
Modular Systems
For Exploration
3/17/2004

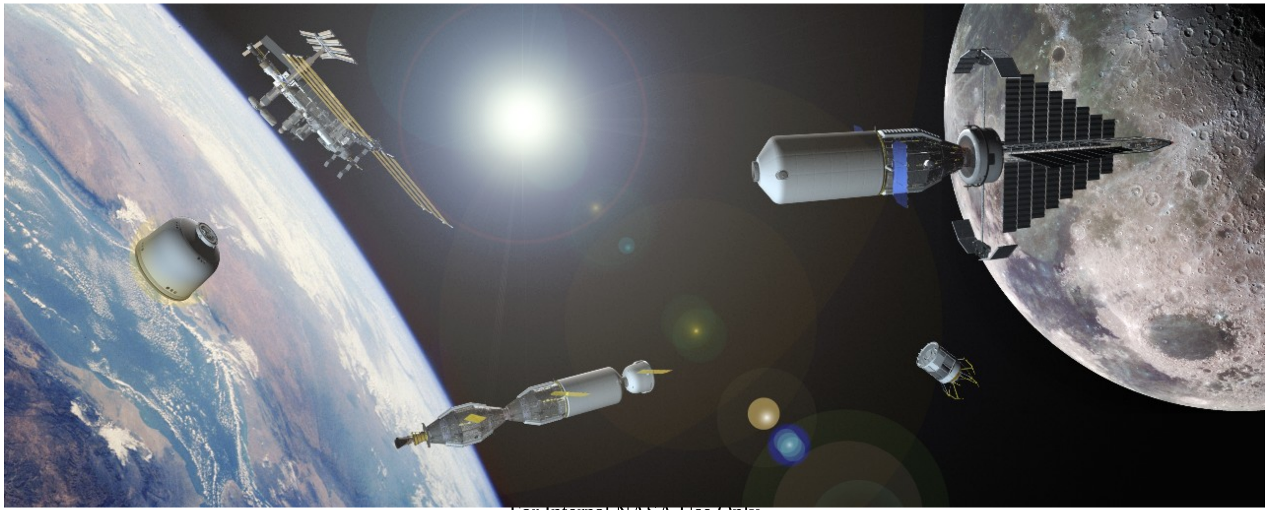
Modular Systems for Exploration

Objectives:

- **Develop robust and cost effective concepts in support of future space exploration missions assuming the application of replicated systems to return humans to the moon.**
- **Leverage potential OSP concepts and associated ELV systems to maximize synergy.**

Accomplishments:

- **Two architectures were derived; Focused and Broad. Enabling capabilities, rough cost estimates, ELV launch requirements and associated OSP design requirements were identified.**



High Level Assumptions:

Mission:

Primary mission is to send a crew of two to four to the south pole of the moon (1 week). Science objectives involve search for resources.

Timeframe:

Begin investments in 2005 to enable the mission around 2015.

Supporting Infrastructure Available:

ISS, Existing ELVs, Shuttle, OSP (configuration assumed)

Supporting Infrastructure Options:

Enhanced ELV in support of OSP (35 MT to ISS), NSI based NEP Tug

Approaches:

***Focused* – Utilize modular components to rapidly achieve primary objectives while minimizing technology development costs**

***Broad* – Utilize modular components enabled by technology investments to achieve primary objectives while also maximizing the ability to support expanded exploration**

Architecture Executive Summary – Focused Approach: Case 1

Architecture Description

Enable early human exploration missions to the lunar south pole by minimizing required investment in technologies, mission assets, and launch infrastructure. Utilize 22.6 MT Delta 4 heavy launch vehicle

Launch Requirements

Vehicle	Launches 1st Mission	Launches 10 Missions
Shuttle	0	0
Delta 4 Heavy	13	67
Aug. D4 Heavy	0	0

Cost Estimates *(1st order - $Billions)*

COST	1st Mission	10 Missions
Element Fleet		
Launch Systems		
Operations & Facilities		
Totals	_____	_____

	Elements	*Enabling Capabilities*
	XTV – Exploration Transfer Vehicle (Crew module based on mid-L/D Orbital Space Plane)	Descent & Landing Systems High Temperature TPS
	PPM – Power & Propulsion Module (XTV Propulsion system and mission consumables storage module)	PEM Fuel Cells O_2/CH_4 OMS/RCS Engines & Cryocoolers
	LL – Lunar Lander (Delivers 2 crew from XTV in lunar orbit to lunar surface and back)	Precision Landing & Hazard Avoidance Surface EVA Suit
	IS – High-Energy Injection Stage (Centaur-like injection stage for performing major orbital maneuvers)	Gaseous H_2/O_2 RCS system Zero Boil off systems
	OMV – Orbital Maneuvering Vehicle* (Orbital tug potentially used for delivering injection stages from ISS vicinity to ISS)	Automated Rendezvous & Docking Cryogenic propellant transfer

* Note: Inclusion of an OMV in the architecture depends on whether the ISS AR&D function is placed on the injection stages

Focused Approach #3 "CTV/XTV Commonality, EELV+" Architecture Elements

Architecture Description

Enable early human exploration missions to the lunar south pole by minimizing required investment in technologies, mission assets, and launch infrastructure. Utilize <35 MT Augmented EELV.

Launch Requirements

Vehicle	Launches: 1st Mission	Launches: Subsequent
Aug. EELV	5	4

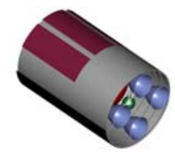
Cost Estimates *(1st order - $Billions)*

COST	1st Mission	Subsequent
Element Fleet	$ TBD	$ TBD
Launch Systems	$ TBD	$ TBD
Operations & Facilities	$ TBD	$ TBD
Totals	$ TBD	$ TBD

Elements / *Enabling Capabilities*

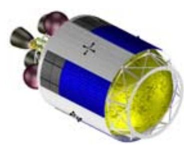
XTV – Exploration Transfer Vehicle (Crew module based on mid-L/D Orbital Space Plane)

Enabling capabilities: Descent & Landing Systems; High Temperature TPS



PPM – Power & Propulsion Module (XTV Propulsion system and mission consumables storage module)

Enabling capabilities: PEM Fuel Cells; O_2/CH_4 OMS/RCS Engines & Cryocoolers



IS – High-Energy Injection Stage (Centaur-like injection stage for performing major orbital maneuvers)

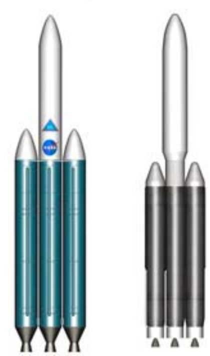
Enabling capabilities: Gaseous H_2/O_2 RCS system; Zero Boil off systems

OMV – Orbital Maneuvering Vehicle* (Orbital tug potentially used for delivering injection stages from ISS vicinity to ISS)

Enabling capabilities: Automated Rendezvous & Docking; Cryogenic propellant transfer

LL – Lunar Lander (Delivers 2 crew from XTV in lunar orbit to lunar surface and back)

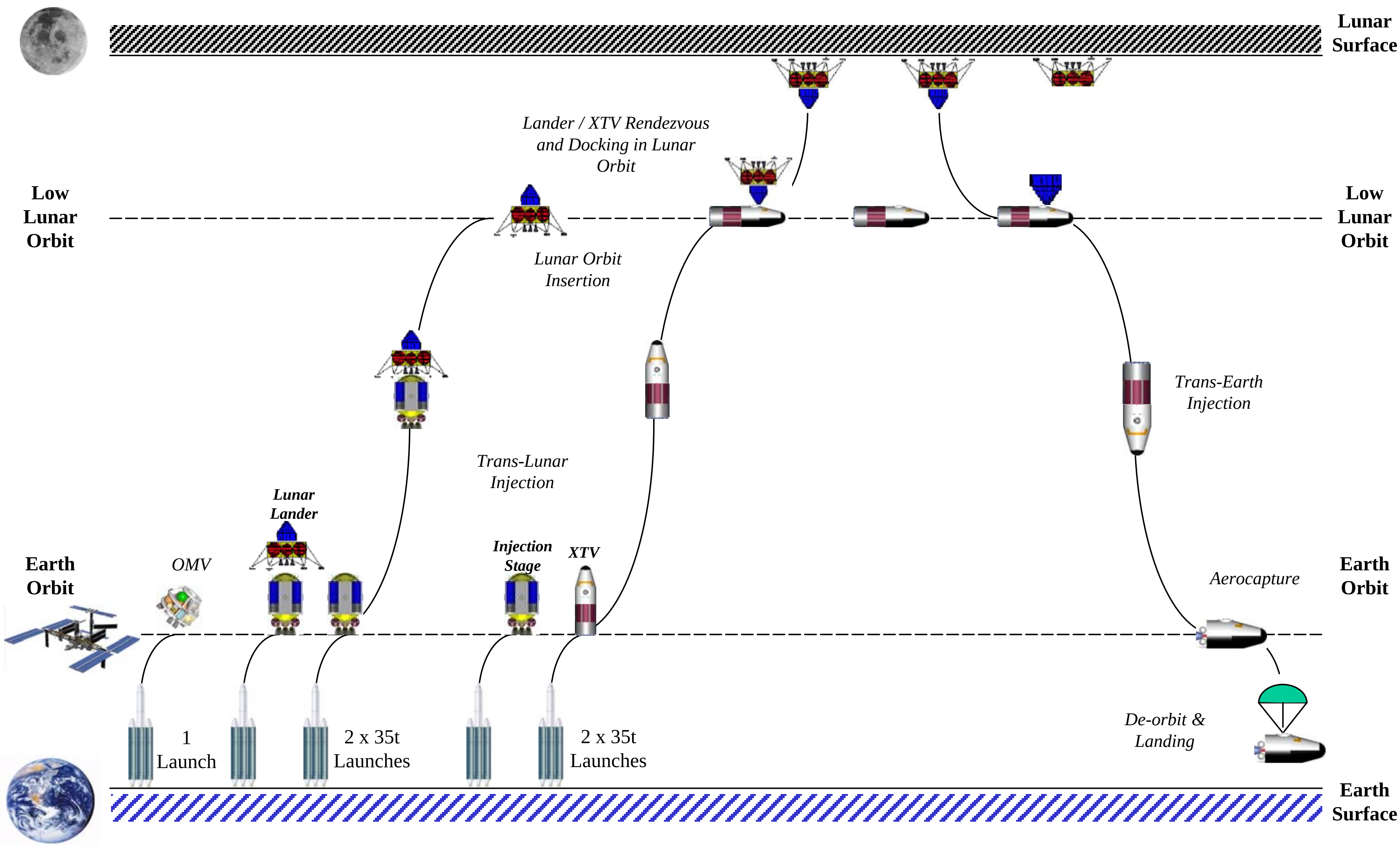
Enabling capabilities: Precision Landing & Hazard Avoidance; Surface EVA Systems



Augmented EELVs

* Note: Inclusion of an OMV in the architecture depends on whether the ISS AR&D function is placed on the injection stages.

Focused Approach #3 "CTV/XTV Commonality, EELV+" Mission Description



Potential Core Modular Building Blocks

Infrastructure Supports Earth Science, Space Science, Exploration, Commercial and DOD missions

Platform deployment and servicing from LEO to GTO

Crew transportation in LEO (includes polar inclinations)

Expanding Capabilities

Range expanded to GEO and Lagrange points

Lunar surface access

Space-Based High Energy Transfer System

In-Space, Reusable Propellant Storage

Exploration Transfer Vehicle

Low-Thrust Propulsion Systems (Solar or Nuclear)

Reusable Lunar Lander

In-Space

TIME

ETO

Existing Earth-to-Orbit Transportation: **Initial Modular Building Blocks deployed via existing large ELVs or the Shuttle.**

Optional Propellant Logistics Transportation: **A new class of mass produced ELVs designed for propellant only delivery (significant cost savings).**

Heavy Lift Launch Vehicles: **The Low-thrust propulsion systems require an upgraded Heavy ELV or shuttle derived launcher for deployment.**

Broad Approach - Reusable Exploration Infrastructure Supporting Concepts

The Hybrid Propellant Module (HPM) is a reusable tank farm that combines both chemical and electrical propellant in conjunction with modular transfer/engine stages.

The eXploration Transfer Vehicle (XTV) is used to transfer crew in a shirt sleeve environment from LEO to L1, L1 to the lunar surface and back. It can also be used as a safe haven for non-ISS orbits or as a commercial free flyer/ISS lab module.

The Reusable Lunar Lander (RLL) docks with the XTV to transport the crew to the surface and back to L1

The Chemical Transfer Module (CTM) serves as a high energy injection stage when attached to an HPM and an autonomous orbital maneuvering vehicle for proximity operations such as ferrying payloads a short distance, refueling and servicing.

The Nuclear Electric Propulsion (NEP) module serves as a low thrust transfer stage when attached to an HPM for pre-positioning large elements or for slow return of elements for refurbishing and refueling.

Architecture Executive Summary – Broad Approach: Reusable Exploration Infrastructure

Architecture Description

Establish reusable space-based infrastructure that can support yearly mission to lunar south pole for crew of 4 by 2016 in conjunction with support of commercial satellite delivery.

Launch Requirements

Vehicle	Launches 1st Mission	Launches Subsequent (crew & prop only)
Shuttle	0	0
Delta 4	0	0
Aug. D4 Heavy	8	4~5

Cost Estimates *(1st order - $Billions)*

COST	1st Mission	10 Missions
Element Fleet		
Launch Systems		
Operations & Facilities		
Totals	_____	_____

Elements

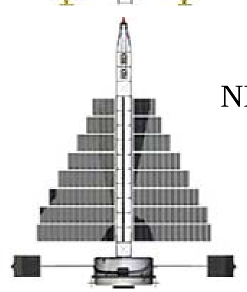
OSP – Capsule Configuration

XTV – EXploration Transfer Vehicle (Crew module based on OSP capsule)

HPM – Hybrid Propellant Module (Propellant depot and Injection stage tank)

CTM – Chemical Transfer Module (Orbital tug used for LEO aggregation and lunar injection when coupled to HPM)

RLL – Reusable Lunar Lander (Lands in combination with the XTV and returns to L1)

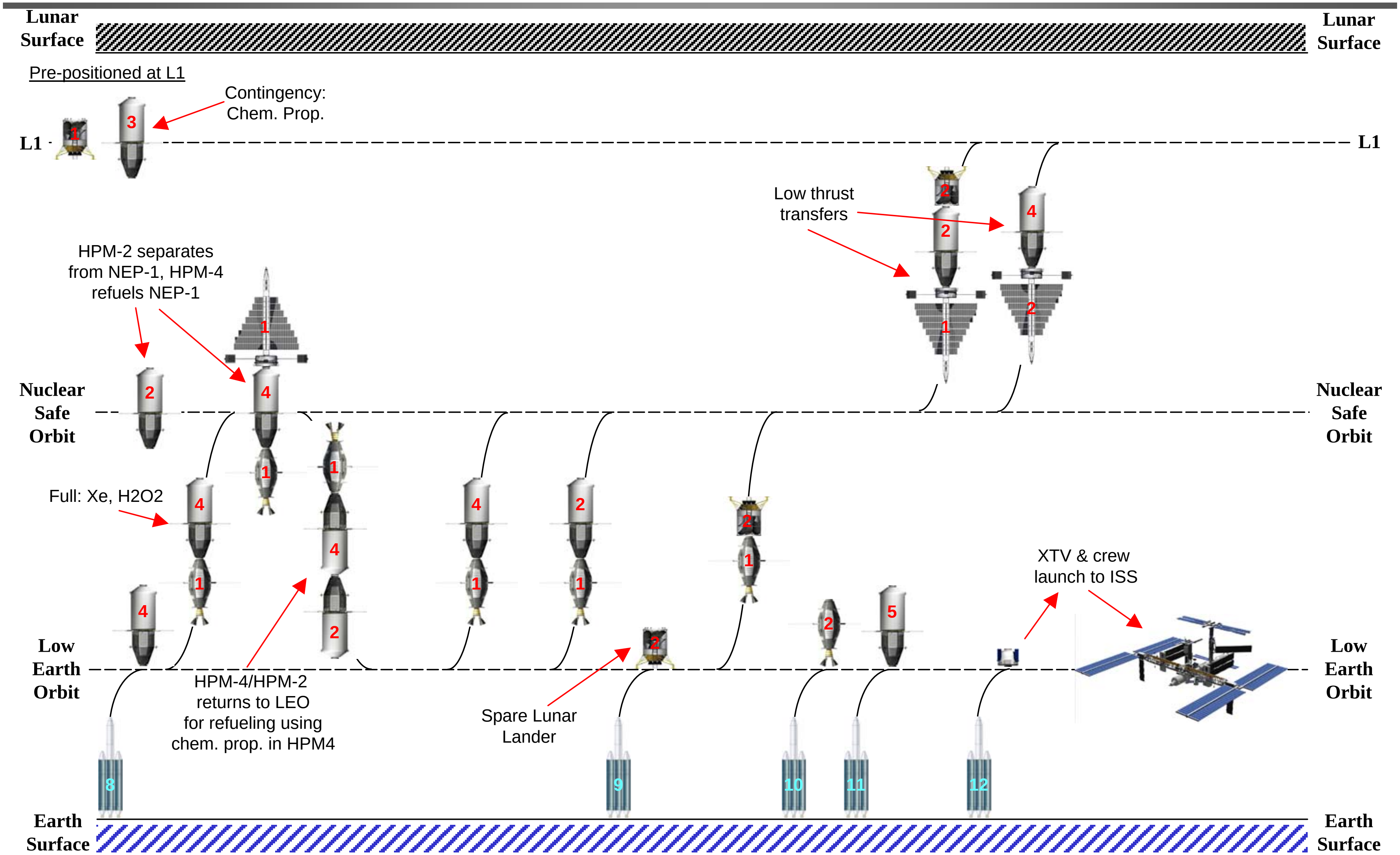


NEP – Nuclear Electric Propulsion tug (Derived from NSI/Prometheus vehicle. Used for pre-positioning or return of empty elements)

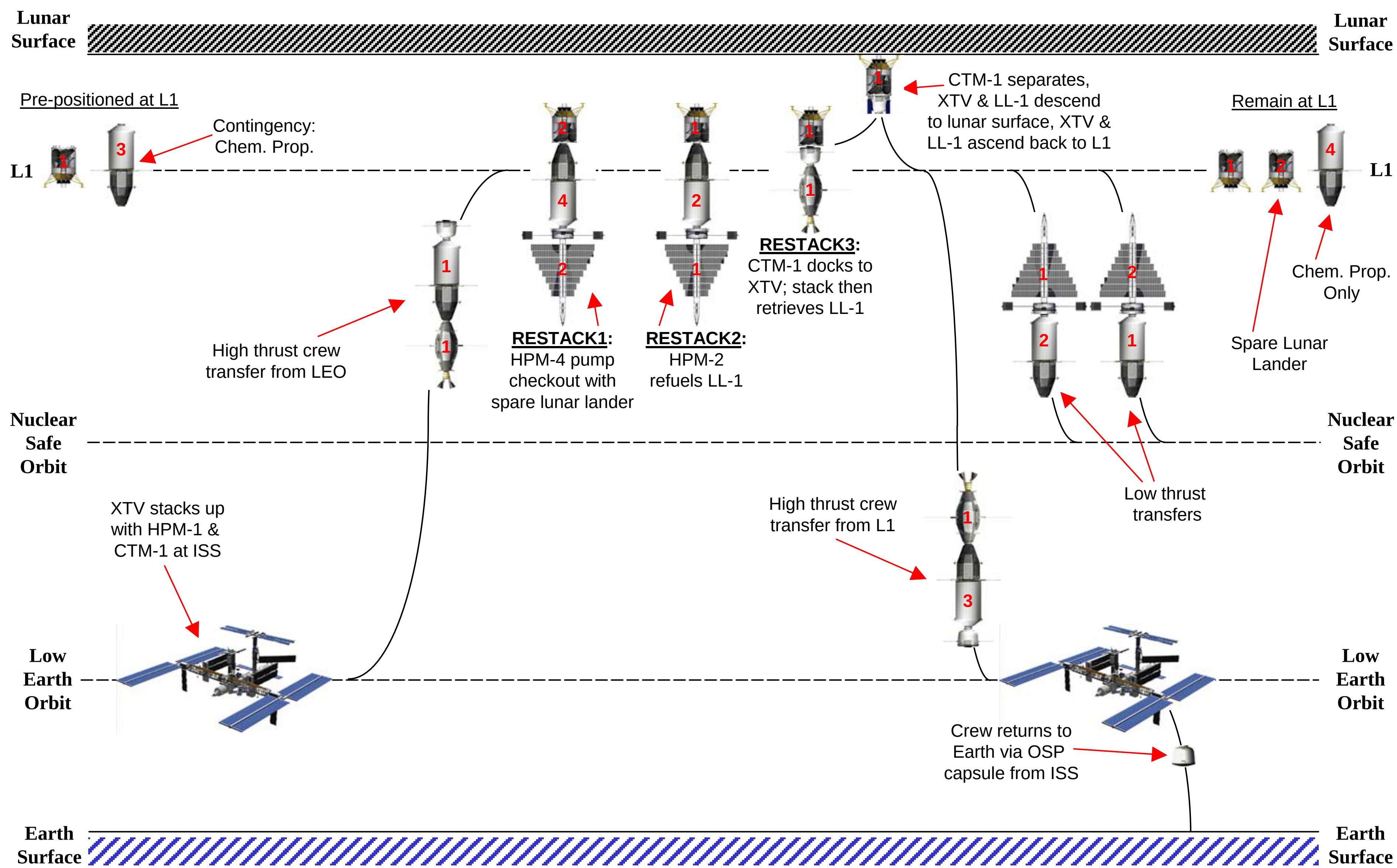
Enabling Capabilities

- Automated Rendezvous & Docking
- International Berthing & Docking Mechanism
- Advanced Multi-function Structures
- Zero Boil off systems
- Cryogenic propellant transfer
- Gaseous H2 O2 RCS system
- Reusable liquid hydrogen/oxygen engines
- Long-life autonomous systems
- High efficiency gridded ion engines
- 250 kW class nuclear reactor

Broad Approach Mission Chronology
Crewed Mission (Part 1: Element Pre-positioning)



Broad Approach Mission Chronology
Crewed Mission (Part 2: Lunar Expedition 1)



Modular Systems Summary

All scenarios require enabling capabilities such as automated rendezvous and docking, autonomous systems, zero boil-off systems, advanced fuel cells and a lunar EVA system.

Linkage to other initiatives:

- **OSP – A "sled" or "capsule" configuration is a key enabler for any exploration beyond low Earth Orbit.**

- **NSI – For the reusable scenarios, target sizing for "Prometheus" Jupiter mission vehicle (100 kW) is inadequate to facilitate pre-positioning and return of elements in the Earth-moon system. At a minimum, a 250kW reactor with more efficient thrusters will be required. Solar Electric Propulsion (SEP) seems to be the superior approach in Earth neighborhood scenarios.**

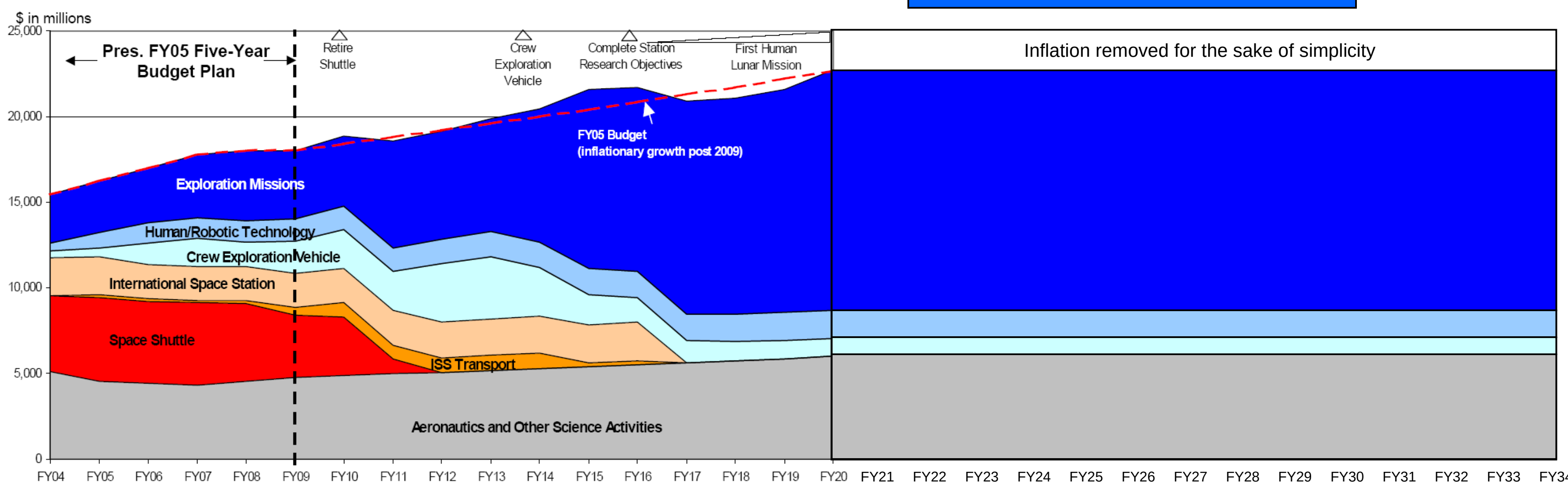
Primary Architecture Scenarios for President's Exploration Initiative

Shuttle-Derived Heavy Lift Enabled (Push to Mars)

- Develop ELV Based CEV
- Develop Lander
- Crewed Lunar Sorties
- Develop Mars Transfer, Surface Access and Habitat Systems
- Go to Mars
- Enhance ELV for CEV
- Develop Shuttle Derived launcher
- Develop Mars Class Nuclear Propulsion
- Develop Injection Stage
- Upgrade to HLLV (80MT+)

Enhanced ELV for Lunar Missions with Clean Sheet HLLV for Mars

- Develop ELV Based CEV
- Sustained Crewed Lunar Surface Access
- Develop Mars Transfer, Surface Access and Habitat Systems
- Go to Mars
- Enhance ELV for CEV
- Develop Lander
- Sustained Earth Neighborhood Access
- Develop Injection Stage
- Develop Mars Class Nuclear Propulsion
- Develop Clean sheet HLLV (80MT+)



What Could the Future Look Like?