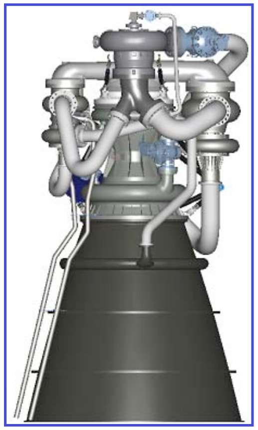
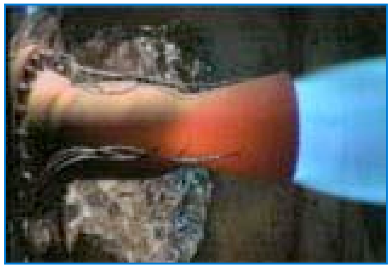
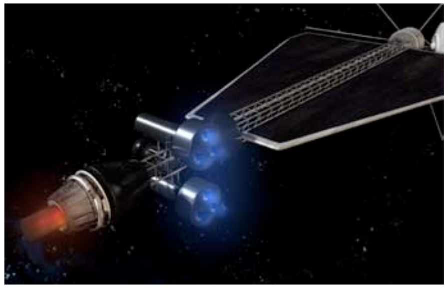






Future Directions for Space Transportation and Propulsion at NASA

5th International Symposium on Liquid Space Propulsion
Long-Life Combustion Devices Technology
Chattanooga, TN
October 27-30, 2003

Robert L. Sackheim
Assistant Director and
Chief Engineer for Propulsion
NASA Marshall Space Flight Center

The NASA Mission:

To understand and protect our home planet,

To explore the universe and search for life,

To inspire the next generation of explorers . . .

. . . as only NASA can.

Space Is Critical to the World

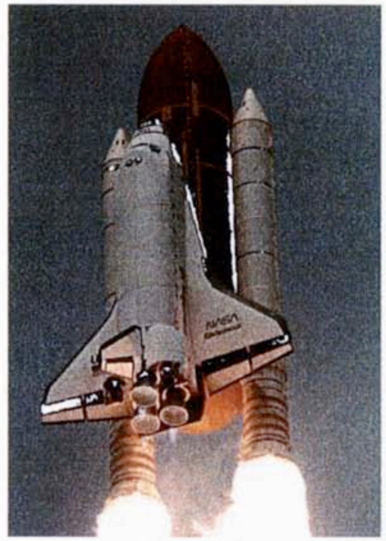
The New International "Ocean"

- Scientific Discovery
  - The Search for Life Beyond Earth
  - Understanding our Planet
  - Understanding our Universe
  - Exploration of the Planets and Beyond
- The Ultimate High Ground for National Security
  - Intelligence, Communications, Rapid Response, GPS . . . World Wide
- "Space-Based" Commerce
  - Communications and Earth Observing

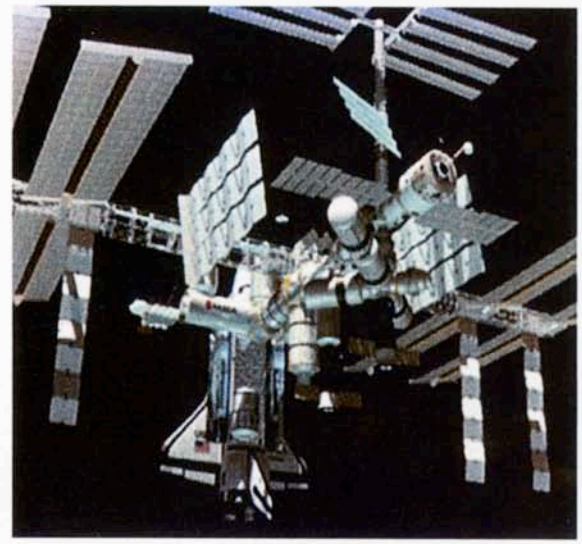
Yet it Remains the Last, Largely Untapped Frontier

MSFC's Heritage – Complex Programs Requiring a Strong Systems Engineering Focus

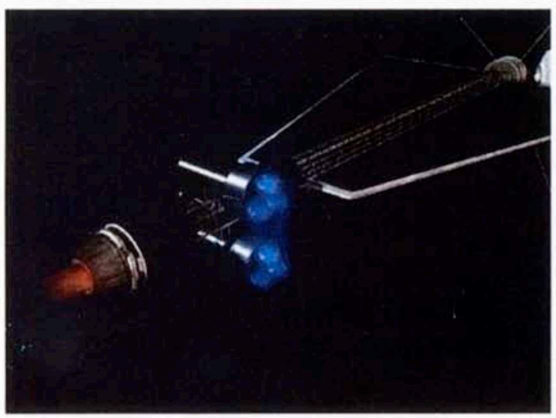
SATURN V



SHUTTLE



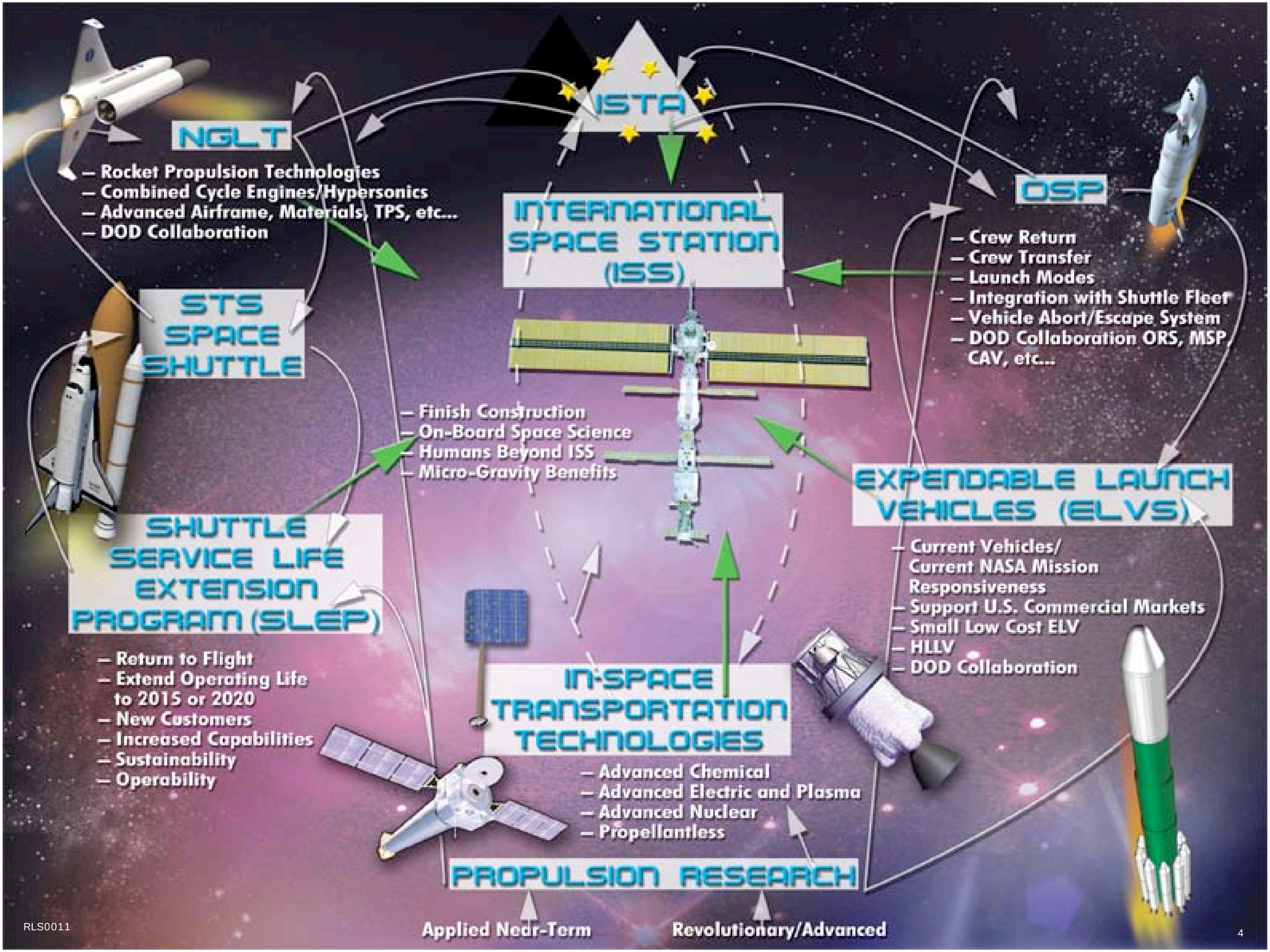
SPACE STATION



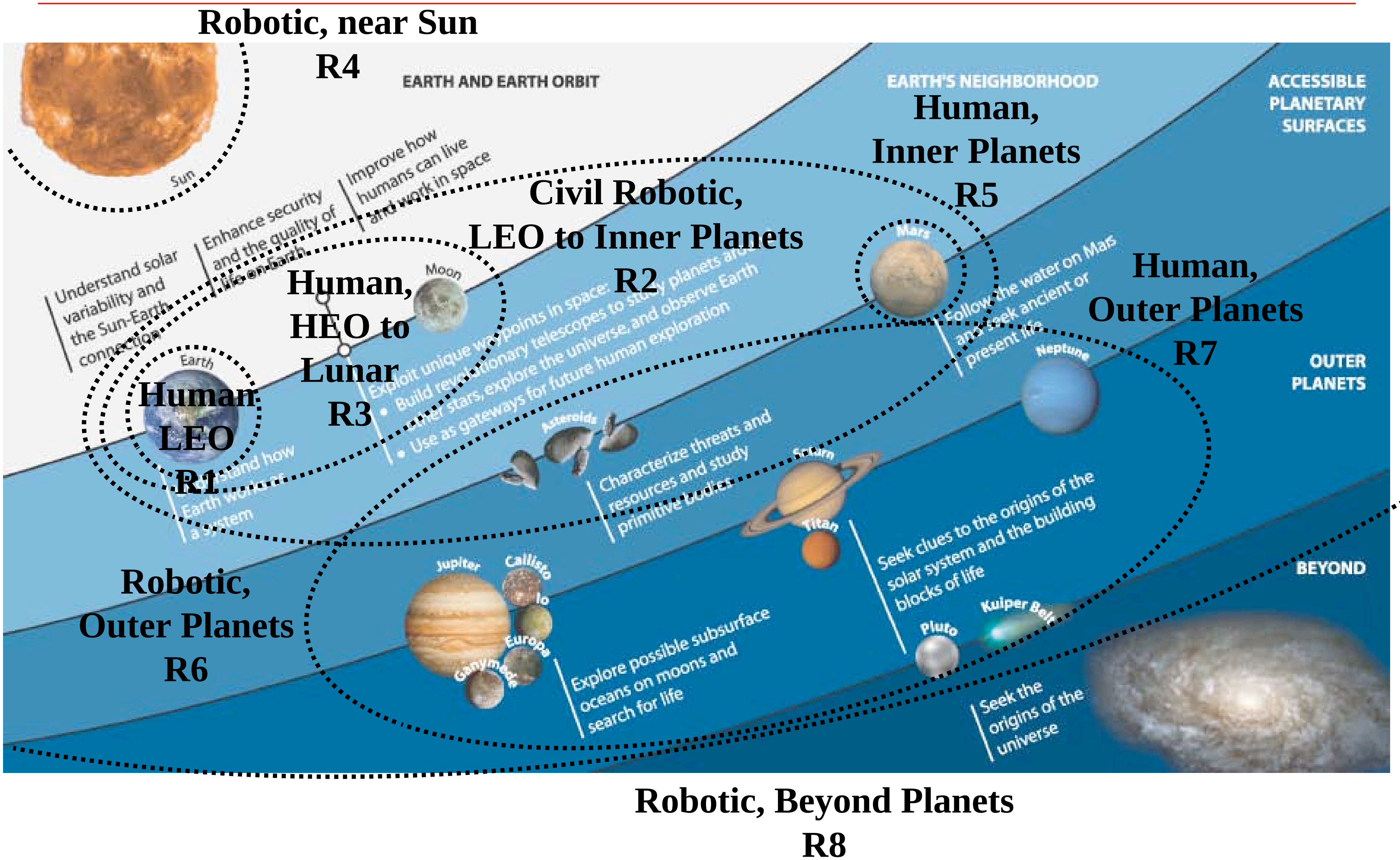
NEP VEHICLE DESIGN

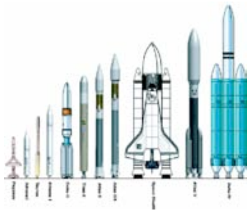
CHANDRA

INERTIAL UPPER STAGE


ISTA
NGLT
– Rocket Propulsion Technologies
– Combined Cycle Engines/Hypersonics
– Advanced Airframe, Materials, TPS, etc...
– DOD Collaboration
INTERNATIONAL SPACE STATION (ISS)
OSP
– Crew Return
– Crew Transfer
– Launch Modes
– Integration with Shuttle Fleet
– Vehicle Abort/Escape System
– DOD Collaboration ORS, MSP, CAV, etc...
STS SPACE SHUTTLE
– Finish Construction
– On-Board Space Science
– Humans Beyond ISS
– Micro-Gravity Benefits
EXPENDABLE LAUNCH VEHICLES (ELVS)
– Current Vehicles/ Current NASA Mission Responsiveness
– Support U.S. Commercial Markets
– Small Low Cost ELV
– HLLV
– DOD Collaboration
SHUTTLE SERVICE LIFE EXTENSION PROGRAM (SLEP)
– Return to Flight
– Extend Operating Life to 2015 or 2020
– New Customers
– Increased Capabilities
– Sustainability
– Operability
IN-SPACE TRANSPORTATION TECHNOLOGIES
– Advanced Chemical
– Advanced Electric and Plasma
– Advanced Nuclear
– Propellantless
PROPULSION RESEARCH
Applied Near-Term
Revolutionary/Advanced
RLS0011

Stepping Stones Overlay on Space Transportation Regimes



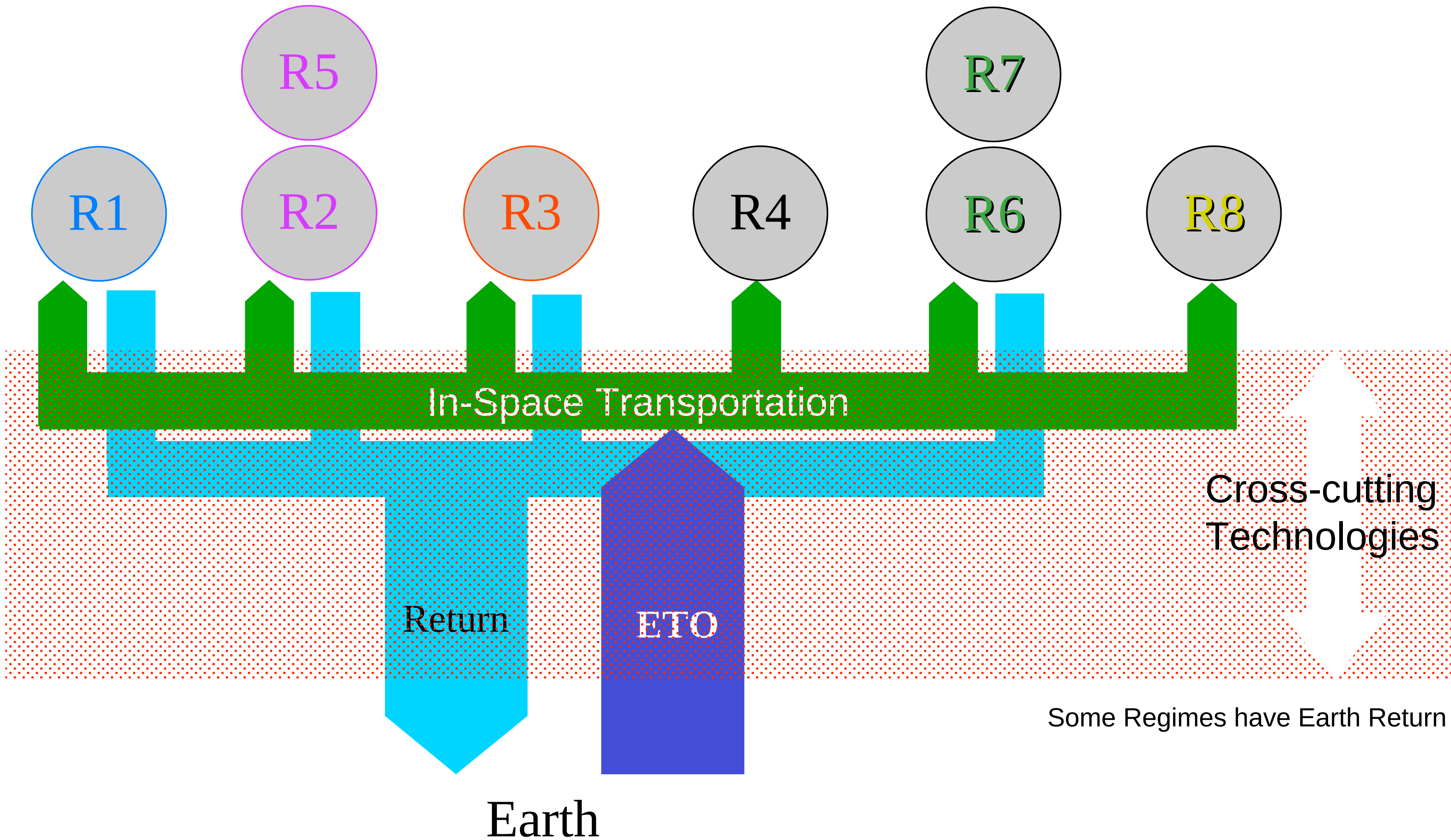


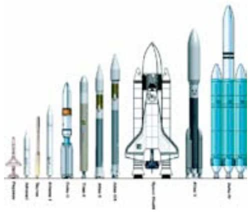
Regime Descriptors and Needs

R1	Human Earth Orbit	ISS and other near-Earth missions	Frequent access; safety; medium cargo; reduced cost
R2	Robotic LEO to near planets	Earth & space observation; planetary science; sample return	State of art mainly OK; reduced cost; higher reliability; landing & ascent systems
R3	Human HEO and lunar	Missions in cislunar space & lunar surface and basing	Medium space transfer/cargo, landing, safety, reduced cost
R4	Robotic near-Sun	Mercury, solar probes, solar polar	High delta V, reduced cost, ETO state of art OK
R5	Human near planets	Mars and Mars surface, asteroids, exploration and basing	Increased lift to LEO, heavy space transfer, short trip time, reduced cost, safety, artificial g
R6	Robotic outer planets	Orbiters, probes, landers, sample return	Reduced trip time, high/very high delta V, nuclear electric power, reduced cost, ETO state of art OK
R7	Human outer planets	To Jupiter and Saturn moons, landing, return	Fast trips, very high delta V, heavy space transfer, nuclear power
R8	Robotic beyond planetary system	Kuiper belt, Oort cloud, interstellar medium	Very/extremely high delta V, nuclear electric power

End-to-End Regimes Capture Mission Requirements

Equal emphasis over all Regimes favors NASA-Wide Propulsion Requirements





Office of the Space Architect

Work Breakdown Structure

Space Architect

1.0 Management & Integration

- Policy & Governance
- Systems Engineering
- Integrated Space Plan
- Annual SA Program Formulation
- Architecture Study Direction
- Integrated Reference Architectures
- New Initiative Evaluations
- Current Program Evaluations
- SA Board Recommendations
- Communications Strategy

2.0 Architecture Studies

- Management Integration & Administration
- Architecture Options
- Reference Missions
- Capability/needs Identification
- Leveraged Studies
- ISP Support
- CRAI Support
- System Support

3.0 Transportation

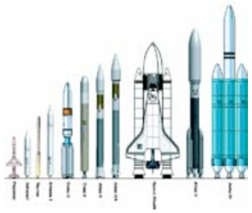
- Management Integration & Administration
- ISTP
- ISP Support
- CRAI Support
- Architecture Support
- Special Studies
- Leveraged Studies

4.0 CRAI

- Management Integration & Administration
- Integrated Roadmaps
- Capability/need Identification
- Capability/need analysis & Assessment
- Gap Analysis
- Investment Strategies
- ISP Support
- Architecture Support
- System Support
- Leveraged programs

5.0 Special Studies and Leveraging

- Management Integration & Administration
- Leveraged Studies



Integrated Space Transportation Architecture Inputs to the Space Architecture Work Breakdown Structure Format

1.0 Space Architect - Gary Martin, Headquarters

2.0 Integrated Space Transportation Architecture (ISTA)

3.0 MSFC POC/Bob Sackheim

Inputs to/from CRAI Team

3.1 ETO/ISTP

3.1.1 Shuttle (SSP)
- RTF
- Sustained Operations
- SLEP

3.1.2 NGLT
- ORSC Engine
- Green RCS/OMS
- Advanced Avionics
- Thermal Protect Systm
- Structure
- Tanks
- Upgraded Liquid Oxygen
- Liquid Hydrogen (Cobra Type)
- (LH_2 TCA)
- IVHM
- Hypersonics/NAI, CCEs

3.1.3 OSP
- Capsule
- Winged/Aero
- Lifted Body/Aero

3.1.4 ELVs
- Small Launchers (SELV's)
- Existing ELV's
- HLLVs

3.2 Baseline Enabling Research

3.2.1 Applied Research
- Better Nozzles, etc.

3.2.2 Fundamental Research
- Antimatter
- Advanced Nuclear, etc.

3.3 In-space Propulsion

3.3.1 Conventional Functions

3.3.1.1 Orbit Transfer
3.3.1.2 AVCS
3.3.1.3 Pointing
3.3.1.4 NSSK
3.3.1.5 EWSK
3.3.1.6 Orbit Adjust
3.3.1.7 Drag Make-up

3.3.2 Non-conventional Approach

3.3.2.1 Sails
3.3.2.2 Tethers
3.3.2.3 Aero Assist Tech

3.3.3 Orbiter Vehicle In-Space Control Functions

3.3.3.1 OMS & RCS

3.3.4 Nuclear Propulsion

MMRPS/RTG/RPS

REP

NEP

Nuclear Power /EP/NTR/Converter Technology

3.4 Planetary Operations

3.4.1 Aero Assist
- Aero Braking
- Aero Capture

3.4.2 Entry Descent & Landing (EDL)

3.4.3 Ascent Vehicles

3.5 In-space Infrastructure

3.5.1 ISRU

3.5.2 Fluid/Propellant Depots

3.5.3 In-Space Fluid Transfer Systems

3.6 Special Studies

3.6.1 Special Architecture Studies

3.6.2 Special Study Support

3.6.3 Humans Beyond ISS

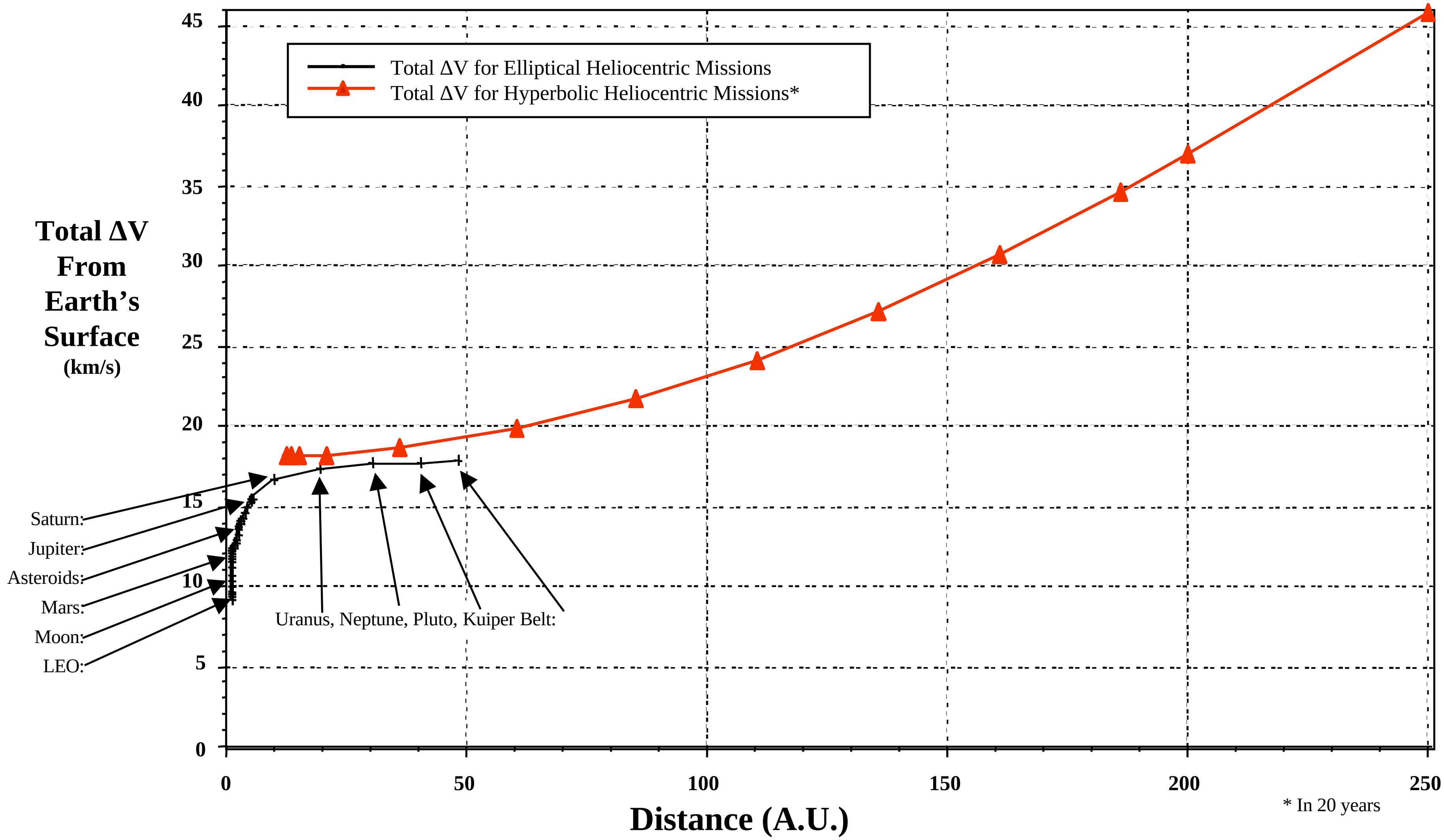
3.6.4 Stations at Lagrange L-1/L-2 Moon/Sun

3.6.5 Studies/Analysis tools, e.g. ISEAP

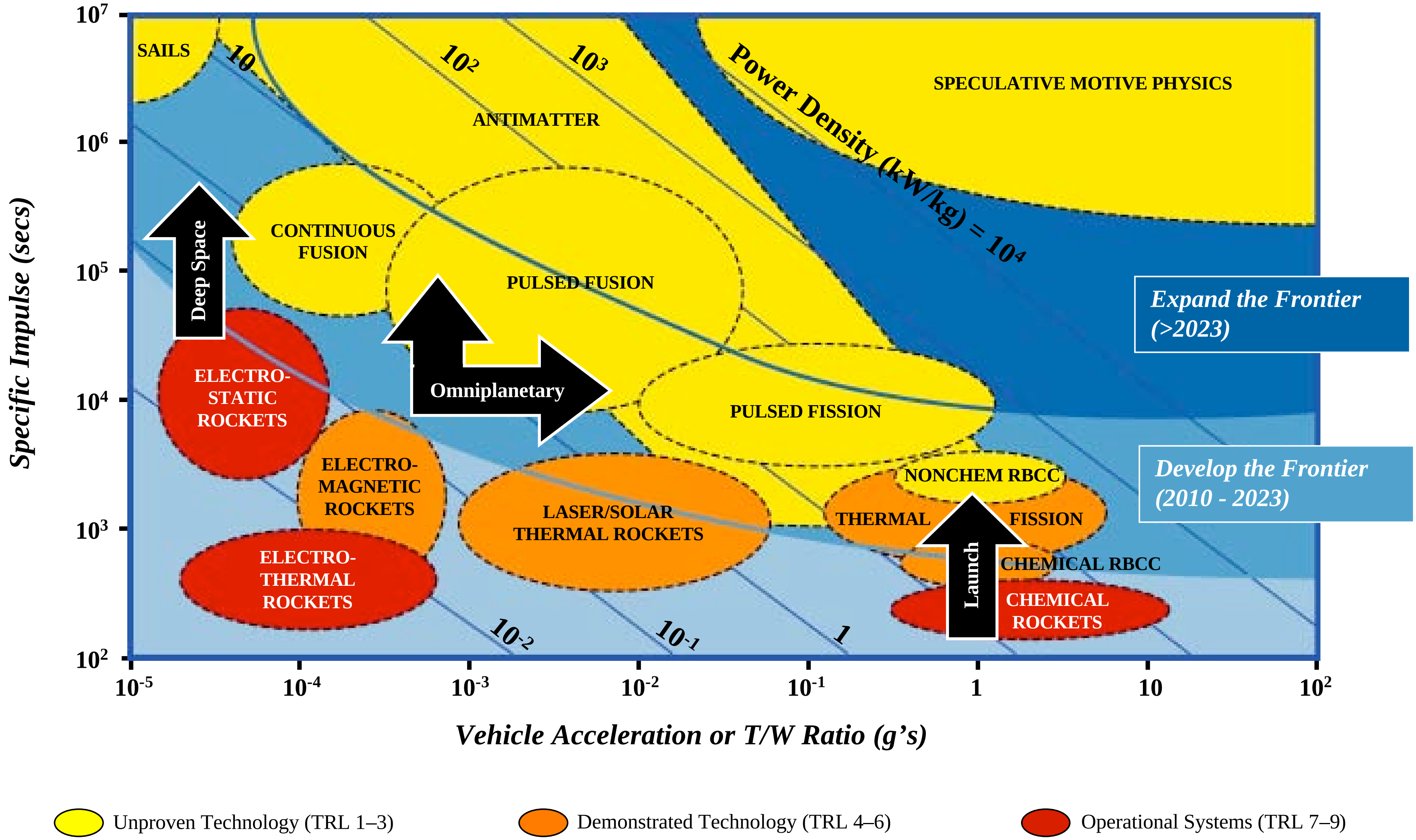
The Physics Problem

Energy Comparison for Various Distances

Single Burn Delta V From LEO, ETO ΔV = 9.3 km/s



New Propulsion Technologies are Needed to Meet NASA's Most Ambitious Goals



NGLT
NEXT GENERATION LAUNCH TECHNOLOGY

Safe
Reliable
Affordable

NASA's New Integrated Space Transportation Plan (ISTP)

Space Shuttle Life Extension Upgrades

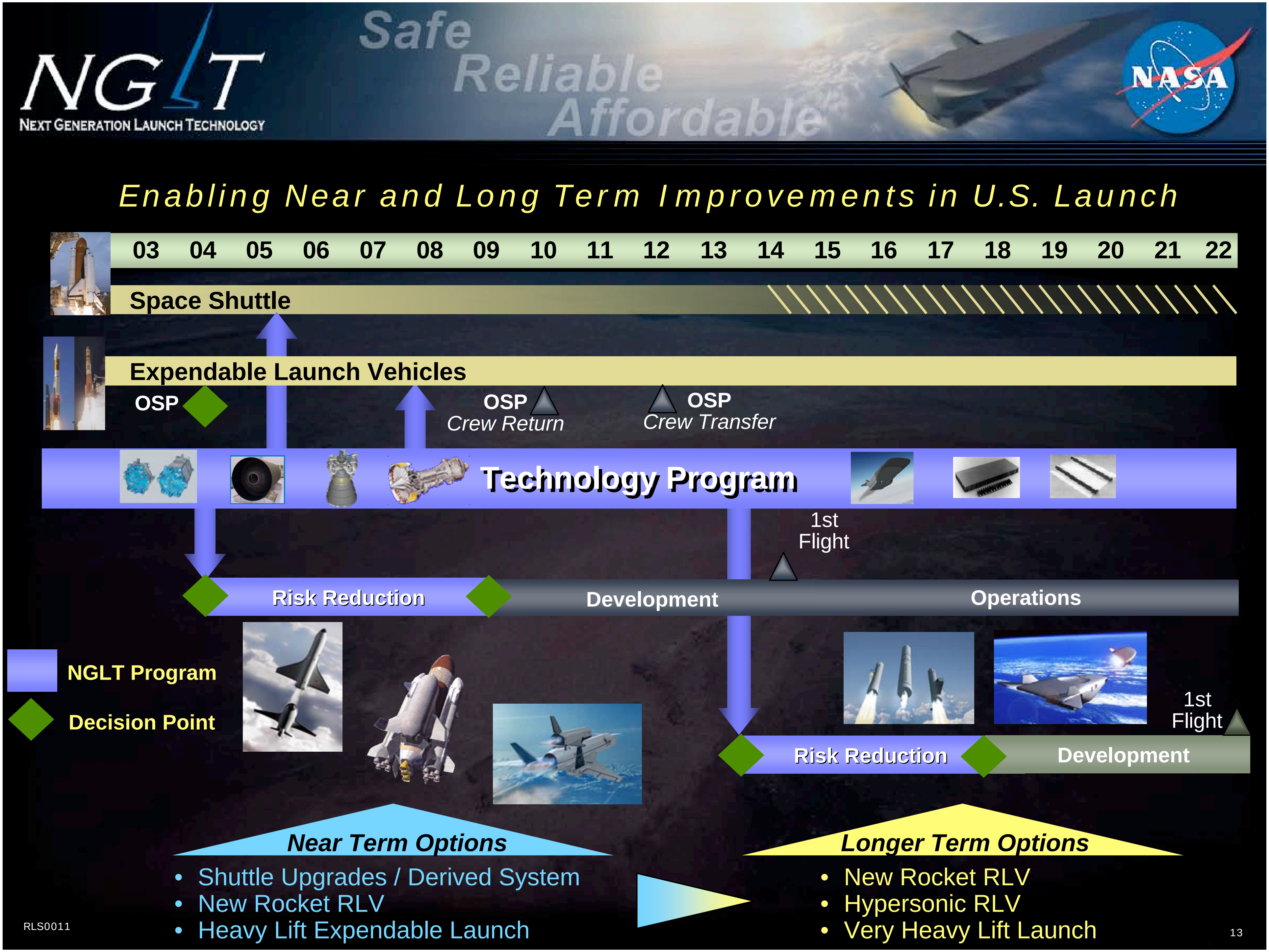
Orbital Space Plane (OSP)

- ***ISS Crew Rescue by 2010***
- ***ISS Crew Transfer by 2012***

SLI
SPACE LAUNCH INITIATIVE

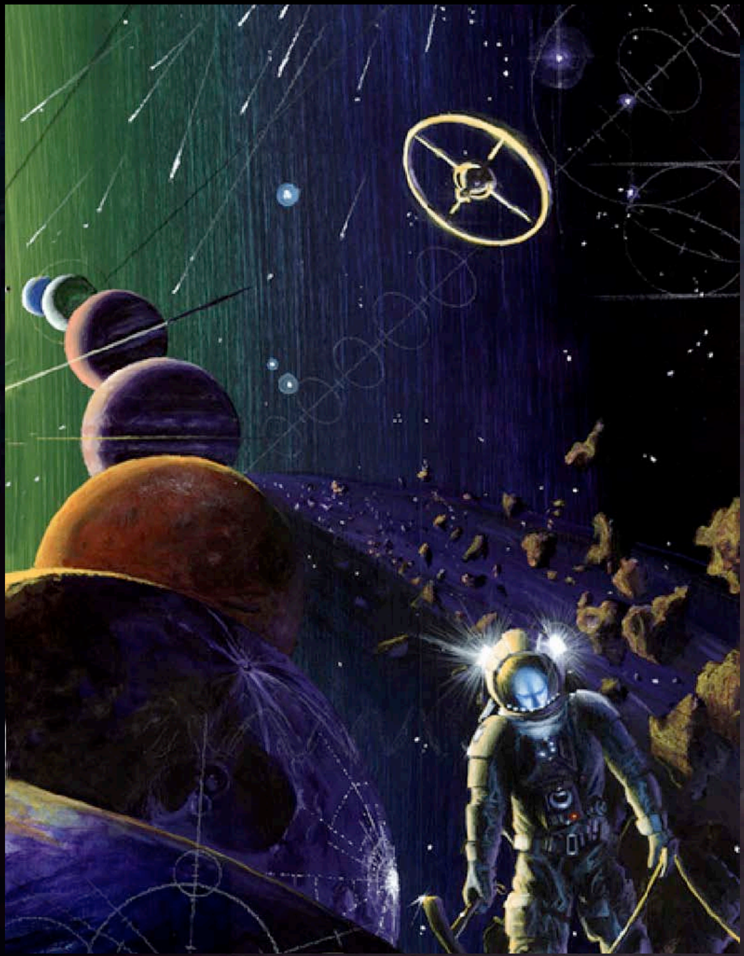
Next Generation Launch Technology (NGLT)

- ***Enabling Future National Launch Capabilities***



NGLT
NEXT GENERATION LAUNCH TECHNOLOGY
Safe
Reliable
Affordable
NASA
Enabling Near and Long Term Improvements in U.S. Launch
03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22
Space Shuttle
Expendable Launch Vehicles
OSP
OSP
Crew Return
OSP
Crew Transfer
Technology Program
1st
Flight
Risk Reduction
Development
Operations
NGLT Program
Decision Point
1st
Flight
Risk Reduction
Development
Near Term Options
• Shuttle Upgrades / Derived System
• New Rocket RLV
• Heavy Lift Expendable Launch
Longer Term Options
• New Rocket RLV
• Hypersonic RLV
• Very Heavy Lift Launch
RLS0011
13

Imagine the Possibilities....

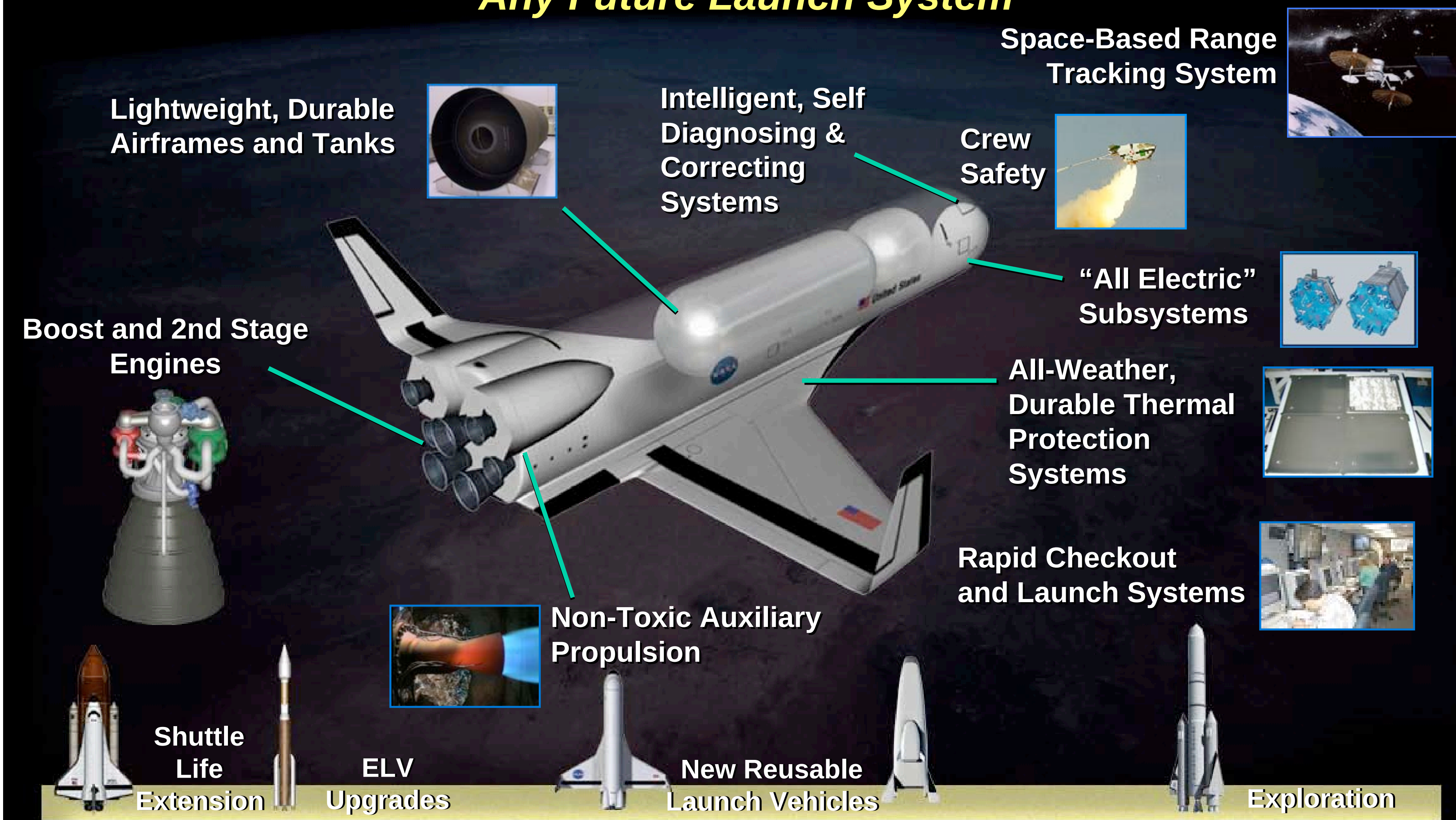


- Significant Expansion in Robotic Probes Going Throughout the Solar System and Beyond
- Humans Exploring Space Beyond Low Earth Orbit
- Space Solar Power Systems Supplying Cheap Electricity Around the Globe
- Daily Tours To and From Space
- Industrial Space Platforms Developing New Materials and Medicines

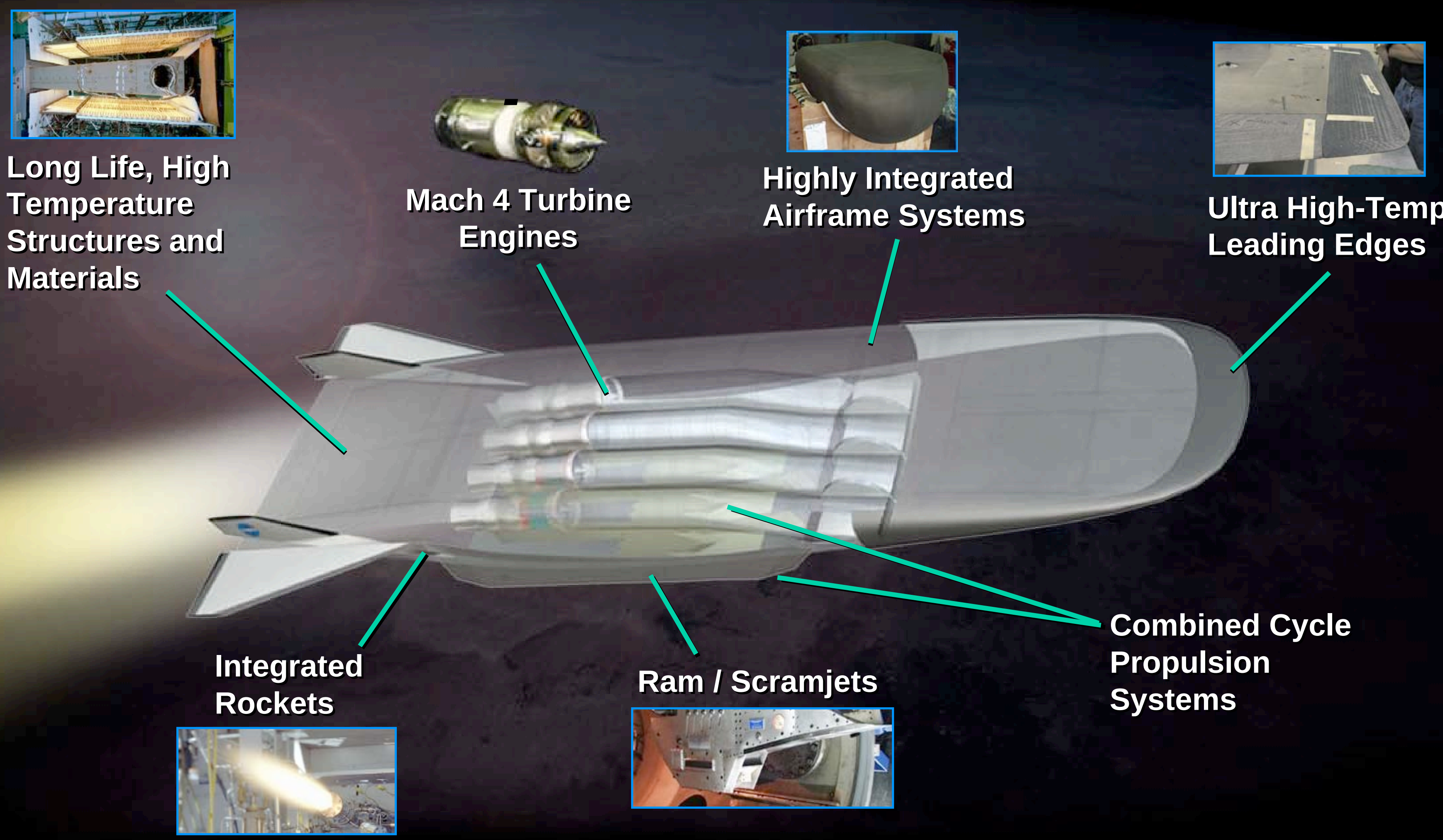
A Primary Limitation is
Safe, Reliable and Affordable Space Launch

Safe
Reliable
Affordable

High Leverage, Cross-Cutting Technologies for Any Future Launch System



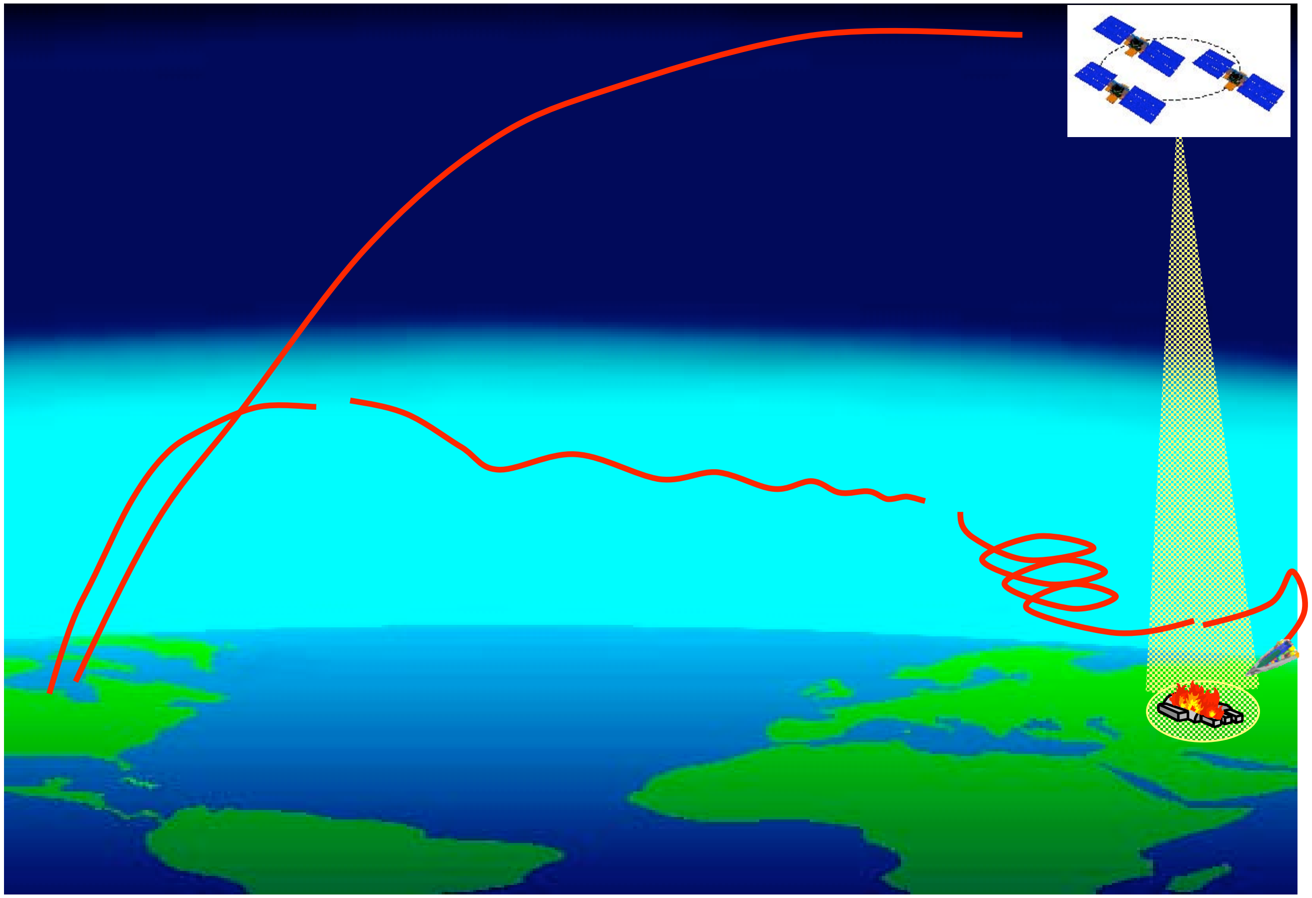
Cutting Edge Hypersonics Technologies for Future, Aircraft–like Operations



DARPA/USAF Small Launcher Initiative

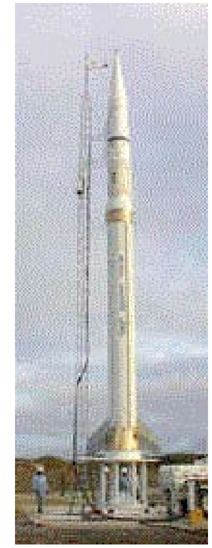
- DARPA and the Air Force have established a joint program
- DARPA has overall program management primacy
- The program is called FALCON (Force Application Launch from CONUS)
- FALCON RFP released on July 29, 2003
- The FALCON SLV initiative has some similarities to MSFC's original Bantam Project

FALCON



FALCON

Many respondents to FALCON RFI (1/30/2003)

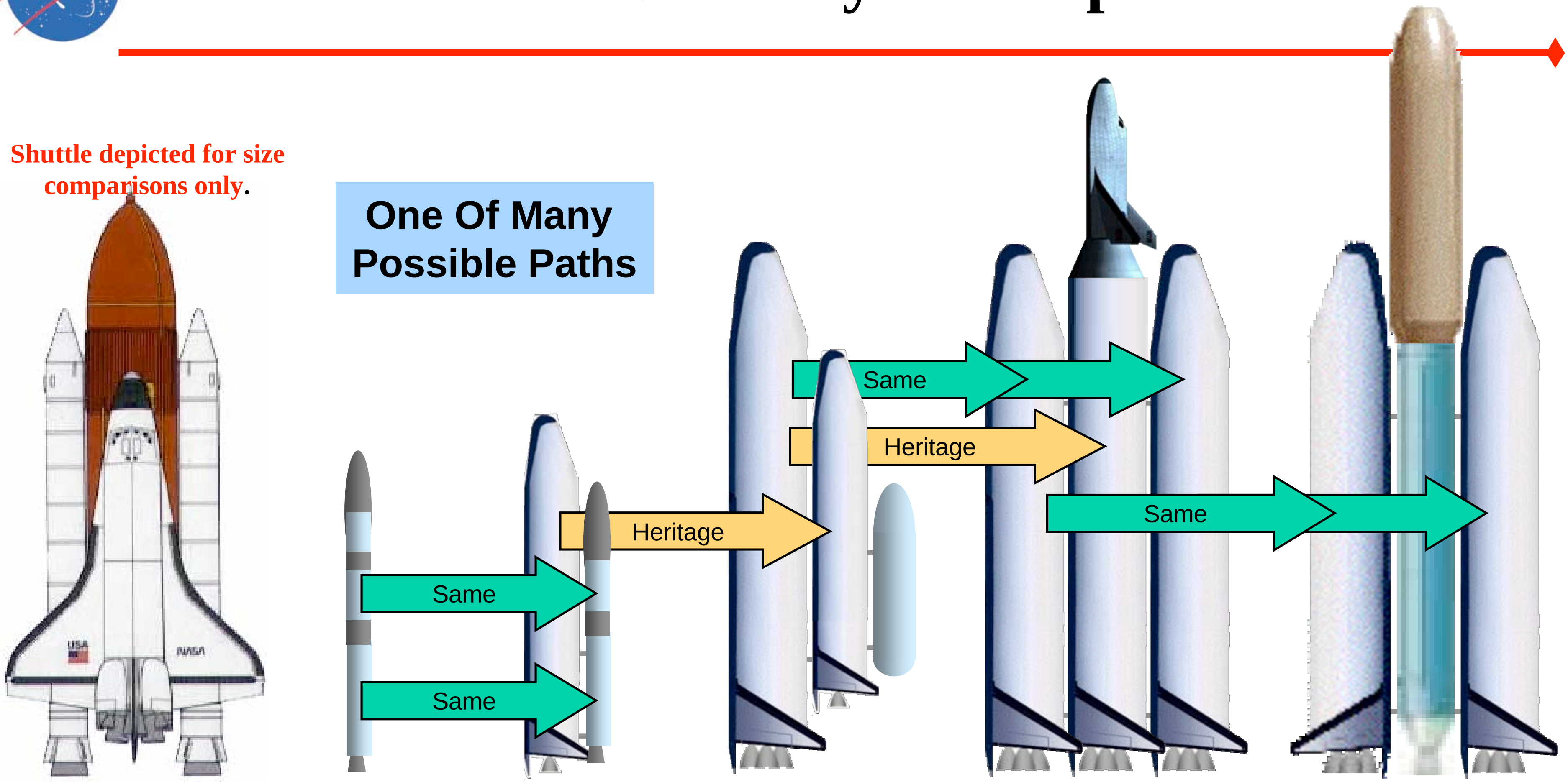


Why Will It Work This Time?

- Simplicity of Design
  - Some simple designs are inherently more reliable and lower cost than others
    - See RLS papers for last 20 years
    - NASA and DOD have really shown zero interest in inherently low costs
- Trade Design Margin Against Performance and Weight
  - Nontraditional aerospace design philosophy
  - Greater design margins enhance reliability
  - Very high Thrust-to-Weight is not that critical for low cost, vertical launch
  - Lower Thrust-to-Weight is more reliable (but vehicle T/W >1.1 @ liftoff)
- Trade Design Margin Against Redundant Systems
  - Redundancy adds complexity and cost
- Use Rack and Stack Design Approach to Achieve Component Commonality
  - Commonality enables simplicity and lowers cost
  - Commonality enhances reliability
  - Provides evolutionary design approach for heavy lift using flight-proven building blocks
- Use Commercial (non-aerospace) Processes and Components As Much as Possible
  - Leverage commercial industry's production rate
  - Commercial components are inherently higher margin; not optimized for performance
  - Commercial hardware is dramatically lower cost than comparable aerospace hardware

Notional Evolutionary Development Path

Shuttle depicted for size comparisons only.



	FALCON	Spiral 1	Spiral 2	Spiral 3	Spiral 4
Stage 1 Engine	New RP	2 SSME	New LH Engine (4)	Same as Spiral 2	Same as Spiral 2
Stage 2 Engine	New RP	FALCON Stage 2	Spiral 1 Stage 1	Same as Stage 1	EELV Core
Stage 3 Engine	New RP	FALCON Stage 3	--	--	EELV US

RLS0011

NGLT
NEXT GENERATION LAUNCH TECHNOLOGY

Safe Reliable Affordable

NASA

Technology Application to Shuttle Upgrades *(Initial NGLT Assessment)*

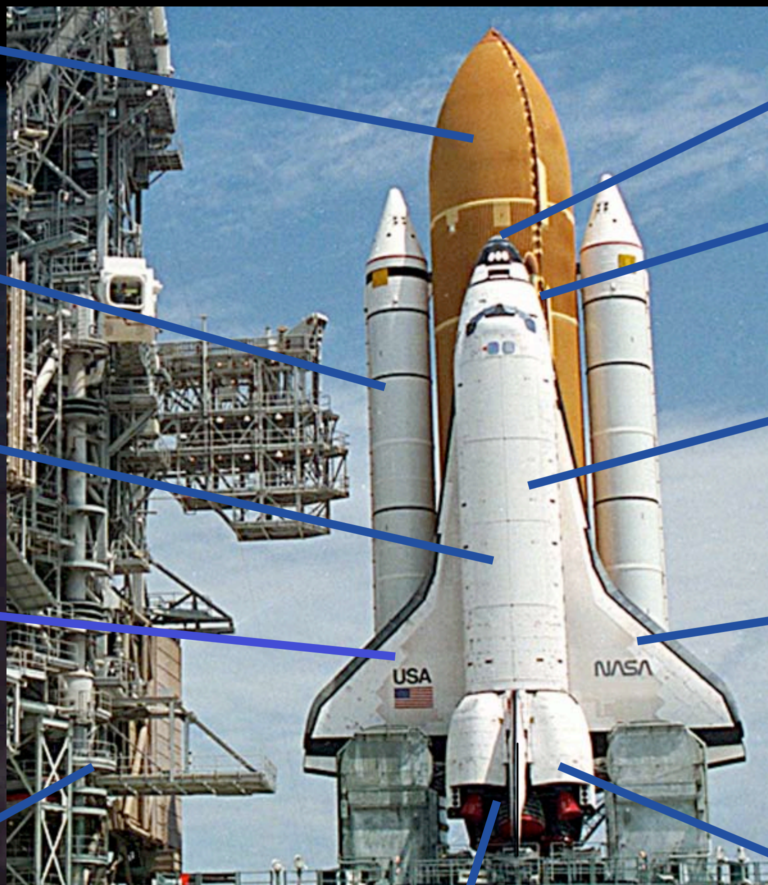
External Tank
- Self Reacting Friction Stir Welding
- Advanced Cryoinsulation

Booster
- LOx/RP liquid booster replacement (1+Mlb Prototype Engine)

Airframe Structure
- Ceramic Matrix Composite Control Surfaces
- Structural Health Monitoring Sensors

Thermal Protection Systems
- Light Weight, Intelligent Micrometeoroid Resistant Ceramic TPS
- Durable, Conformal Reusable Insulation
- Long Life, Durable Thermal Seals
- Rapid Waterproofing

Ground Operations
- Space Based Telemetry and Range Safety
- Silent Sentry/Passive Coherent Location (Advanced Range Technology)
- Range Architecture Development
- Advanced Umbilical Development
- Improved Propellant Management
- Densified Propellants
- Advanced Checkout Control and Maintenance System
- Launch Acoustic Environment Prediction



RCS/OMS
- LOx/Ethanol Dual-Thrust Level RCS Thrusters

IVHM System Integration
- Advanced Systems/Subsystems Diagnostic Algorithms
- IVHM/Flight Operations Integration

Subsystems
- High Horsepower, Electrically Driven Actuators
- PEM Fuel Cells
- Nontoxic Turbine Power Unit

Aero & GN&C Tools
- Separation and Abort Scenarios
- Reentry Heating Environments
- Localized Heating
- Integrated Development and Operations System
- Integrated Aerothermal/TPS Sizing

Aft Compartment
- Oxygen and Hydrogen Leak Detectors

SSME
- IPD Channel Wall Nozzle
- Advanced Turbomachinery
- GRCop-84 Main Combustion Chamber Liner
- Advanced Engine Health Management

Technology Application to Expendable Launch Upgrades *(Initial NGLT Assessment)*

Tanks
- Self Reacting Friction Stir Welding
- Advanced Cryoinsulation

Structures
- Structural Health Monitoring Sensors
- Lightweight metal matrix and polymer matrix composite structures

Ground Operations
- Space Based Telemetry and Range Safety
- Silent Sentry/Passive Coherent Location (Advanced Range Technology)
- Range Architecture Development
- Advanced Umbilical Development
- Improved Propellant Management
- Densified Propellants
- Advanced Checkout Control and Maintenance System
- Launch Acoustic Environment Prediction

IVHM System Integration
- Advanced Systems/Subsystems Diagnostic Algorithms
- IVHM/Flight Operations Integration

Subsystems
- High Horsepower, Electrically Driven Actuators
- PEM Fuel Cells
- Nontoxic Turbine Power Unit

Aero & GN&C Tools
- Separation and Abort Scenarios
- Reentry Heating Environments
- Localized Heating
- Integrated Development and Operations System

Aft Compartment
- Oxygen and Hydrogen Leak Detectors

Replacement RP Engine
- LOx/RP liquid booster replacement (1+Mlb Prototype Engine)

LH_2 Engine Upgrades
- IPD Channel Wall Nozzle
- Advanced Turbomachinery
- GRCop-84 Main Combustion Chamber Liner
- Advanced Engine Health Management

Enabling "Firsts" in Space Launch Technology

Booster Engine Prototype

- Highly reliable hydrocarbon fueled rocket booster engine
- High reliability, long life hydrogen rocket engines

Auxiliary Propulsion

- Non-toxic propellants for orbital propulsion

Vehicle Research and Technology

- Airframes capable of containing cryogenic propellants and reentering the Earth's atmosphere
- Durable high temperature thermal protection systems
- An intelligent, autonomous "all electric" launch system

Propulsion Research & Technology

- Long life, lightweight high temperature materials, seals and components

X-43A and C

- 1st controlled flight of a vehicle powered by a scramjet from Mach 5 - 7 and 10

Revolutionary Turbine Accelerator

- Lightweight, long life jet engines capable of flight at Mach 4

Think of What We Have Accomplished in the 100 years Since the Wright Brothers 1st Flight ……

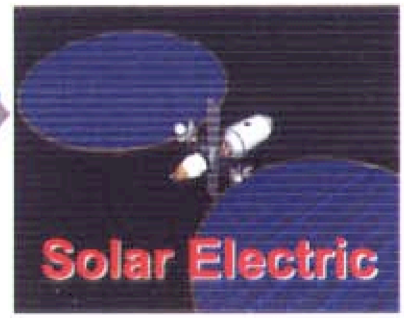
…… Imagine What We Will Do On the New "Ocean of Space"

In-Space Focused Scope

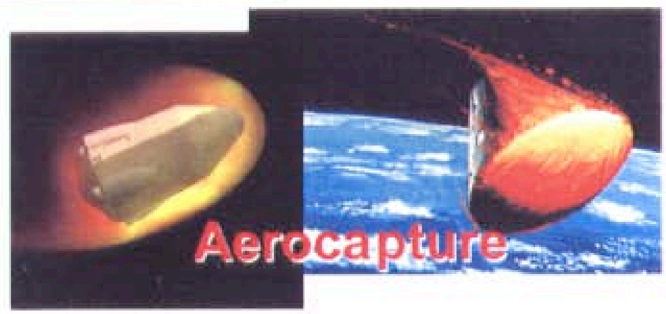
Orbital Transfer Vehicles

Reusable Upperstage

Interplanetary Transfer Stages

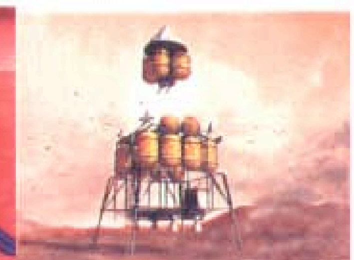


Planetary Capture



Ascent/Descent Stages

Sample return



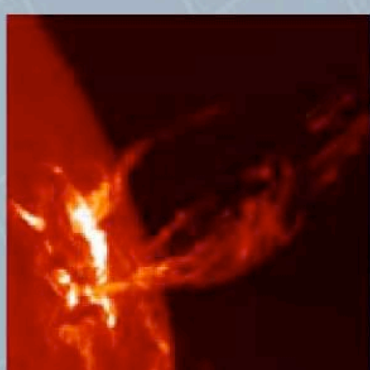
In-Situ Prop/ Ascent Chem Prop Stage

Enabling New Scientific Discoveries

Solar System Exploration

♦ **Planetary Exploration Examples:**
- Orbiters
- Landers
- Sample Return

Sun Earth Connection



♦ **Solar Science Examples (inc. Solar Sails):**
- LaGrange Missions
- Orbiters
- Pole Sitters

In-Space Propulsion Systems

- Space Propulsion Systems for Space Access/Transportation
  - Earth to Orbit
  - In-Space
    - Chemical
      - Liquid Rockets
        - Pump Fed
          - Expander
          - Gas Generator
          - Staged Combustion
          - Enhanced Cycles
          - Hybrids
        - Pressure Fed
          - Liquid
          - Hybrids
      - Solid Rockets
        - see solid propellant options
    - Thermal
      - Solar
      - Fission
      - Fusion
      - Antimatter
    - Electric Propulsion
      - Electro Thermal
      - Electrostatic
      - Electromagnetic
      - Stored Electric Energy Conversion (e.g. Super Flywheels)
    - Proppellantless Propulsion
      - Tethers
      - Sails
        - Solar
        - Plasma
      - Gravity Assist
      - Aeroassist
        - Aerobrake
        - Aerocapture
    - Beamed Energy
      - Laser
        - Thermal
        - Electric
      - Microwave
    - Breakthrough Propulsion Physics
      - Black Hole Assist
      - Space Warps
      - Gravo Magnetic
      - Enhanced Weak Forces
    - Propellants & Propellant Systems
      - In Situ Production
      - Low G Fluid Management
        - Storage
        - Liquid Slush
      - Solids
        - Conventional (1.1 to 1.3)
        - High Energy
      - Liquids
        - Bipropellants
        - Monopropellants
        - Gels
        - Metallized Gels
        - Endothermic
        - High Energy/ Density Mtls
        - LO2/HC
        - All Cryogenic
        - Green/non-toxic
      - Tanks, Fuel lines, Valves and Controls
      - Hybrids

ISP Applic. Range

Expendable
- Small Indep. Upper stage (eg. Centaur, IUS)
- Dumb US (eg. ASUS)
- S/C IPS

Micro-spacecraft
- Formation Flying

Reusable
- Space-Based
- Earth-Based

High-Value Manned Asset Ctrl
- ISS
- Planetary Return/Ascent (w/people)
- Shuttle/RLV OMS and RCS
- Space Tourism

Spacecraft Ctrl (Robotic/Unmanned)
- Drag Makeup
- Station Keeping
- Pointing and ACS
- Controlled Reentry/Disposal

Interstellar Flight

RLS0011

Missions Often Characterized by “Delta V”

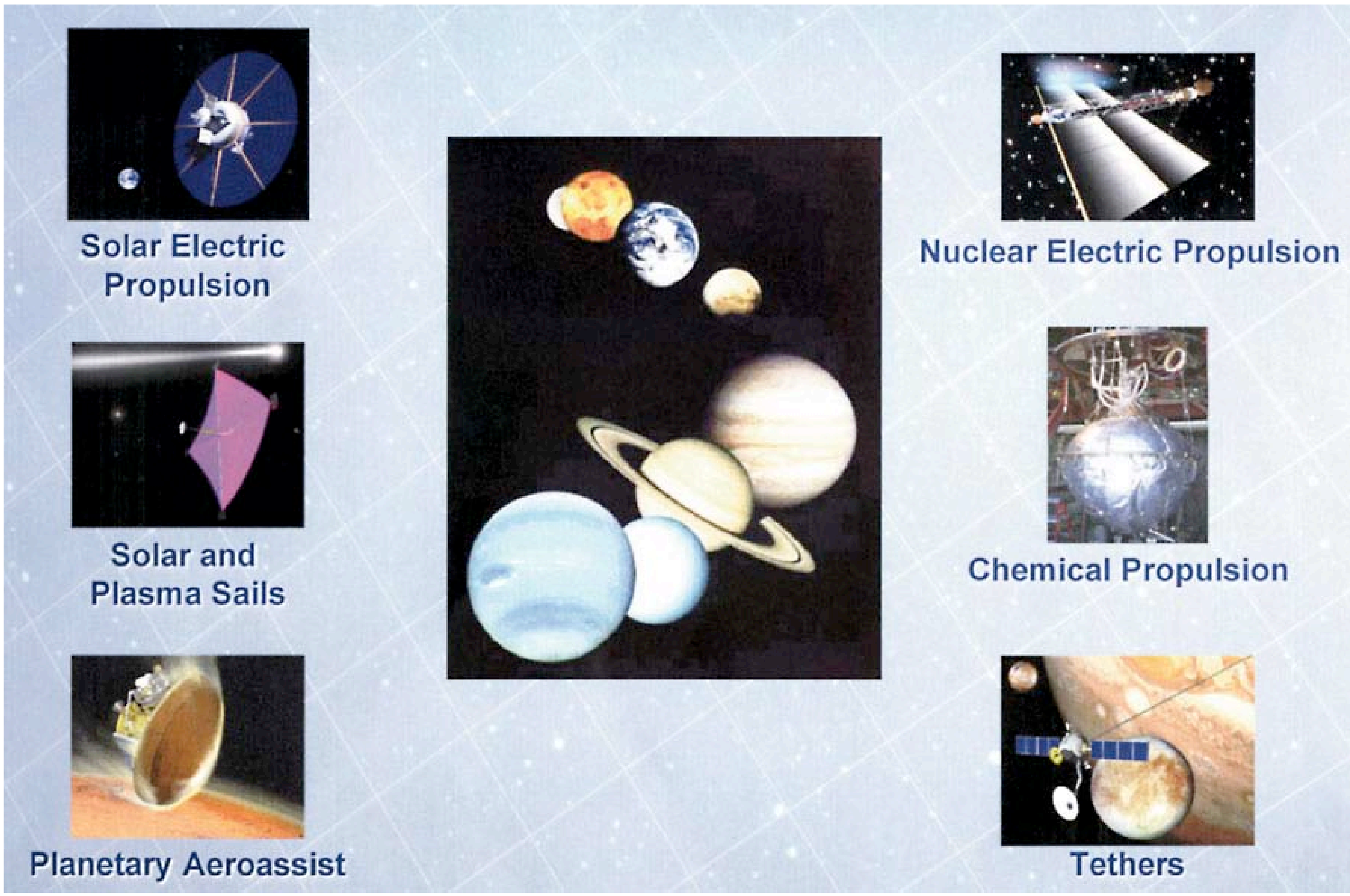
Typical Mission Examples

	ΔV Required KM / SEC
• 10 Year GEO Stationkeeping	~0.5
• LEO to GEO (0.3 days)	~4
• LEO to GEO (250 days)	~6
• Titan Orbiter (1way)	~11
• Neptune SR (NEP)	~85
• LEO to Alpha Centauri	30000.0

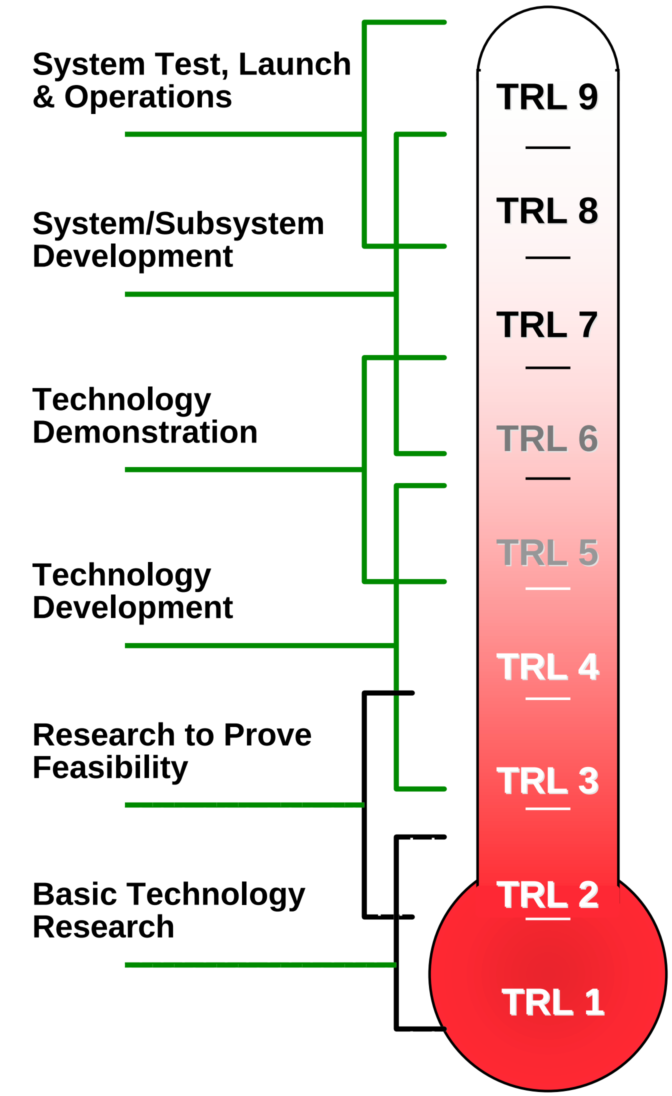
Far Away Places Truly Stress the Bounds of Propulsion

In-Space Transportation

Enabling New Scientific



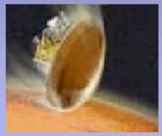
In-Space Propulsion Program Will Advance Mid-TRL Technologies to Support NASA Mission Applications



NASA Implementation: (Deep Space One Ion Engine Example)

In-Space Propulsion Technologies

Aeroassist



Adv. Electric Propulsion

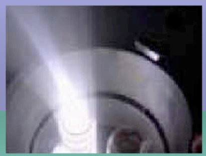
Solar Thermal

Adv. Chemical

Tethers

Solar Sails

Plasma Sails



Low-TRL Technologies For the Future

External Pulsed Plasma

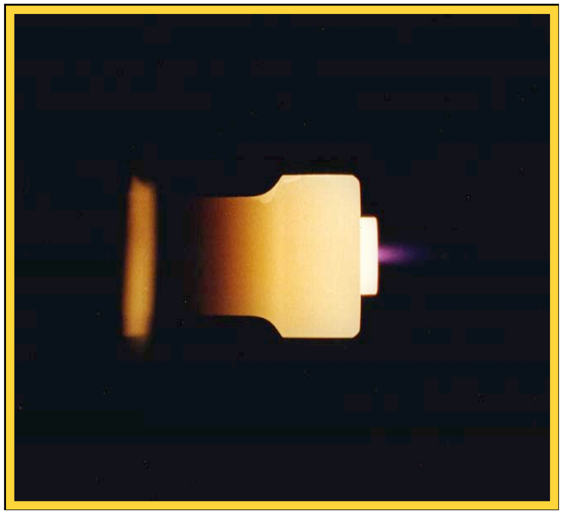
Fusion & Antimatter

Beamed Energy

Electric Propulsion Overview
Three Classes of Concepts

Electrothermal:

Gas heated via resistance element or discharge and expanded through nozzle



Examples -
- **Arcjets**
- **Resistojets**
- **Microwave**

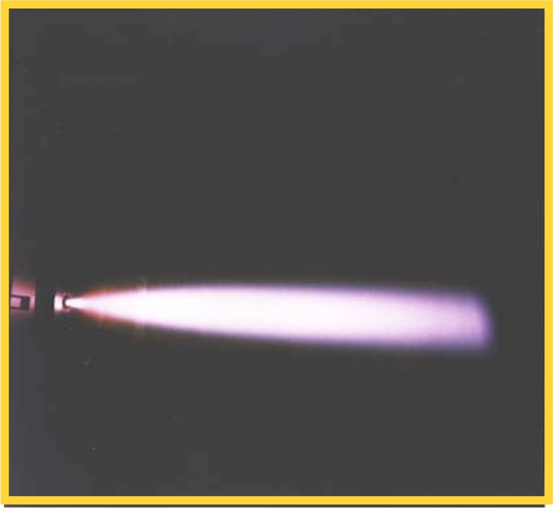
Electrostatic:

Ions created and accelerated in an electrostatic field

Examples -
- **Ion Engines**
- **Hall Accelerators**

Electromagnetic:

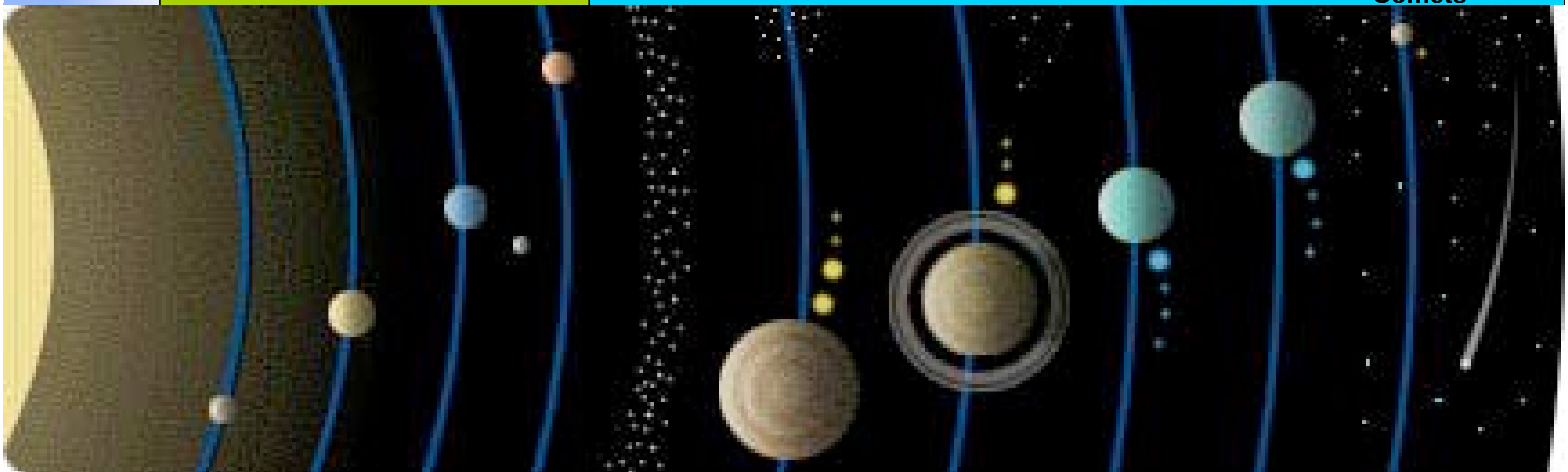
Plasma accelerated via interaction of current and magnetic field



Examples -
- **Pulsed Plasma**
- **MPD/LFA**
- **Pulsed Inductive**

Match the Power System to the Destination

Main Asteroid Belt | Trojan Asteroids | Centaur Minor Planets | Trans-Neptunian Objects | Kuiper Belt Objects / Comets



Inner Planets

Jupiter and Moons | Saturn and Moons | Uranus and Moons | Neptune and Moons | Pluto/Charon

Solar Electric Confined to Inner Solar System

- Also limited reach to large outer planetary bodies with aerocapture (Jupiter, Saturn, Uranus, Neptune only)

Radioisotope Electric for New Frontiers Class Outer Solar System Missions

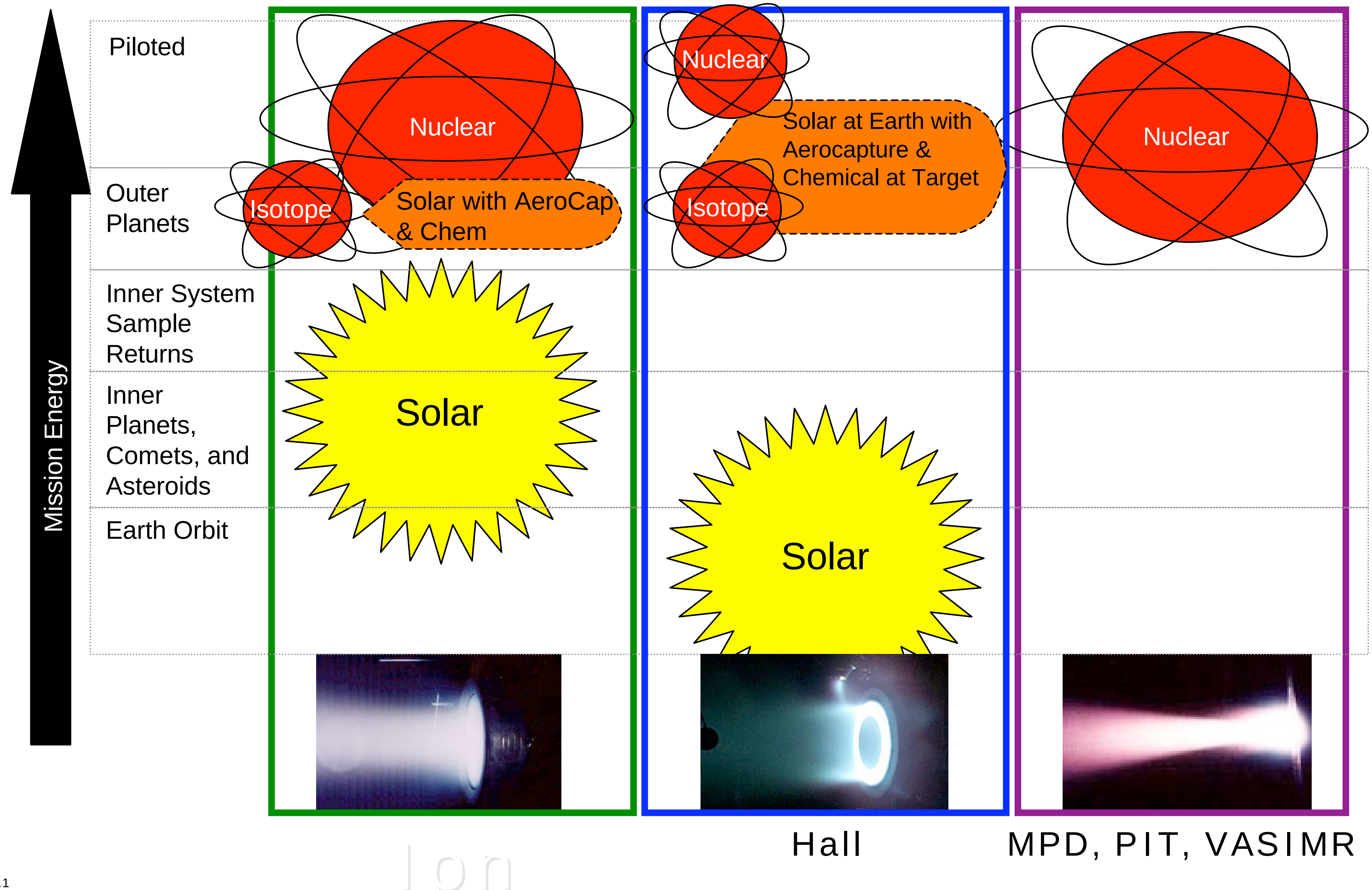
- Targets with low Mass
- 500 W Class RTG
- <50 kg payload
- Delta II Launchers

Nuclear Electric for Large Flagship Missions to Outer Planets

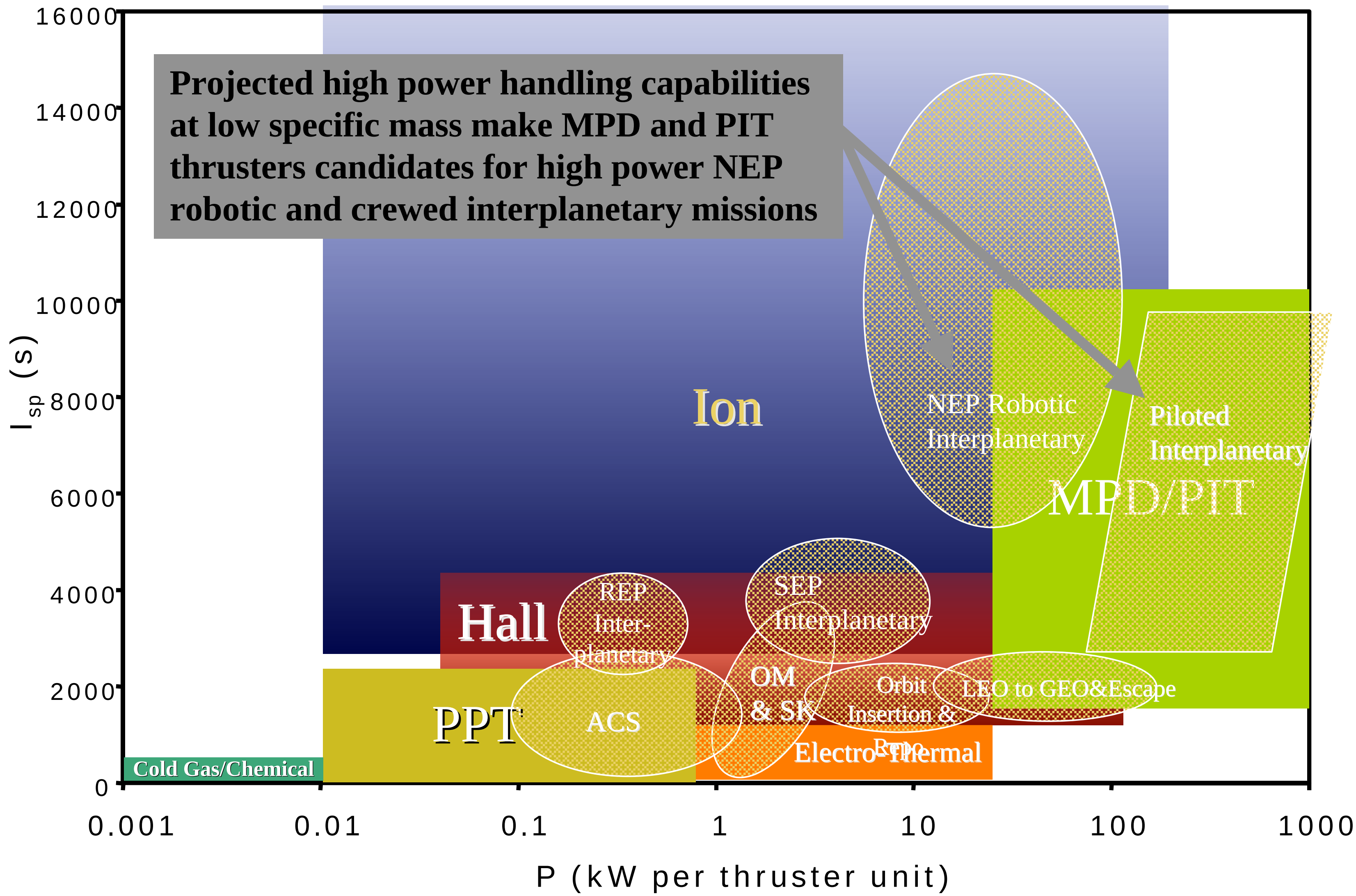
- Large Targets
- 100 kW Class Reactor
- >500 kg Payloads
- Delta IV Launch Vehicles

RTG for Surface Lander

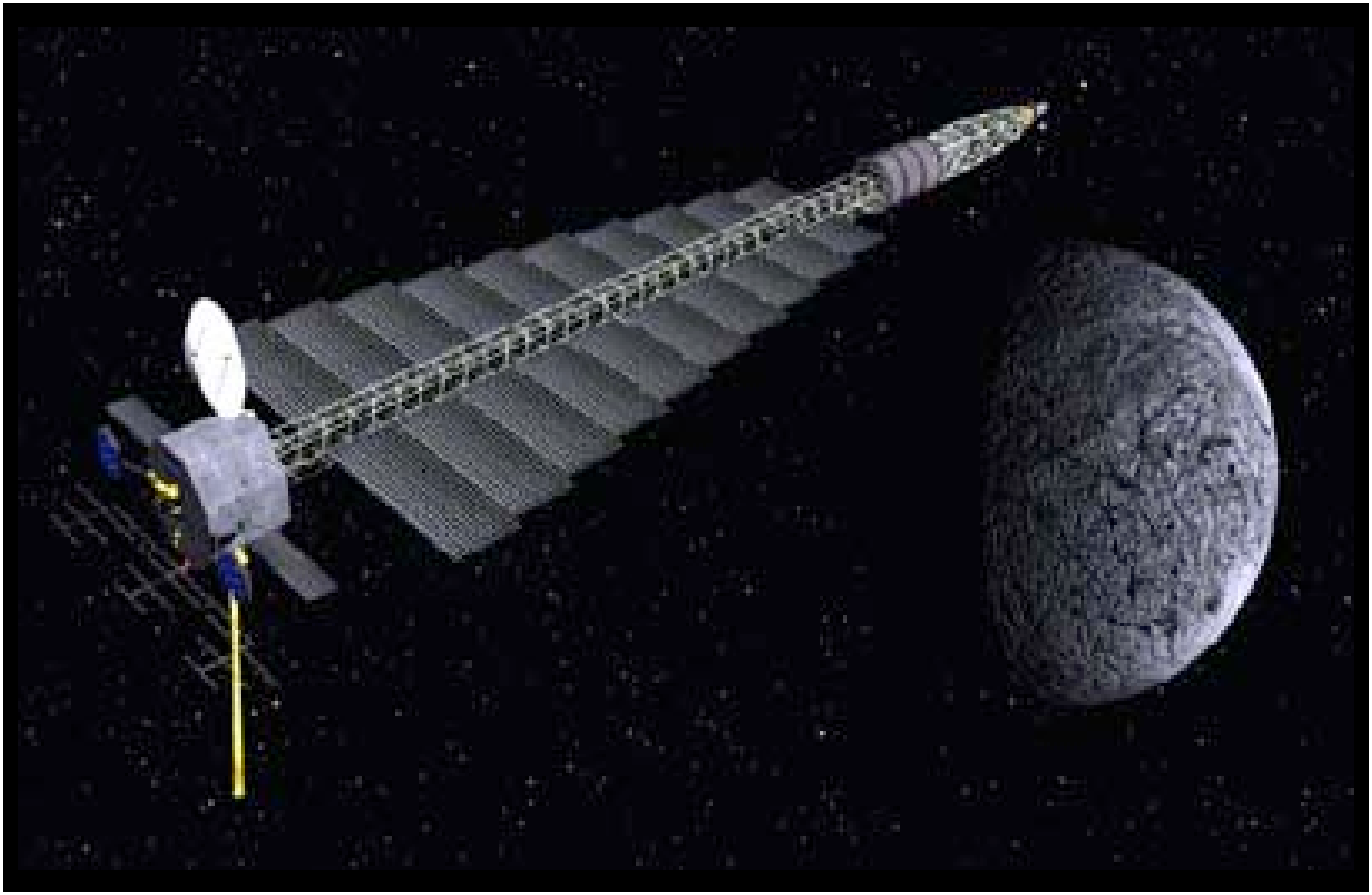
Electric Propulsion and Power Source for Space Missions



Electric Propulsion Performance



Project Prometheus



"Jupiter Icy Moons Orbiter"

Established Nuclear Energy Sources: Fission

= 50 x

Fissioning 12 fl oz (341 ml) of Uranium yields 50 times the energy contained in a Shuttle External Tank

Energy Density: 82 billion joules per gram

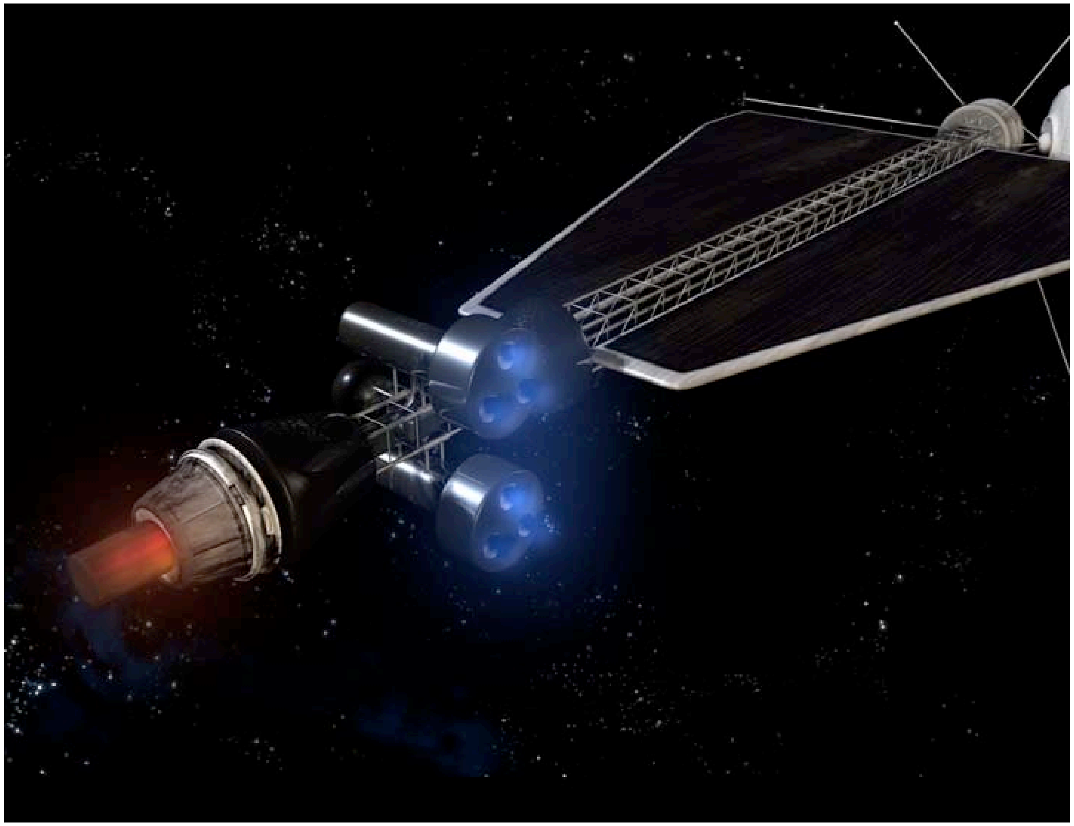
- **Overcomes limitations of other candidate power sources**
  - **Chemical: already near theoretical performance limits**
  - **Radioisotopes: versatile and long-lived, but low power density and limited Pu-238 supply**
  - **Natural sources (e.g., solar, EM tethers): highly dependent on location w/respect to sun or planet**
  - **Advanced concepts (e.g., beamed energy, fusion): too immature, may not work, and/or require substantial in-space infrastructure and investment**
- **Greatly extends capability, sophistication and reach of future science missions**
  - **Enables use of high-performance electric propulsion beyond inner solar system**
  - **Provides long-duration, power-rich environments for sophisticated scientific investigations, high-data rate communications and complex spacecraft operations**
- **Improves safety, capability and performance of future human planetary missions**
  - **Power-rich spacecraft and surface operations**
  - **Rapid transportation to reduce extended exposure to solar/cosmic radiation and zero-g**

Mission Objectives

- This mission responds to the National Academy of Sciences' recommendation that a Europa orbiter mission be the number one priority for a flagship mission in Solar System exploration
- JIMO will search for evidence of global subsurface oceans on Jupiter's three icy moons: Europa, Ganymede, and Callisto.
- JIMO will be the first flight mission to use nuclear power and propulsion technologies.
- This mission will set the stage for the next phase of exploring Jupiter and will open the rest of the outer Solar System to detailed exploration.

Nuclear Electric Propulsion

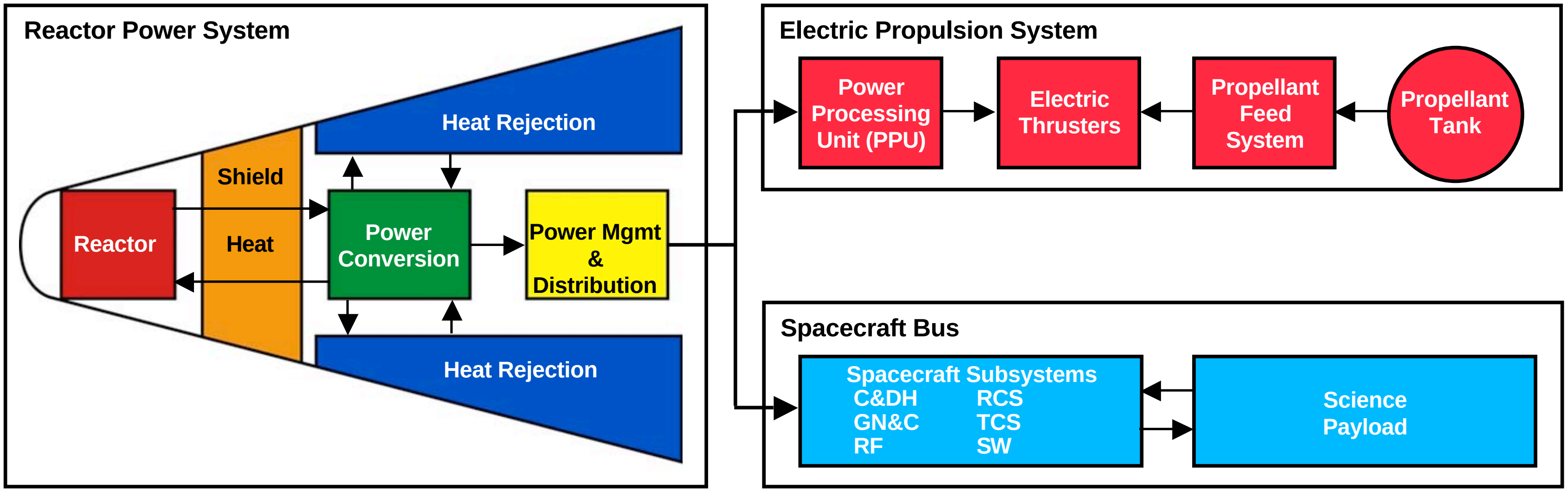
Nuclear Systems Initiative; Revolutionizing Space Exploration



Broad Set of Concept Options with Common Technologies

- **Faster Missions into Deep Space**
- **Power-rich Spacecraft for Sophisticated Investigations**
- **Ambitious Missions involving Multiple Planetary Destinations**
- **High-data Rate Communication**
- **Civil and Military Power Spinoffs**

Fission Electric Power & Propulsion System Diagram & Representative Technology Options



Reactor

Heat pipe cooled
Liquid metal cooled
Gas cooled

Power Conversion

Thermoelectric
Segmented thermoelectric
Stirling
Brayton
Thermo photovoltaic

Electric Propulsion

Ion thruster
Hall thruster
MPD, PIT

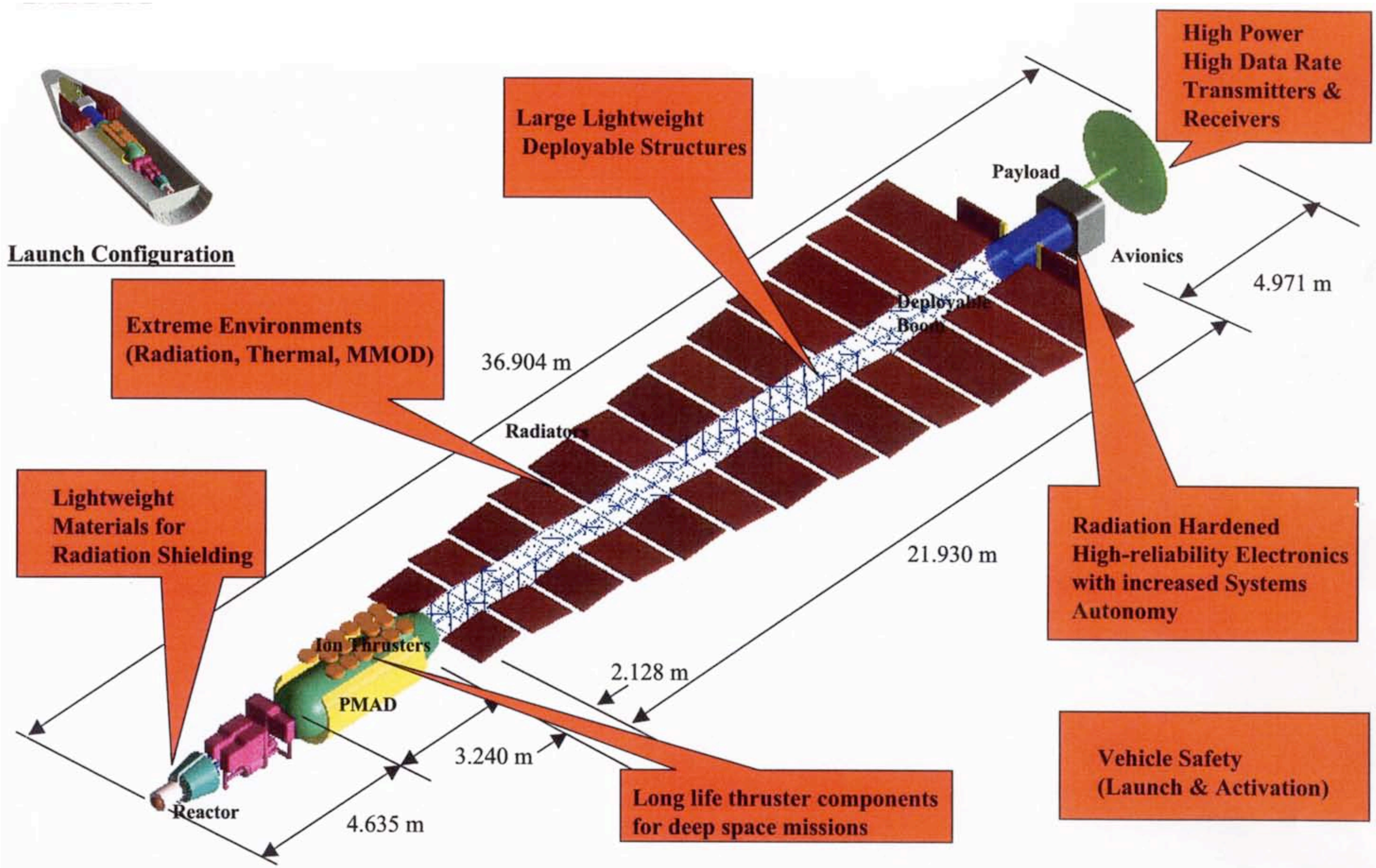
Heat Rejection

2-phase loops (capillary pumped loop, loop heat pipes)
Heat pipes
Pumped loops

Power Management and Distribution

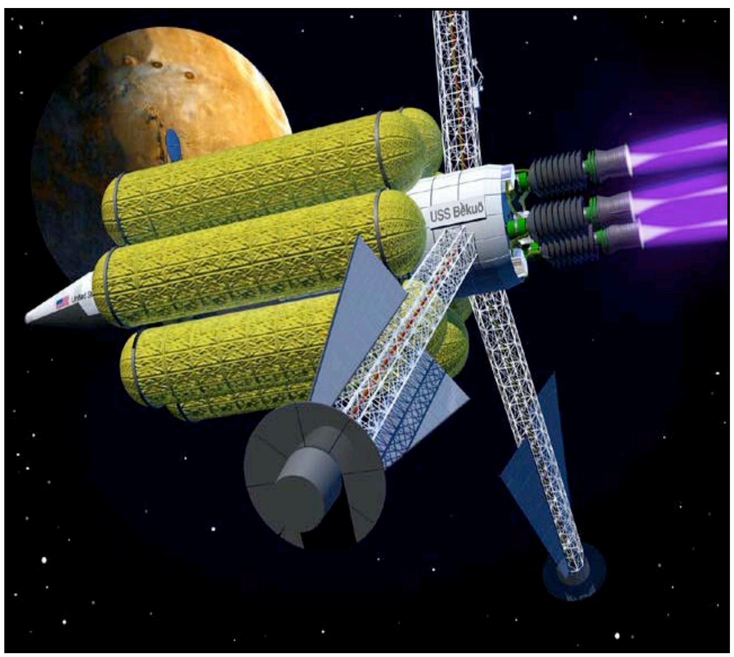
Depends upon power conversion:
AC
DC
Low/high input voltage

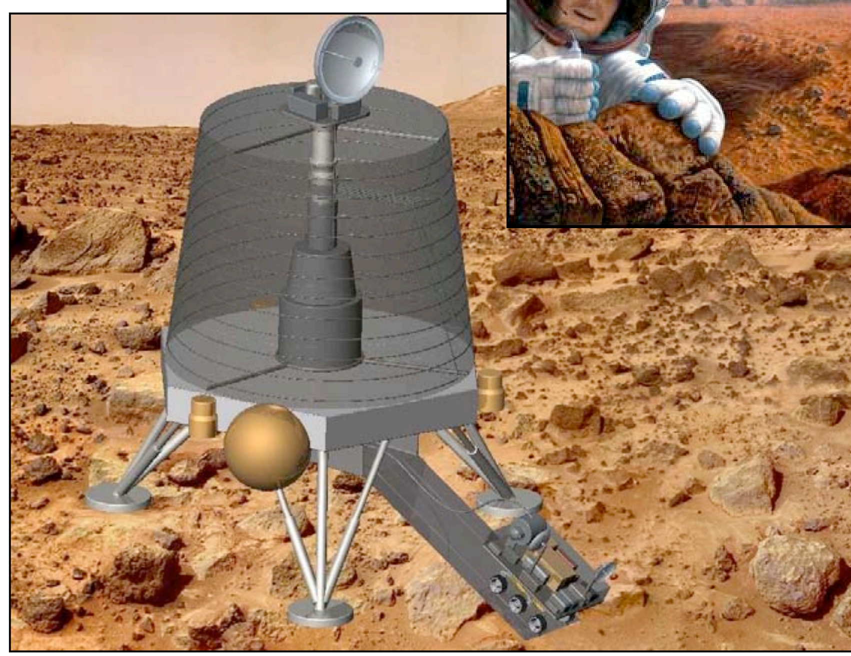
Technical Challenges Required For NEP Systems Development



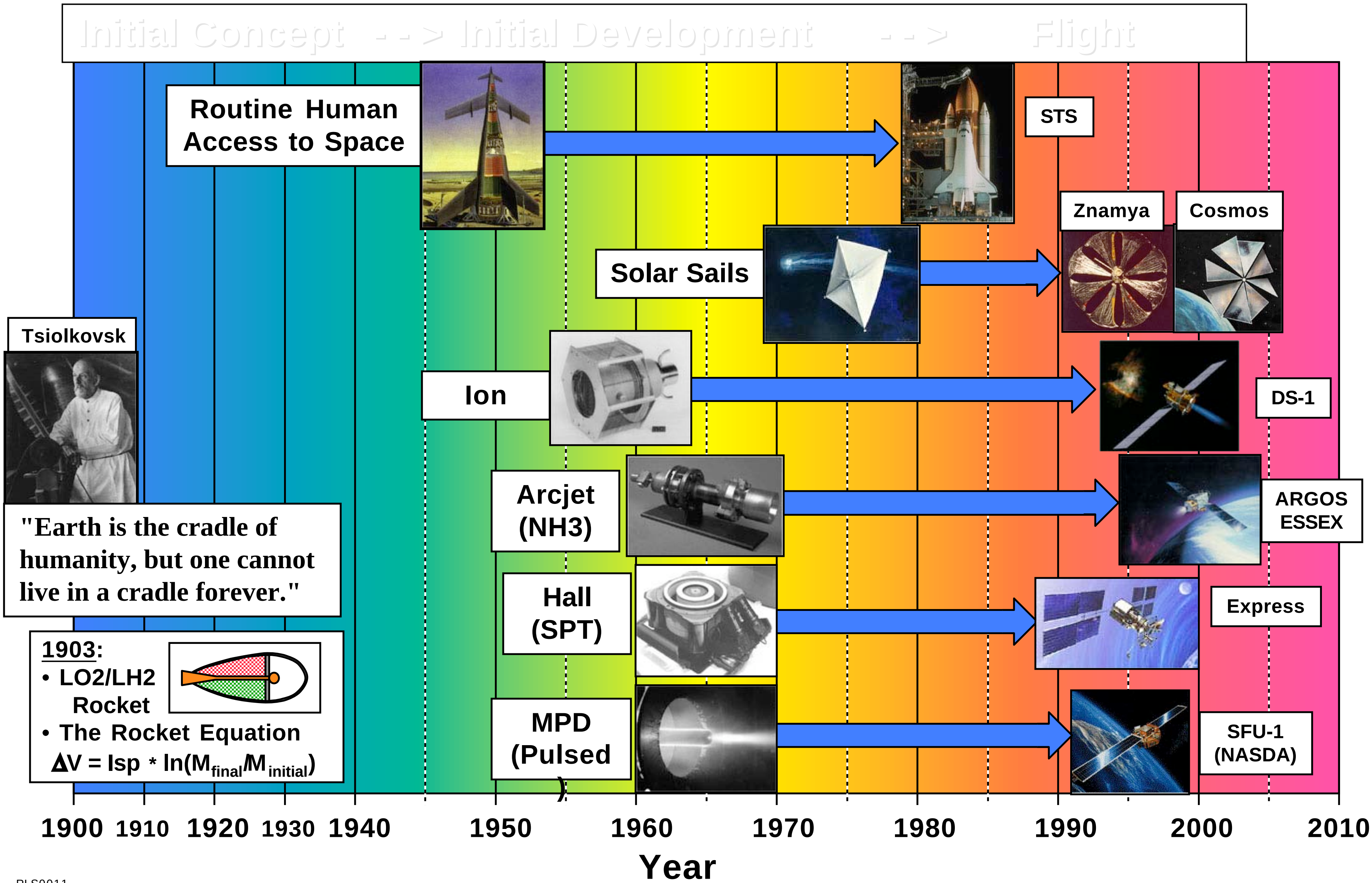
Potential Support to Human Space Exploration

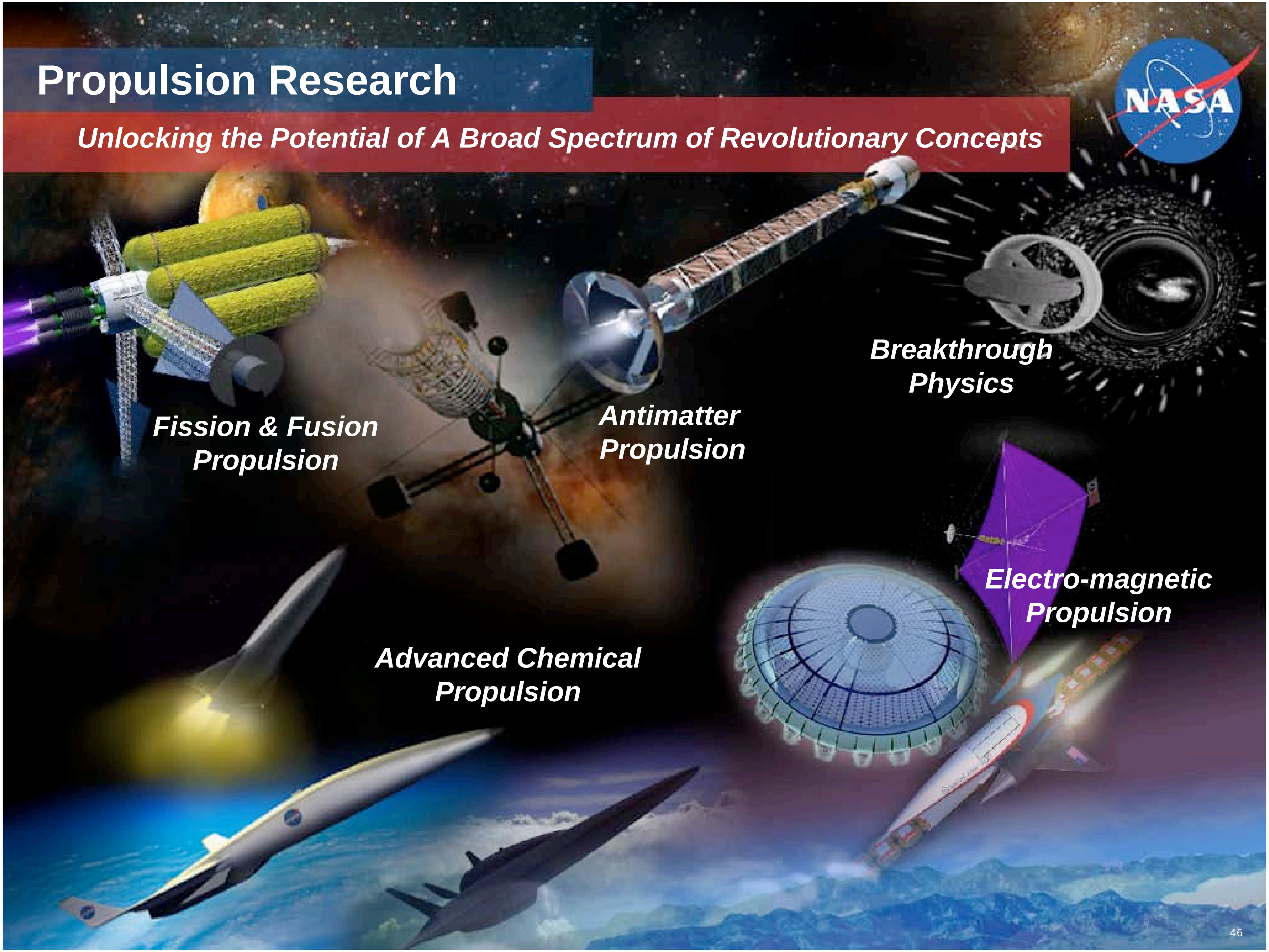
- Nuclear power and propulsion are key enablers of expanded human exploration
  - Enables human exploration beyond earth orbit
  - Provides high power for human protection against charged solar particles
  - Provides abundant power at destination
  - Enables complex, long duration missions
- Nuclear surface power is essential for extended reconnaissance of the Mars surface
  - Long-range surface and sub-surface exploration
  - Human habitat and life support
  - *In-situ* manufacturing of consumables
  - *In-situ* propellant production





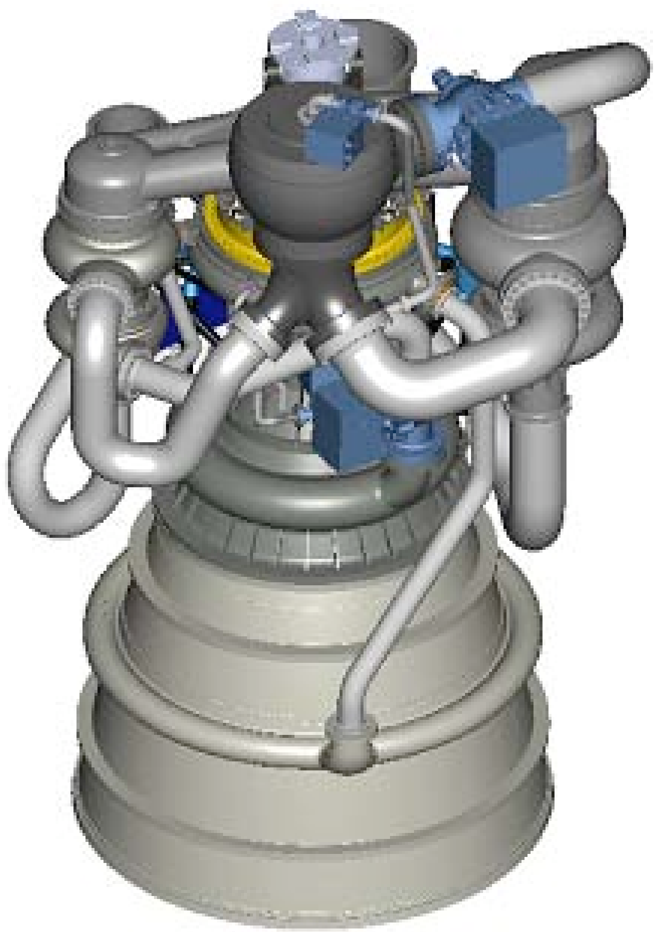
Development of Low-TRL Propulsion Technologies Can Take Decades




Propulsion Research
Unlocking the Potential of A Broad Spectrum of Revolutionary Concepts
NASA
Fission & Fusion Propulsion
Antimatter Propulsion
Breakthrough Physics
Electro-magnetic Propulsion
Advanced Chemical Propulsion

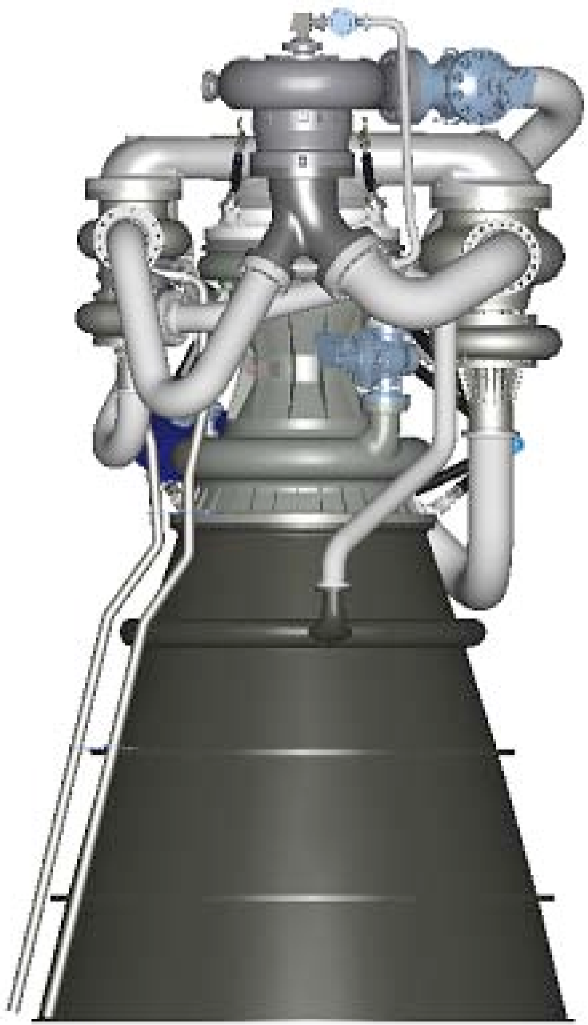
Rocket Engine Prototype (REP) Project Overview

- ♦ **Objectives**
  - Provide risk mitigation for large class, Oxygen Rich Stage Combustion Engine (ORSC)
  - Design and Test a high-fidelity prototype engine
  - Validate existing analytical tools
  - Develop and validate new analytical tools as required to develop the flight ORSC engine system
- ♦ **Success Criteria**
  - ORSC Engine System @ TRL 6 (demonstration in relevant environment)
- ♦ **Goals**
  - Improved Safety
  - Reduced Cost
  - Improved Operability and Responsiveness
- ♦ **Current Activity limited to Prototype Engine Design and Technology Development**



ORSC Prototype Engine Characteristics

NEXT GENERATION LAUNCH TECHNOLOGY

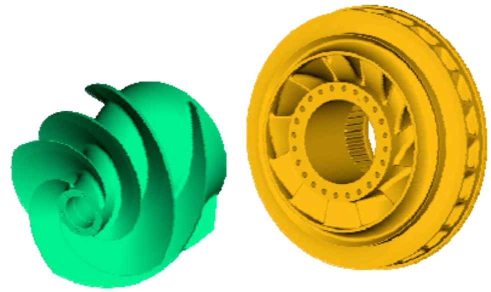


	Prototype	Reference
Thrust		
• Sea Level klb.	1064	1049
• Vacuum klb.	1130	1160
Reliability		
• Failures Per Million Missions	traceable	18
Operability		
• Shift turn time	8	8
Specific Impulse		
• Sea level sec.	305	301
• Vacuum sec.	324	335
Weight		
• Dry lbm.	17,922	14,956
Life		
• Missions	100	100
Dimensions		
• Length in.	147	184
• Diameter in.	108	108
• Area Ratio	20:1	36:1

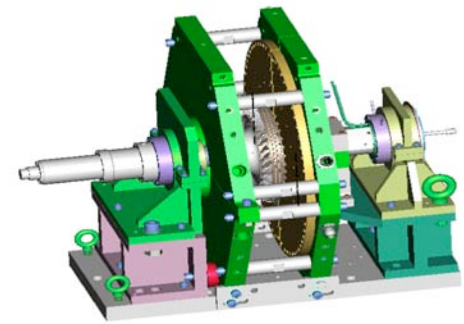
Rocket Engine Prototype Project Overview

- **Deliverables**
  - Oxygen Compatible Materials
  - Manufacturing Technology Demonstrations
  - Turbopump Inducer Waterflow Test
  - Turbine Damping “Whirligig” Test
  - Single Element Preburner and Main Injector Test
  - 40K Multi-Element Preburner and MI
  - Full-Scale “Battleship” Preburner
  - Prototype Preburner Test Article
  - Full-Scale Prototype TCA
  - Turbopump Hot-Fire Test Article
  - Prototype Engine
  - Validated Analytical Models

On Current Contract

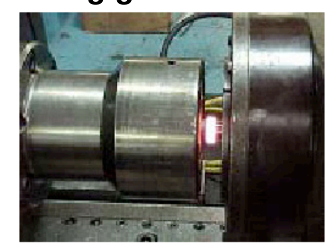


Inducer & Impeller Test Articles

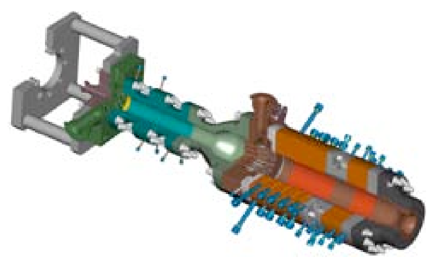


Whirligig Test Article

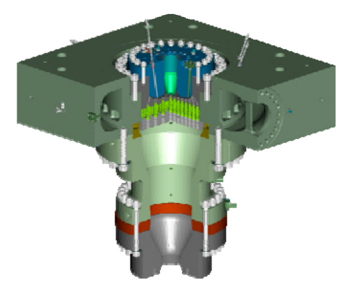
Single Element Test Rig



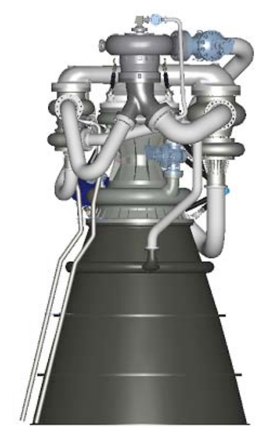
Inertial Weld Sample



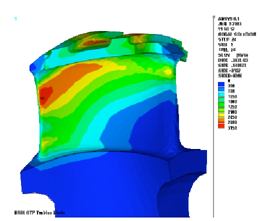
40K Test Rig



Battleship Preburner



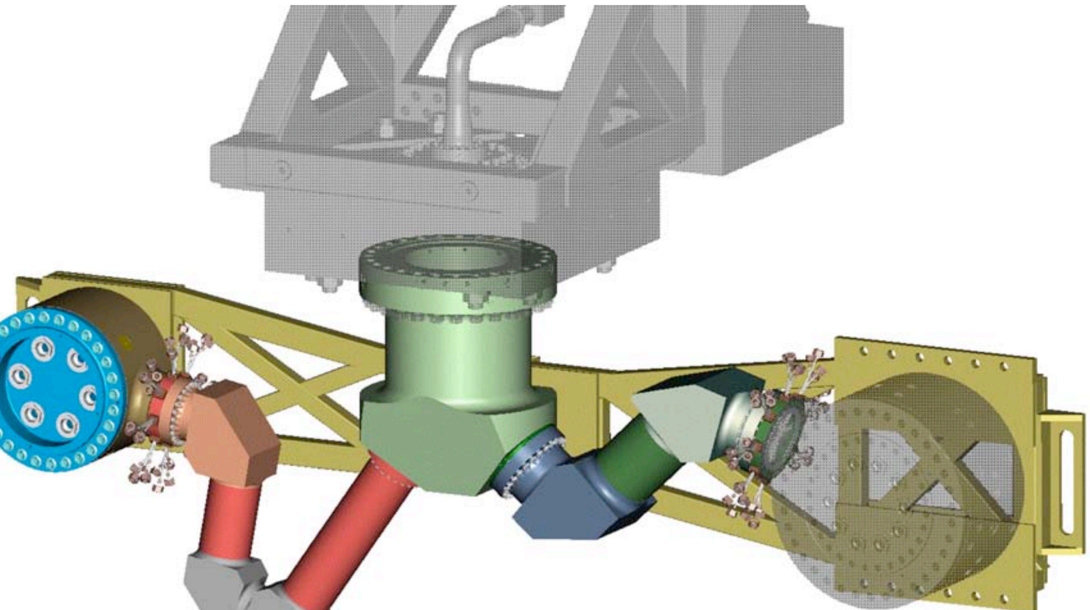
Prototype Engine

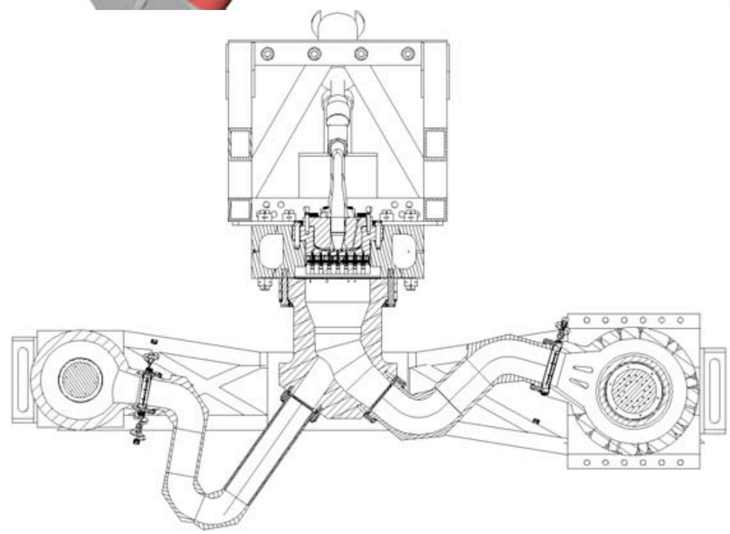


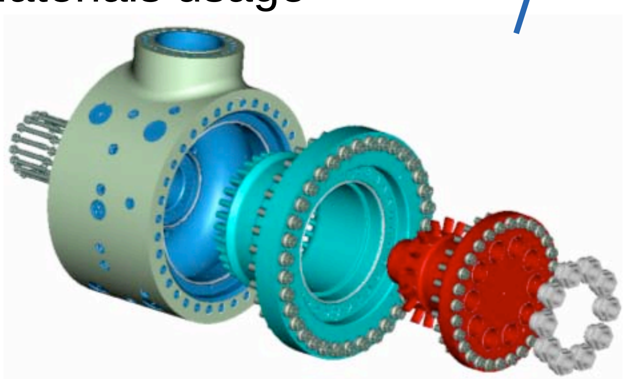
Turbine Blade Analytical Model

Full Scale Battleship Preburner

- ♦ **Full-Scale Preburner**
  - High fidelity simulation of internal flow geometry
  - Injectors, Chamber, Splitter Ducts, and Turbine Simulators
- ♦ **Objectives**
  - Stability demonstration
  - Flow uniformity at turbine inlets
  - Materials usage



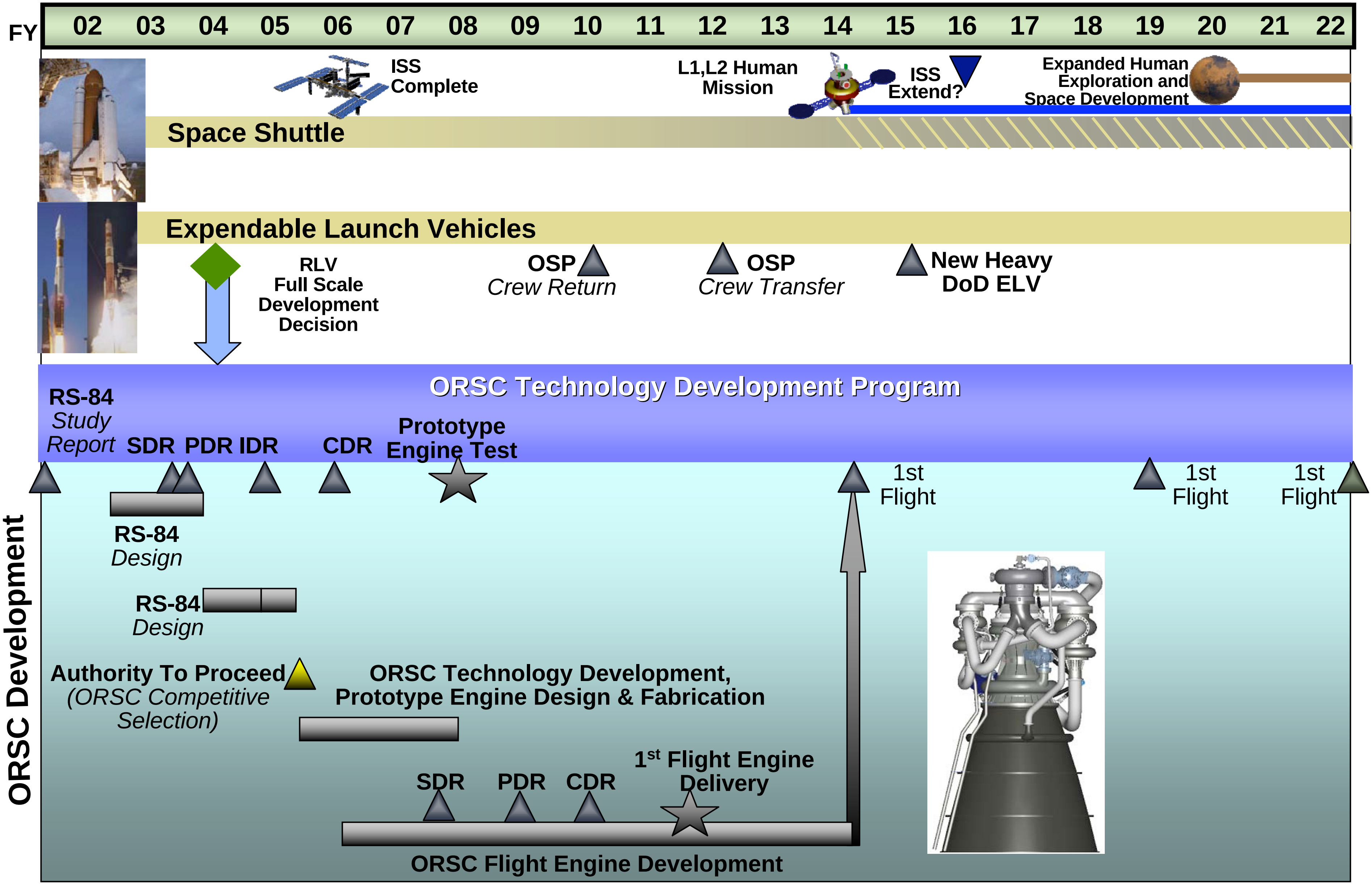




Turbine Simulator

NEXT GENERATION LAUNCH TECHNOLOGY

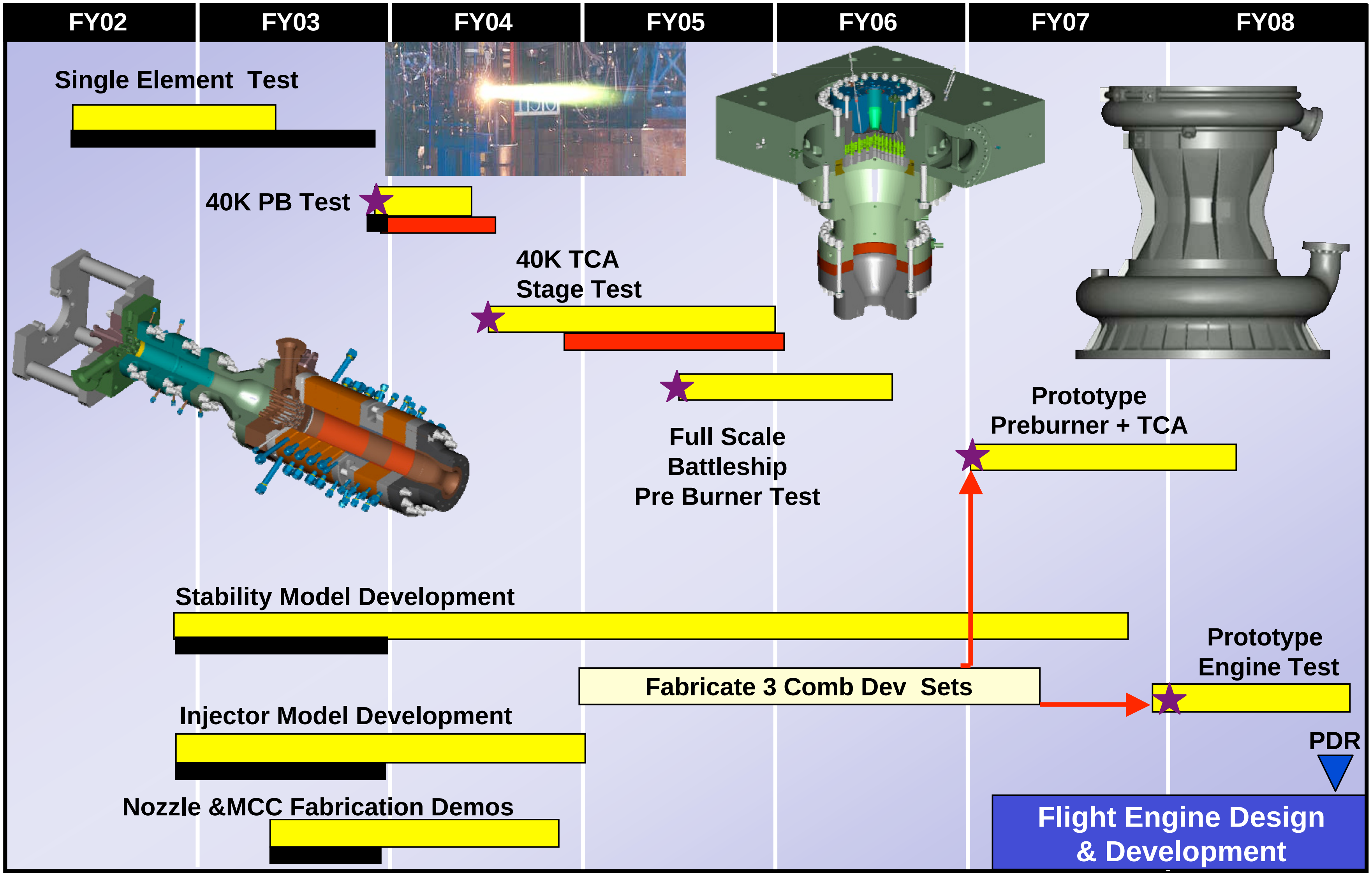
NGLT & REP ORSC Future Space Launch Roadmap



NGLT Next Generation Launch Technology

REP ORSC Combustion Devices Roadmap

Combustion Devices



RLS0011 ★ Program Milestone

REP ORSC Turbomachinary Roadmap

Turbomachinary