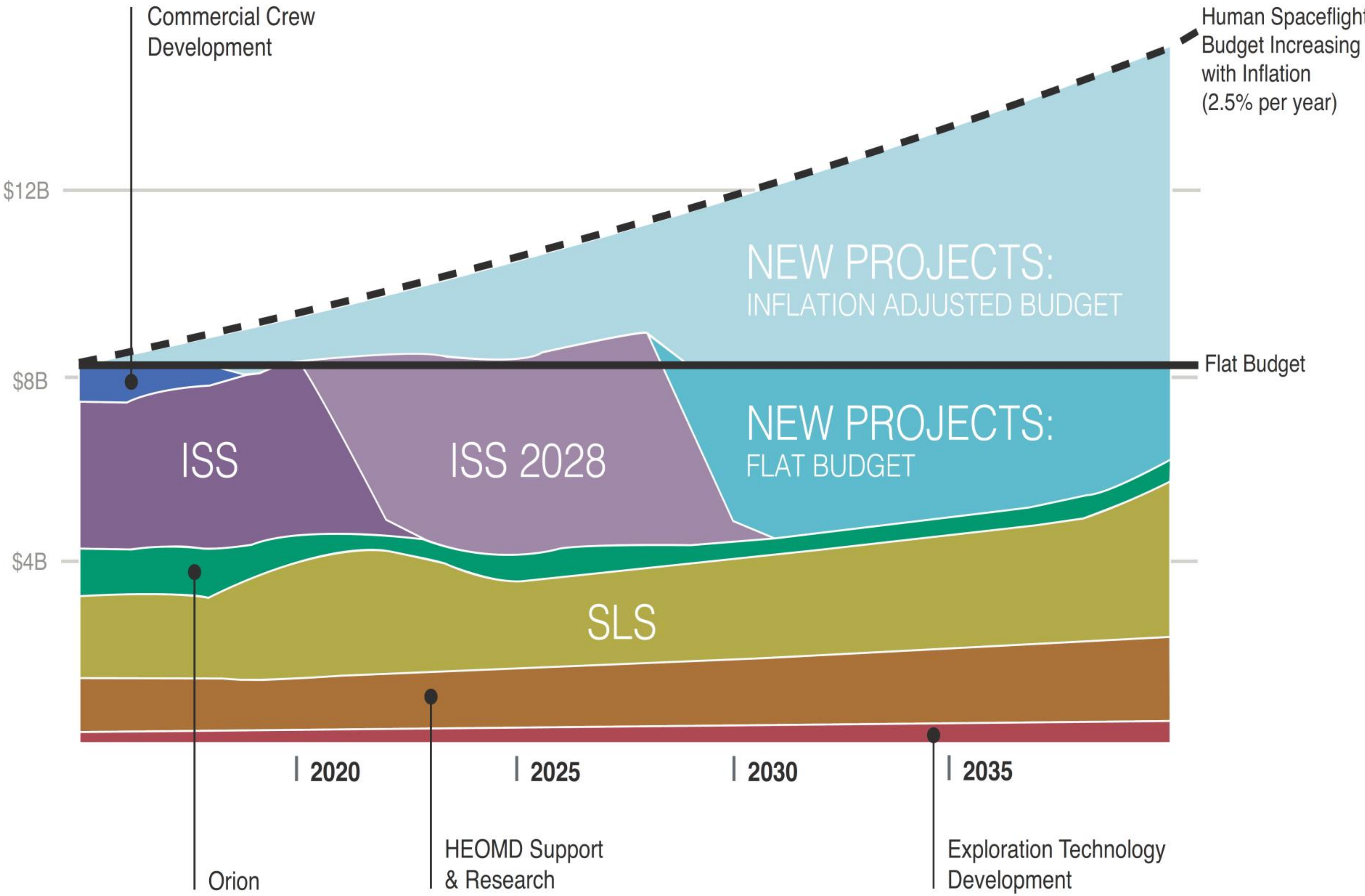
NASA HUMAN SPACEFLIGHT PROJECTED AVAILABLE BUDGET (THEN-YEAR $)



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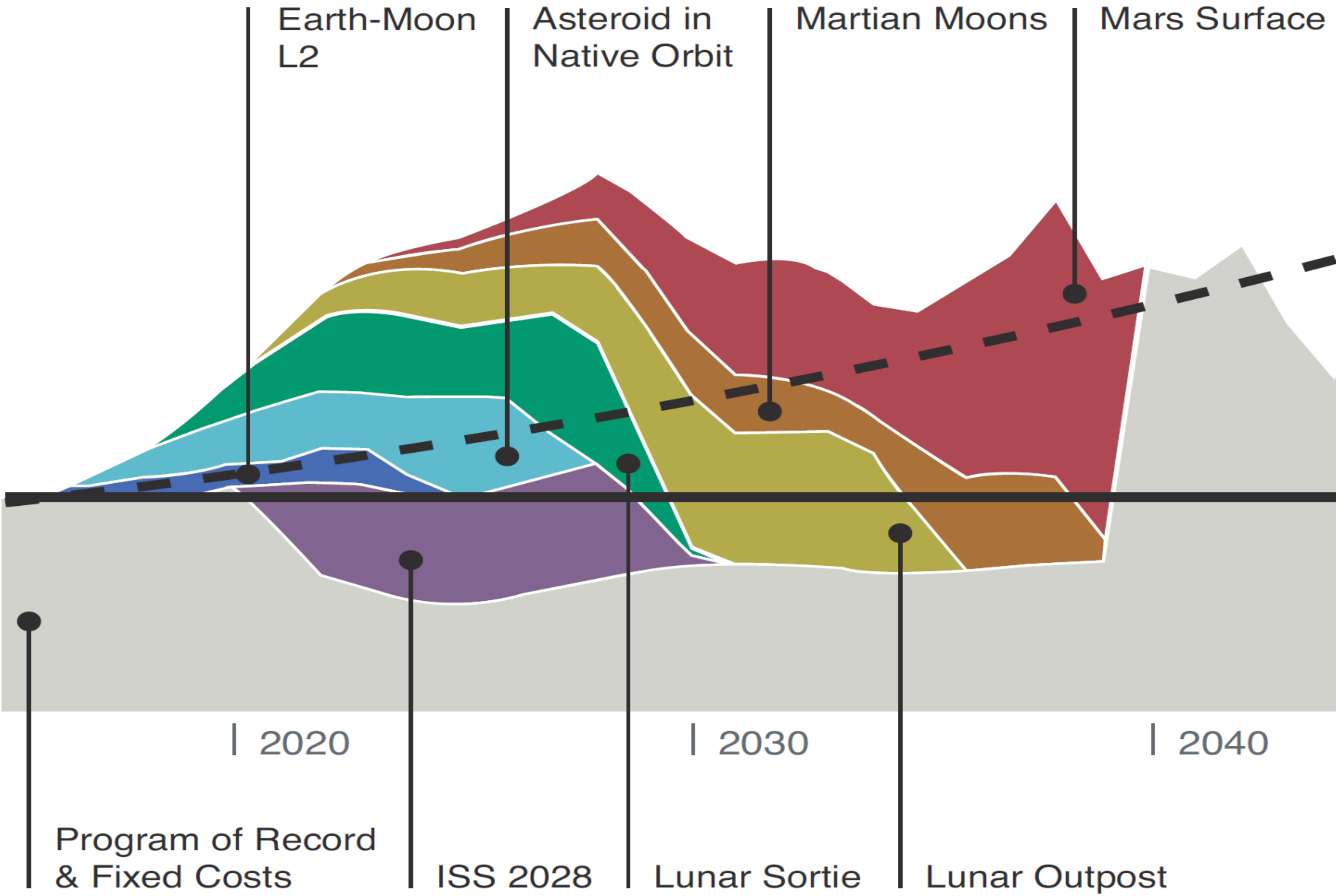
Schedule-Driven Affordability Scenario: Annual Cost of the Enhanced Exploration Pathway



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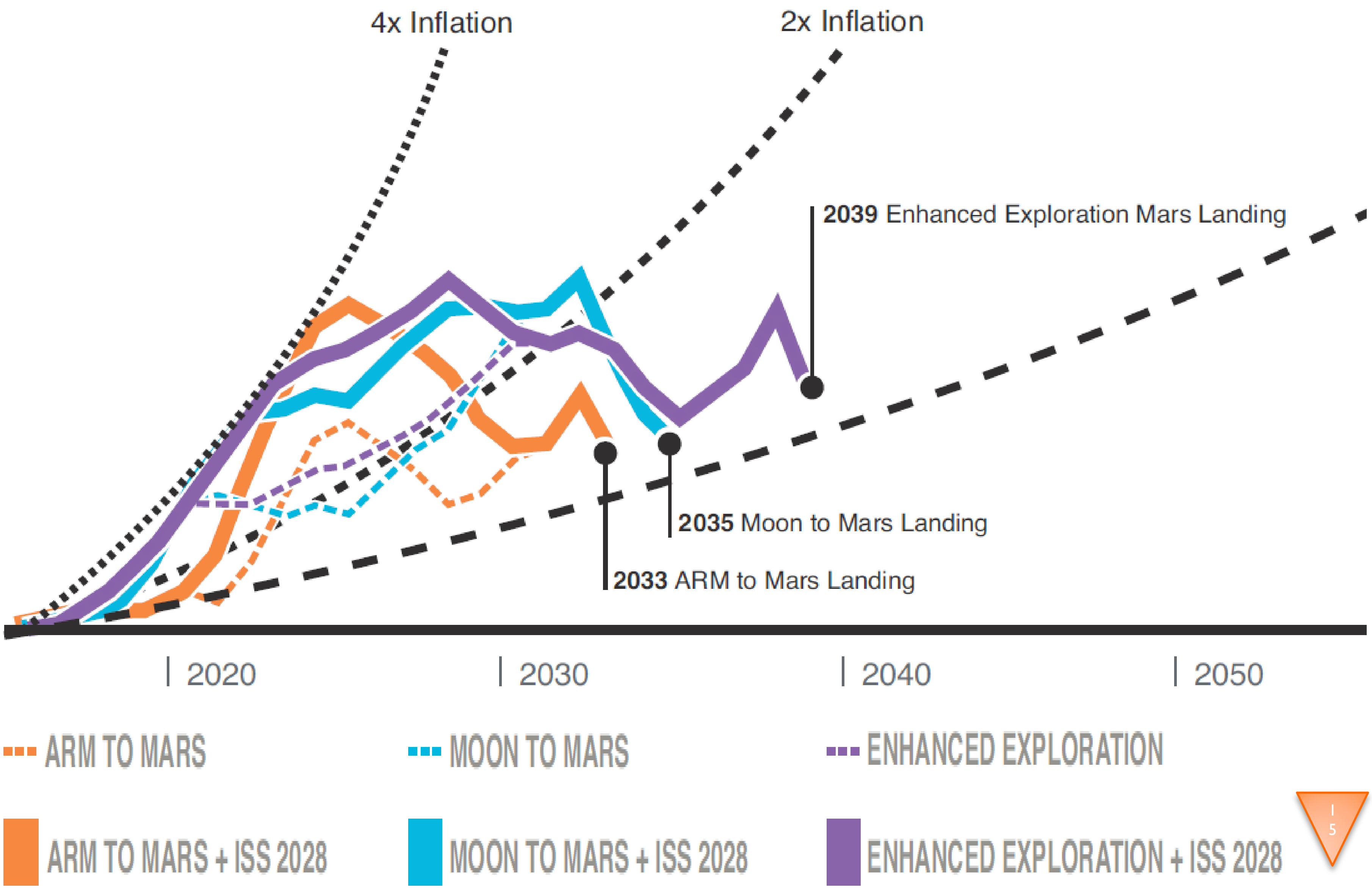
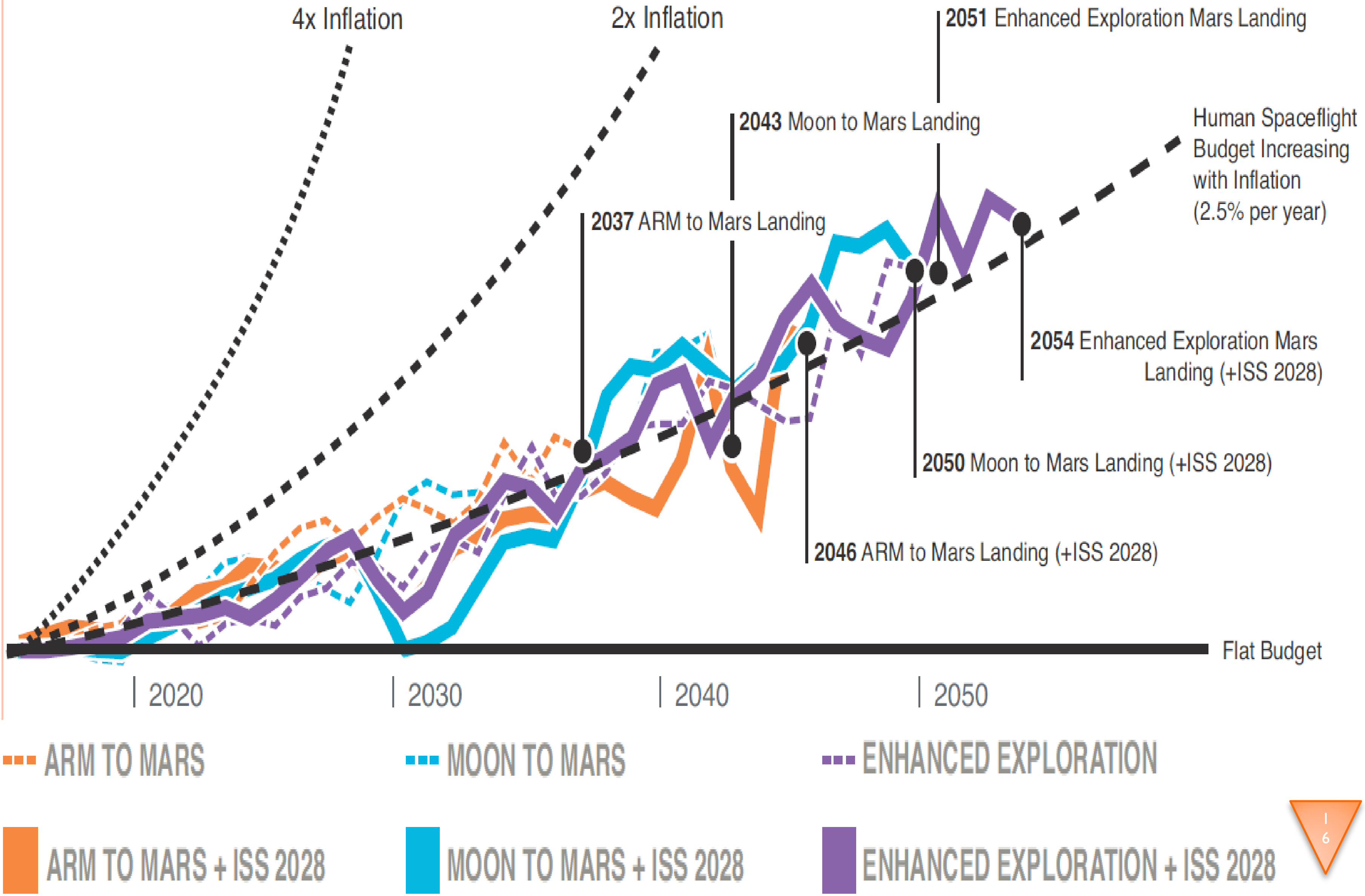
Schedule-Driven Affordability Scenario: Annual Cost of all three Pathways



Budget-Driven Affordability Scenario: Annual Cost of all three Pathways

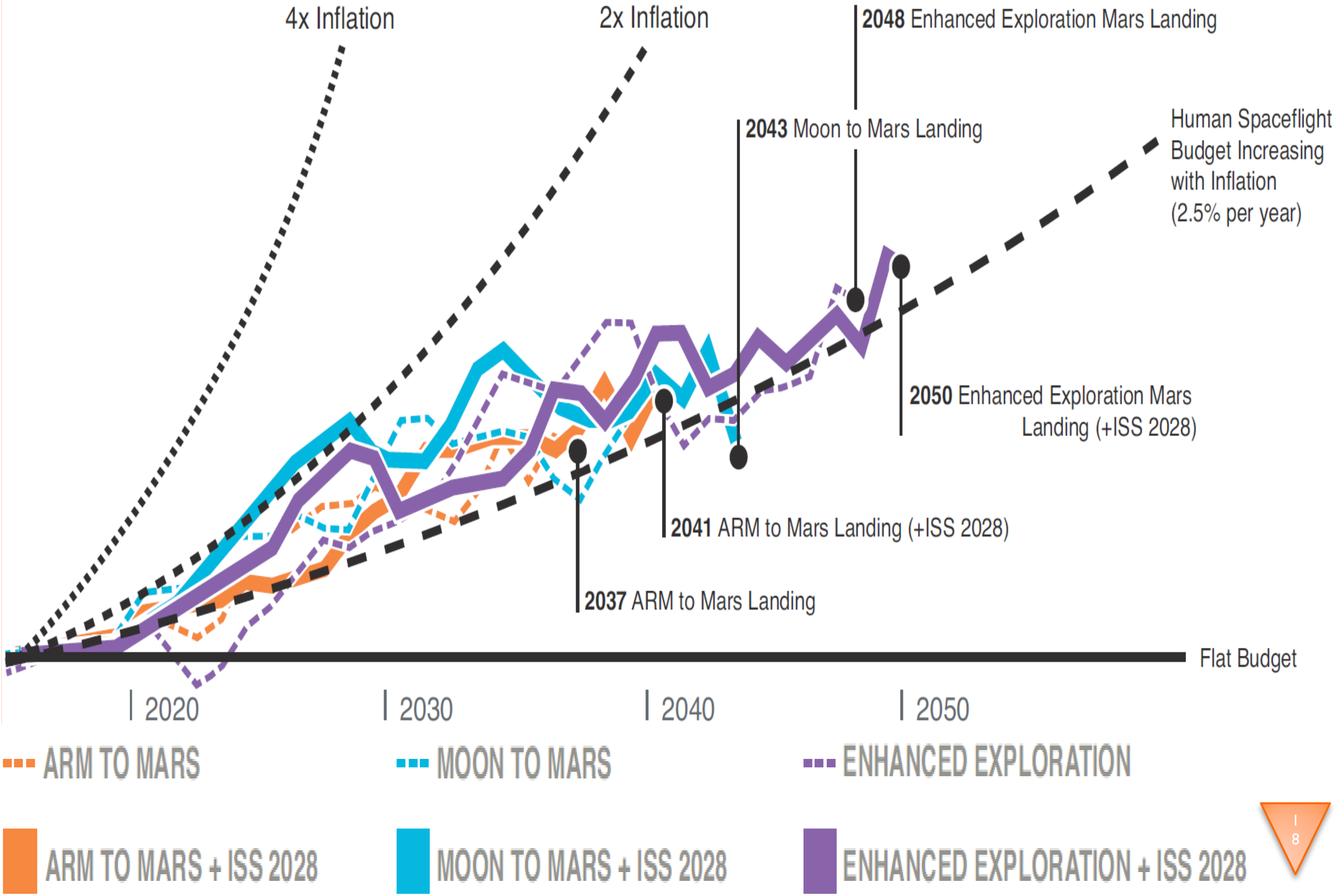


Operational Tempo: SLS Launches and Crewed Missions

Pathway	ARM-to-Mars		Moon-to-Mars		Enhanced Exploration	
Year of ISS Retirement	2020	2028	2020	2028	2020	2028
Average time between SLS flights (from 2022 until first launch for Mars Moons or Mars surface mission, in months)						
• Schedule-driven scenario	16	16	4	4	3	3
• Budget-driven scenario	24	32	9	12	9	8
• Operationally viable scenario	18	29	6	7	5	5
Average time between crewed missions (from ISS retirement through first Mars moons or Mars surface mission, in months)						
• Schedule-driven scenario	17	12	11	7	11	7
• Budget-driven scenario	30	40	46	44	33	29
• Operationally viable scenario	16	18	28	23	22	19

Pathway scenarios with historical mission rates are not affordable, and pathway scenarios based on a human spaceflight budget increasing with inflation are not sustainable.

Operationally Viable Affordability Scenario: Annual Cost of all three Pathways



Pathway Comparison

		ARM TO MARS		MOON TO MARS		ENHANCED EXPLORATION	
		ISS 2020	ISS 2028	ISS 2020	ISS 2028	ISS 2020	ISS 2028
TOTAL # CREWED FLIGHTS	Schedule driven:	9	9	17	17	20	20
	Budget driven:	7	9	7	7	11	14
	Operationally viable:	9	9	9	8	14	14
EARLIEST POSSIBLE YEAR MARS LANDING	Schedule driven:	2033	2033	2035	2035	2039	2039
	Budget driven:	2037	2046	2043	2050	2050	2054
	Operationally viable:	2037	2041	2041	2043	2048	2050
OPERATIONAL TEMPO SATISFACTORY	Schedule driven:	NO		YES		YES	
	Budget driven:	NO		NO		NO	
	Operationally viable:	MARGINAL		MARGINAL		MARGINAL	
AFFORDABLE[a]	Schedule driven:	NO		NO		NO	
	Budget driven:	YES		YES		YES	
	Operationally viable:	MARGINAL		MARGINAL		MARGINAL	
DEVELOPMENT RISK	Schedule driven:	EXCEEDINGLY HIGH		VERY HIGH		HIGH	
	Budget driven:	EXCEEDINGLY HIGH		VERY HIGH		HIGH	
	Operationally viable:	EXCEEDINGLY HIGH		VERY HIGH		HIGH	

Budgetary Observations

- Any proposed pathway to Mars must be affordable for the U.S. and its international partners to be sustainable
- With current flat or even inflation-adjusted budget projections for NASA's human spaceflight program, there are no viable pathways to Mars.
- Increasing NASA's budget to allow increasing the human spaceflight budget by 5 percent per year would enable pathways with potentially viable mission rates
- If large enough, international contributions could overcome the cost increases associated with the additional complexity of a large international program, but that was not the case with ISS
- Unclear how the goals of the various spacefaring nations will translate to budget commitments

Game-Changing Vision of Robotics

- Fundamental technology of chemical propulsion has hardly advanced in the last 50 years, even as the capability of computers has advance at an exponential pace with no end in sight
- Ongoing advances in robotics reflect exponential increases in computational capabilities, sensor quality, and control technologies
- In coming decades, advances in robotic capabilities may present new options for space exploration and open new pathways that are technologically achievable and affordable without unacceptable developmental risk

The most significant factors in advancing human space exploration beyond LEO are

- Development of a strong U.S. and international consensus about the pathway to be undertaken
- Sustained discipline to maintain course over many U.S. administrations and Congresses

Without consensus and discipline, it is all too likely that the potential of the Space Launch System will be wasted, human spaceflight to LEO will be increasingly routine (although still with risk to life), and the horizons of human existence will not be expanded—at least not by the United States.

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