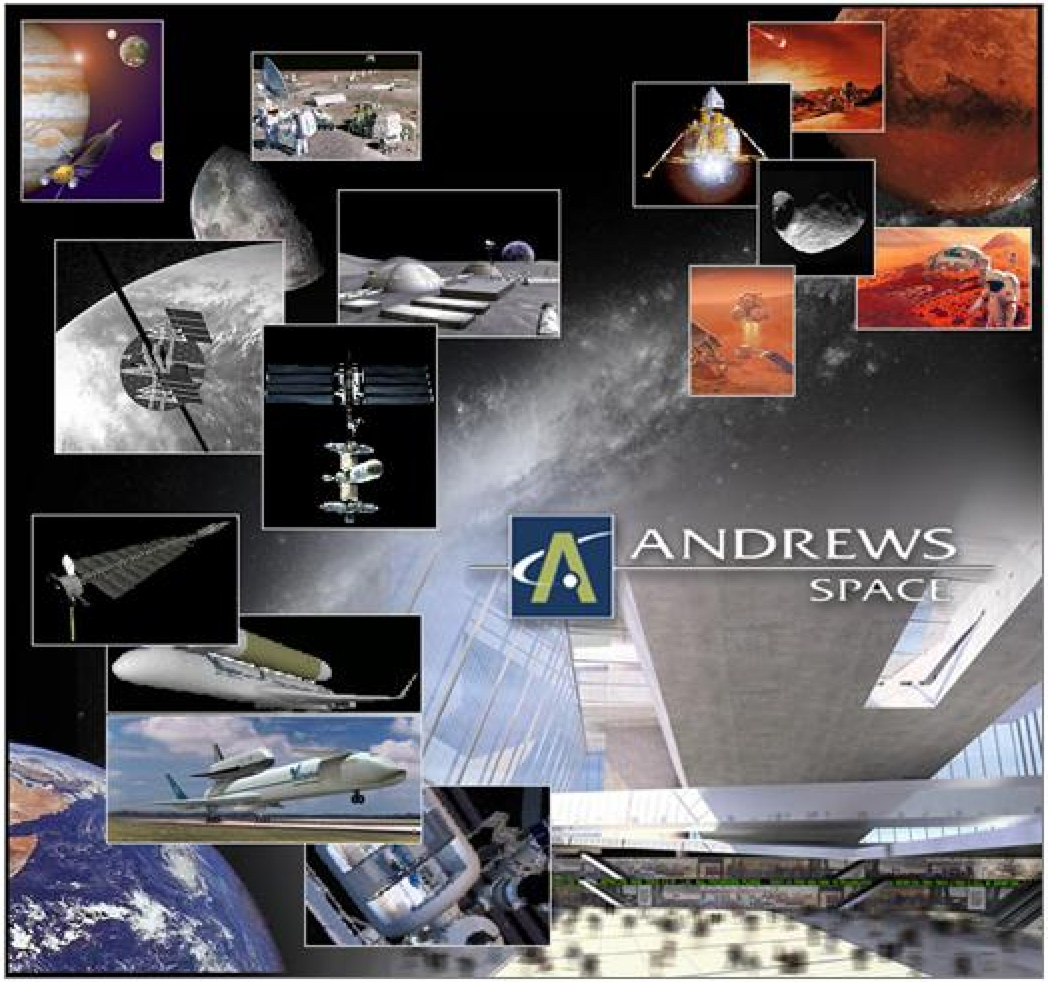


CE&R CA-1 Architecture Design & Analysis at Andrews Space

September 2004

www.andrews-space.com

Approach to CA-1

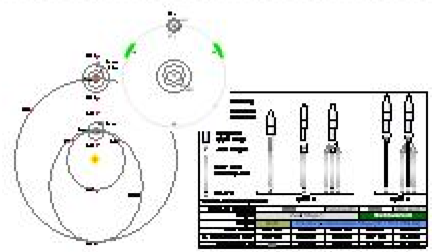
- Andrews will leverage its cost, performance, and operations experience base to define architecture and CEV requirements that best address the exploration goals and objectives:
  - Alternate Access to Station
  - DARPA Small Launch Vehicle Program
  - DARPA Hypersonic Weapons System Program
  - Orbital Space Plane
  - Next Generation Launch Technology
  - 3rd Generation RLV
  - 2nd Generation RLV
  - Space Exploration Initiative

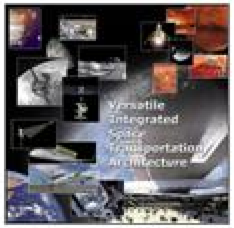
We look forward to working with NASA and Industry to establish a common set of requirements

Exploration Architecture Derivation Process

Project Constellation

Problem Definition	Option Space	Solution
Stakeholders → Architecture Objectives → System Requirements	Node Placement; Element Options	Architecture Definition → Architecture Implementation → Requirements Verification





Problem definition derived from stakeholders short and long-term objectives

Option Space surveyed for
- Node placement options
- Historic, present, and projected element capabilities

Solution based on understanding of the problem

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Stakeholders

Stakeholder	Definition
Government Civilian Agencies	A government agency (or collection of agencies) with a primary mission of government functions / social activities (e.g. legislature, executive, judiciary).
Government Defense Agencies	A government agency (or collection of agencies) with a primary mission of military activities aimed at people outside its own constituency (e.g. intelligence gathering, force projection, force deflection, military logistics).
Commercial Service Providers	A grouping of people with a primary objective of achieving profit by providing services or goods to others (e.g. launch service providers, satellite manufacturers, etc.).
Commercial Customers	A grouping of people with an interest of acquiring goods or services obtained through space activities for the purpose of achieving profit (e.g. telecommunications companies, remote imaging brokers, etc.).
General Public Customers	Any individual (or group of individuals) not acting with the primary goal of obtaining profit or affecting social change (e.g. individuals, non-profit organizations, etc.).

To successfully return to the Moon and Mars, we (NASA & Industry) must appeal to ALL stakeholders.

Architecture Stakeholders & Objectives

Andrews has identified scientific, economic and military objectives.

Objective	Definition	Stakeholders				
		GC	GD	CS	CC	GP
Human Outpost	Establish a sustainable human outpost on the Lunar surface, with growth path to a crewed Mars mission.	●			●	●
Robotic Exploration	Allow for sustainable robotic exploration of all bodies in the solar system.	●			●	●
Natural Observation	Allow for the observation of objects both within and outside the solar system (planets, stars, etc).	●				●
Commercialization	Provide a growth path for the transition of government activities to private enterprise via economically attractive opportunities for the sustainable involvement of private enterprise in the development, manufacturing, and operations of space systems.	●		●	●	●
Commercial Transport	Provide economically attractive, sustainable access to space resources for the transport of data, goods, people, and energy to/from and through space.			●	●	●
Public Involvement	Provide opportunities to the general populous to contribute to space activities, and experience and interact with the space environment.			●		●
Military Logistics	Assured access to space for deployment of force projection systems, and movements of logistics.		●			
Military Intelligence	Provide nationally assured access to orbital locations for the placement of observation systems.		●			

GC = Government Civil
GD = Government Defense,
CS = Commercial Services
CC = Commercial Customers
GP = General Public

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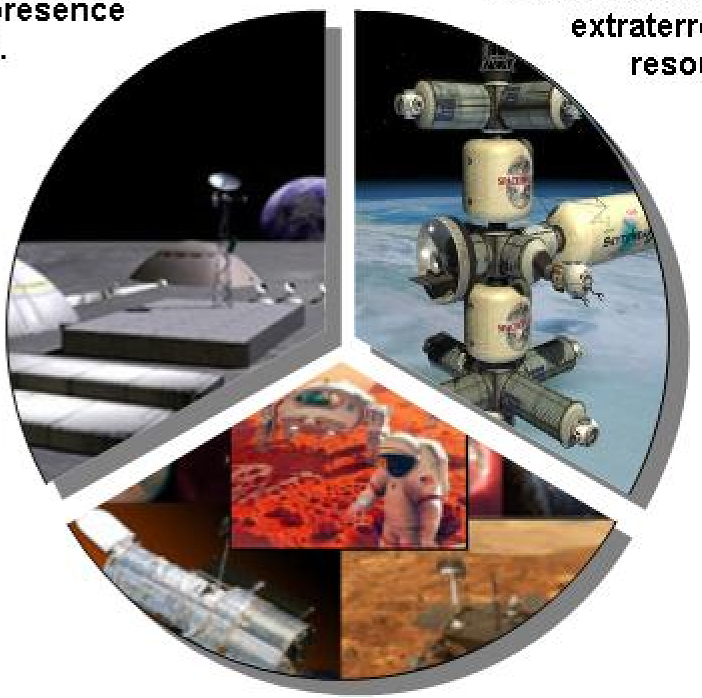
Goals of Human Space Activities

Establish a permanent human presence off Earth.

Enable utilization of extraterrestrial resources.



Explore space and broaden our understanding of nature.

1. Capable
2. Sustainable
3. Affordable
4. Reliable (Safe)

What is “Sustainability”?

Goal: Sustained Space Program

- Smooth funding demand
- Steady funding supply

Goal: Smooth Required Funding

- Step-ladder (modular) development approach
- Commercialization of mature elements, enabling development of the next level

Goal: Steady Funding Availability

- Sustained public support
- Sustained industry support

Goal: Sustained Public Support

- Regularly spaced visible program milestones
- Visible growth towards Public Space Access

Goal: Sustained Industry Support

- Steady availability of funding
- Commercial Opportunities

Sustainability Requirements

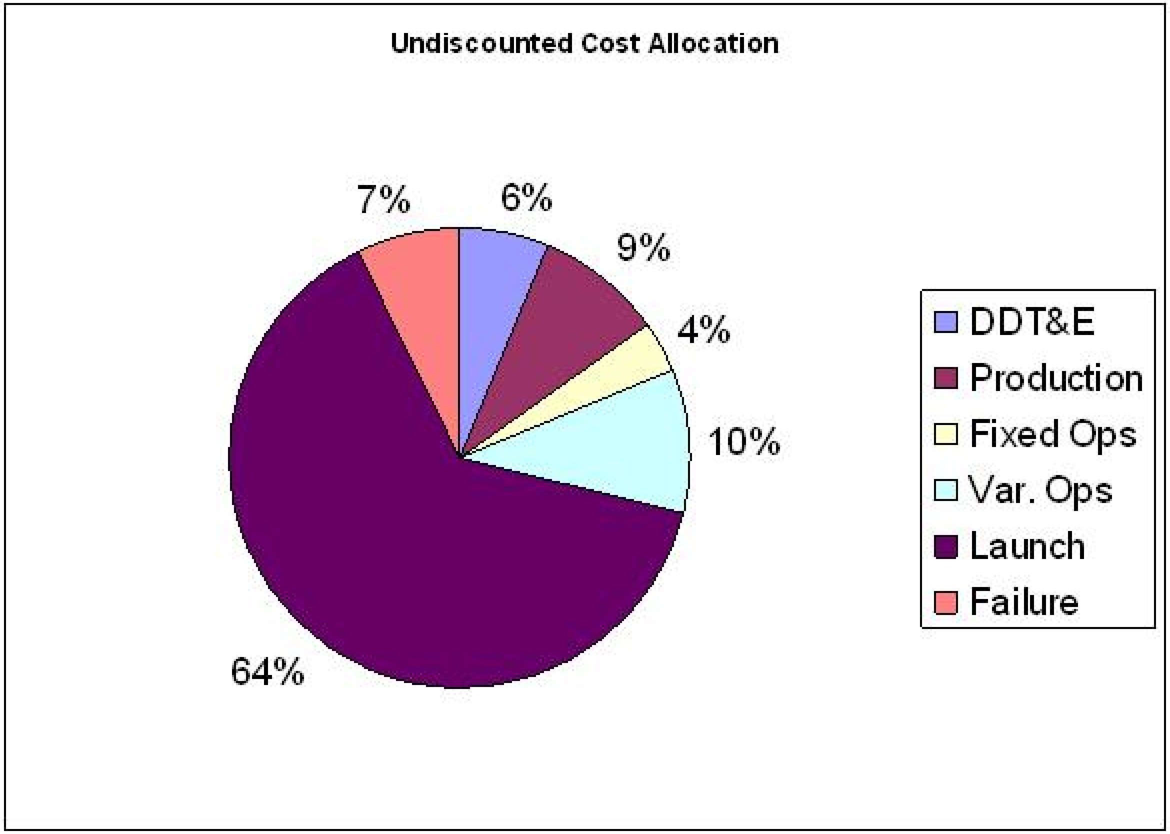
- Modular approach
- Commercialization of mature elements
- Regular milestone achievements
- Growth towards commercial Public Space Access

Affordable - Lessons Learned from NASA AAS

Life Cycle Cost Based on:

-100,000 lb of annual cargo to ISS

- Recovery of ~50% of ISS cargo (downmass)
- Six Years of Operations
- NASA EELV Pricing



Launch cost accounts for 2/3 of total life cycle cost (including launch portions of the cost of failure).

ETO Segment Impact on Architecture

Goal: Sustained Space Presence

- Sustained, crewed Moon / Mars Exploration requires capacity beyond existing ELVs
- Sustainability requires commercial viability

Goal: Commercially Viable ETO

- Requires low cost to orbit

Goal: Low Cost to Orbit

- Requires high flight rate
- Requires reusability

Goal: High Flight Rate

- Requires high reliability
- Requires high versatility

Goal: High Versatility

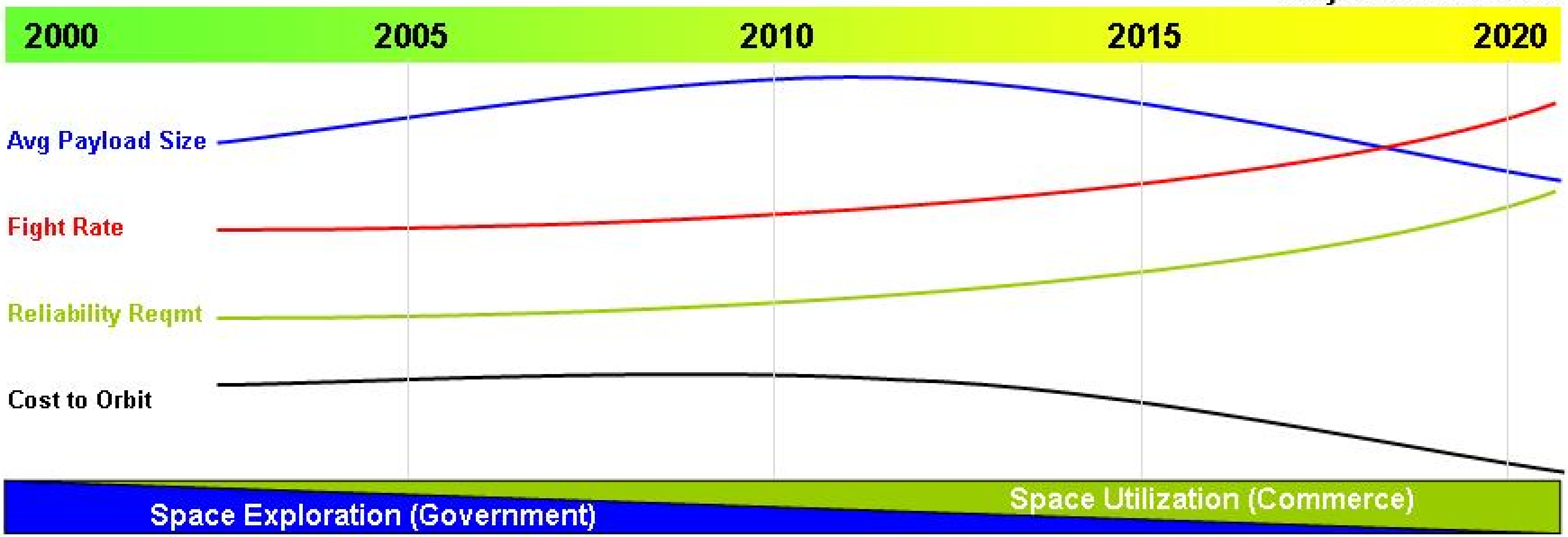
- Need medium & heavy lift
- Requires booster with support for various upper stages

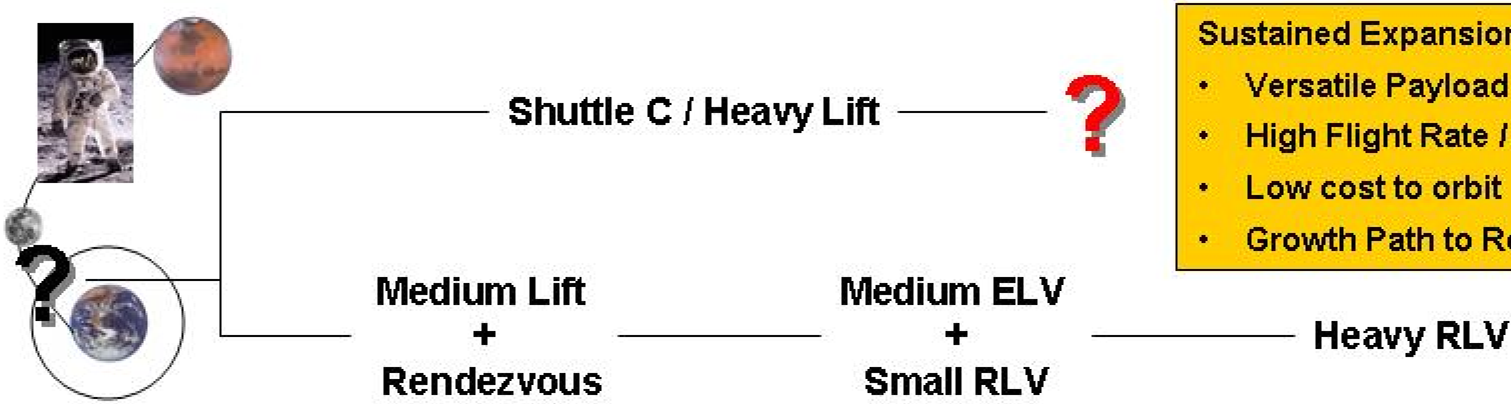
Goal: High Reliability

- Requires HTHL

Solution: TSTO HTHL RLV

Long Term Impact of Near Term ETO Strategy





Sustained Expansion Requires

- Versatile Payload Size
- High Flight Rate / Reliability
- Low cost to orbit
- Growth Path to Reusability

Technology Advancements

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Architecture Key Trades (1)

Project Constellation

Title	Options	Motivation	FOMs
Crew Size	Any Integer (0-6+)	Number of humans at any given system within the architecture has a high impact on operations, cost, capability, launch requirements, etc.	- Milestone Frequency - Gov. Campaign Cost - Suitability to Habitation
Node 1 Location	Moon Direct LEO Hub L1 Hub LLO Hub Lunar Surface Hub	First staging node has a key impact on the safety, evolvability, and capability of the architecture; strongly drives ETO lift requirements, and determines dependencies on autonomous rendezvous and docking technologies.	- Emergency Access Time - Payload Mass Fractions - Milestone Frequency - Gov. Campaign Cost - Resource Availability - Suitability to Habitation
Node 2 Location	Mars Direct Phobos Earth/Mars Cycler	Similar to A1 the placement (or absence) of an intermediate node to support crewed Mars missions has a high impact on all aspects of the architectures potential to successfully meet the desired exploration objectives.	- Emergency Access Time - Payload Mass Fractions - Milestone Frequency - Gov. Campaign Cost - Resource Availability - Suitability to Habitation
ISRU Selection	No ISRU ISRU & Non-ISRU All ISRU segments	This trade will identify what segments of the transportation architecture will benefit from the use of local resources. It also investigates what specific substances are worthwhile extracting (e.g. water, methane, CO, O2, etc.).	- Integrated Payload Limit - Payload Mass Fractions - Annual ETO manifest - Commercialization Potential

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Architecture Key Trades (2)

Title	Options	Motivation	FOMs
ETO	(E)ELV only RLV only Heavy Lift Mixed Fleet Time Phased	Lifting materials out of Earth's gravity well is a formidable obstacle towards the expansion of human space activities. An ill-defined approach to the ETO segment can potentially doom an entire architecture. In this trade all ETO options will be evaluated.	- Int. Payload Limit - Payload Mass Fractions - Annual ETO Capacity - Annual Loss Rate - ETO Cost - Commercialization Potential
Orbital Mechanics	Classic Orbits N-Body Orbits	Multi-body orbital mechanics trajectories have the potential to significantly reduce Dv requirements and widen launch windows, but come at a price of increased transit times.	- Integrated Payload Limit - Payload Mass Fractions - Annual ETO Capacity - Milestone Frequency - Emergency Access Time
Robotic Autonomy	Autonomous Teleoperated	Teleoperation has the advantages of reduced technology risk and human-in-the-loop decision capability. However, in order for teleoperation to be feasible node placements must be adjusted to account for light-speed lag time.	- Milestone Frequency - Gov. Campaign Cost - Annual Loss Rate - Commercialization Potential
Power Source	Nuclear Power Solar Power Mixed Power	Nuclear power offers higher power densities and improved performance for electric propulsion vehicles, but comes at the cost of increased technology risk, development time, and socioeconomic cost/risk.	- Integrated Payload Limit - Payload Mass Fractions - Annual ETO Capacity - Government Funding Profile - Milestone Frequency - Campaign Cost

Earth/Moon L1 Transportation Hub

- Architecture nodes are placed based on an evaluation of critical node characteristics
- Environmental factors (gravity topography, resources, etc) are key drivers in node suitability
- Operational characteristics such as Time-to-Safety (or "forward basing") are additional factors

Identified Nodes

Node	Type	Alt [km]	Description
ESN	Surface	0	Earth Surface Node
LEO	2-Bod	300	Low Earth Orbit
MEO			
GEO			
LL1	Lagra		
LL2			
LL3			
LL4			

Node Attributes

Characteristic	Description
Specific Energy	The specific energy (expressed as ideal Δv from the Earth's surface) at the nod… Mo… hel…
Accessibility	The… inte… of…

Node Assessment

Node	ε [km^2/s^2]	Accessibility	Gravity [g]	Stability	Resources	MMOD	Radiation
ESN	-62.39	Poor	1.00	Excellent	Excellent	Excellent	Excellent
LEO	-29.84	Good	0	Poor	Poor	Medium	Good

Andrews chose the L1 Node based on:

- Gateway between Earth / Moon / Mars and other planetary bodies
- Increases the number of launch opportunities between Earth and Moon / Planets
- Low amount of station keeping ΔV (~10 m/s per year)
- Supports Earth / L1 Gateway / Moon communications infrastructure

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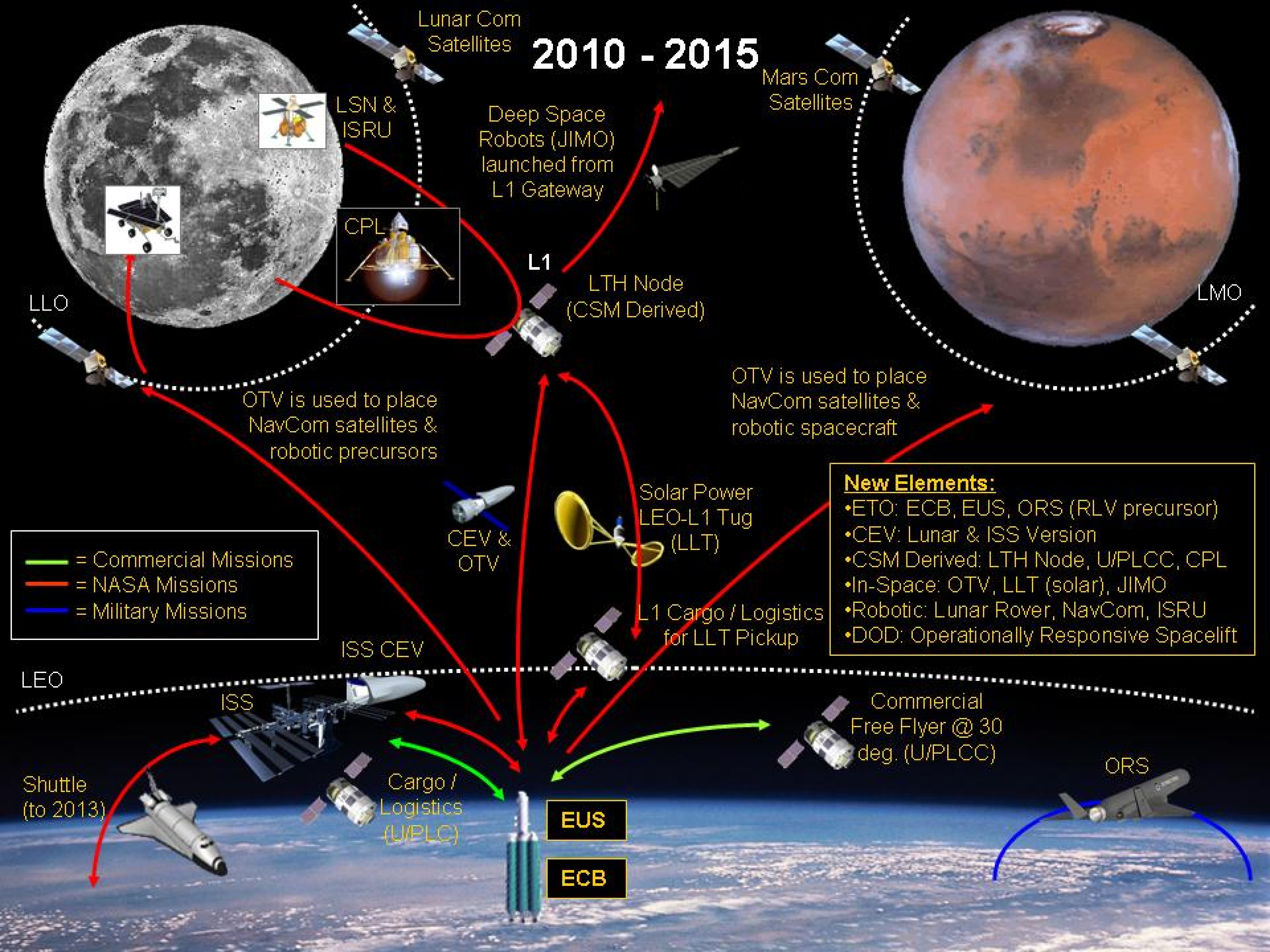
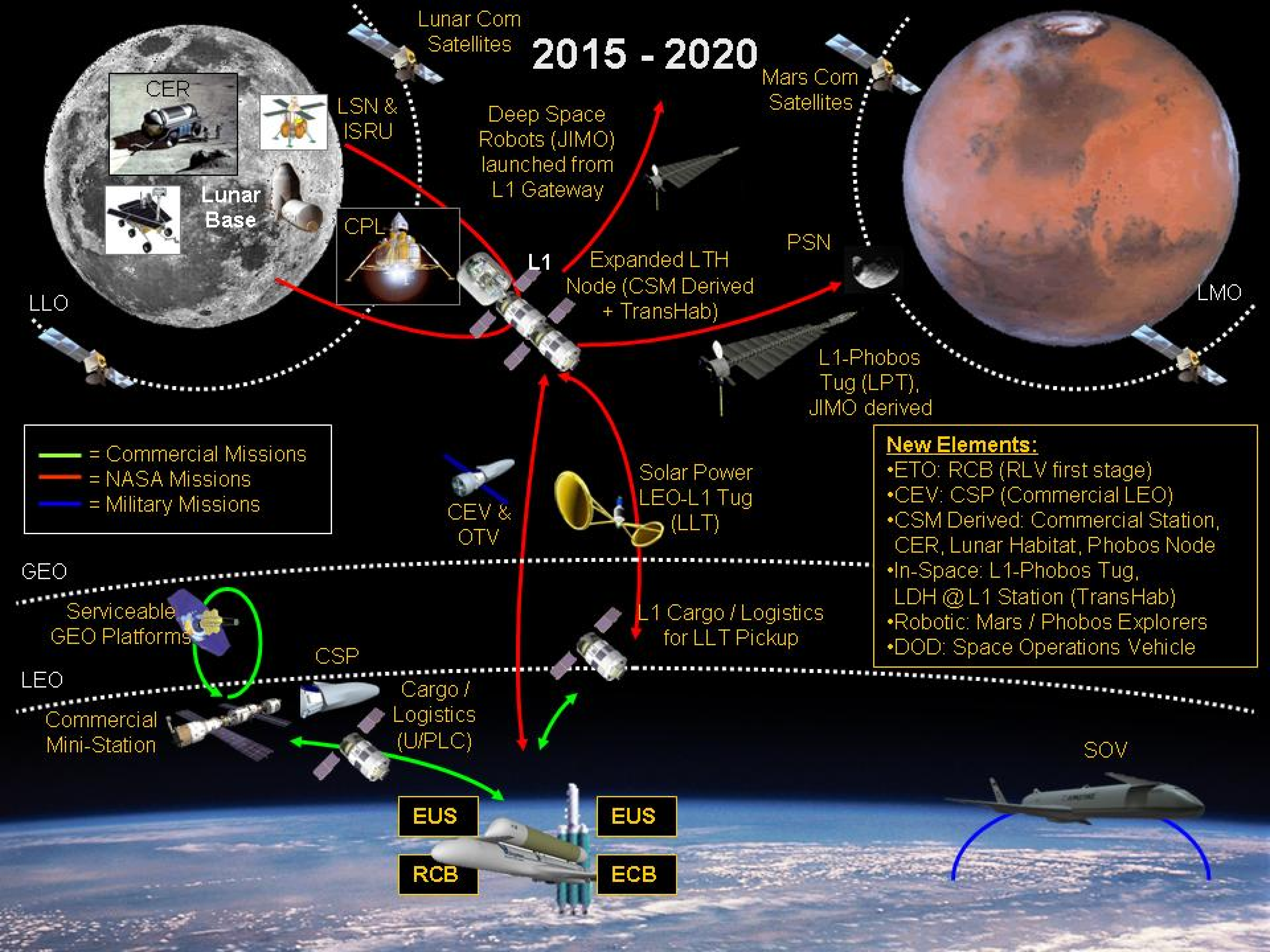
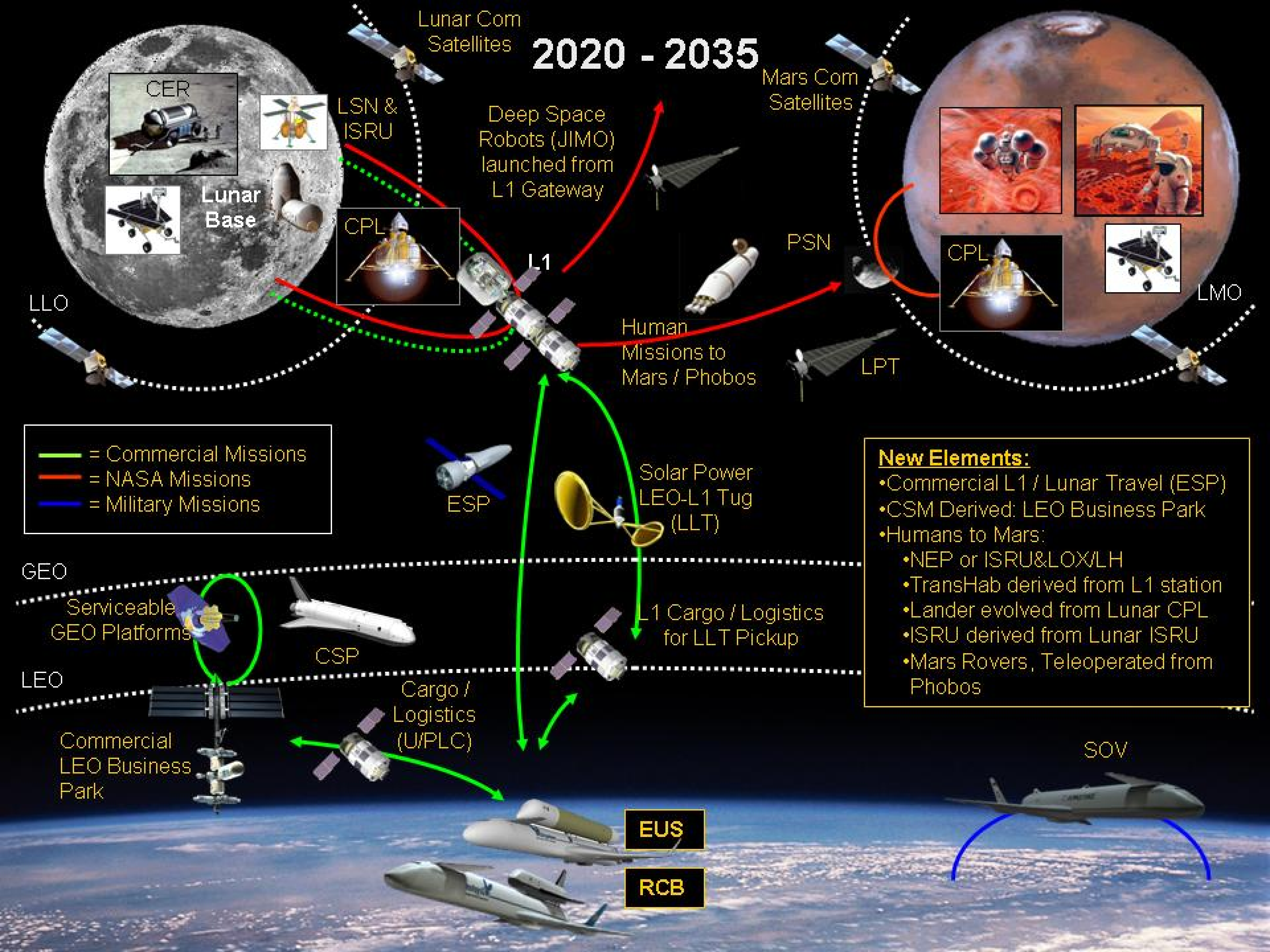


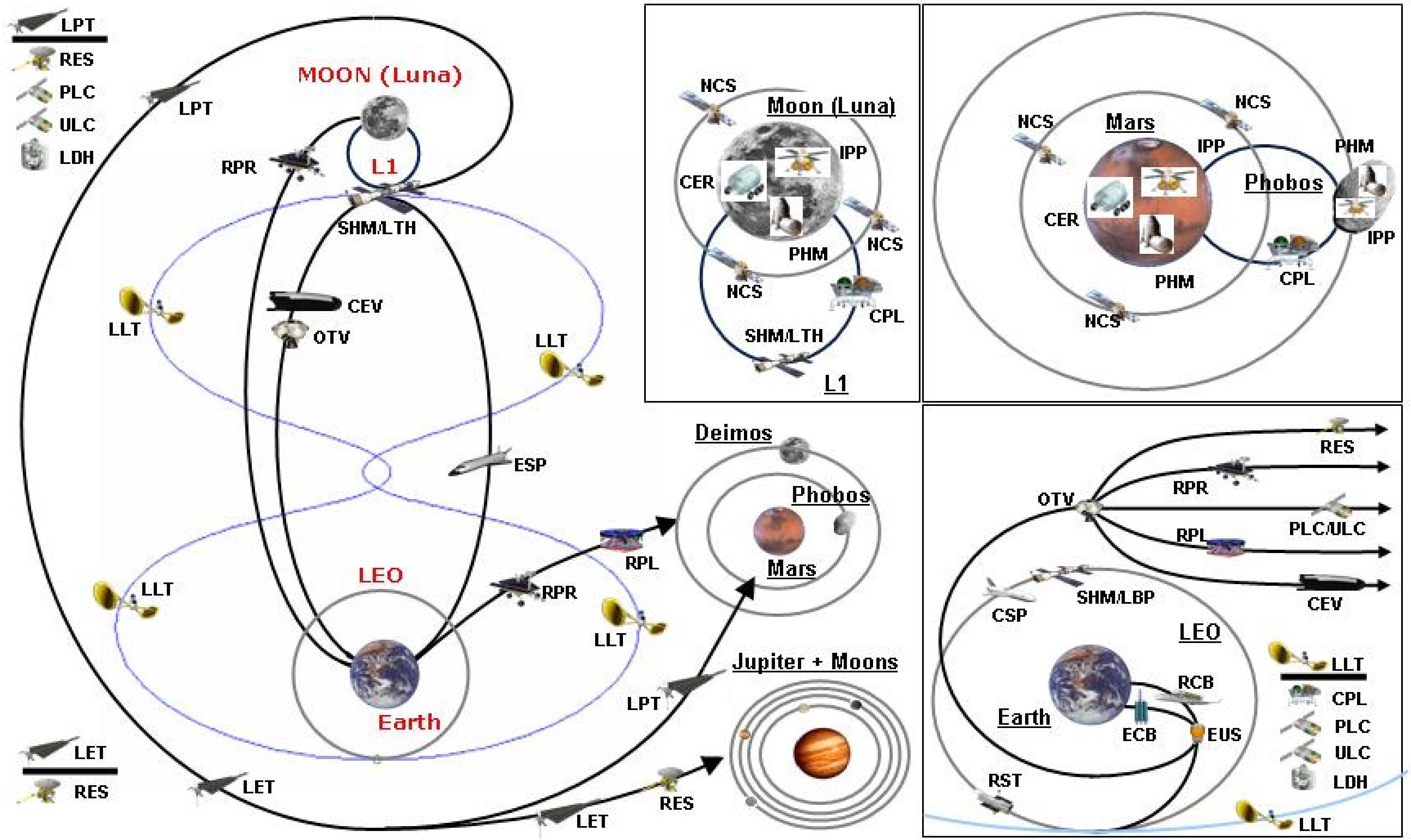
2010 - 2015
Lunar Com Satellites
Mars Com Satellites
LSN & ISRU
Deep Space Robots (JIMO) launched from L1 Gateway
CPL
L1
LTH Node (CSM Derived)
LLO
LMO
OTV is used to place NavCom satellites & robotic precursors
OTV is used to place NavCom satellites & robotic spacecraft
New Elements:
•ETO: ECB, EUS, ORS (RLV precursor)
•CEV: Lunar & ISS Version
•CSM Derived: LTH Node, U/PLCC, CPL
•In-Space: OTV, LLT (solar), JIMO
•Robotic: Lunar Rover, NavCom, ISRU
•DOD: Operationally Responsive Spacelift
CEV & OTV
Solar Power LEO-L1 Tug (LLT)
= Commercial Missions
= NASA Missions
= Military Missions
L1 Cargo / Logistics for LLT Pickup
ISS CEV
LEO
ISS
Commercial Free Flyer @ 30 deg. (U/PLCC)
Shuttle (to 2013)
Cargo / Logistics (U/PLC)
ORS
EUS
ECB



2015 - 2020
Lunar Com Satellites
CER
LSN & ISRU
Lunar Base
CPL
Deep Space Robots (JIMO) launched from L1 Gateway
Mars Com Satellites
L1
Expanded LTH Node (CSM Derived + TransHab)
PSN
LLO
LMO
L1-Phobos Tug (LPT), JIMO derived
= Commercial Missions
= NASA Missions
= Military Missions
CEV & OTV
Solar Power LEO-L1 Tug (LLT)
New Elements:
•ETO: RCB (RLV first stage)
•CEV: CSP (Commercial LEO)
•CSM Derived: Commercial Station, CER, Lunar Habitat, Phobos Node
•In-Space: L1-Phobos Tug, LDH @ L1 Station (TransHab)
•Robotic: Mars / Phobos Explorers
•DOD: Space Operations Vehicle
GEO
Serviceable GEO Platforms
L1 Cargo / Logistics for LLT Pickup
CSP
LEO
Cargo / Logistics (U/PLC)
Commercial Mini-Station
SOV
EUS
EUS
RCB
ECB


2020 - 2035
Lunar Com Satellites
CER
LSN & ISRU
Lunar Base
CPL
LLO
Deep Space Robots (JIMO) launched from L1 Gateway
L1
Mars Com Satellites
PSN
CPL
LMO
Human Missions to Mars / Phobos
LPT
= Commercial Missions
= NASA Missions
= Military Missions
ESP
Solar Power LEO-L1 Tug (LLT)
New Elements:
•Commercial L1 / Lunar Travel (ESP)
•CSM Derived: LEO Business Park
•Humans to Mars:
•NEP or ISRU&LOX/LH
•TransHab derived from L1 station
•Lander evolved from Lunar CPL
•ISRU derived from Lunar ISRU
•Mars Rovers, Teleoperated from Phobos
GEO
Serviceable GEO Platforms
CSP
L1 Cargo / Logistics for LLT Pickup
LEO
Cargo / Logistics (U/PLC)
Commercial LEO Business Park
SOV
EUS
RCB

Architecture Node / Segment Overview (2010 to 2035+)



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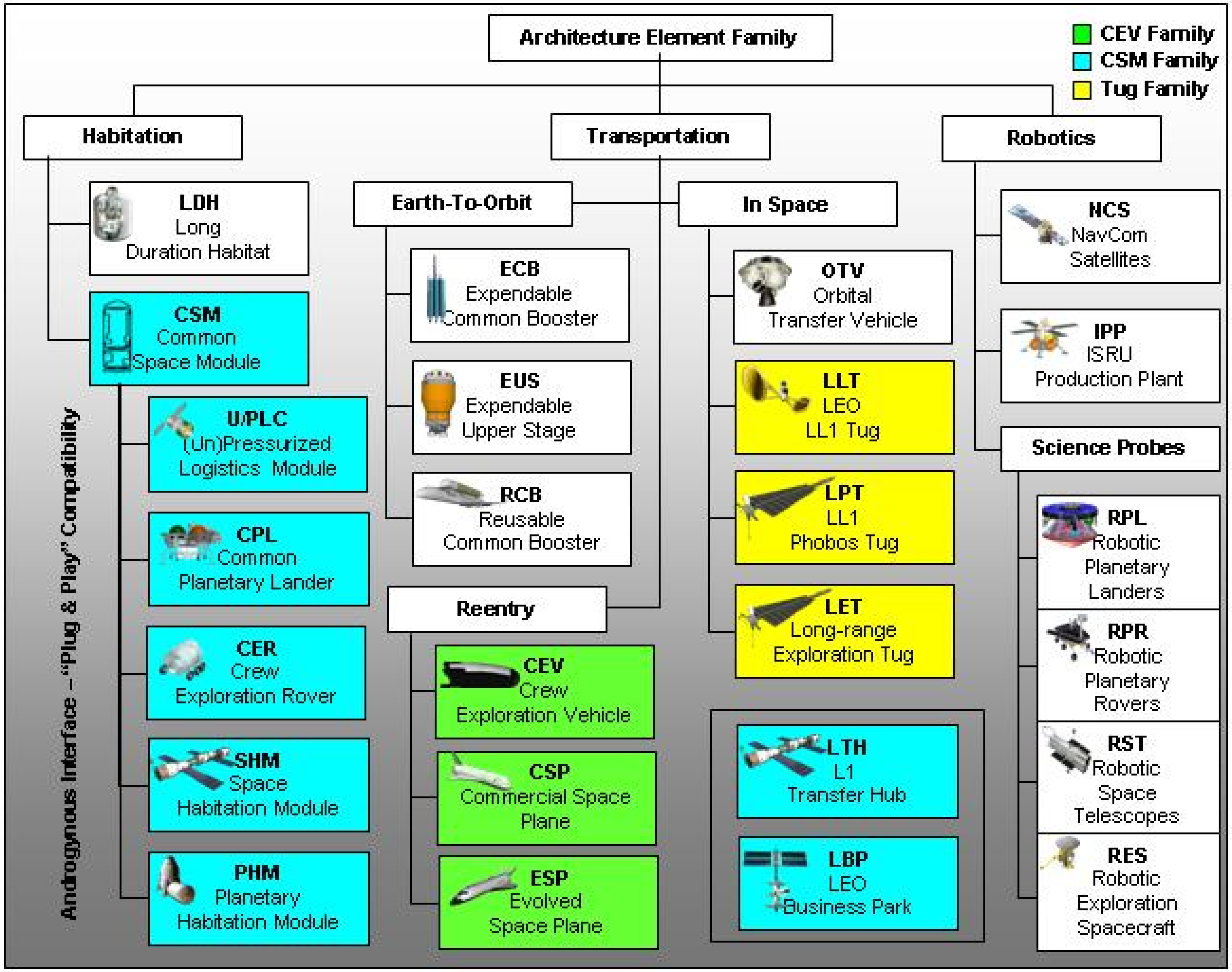
Modular Element Families



- **Reduces individual launch mass requirements**
- **Reduces development time (heritage utilization)**
- **Reduces overall cost (smaller number of unique systems)**
- **Reduces technology risk (interchangeable backup options)**

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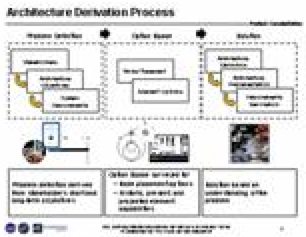
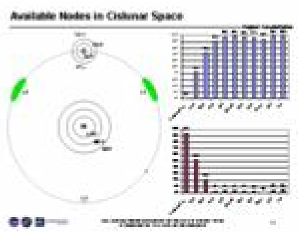
Architecture Tasks Summary



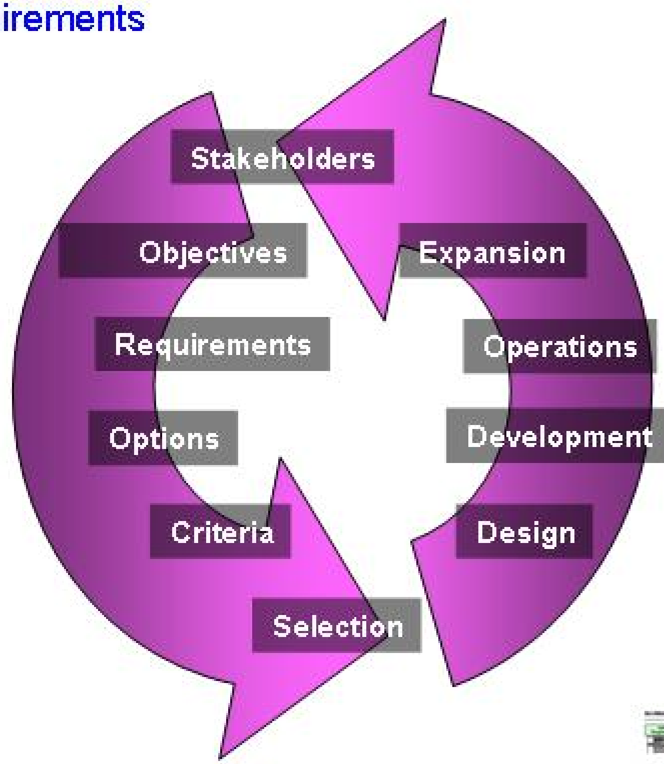
Identify Stakeholder Objectives and Requirements

Expand to additional Stakeholders / Objectives and iterate to determine Impact

Define and Execute Trades to Optimize Design



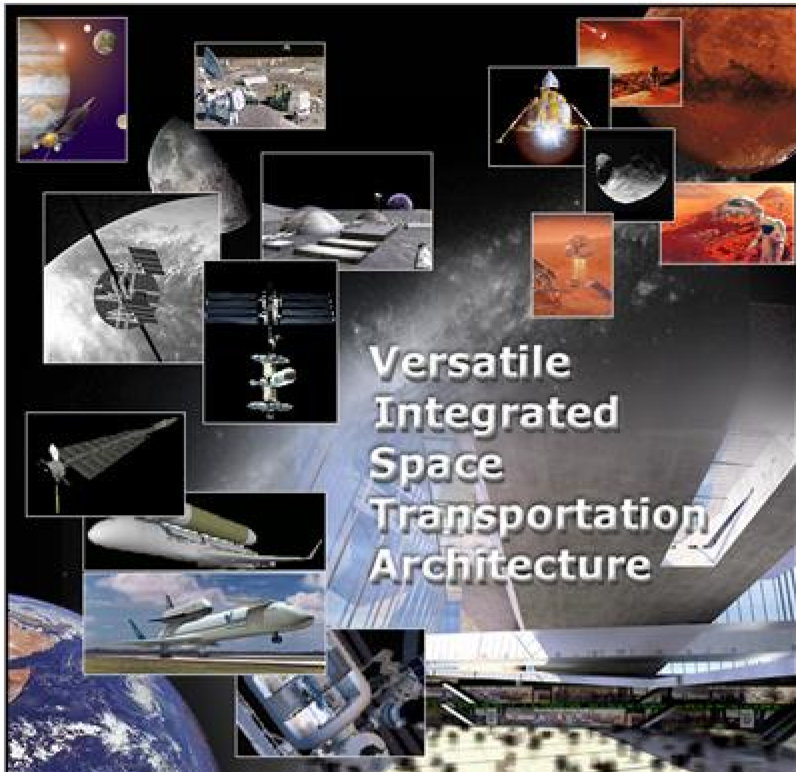
Determine and Characterize (FOM) Option Space



Define Baseline Architecture Candidate

Perform Detail Analysis and determine FOM Values

Summary



- **Advanced Orbital Mechanics:** Transportation Hub at Earth/Moon L1 for superior "time-to-safety" and gateway to low Δv trajectories throughout the Solar System.
- **ISRU:** Use of local bulk resources (water, regolith) reduces payload requirements.
- **Modular System-of-Systems:** standardized interfaces for "plug & play" functionality, diverse technology base reduces program risk.
- **Exploration enables Commercialization:** Elements are extensible in support of Public Space Access, the most critical factor for a sustained space program.

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