Weighing the Future: Strategic Options for U.S. Space Nuclear Leadership

Authors

Bhavya Lal, Ph.D.
Former Associate Administrator for Technology, Policy, and Strategy,
Former Chief Technologist (Acting), NASA

Roger Myers, Ph.D.
Former Executive, Aerojet Rocketdyne
Member, National Academy of Engineering

Sponsor

Justin Coleman, Ph.D.
Idaho National Laboratory

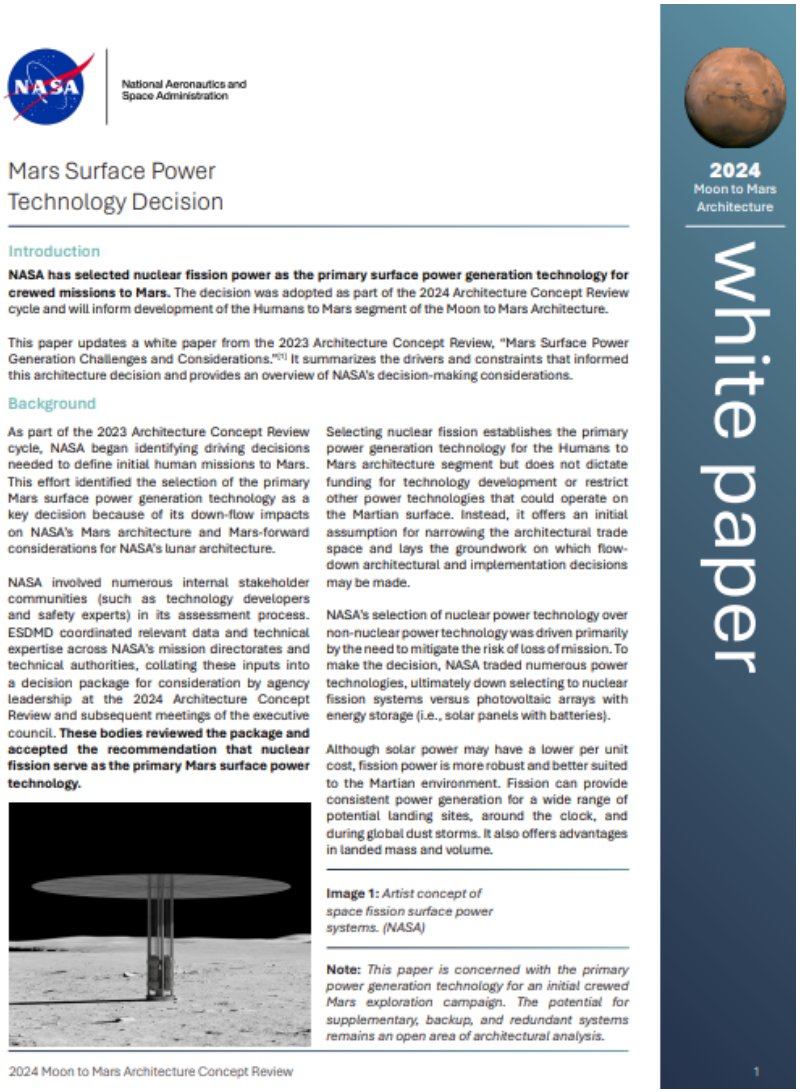
A Shifting Landscape

- **Geopolitical Imperative**
- Newly Emerging Mission Pull
- Accelerating Technological Maturation
- Spillover from Terrestrial Nuclear Investments
- Greater Policy Certainty
- Private-Sector Readiness

NASA's Stated Need for Nuclear Power

"NASA has selected nuclear fission power as the primary surface power generation technology for crewed missions to Mars. The decision was adopted as part of the 2024 Architecture Concept Review cycle and will inform development of the Humans to Mars segment of the Moon to Mars Architecture."

NASA 2024



National Aeronautics and Space Administration

Mars Surface Power Technology Decision

2024 Moon to Mars Architecture

white paper

Introduction

NASA has selected nuclear fission power as the primary surface power generation technology for crewed missions to Mars. The decision was adopted as part of the 2024 Architecture Concept Review cycle and will inform development of the Humans to Mars segment of the Moon to Mars Architecture.

This paper updates a white paper from the 2023 Architecture Concept Review, "Mars Surface Power Generation Challenges and Considerations."[1] It summarizes the drivers and constraints that informed this architecture decision and provides an overview of NASA's decision-making considerations.

Background

As part of the 2023 Architecture Concept Review cycle, NASA began identifying driving decisions needed to define initial human missions to Mars. This effort identified the selection of the primary Mars surface power generation technology as a key decision because of its down-flow impacts on NASA's Mars architecture and Mars-forward considerations for NASA's lunar architecture.

NASA involved numerous internal stakeholder communities (such as technology developers and safety experts) in its assessment process. ESDMD coordinated relevant data and technical expertise across NASA's mission directorates and technical authorities, collating these inputs into a decision package for consideration by agency leadership at the 2024 Architecture Concept Review and subsequent meetings of the executive council. **These bodies reviewed the package and accepted the recommendation that nuclear fission serve as the primary Mars surface power technology.**

Selecting nuclear fission establishes the primary power generation technology for the Humans to Mars architecture segment but does not dictate funding for technology development or restrict other power technologies that could operate on the Martian surface. Instead, it offers an initial assumption for narrowing the architectural trade space and lays the groundwork on which flow-down architectural and implementation decisions may be made.

NASA's selection of nuclear power technology over non-nuclear power technology was driven primarily by the need to mitigate the risk of loss of mission. To make the decision, NASA traded numerous power technologies, ultimately down selecting to nuclear fission systems versus photovoltaic arrays with energy storage (i.e., solar panels with batteries).

Although solar power may have a lower per unit cost, fission power is more robust and better suited to the Martian environment. Fission can provide consistent power generation for a wide range of potential landing sites, around the clock, and during global dust storms. It also offers advantages in landed mass and volume.

Image 1: *Artist concept of space fission surface power systems. (NASA)*

Note: *This paper is concerned with the primary power generation technology for an initial crewed Mars exploration campaign. The potential for supplementary, backup, and redundant systems remains an open area of architectural analysis.*

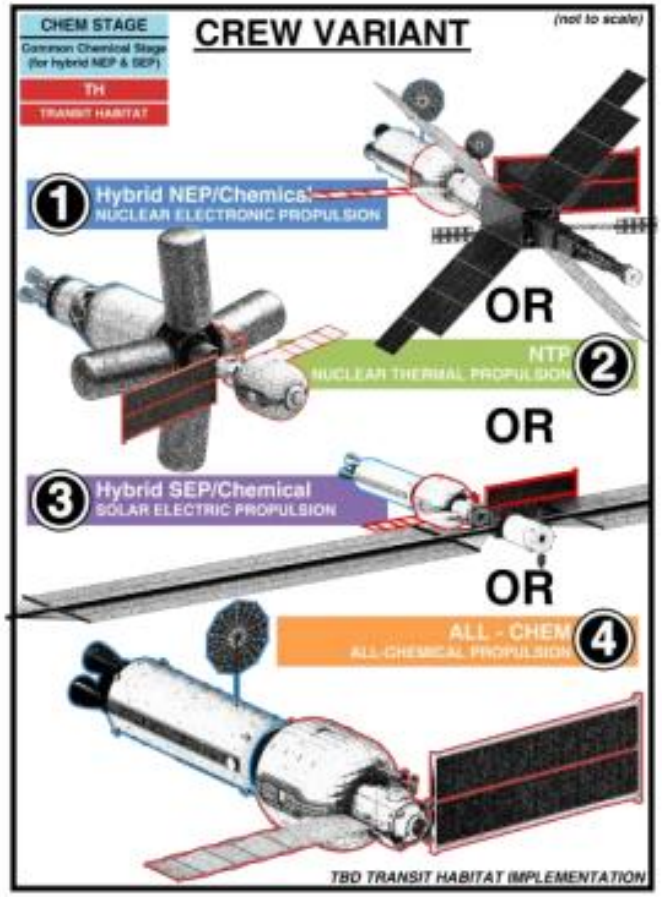
2024 Moon to Mars Architecture Concept Review

1

NASA's Official Statement on Propulsion

"Selection of a human Mars transportation system will be a complex decision shaped by numerous factors, such as mission objectives, exploration partner contributions and commitments, programmatic factors, schedules, and integrated risk assessments. The four transportation propulsion systems presented here represent the range of options currently being analyzed."

NASA April 2025



NASA's Moon to Mars Architecture - Architecture Definition Document, April 2025
https://www.nasa.gov/wp-content/uploads/2024/12/esdmd-001-add-rev-b.pdf?emrc=5ffbf4

DOD's Response to Congress on Propulsion

- Page 1315 of H. Rept 118-301 HR 2670 NDAA FY 2024 asked Space Force to describe how USSF plans to use NEP and NTP vehicles
- Response noted USSF will "continue to monitor SNP investment and developments" and "as critical technologies mature to a point of operational relevance, SNP technologies will be considered through the force design and requirements generation process as potential options to fulfill operations requirements"

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES SPACE FORCE

Space Force Use of Nuclear Thermal and Nuclear Electric Propulsion

This report describes Department of Defense use of space nuclear propulsion (SNP) and on-going activities to mature nuclear thermal propulsion and nuclear electric propulsion technologies in accordance with page 1315 of H. Rept. 118-301, The Conference Report on H.R. 2670, National Defense Authorization Act for Fiscal Year 2024.

The DoD national security space architecture does not currently incorporate SNP systems. To inform future Force Design and Space Systems Architectures, the DoD is investing with United States Government partners to mature, prototype and experiment with SNP technologies. Once matured to operational relevance, these technologies offer potential benefits to bolster the national security of the United States through increased mission longevity, rapid transit, greater payload mass, enhanced maneuverability regardless of the position of the sun or orbit, and the ability to power new sensors or mission concepts.

The Department of the Air Force is focused on fielding an affordable, resilient space architecture which provides freedom of operation for the United States in, from, and to space. Current SNP science and technology projects enable the Space Force to develop and refine future concepts through experimentation, helping to plan the capabilities required for the future force. Space capabilities must be designed and fielded as part of a system-of-systems to optimize mission performance, reduce unnecessary redundancies, and address current and emerging threats.

The Department of the Air Force appreciates Congress' continued support as the Space Force pursues these technologies to meet future emerging challenges.

Sincerely,

B. CHANCE SALTZMAN
General, USSF
Chief of Space Operations

Option 1

- 100–500 kWe demo – Power or NEP
- Ground test by 2028
- Flight by 2030
- ~$3B over 5 years
- Government owned and operated

"Manhattan Project Test"

- A **centralized lead** with real budget and milestone **authority**
- **Stable**, multi-year large **funding** insulated from annual swings
- A **strategic imperative** strong enough to align leadership and unlock institutional will

Option 2: Chessmaster's Gambit

- Two 10-100 kWe privately-led demos
- Ground test by 2028
- Flight by 2030
  - NASA-led surface power*
  - DOD-led in-space power
- Technology agnostic
- Fixed price milestone-based contracts
- ~$1B per Agency over 5 years

Demands

- Strategic clarity, not technical micromanagement
- Clear articulation of high-level mission requirements upfront —scope, scale, and timeline—*without over-specifying design solutions*

* NASA surface power demo will be constrained by available lander capability and other architectural considerations

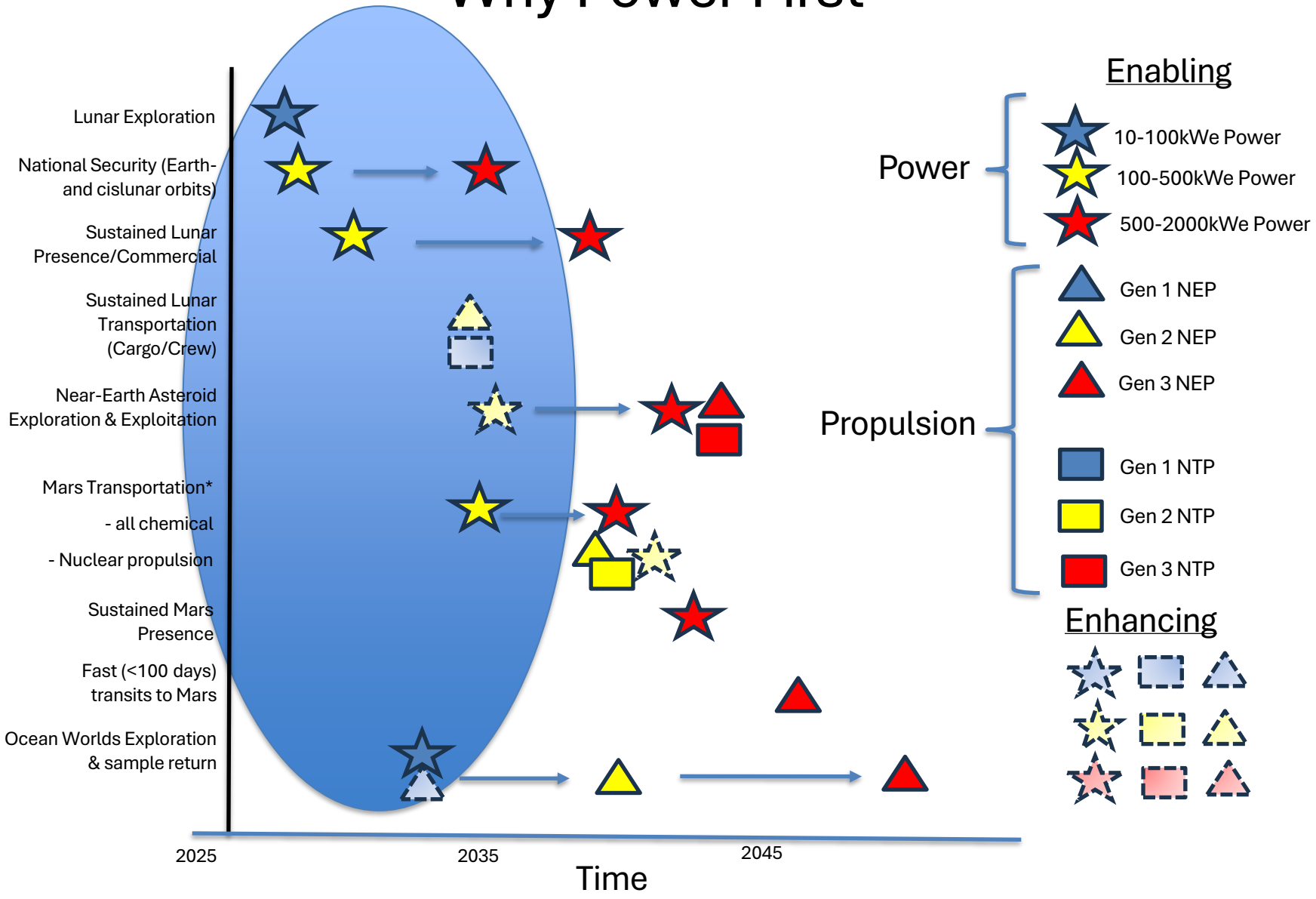
(In Parallel) Option 3: Light the Path

- Commercial-led RPS to Moon by 2028
- Am-241 or Sr-90 (non-Pu-238 isotopes)
- Tests launch licensing, indemnification
- Low-cost, early win

Still underdeveloped; needs further analysis

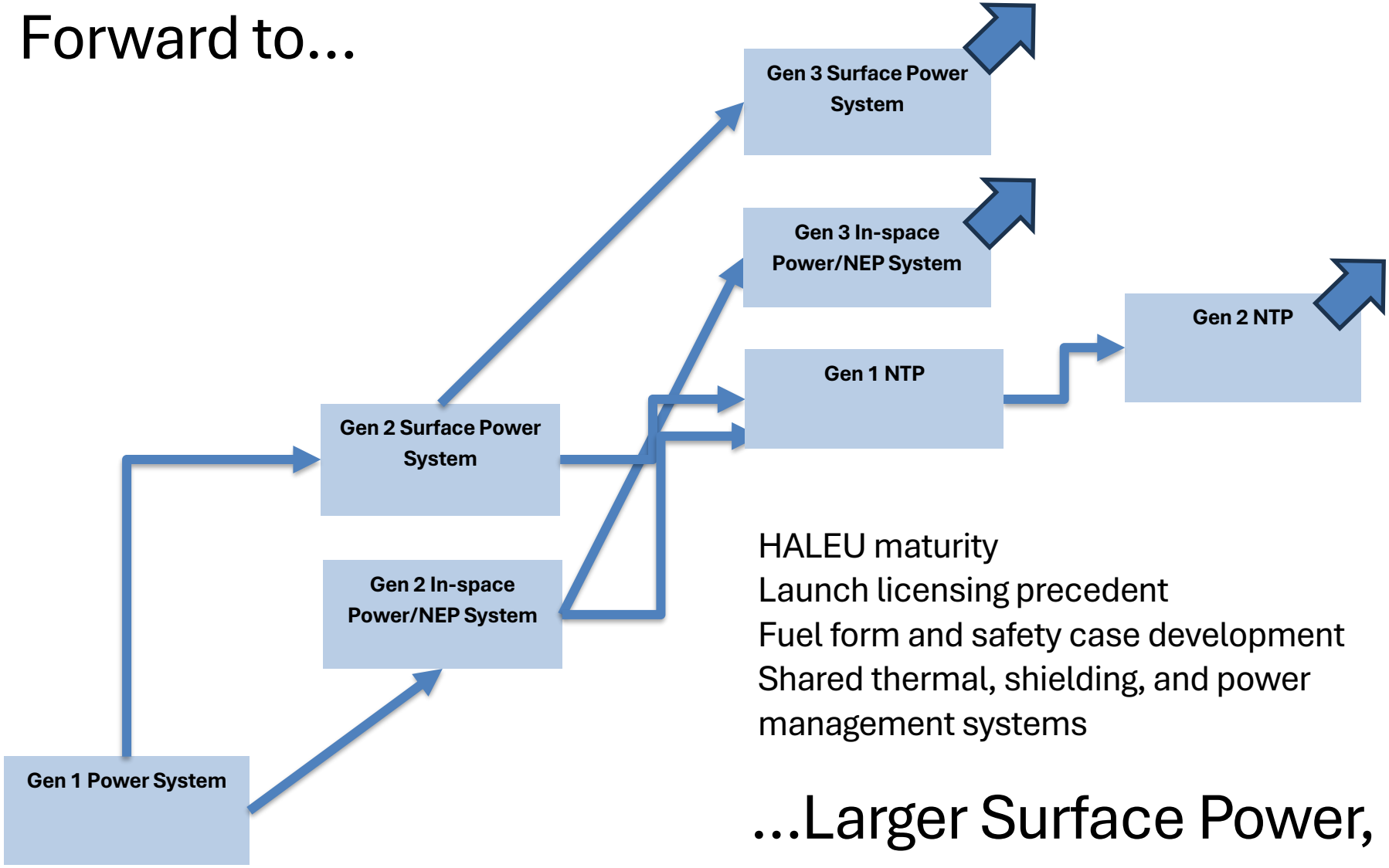
A hedge - does not deliver high power, but learning, credibility, and momentum—at relatively low cost and political risk

Why Power First



*NASA has not selected the propulsion option for initial Mars missions. Nuclear power is required for the all-chemical option to produce Earth-return propellant. If nuclear propulsion is selected then in-situ propellant production is not required (but is enhancing).

Strategic Sequencing: A Gen 1 Power Demo Feeds Forward to…



HALEU maturity
Launch licensing precedent
Fuel form and safety case development
Shared thermal, shielding, and power management systems

…Larger Surface Power, In-Space Power, NEP and NTP

Selecting Among Options: Balance of Ambition Risk and Realism

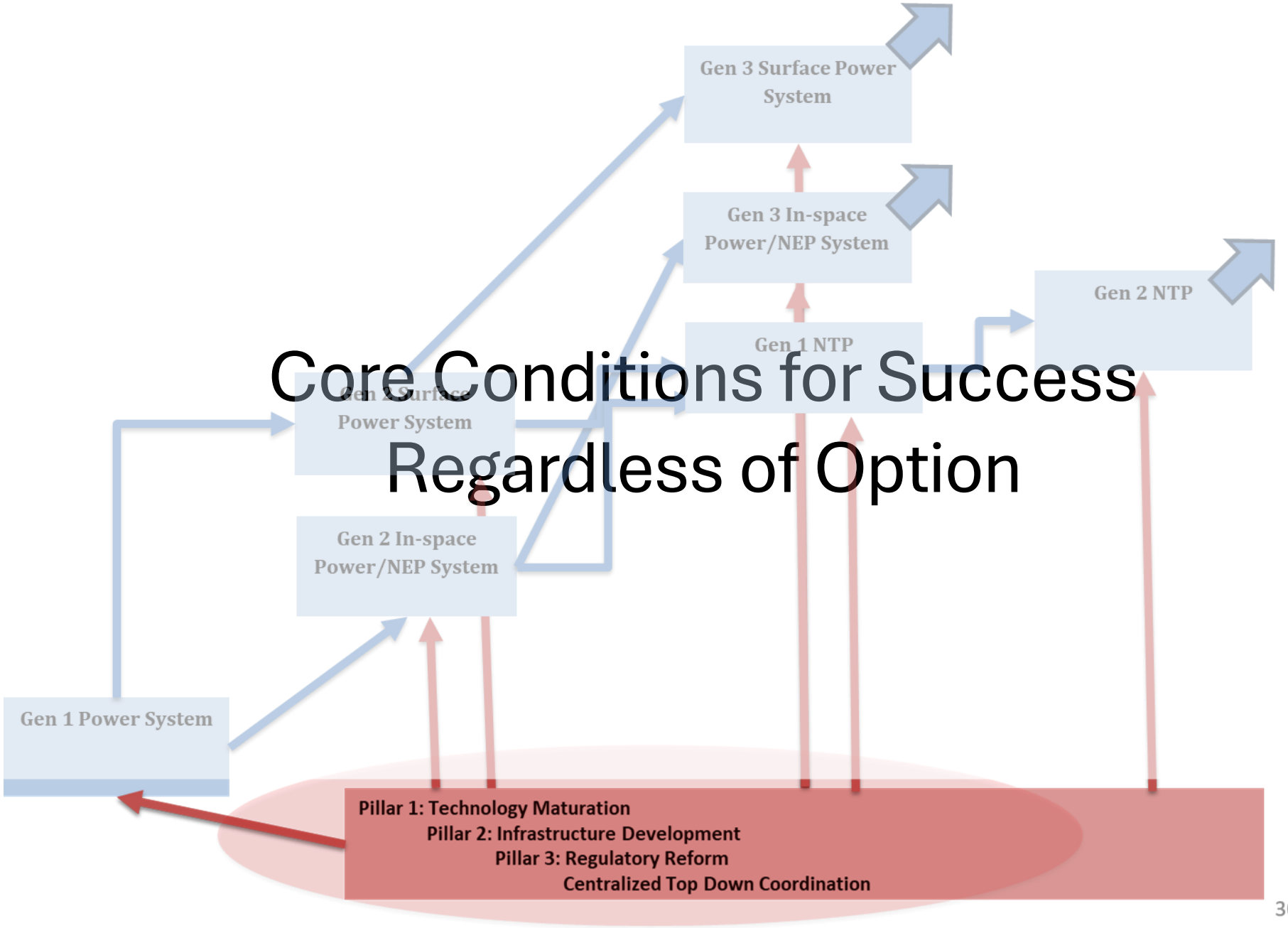
Option	Demonstration	Scale***	Lead Organizations	Rough Cost to Govt.	Risk Profile
Go Big or Go Home*	Power or NEP flight demo by 2030 *Ground test by 2028*	100–500 kWe class	**NASA or DoD** with DOE as partner	~$3B over 5 years	High
Chessmaster's Gambit	Two power demos - in-space or surface - by 2030 *Ground test by 2028*	10-100 kW class	**Industry**, NASA/DoD, DOE, FAA	~$2B over 5 years	Medium
(Potential) Light the Path**	Commercial RPS demo by 2028	<1 kWe class	**Industry**, NASA/DoD, DOE, FAA	~$100M (illustrative)	Low

**Should be pursued only if political, budgetary, and leadership conditions are aligned.*

*** Could proceed in parallel with either major Option. Requires further assessment.*

**** Actual power levels may be driven by lift and lunar lander capacity and other architectural constraints.*

Core Conditions for Success Regardless of Option




QUESTIONS