GO: Advanced Propulsion
NASA Space Technology Mission Directorate

STMD welcomes feedback on this presentation. Please visit https://techport.nasa.gov/framework/feedback if you have any questions or comments regarding this presentation.

SPACE FLIGHT ARCHITECTURE DOMAINS

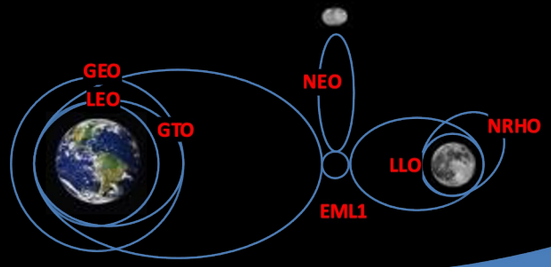
Exploration, Science, Commerce & Security

LEO TO CIS-LUNAR

CLPS/Artemis & Cis-Lunar Development

- Human Transportation
- Lunar & Inner Solar System Payloads
- Mining & Resource Extraction
- Manufacturing
- Fuel Depots / In Situ Derived Prop
- Space Solar Power
- Outposts (In-Space & Surface)
- Orbital Debris Mitigation and Remediation
- Planetary Defense Assets
- National Security Space Assets

"Commercially Sustained Cis-Lunar Infrastructure"



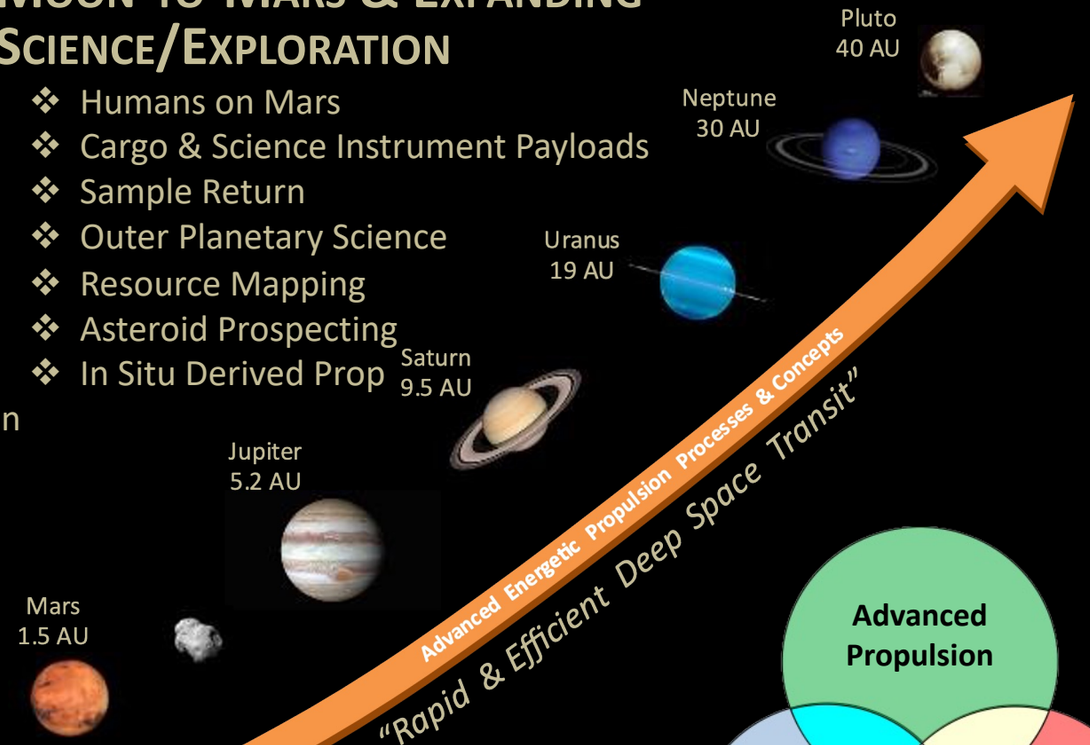
CP | SEP | NTP | NEP

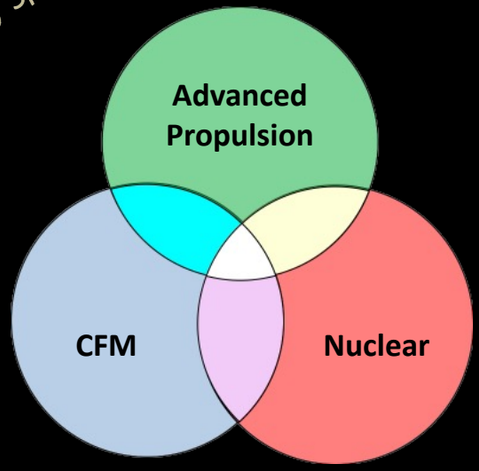
"Littoral & Blue Water Mobility Analog"

MESO-SOLAR

Moon-to-Mars & Expanding Science/Exploration

- Humans on Mars
- Cargo & Science Instrument Payloads
- Sample Return
- Outer Planetary Science
- Resource Mapping
- Asteroid Prospecting
- In Situ Derived Prop





Go Thrust Touchpoints

EXTRA-SOLAR

Outer Solar System & Interstellar

KBOs & Primitive Bodies	>50 AU
Heliosphere / Local ISM	100-200 AU
Pristine ISM	200-400 AU
Solar Gravity Lens	500-800 AU
Nearby Stars / Exoplanets	4.5-20 LY

STMD STRATEGIC FRAMEWORK ENVISIONED FUTURE

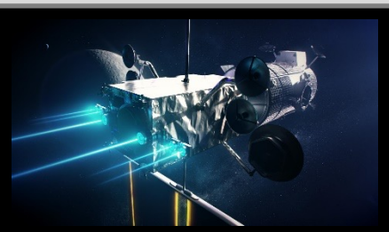
GO Thrust – Advanced Propulsion Vision

Produce advanced propulsion technologies that enable future exploration/science/commercial missions

Developing advanced propulsion technologies to push the cutting edge farther and faster than ever before

Architecture Driven Propulsion Technologies

Science/Exploration/Commerce/Security Capabilities



High-ΔV EP Spacecraft

High-ΔV XX-kWe EP Capability

- 12-kWe Class HET → Gateway/PPE SEP
- 7-14-kWe Class GIT → Advanced NEXT
- 100-kWe Class Electric Thrusters including HET, MPD, VASIMR, & other options → Mars Transportation System

Outer Planetary Robotic NEP Spacecraft

Deep Space Nuclear Flagship Capabilities

- Propulsion Technologies Enabling Nuclear Propulsion Robotic Spacecraft
  - Fission Surface Power Derived NEP
  - Dynamic-RPS Derived NEP
  - Advanced LCF Derived NEP

Earth Pole Sitting Observatories

Sun Pole Sitting Observatories

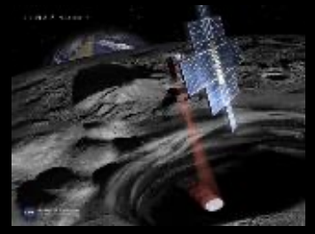
Observational Platforms for Science, Commercial & Security Missions Requiring Unlimited ΔV Capability

- Solar Sail Development & Demonstration
  - Monitor Solar Cruiser Project
  - Supplement SMD Technology Development as Warranted
  - Support Early-Stage Concept R&D

High-ΔV ESPA-Class Deep Space Spacecraft

Small Spacecraft Science, Commercial & Security Missions Requiring High-ΔV EP Capability

- Focus on ESPA-Class Sub-kW EP
- Flight Qualify & Demonstrate
- SMD SIMPLEx Mission Infusion



Green Propellant Deep Space Spacecraft

Green Propellant Adoption & Infusion into Missions of Opportunity

- Facilitate Provider/User Transition
- Incentivize Mission Opportunities
- Lunar Flashlight Mission Infusion

Thruster Advancement for Low Temperature Ops in Space

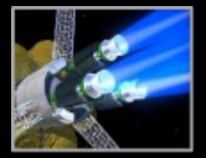
Deep Space Science Missions Requiring Cold Tolerant Storable Propulsion for Extreme Environments Access

- MON-25/MMH Bipropellant Thruster Technology
- Compact Lander Propulsion – TALOS → CLPS Infusion
- Deep Space Variant – Extensible TALOS → Enceladus

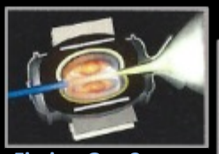
Inspiration Driven Research

Transformational Capabilities

Sustained investment in Advanced Energetic Propulsion research & innovation enables new breakthrough technologies

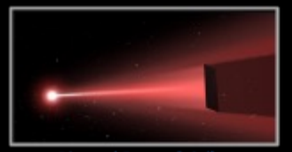


Low-α NEP



Fission Gas Core or Advanced Solid Core

Pulsed Fission



Directed Energy & Sails

Fusion

Antimatter

Breakthrough Science

Capability Goals:

- **α ≤ 5 kg/kW**
- **Thrust-to-Weight ≥ 0.6**
- **Relativistic S/C Velocity ≥ 0.1c**

All activities depicted not currently funded or approved. Depicts "notional future" to guide technology vision.

ADVANCED PROPULSION CAPABILITY OUTCOMES

Propulsion Technology Development Streams

Lunar Gateway	Artemis/Mars	Mars Transport	
Exploration (E)1: Gateway/PPE SEP	**E2: Cryogenic CP**	**E3-A: NEP/CP Hybrid**	**E3-B: NTP**
Develop 12.5-kWe SEP string and enable 50-kWe thruster array for lunar orbit maneuvering and NRHO station keeping	Affordable, highly reusable cryogenic propulsion to provide in-space transport and lunar surface access with extensibility to Mars	Multi-MW NEP to provide cruise ΔV plus affordable & highly reusable cryogenic propulsion to provide gravity well ΔV	High thrust NTP to provide gravity well ΔV plus reactor integrated Orbital Maneuvering System (OMS) to provide supplemental ΔV

Exploration Architecture Systems Development — TRL 6-8

Flagship SEP	Extreme Access Storable Propulsion		High-ΔV Small S/C	Unique Platforms	Green Prop Adoption
Science (S)1: High-ΔV SEP	**S2-A: Baseline TALOS**	**S2-B: Extensible TALOS**	**S3: ESPA Sub-kW SEP**	**S4: Solar Sail**	**S5: Green Propulsion**
Develop 7-14 kWe gridded ion EP string to enable more ambitious very high-ΔV deep space robotic missions	Baseline TALOS: In-space cold tolerant storable pulse-mode bi-propulsion to enable universal surface access	Extensible TALOS: Deep space variant modifications & qualification for high-throughput, long-burn orbit transfer and extreme access	Fully flight qualified high-throughput, radiation-tolerant sub-kW Xenon HET enabling high-ΔV ESPA-class deep space missions	Matured solar sail technology to provide essentially unlimited S/C ΔV as an enabler of unique platform capabilities	Facilitate green propellant infusion by incentivizing mission adoption and PPP opportunities to mature a wide range of thrust classes

Science, Commerce & Security Technology Development — TRL 6-8

Transformational CP	Flagship NEP	Rapid Transit Interstellar Probe	Advanced Energetic Propulsion
Transformational (T)1: RDRE	**T2: Robotic S/C NEP**	**T3: Near Sun STP**	**T4: Fusion/AEP Concepts**
Early-stage R&D focused on RDRE maturation & prototype demonstrations to achieve transformational gains in CP performance for launch, in-space, and lander systems	Propulsion technologies enabling low-to-moderate power NEP transportation systems (FSP/Dynamic-RPS/LCF Derived NEP)	Early-stage R&D focusing on transformational STP capability to enable solar perihelion burn Oberth maneuvers and the attainment of high solar system escape velocities	Early-stage R&D focused on rapid prototype demonstration of nuclear fusion propulsion technologies and AEP concepts to achieve transformational capabilities for fast & efficient solar system wide access

Transformational Capability R&D — TRL 3-6

Near Term — **Long Term**

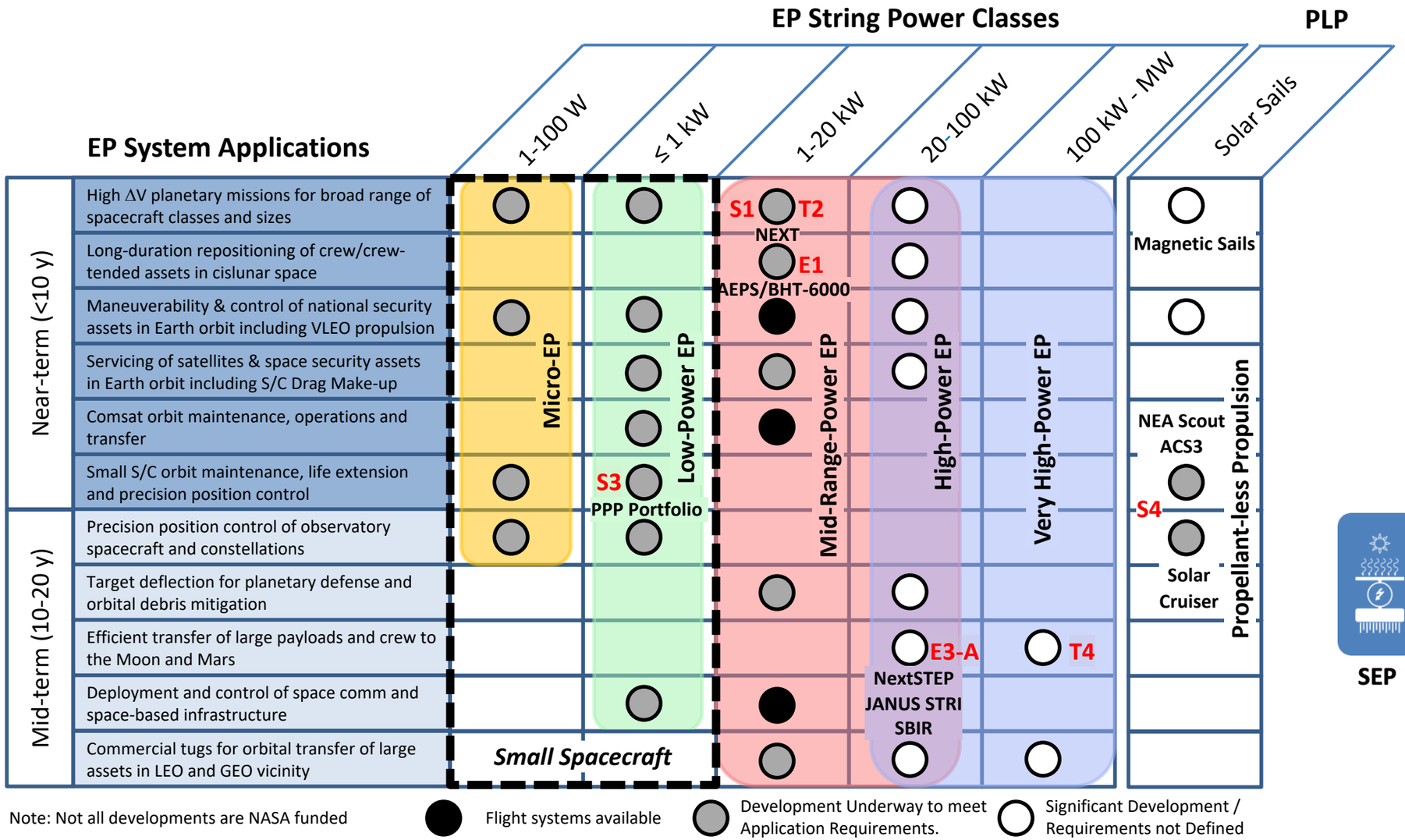
Exploration Architectures

Science, Commerce & Security

Inspiration Driven Research

SOA – ELECTRIC PROPULSION SYSTEMS

Historical Developments & Projected Capabilities



Note: Not all developments are NASA funded

● Flight systems available

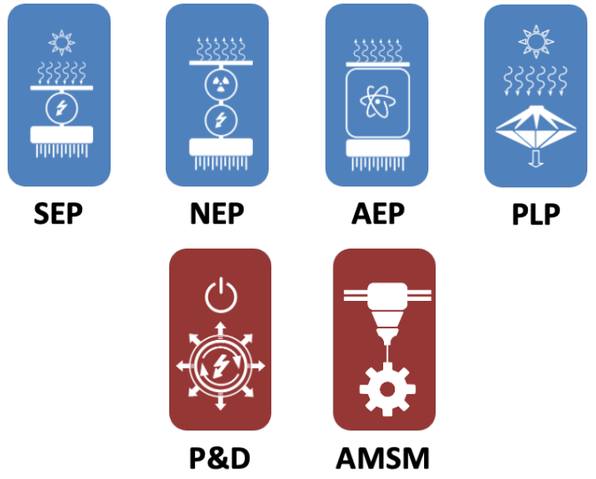
◉ Development Underway to meet Application Requirements.

○ Significant Development / Requirements not Defined

Technology Objective Index

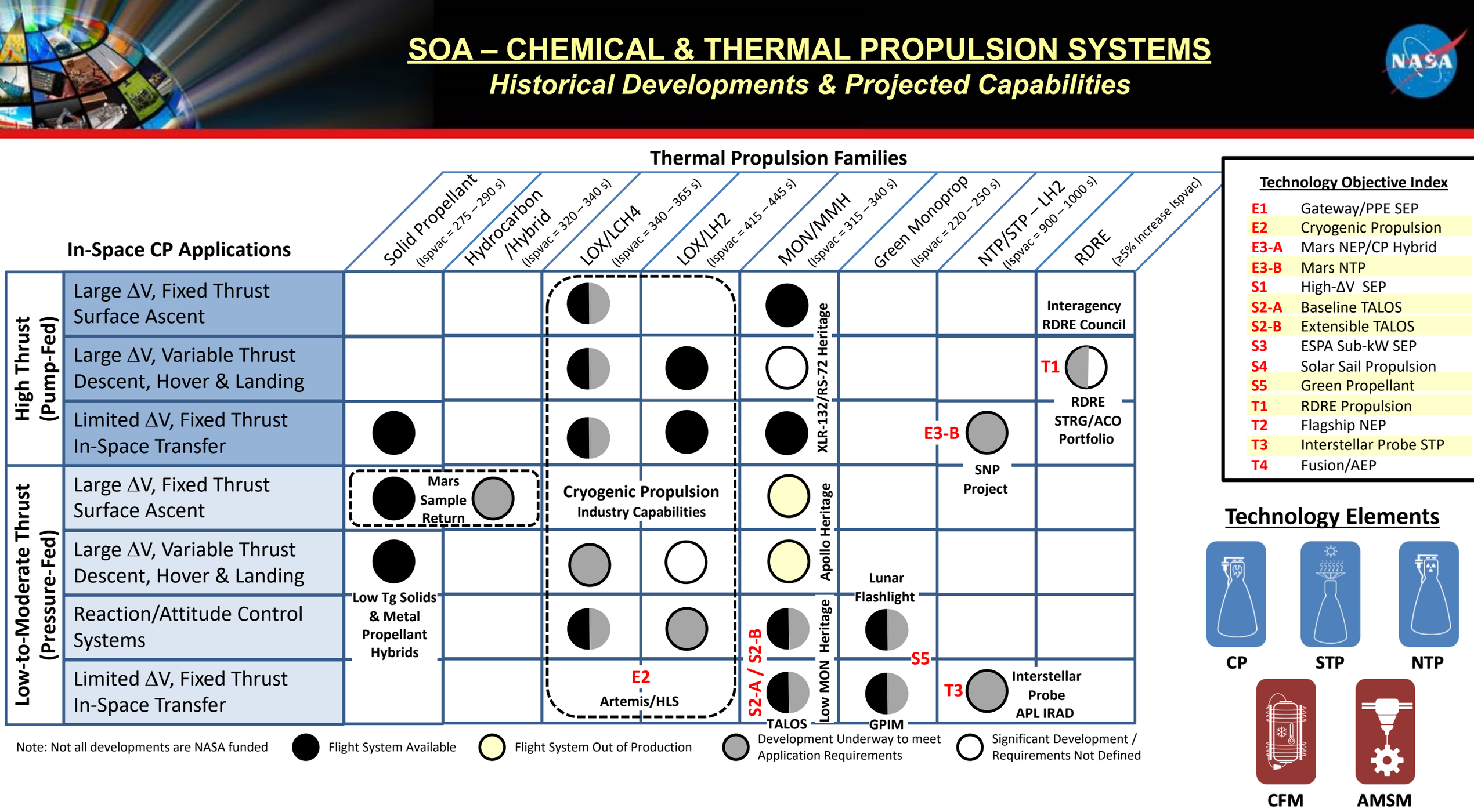
E1	Gateway/PPE SEP
E2	Cryogenic Propulsion
E3-A	Mars NEP/CP Hybrid
E3-B	Mars NTP
S1	High-ΔV SEP
S2-A	Baseline TALOS
S2-B	Extensible TALOS
S3	ESPA Sub-kW SEP
S4	Solar Sail Propulsion
S5	Green Propellant
T1	RDRE Propulsion
T2	Flagship NEP
T3	Interstellar Probe STP
T4	Fusion/AEP

Technology Elements



SOA – CHEMICAL & THERMAL PROPULSION SYSTEMS

Historical Developments & Projected Capabilities



Technology Objective Index

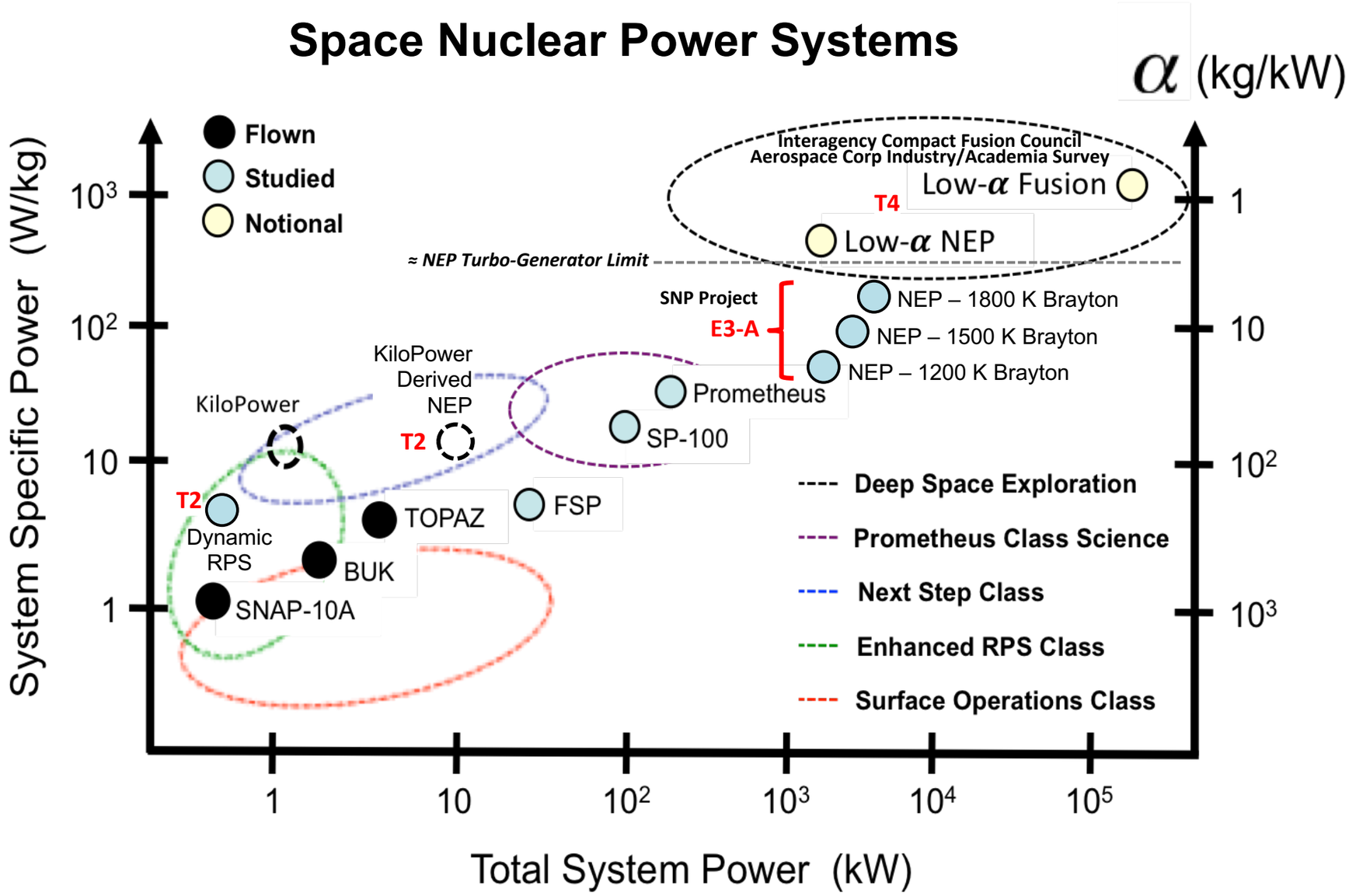
E1	Gateway/PPE SEP
E2	Cryogenic Propulsion
E3-A	Mars NEP/CP Hybrid
E3-B	Mars NTP
S1	High-ΔV SEP
S2-A	Baseline TALOS
S2-B	Extensible TALOS
S3	ESPA Sub-kW SEP
S4	Solar Sail Propulsion
S5	Green Propellant
T1	RDRE Propulsion
T2	Flagship NEP
T3	Interstellar Probe STP
T4	Fusion/AEP

Technology Elements

SOA – SPACE NUCLEAR PROPULSION & POWER SYSTEMS

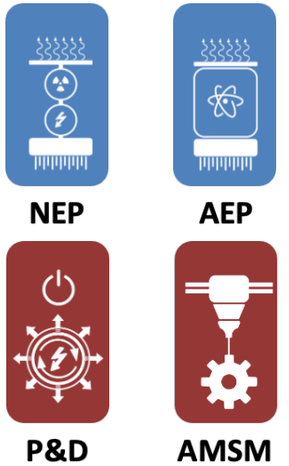
Historical Developments & Projected Capabilities

Space Nuclear Power Systems



Technology Objective Index	
E1	Gateway/PPE SEP
E2	Cryogenic Propulsion
E3-A	Mars NEP/CP Hybrid
E3-B	Mars NTP
S1	High-ΔV SEP
S2-A	Baseline TALOS
S2-B	Extensible TALOS
S3	ESPA Sub-kW SEP
S4	Solar Sail Propulsion
S5	Green Propellant
T1	RDRE Propulsion
T2	Flagship NEP
T3	Interstellar Probe STP
T4	Fusion/AEP

Technology Elements



CONCLUSIONS & HIGH LEVEL DEVELOPMENT STRATEGY

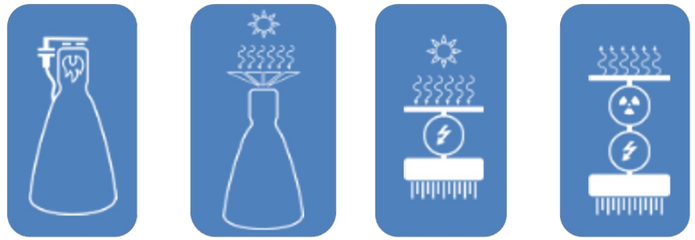
- **Architecture Driven Propulsion Technology Strategy is Essentially On Track**
  - Emphasis on sustained portfolio execution & commitment to deliveries, including accommodation of ground infrastructure impacts
  - Additional mid-TRL investment is needed in a few priority areas (e.g., ESPA-Class Sub-kW EP & Beyond NextSTEP High-Power EP)
- **Transformational Capability R&D Portfolio in need of Programmatic Restructuring & Significant Funding Augmentation**
- **High Level Development Strategy**

Architectural Outcome	Technology Capability Goal	Recommended Action	Investment Trend
Gateway/PPE SEP	12 kWe & 6 kWe HET Strings	Sustain Execution & Commitment to PPE/Gateway Delivery	Sustain
Flagship High-ΔV SEP	7-14 kWe Gridded Ion EP String	Develop Advanced NEXT via Interagency Collaboration + SBIR + PPP	Augment
High-Power Exploration NEP	100 kWe HET, MPD, VASIMR, etc.	Industry Led Development/Qual via STRG + SBIR + PPP (i.e., Beyond NextSTEP)	Augment
ESPA-Class High-ΔV SEP	0.5-1 kWe (nominal) EP String	Industry Led Development/Qualification/Demo via SST/GCD PPP	Augment
Extreme Cold Environment CP	Baseline MON25/MMH TALOS	Sustain Execution & Commitment to PPP CLPS Delivery	Sustain
	Deep Space Variant TALOS	Commit to Industry Led Development/Qualification via PPP	Augment
Green Propellant CP	Reduced Cost / Expanded Thrust Range	Facilitate Infusion & Industry Led Development via SBIR/STTR + PPP + Incentives	Sustain
Unlimited ΔV Platforms PLP	Flight Demonstrated Solar Sail Technology	Monitor Solar Cruiser + Supplemental Tech Dev + SBIR/STTR + Early-Stage R&D	Sustain
RDRE CP	Transformative CP Performance	Sustain Early-Stage R&D & Transition to FY23 Mid-TRL Prototype Development	Augment
Flagship NEP	Transformative Robotic Science NEP	Evaluate/Facilitate FSP/Dynamic-RPS/LCF NEP System Integration & Maturation	Augment
Interstellar Probe Near Sun STP	Transformative Near Sun STP Capability	Sustain Early-Stage R&D & Transition to FY23 Mid-TRL Prototype Development	Augment
Fusion/AEP Concepts	Transformative Fusion/AEP Capability	Establish Comprehensive Nuclear Fusion/AEP Early-Stage R&D Portfolio	Augment

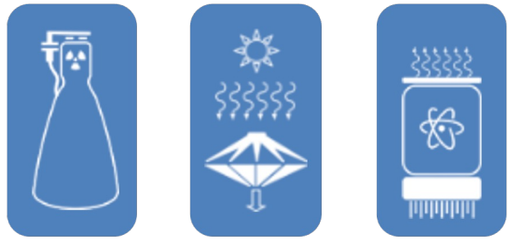
ADVANCED PROPULSION TECHNOLOGY DOMAIN

Taxonomy & Acronym Glossary

PROPULSION TECHNOLOGIES



CP STP SEP NEP



NTP PLP AEP

CROSS-CUTTING SUPPORT TECHNOLOGIES

CFM AMSM P&D

AEP – Advanced Energetic Propulsion
ACO – Announcement of Collaborative Opportunity
ACS – Attitude Control System
AMSM – Advanced Materials, Structures & Manufacturing
AU – Astronomical Units
BHT-6000 – Busek Hall Thruster (6kWe)
BUK – Soviet Era Fast Fission Space Reactor (Derived from Bouk → "Beech Tree")
CP – Chemical Propulsion
c – Speed of Light
CFM – Cryogenic Fluid Management
CLPS – Commercial Lunar Payload Services
EML1 – Earth Moon Lagrange Point 1
Enceladus – Icy Moon of Saturn
EP – Electric Propulsion
ESPA – Evolved Secondary Payload Adaptor
FSP – Fission Surface Power
GCD – Games Changing Development (Program)
GEO – Geo Synchronous Orbit
GIT – Gridded Ion Thruster
GPIM – Green Propulsion Infusion Mission
GTO – Geo Transfer Orbit
HET – Hall Effect Thruster
HLS – Human Landing System
IRAD – Internal R&D
ISM – Interstellar Medium
Ispvac – Vacuum Specific Impulse
KBO – Kuiper Belt Object

ACRONYMS

LCF – Lattice Confined Fusion
LEO – Low Earth Orbit
LLO – Low Lunar Orbit
LOX – Liquid Oxygen
LY – Light Year
MMH – Mono-Methyl Hydrazine
MON – Mixed Oxides of Nitrogen
MPD – Magneto Plasma Dynamic (Thruster)
MPS – Main Propulsion System
NASA – National Aeronautics and Space Administration
NEA – Near Earth Asteroid
NEO – Near Earth Object
NEP – Nuclear Electric Propulsion
NEXT – Next Evolutionary Xenon Thruster
NRHO – Near Rectilinear Halo Orbit
NTP – Nuclear Thermal Propulsion
OMS – Orbital Maneuvering System
PLP – Propellant-Less Propulsion
PPE – Propulsion & Power Element (Foundational Gateway)
PPP – Public Private Partnership
PPU – Power Processing Unit
P&D – Power & Distribution
R&D – Research & Development
RCS – Reaction Control System
RDRE – Rotating Detonation Rocket Engine
RPS – Radioisotope Power System
SBIR – Small Business Innovation Research (Program)
S/C – Spacecraft
SEP – Solar Electric Propulsion
SIMPLEx – Small Innovative Missions for Planetary Exploration
SMD – Science Mission Directorate
SOA – State of Art
SNAP-10A – System for Nuclear Auxiliary Power
SNP – Space Nuclear Propulsion (Project)
SP-100 – Space Reactor Prototype
SST – Small Spacecraft Technology (Program)
STP – Solar Thermal Propulsion
STRG – Space Technology Research Grants
STTR – Small Business Technology Transfer
TALOS – Thruster Advancement for Low Temperature Operations in Space
TDM – Technology Demonstration Mission (Program)
TOPAZ – Soviet Era Thermal Fission Space Reactor
TP – Tipping Point
TRL – Technology Readiness Level
T/W – Thrust-to-Weight (ratio)
VASIMR – Variable Specific impulse Magnetoplasma Rocket
VLEO – Very Low Earth Orbit
ZBO – Zero Boil Off
α – System Specific Mass (kg/kW)
ΔV – Spacecraft Velocity Change

CHANGE LOG 2023

Slide 2 – Space Flight Architecture Domains
- New Bullet – “Human Transportation” bullet under LEO to Cislunar
- Change Bullet – “Science Payloads” to “Lunar and Inner Solar System Payloads” under LEO to Cislunar
- New Bullet – “ Cargo & Science Instrument Payloads” under Meso-Solar

Slide 3 – STMD Strategic Framework Envisioned Future
- Change Bullet – “Sustained Investment in Advanced Energetic Propulsion research & innovation enables new breakthrough technologies

Slide 4 – Advanced Propulsion Capability Outcomes
- Change E3-B: NTP – “… OMS …” to “… Orbital Maneuvering System (OMS) …”
- Change S2-A: Baseline TALOS – “… extreme environment …” to “… universal …”

Slide 5 – SOA – Electric Propulsion Systems
- Add Technology Reference – “AEPS/BHT-6000”
- Add Technology Reference – “Magnetic Sails”

Slide 6 – SOA – Chemical & Thermal Propulsion Systems
- Add Technology Reference – “Low Tg Solids & Metal Propellant Hybrids”

Slide 8 – SOA – Conclusions & High Level Development Strategy
- Change Technology Capability Goal for Gateway/PPE SEP – “12 kWe & 6 kWe HET Strings”

Slide 9 – Advanced Propulsion Technology Domain
- Add Acronym – “KBO – Kuiper Belt Object”
- Add Acronym – “OMS – Orbital Maneuvering System”