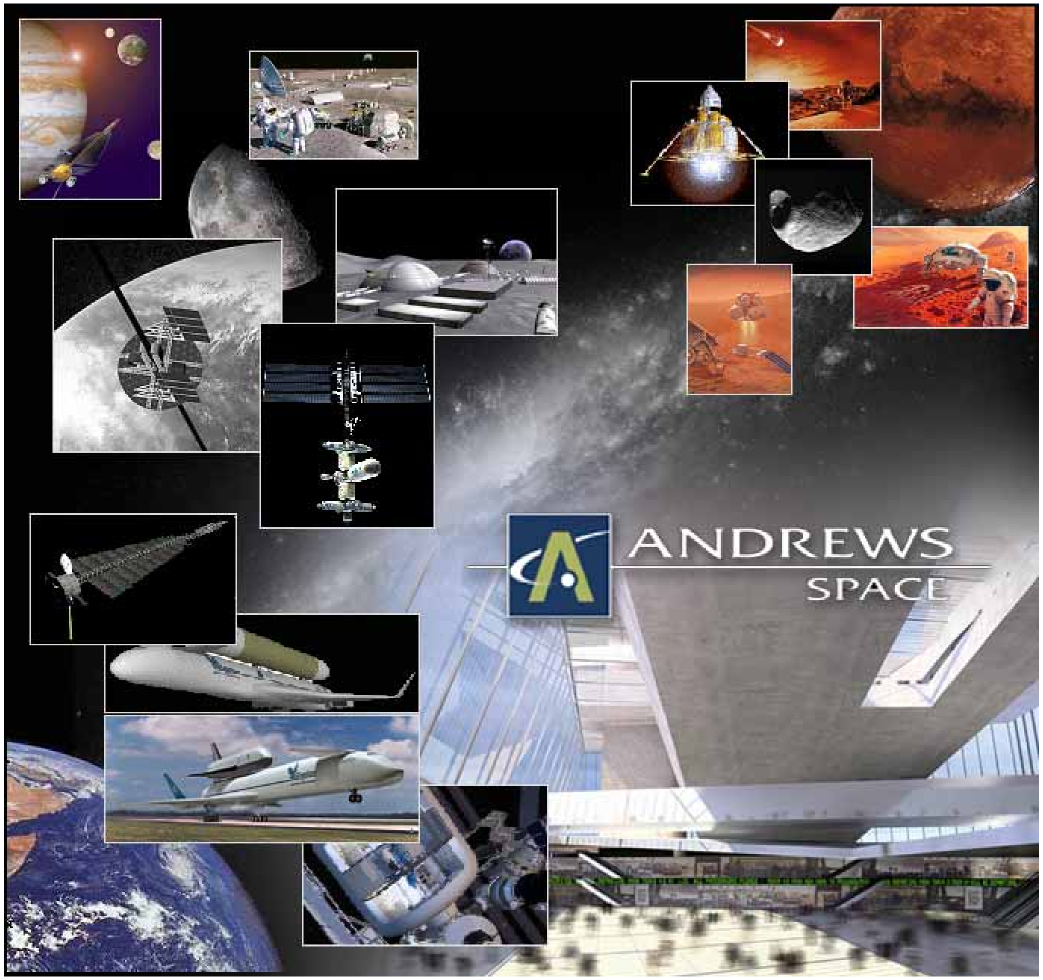

NASA CE&R Midterm Briefing

CA-1: Exploration Super System (ESS)

December 2004

www.andrews-space.com

Overview

- **Introduction**
  - *Overview (Agenda)*
  - *CA-1 Roadmap*
- **Exploration Objectives**
  - *Decomposition & Maturation*
  - *Relationship to Architecture*
- **Architecture Overview/ Definition**
  - *Assumption & Groundrules*
  - *Mission Definition*
  - *System Updates*
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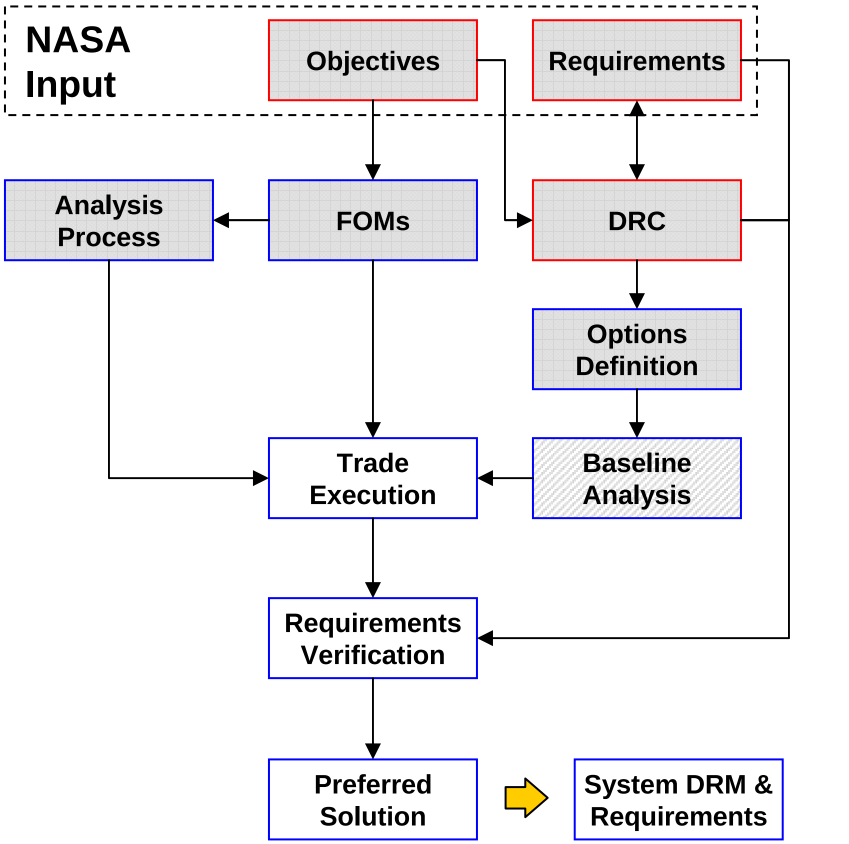
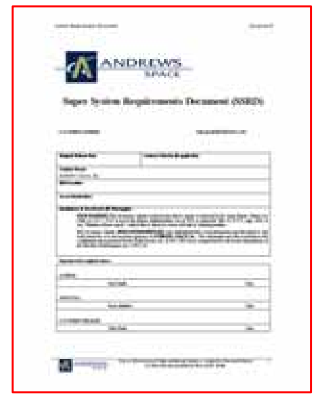
  - *Significant Risk Definition*
  - *Architecture Specific*
  - *Mitigation Approaches*

SuperSystem Roadmap

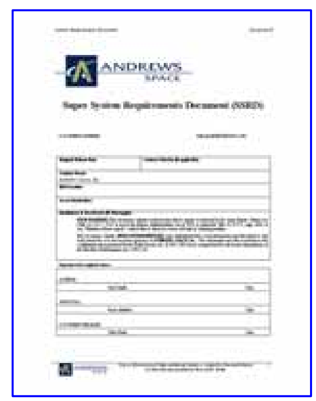


All characteristics of the SuperSystem Design are traceable to NASA Requirements / Objectives

- Progress To Date
- Upcoming Activity



SSRD: SuperSystem Requirements Document



SSDD: SuperSystem Description Document

Exploration Objectives

- Introduction
  - *Overview (Agenda)*
  - *CA-1 Roadmap*

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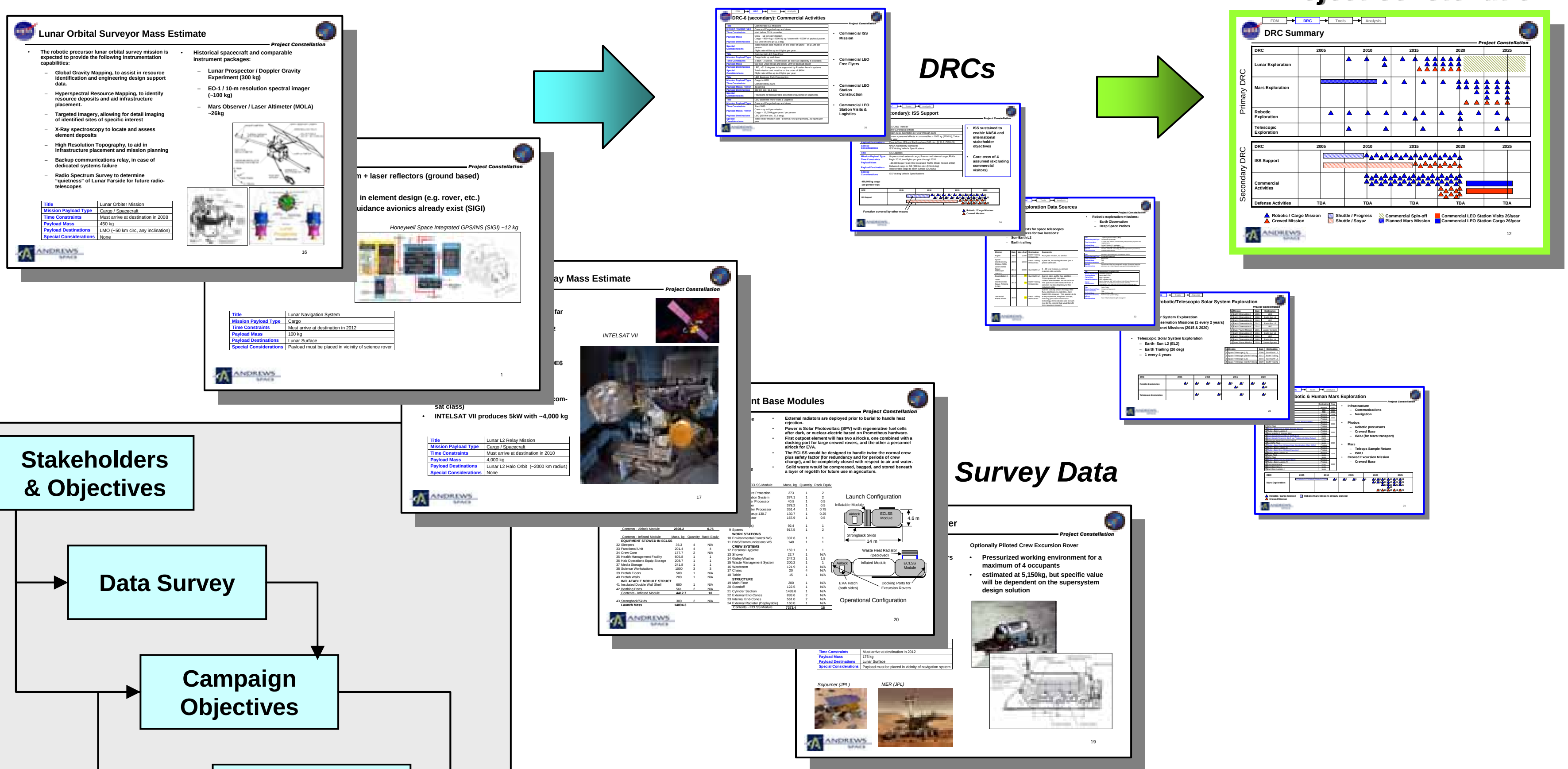
DRC Development Process

Project Constellation



Stakeholders & Objectives → Data Survey → Campaign Objectives → Timing & Sequence → DRC

Process

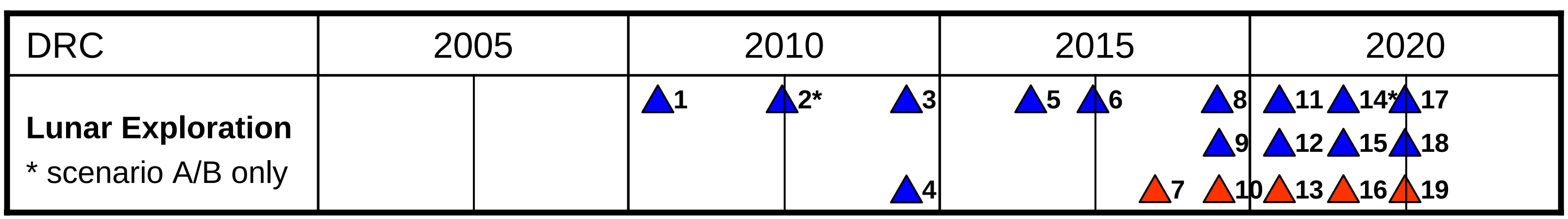
DRC definitions are derived from stakeholder objectives, historical data, and timing / sequence constraints.

DRC-1: Robotic & Human Lunar Exploration

Mission	Title	Date	Crew	Cargo [kg]	Vol.[m^3]
1	Orbital Surveyor	2008	-	450	1.0
2	Communications Relay	2010	-	4,000	8.8
3	Navigation System	2012	-	100	0.6
4	Science Rover	2012	-	175	1.1
5	Optionally Piloted Excursion Vehicle	2014	-	SSV	SSV
6	Permanent Base Modules I	2015	-	SSV	SSV
7	Crewed Lunar Excursion Mission I	2016	4	-	-
8	Permanent Base Modules II	2017	-	SSV	SSV
9	Lunar Power System	2017	-	SSV	SSV
10	Crewed Lunar Excursion Mission II	2017	4	-	-
11	Crew for Permanent Base	2018	4	-	-
12	Logistics to Base I	2018	-	SSV	SSV
13	Engineering Test Facilities Modules	2018	-	15,000	125
14	Crew Rotation / Expansion	2019	6	-	-
15	Logistics to Base II	2019	-	SSV	SSV
16A	Telescope / Science Modules	2019	-	15,000	125
16B	Telescope / Science Modules	2020	-	15,000	125
17	Crew Rotation / Expansion (A/B)	2020	8	-	-
18	Logistics to Base III	2020	-	SSV	SSV
19A	Resource Exploitation Infrastructure	2020	-	15,000	125
19B/C	Resource Exploitation Infrastructure	2019	-	15,000	125

SSV = Solution Specific Value

- **Global access (from orbit), with local crewed rover mobility**
- **Launch any time of the year/month**
- **Multiple lunar locations considered depending on precursor findings (near side equator, far side polar, far side equator)**
- **Nominal Mission Crew of 4**
- **Excursion missions with 10 day surface stay time.**
- **One year nominal crew rotation when permanent base is established**
- **Crew expands from 4 to 8 as base functionality grows**
- **Possible commercial activities after 2020**



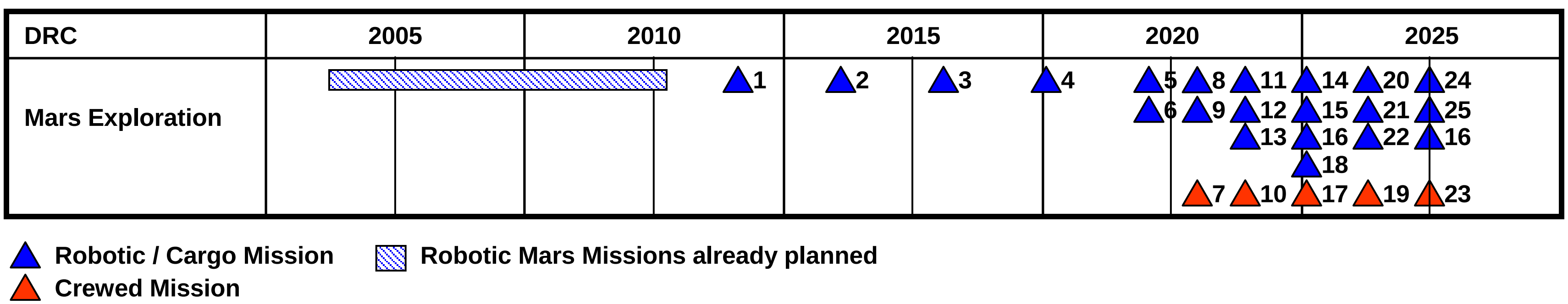
DRC-1:	**44 person-trips**	**8.8 person-trips/year**
Apollo (Lunar Orbit):	**60 person-trips**	**15.0 person-trips/year**
Apollo (Lunar Surface):	**28 person-trips**	**7.0 person-trips/year**

DRC-2: Robotic & Human Mars Exploration

Project Constellation

No	Mission	Destination	Year
1	Orbital Surveyor	Phobos	2012
2	Communications Relay System	TBD	2014
3	Navigation System	TBD	2016
4	Exploration Rover	Phobos	2018
5	Power System	Phobos	2020
6	Base Modules I (habitat)	Phobos	
7	Phobos Base Crew I (Base Construction, Phobos ISRU)	Phobos	2021
8	Phobos Base Logistics I	Phobos	
9	ISRU Plant	Phobos	
10	Phobos Base Crew II (Mars Sample Return)	Phobos	2022
11	Phobos Base Logistics II	Phobos	
12	Base Modules II (science labs)	Phobos	
13	Mars Sample Return Rover (to Phobos)	Mars	
14	Mars Sample Return (to Earth via Phobos with Crew Return)	Earth	2023
15	Optionally Piloted Excursion Vehicle	Mars	
16	Test ISRU Plant	Mars	
17	Phobos Base Crew III (Mars Base Construction, Mars ISRU)	Phobos	
18	Phobos Base Logistics III	Phobos	
19	Phobos Base Crew III (Mars Excursion)	Phobos	2024
20	Phobos Base Logistics III	Phobos	
21	Power Plant	Mars	
22	ISRU Plant	Mars	
23	Phobos Base Crew IV (Mars Base)	Phobos	2025
24	Phobos Base Logistics IV	Phobos	
25	Mars Base Module	Mars	
26	Mars Base Crew I	Mars	
27	Mars Base Logistics I	Mars	

- **Focus on establishing sustainable infrastructure (communications, navigation).**
- **Utilize Phobos moon for crewed base (L1 analogy), and possible ISRU opportunities**
- **Teleoperated (via Phobos) Mars surface exploration, sample return, possible ISRU prior to Mars landing commitment**
- **Mars crewed excursion mission, with long term goal of crewed base on the surface**
- **Nominal mission crew of four**



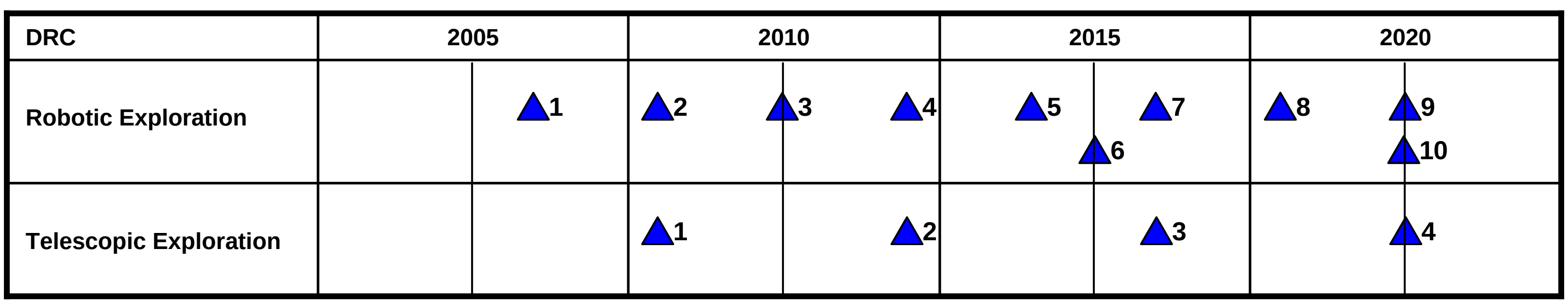
DRC-3/4: Robotic/Telescopic Solar System Exploration

Project Constellation

- **Robotic Solar System Exploration**
  - **Earth Observation Missions (1 every 2 years)**
  - **Outer Planet Missions (2015, 5 year cycle)**
- **Telescopic Solar System Exploration**
  - **Earth- Sun L2 (EL2)**
  - **Earth Trailing (20 deg)**
  - **1 every 4 years**

No	Mission	Date	Destination
1	Earth Observation I	2006	LEO
2	Earth Observation II	2008	Earth-Sun L1
3	Earth Observation III	2010	LEO
4	Earth Observation IV	2012	Earth-Sun L2
5	Earth Observation V	2014	LEO
6	Outer Planet Mission	2015	Jupiter System
7	Earth Observation VI	2016	Earth-Sun L3
8	Earth Observation VII	2018	LEO
9	Earth Observation VIII	2020	Earth-Sun L4
10	Outer Planet Mission	2020	Saturn System

No	Mission	Date	Destination
1	Space Telescope (L2)	2008	Sun-Earth L2
2	Space Telescope (Earth Trailing)	2012	Earth Trailing
3	Space Telescope (L2)	2016	Sun-Earth L2
4	Space Telescope (Earth Trailing)	2020	Earth Trailing



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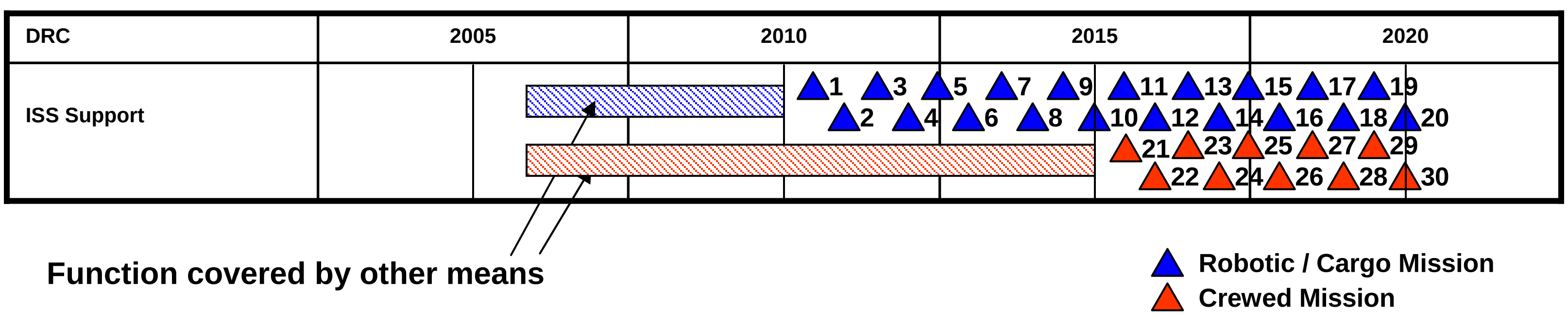
DRC-5: ISS Support

Title	ISS Crew Transfer
Mission Payload Type	Crew & Personal effects
Time Constraints	Begin 2016, two flights per year through 2020
Payload Mass	4 crew + personal effects + consumables = 1000 kg (2200 lb); Twice per year
Payload Destinations	Crew to/from ISS and Earth surface (360 circ. @ 51.6, CONUS)
Special Considerations	NASA habitability standards ISS Visiting Vehicle Specifications

Title	ISS Logistics
Mission Payload Type	Unpressurized external cargo; Pressurized internal cargo; Fluids
Time Constraints	Begin 2010, two flights per year through 2020.
Payload Mass	~48,000 kg per year (ISS Integrated Traffic Model Report, 2002)
Payload Destinations	Delivered cargo to ISS (360 km circ @ 51.6 deg) Recoverable cargo to earth surface (CONUS)
Special Considerations	ISS Visiting Vehicle Specifications

- **ISS sustained to enable NASA and international stakeholder objectives**
- **Core crew of 4 assumed (excluding commercial visitors)**
- **Possible commercial visitors under commercial DRC**

480,000 kg cargo
160 person-trips



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DRC-6: Commercial Activities

Title	Commercial ISS Missions
Mission Payload Type	Crew and Cargo both up and down
Time Constraints	start before 2014 or earlier
Payload Mass	Crew – up to 6 per mission Cargo – 900+ kg (~2000 lb) up / down with ~500W of payload power.
Payload Destinations	ISS 360 km circ @ 51.6 deg.
Special Considerations	Total mission cost must be on the order of $40M – or $7.9M per person Flight rate will be up to 4 flights per year.

- **Commercial ISS Mission**

Title	Commercial LEO Free Flyer
Mission Payload Type	Cargo both up and down
Time Constraints	2 days - 2 weeks. First mission as soon as capability is available.
Payload Mass	900 kg (~2000 lb) up and down, 2kW of payload power
Payload Destinations	LEO, >51.6 degrees to be supported by Russian launch systems
Special Considerations	Total mission cost must be on the order of $40M Flight rate will be up to 4 flights per year

- **Commercial LEO Free Flyers**

Title	LEO Business Park Construction
Mission Payload Type	Cargo to LEO
Time Constraints	Completed by 2020.
Payload Mass / Power	40,000 kg
Payload Destinations	360 km circ, 51.6 deg
Special Considerations	Provisions for teleoperated assembly if launched in segments.

- **Commercial LEO Station Construction**

Title	LEO Business Park Visits & Logistics
Mission Payload Type	Crew and Cargo both up and down
Time Constraints	Start 2020
Payload Mass / Power	Crew – up to 6 per mission Cargo – 12,000 kg per year / per person
Payload Destinations	LEO (360 km circ, 51.6 deg).
Special Considerations	Total visitor mission cost ~$40M ($7.9M per person), 26 flights per year.

- **Commercial LEO Station Visits & Logistics**

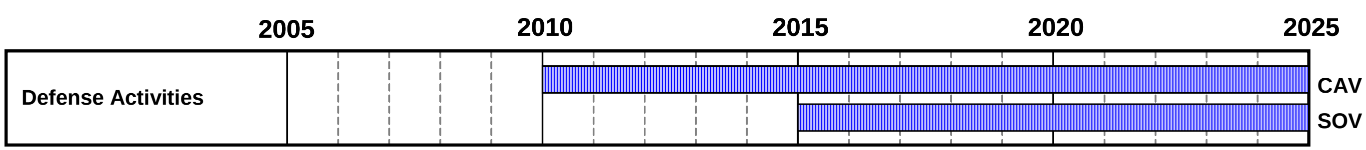
DRC-7: Defense Activities

- **The USAF Transformation Flight Plan document identifies a number of space focused defense activities**
  - **Protection of Space Assets**
  - **Rapid Refueling/Repair/Relocation**
  - **Secure Communications**
  - **Space Superiority**
  - **Space Based Surveillance / Tracking**
  - **Missile Detection / Destruction**
  - **Denial of Space to Adversaries**

Title	CAV Deployment
Mission Payload Type	Cargo
Time Constraints	Start 2010, up to 10 times a year.
Payload Mass / Power	1,000 kg
Payload Destinations	100 km, 8 km/s (100x –2100, 28.5 deg)
Special Considerations	Burst capability with 48h call-up, 72h turnaround

Title	SMV Deployment
Mission Payload Type	Cargo
Time Constraints	Start 2015, up to 6 times a year.
Payload Mass / Power	2,500 kg
Payload Destinations	300 km circ, 28.5 deg
Special Considerations	Burst capability with 48h call-up, 72h turnaround

- **Two Representative Payloads Classes are captured**
  - **Space Maneuvering Vehicle (SMV), in-space / orbital operations**
  - **Common Aero Vehicle (CAV), sub-orbital payload deployment**



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DRCs and Extensibility FOM

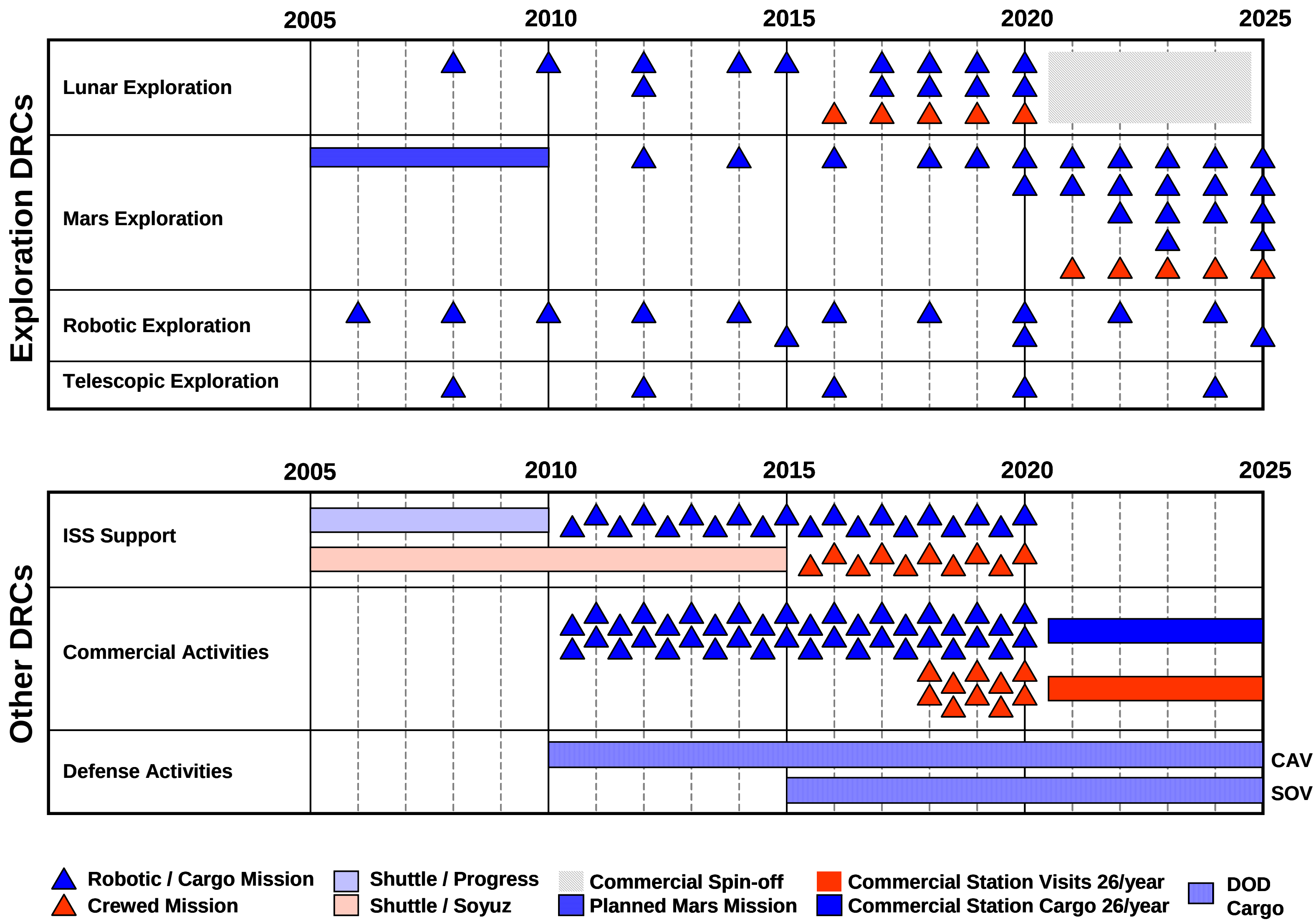
- DRCs are the SuperSystem Analogue to CEV Design Reference Missions (DRM)
- Primary DRCs are directly derived from captured NASA objectives
- Secondary DRCs are derived from other stakeholder objectives, in support of extensibility / sustainability FOMs
- DRCs define the end objectives of the SuperSystem, to the level of detail required to evaluate selected FOMs

- **Primary DRCs**
  - DRC-1: Robotic & Human Lunar Exploration
  - DRC-3: Robotic Solar System Exploration
  - DRC-4: Telescopic Solar System Exploration
- **Secondary DRCs**
  - DRC-2: Robotic & Human Mars Exploration
  - DRC-5: ISS Support
  - DRC-6: Commercial Activities
  - DRC-7: Defense Activities
- **Addresses Extensibility FOMs**
  - Long Term Extensibility
  - Non-Exploration Extensibility

DRC	Title	Primary	Secondary	
			Long-Term	Non-Exploration
1	Robotic & Human Lunar Exploration	●		
2	Robotic & Human Mars Exploration		●	
3	Robotic Solar System Exploration	●		
4	Telescopic Solar System Exploration	●		
5	ISS Support			●
6	Commercial Activities			●
7	Defense Activities			●

DRC Summary

Project Constellation



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Architecture Overview / Definition

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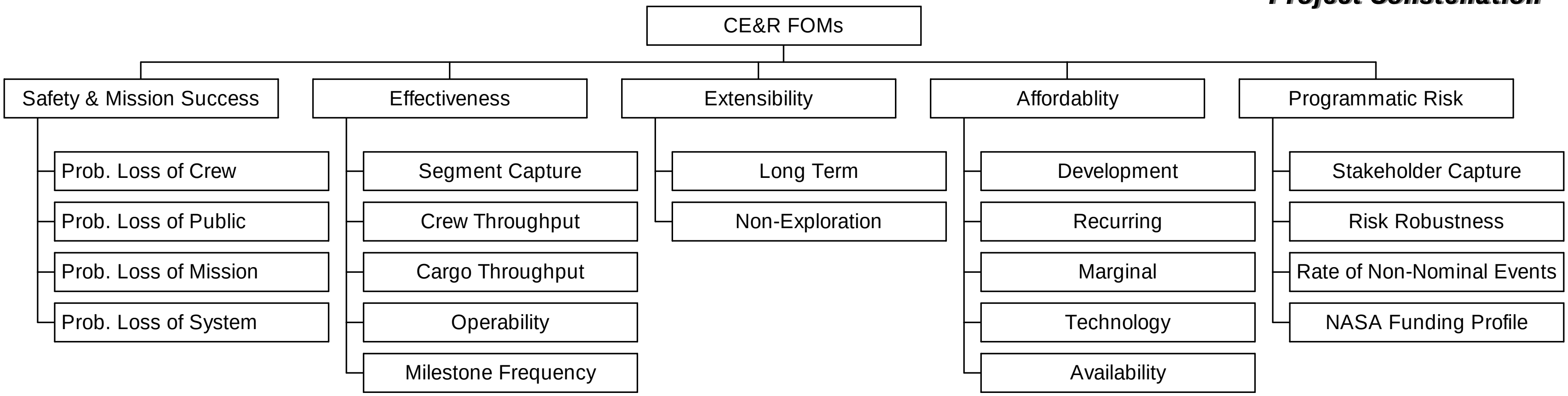
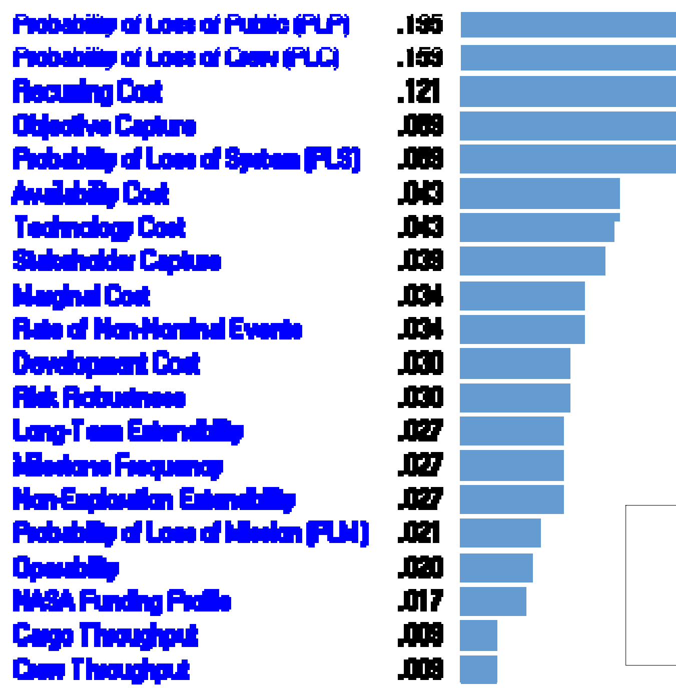
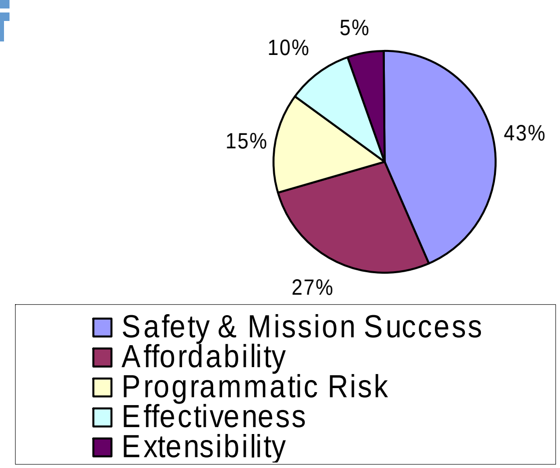
SuperSystem Figures of Merit



- **Primary FOMs are consistent throughout SuperSystem and System (CEV) Trades**
- **Secondary SuperSystem FOMs are subset of list shown above**
- **Secondary CEV FOMs are defined per trade, based on ability to discriminate between identified options**





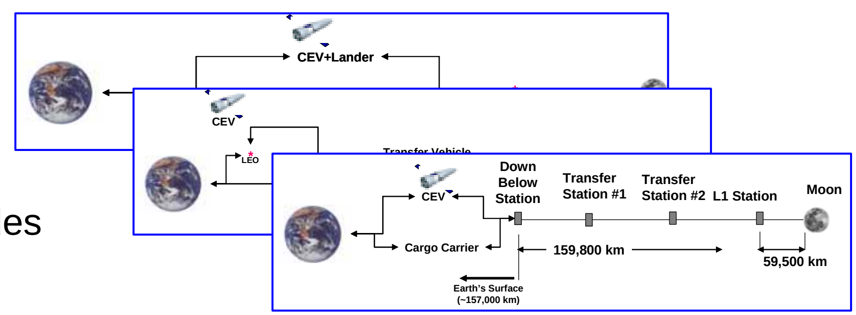
Trade Study Approach

ESS Optimization Trades

Title	Options
Node 1 Location	LEO Hub L1 Hub LLO Hub Lunar / L1 Elevator
ETO Segment	(E)ELV, RLV, Heavy Lift (Saturn-V class), Mixed Fleet Combinations, Time Phased Combinations
ISRU Selection	ISRU vs. No-ISRU, mixed segments, time-phased
Power Source	Nuclear, Solar, Mixed
Node 2 Location	Mars Direct, Phobos, Earth/Mars Cycler
Robotic Autonomy	Automatic Elements vs. Teleoperated Elements
Technology Impact	TBD
Modularity	TBD
Reusability	TBD
Element Trades	TBD

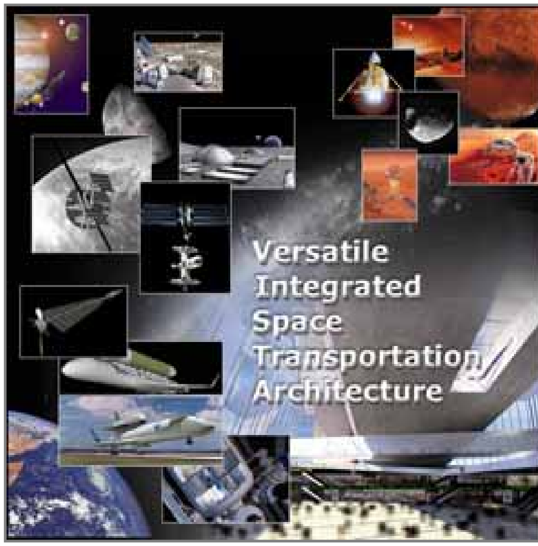
- **Problem "inter-connectedness" requires two flavors of trade studies**
  - **Trading options to optimize a selected architecture baseline**
  - **Trading options to select from multiple, optimized baselines**
- **Applying the same taxonomy to two different baselines will produce different results**
  - **L1 / LLO for VISTA: L1 is selected**
  - **L1 / LLO for Direct: LLO is selected**

ESS Selection Trades

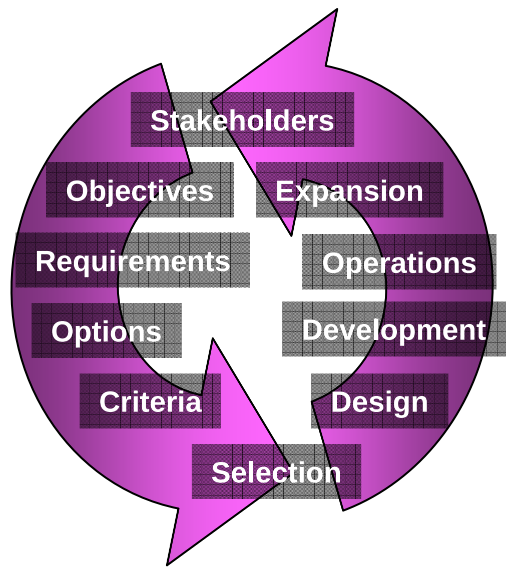


VISTA Philosophy

- **Versatile Integrated Space Transportation Architecture (VISTA)**
  - **Organic concept that grows over time**
  - **Involves a continuously increasing number of stakeholders**
  - **Sacrifices component task optimization for versatility / modularity**
  - **Longer initial built-up, but truly sustained long term achievements**



- **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.



Safe

Reliable

Capable

Affordable

Extensible

Sustainable

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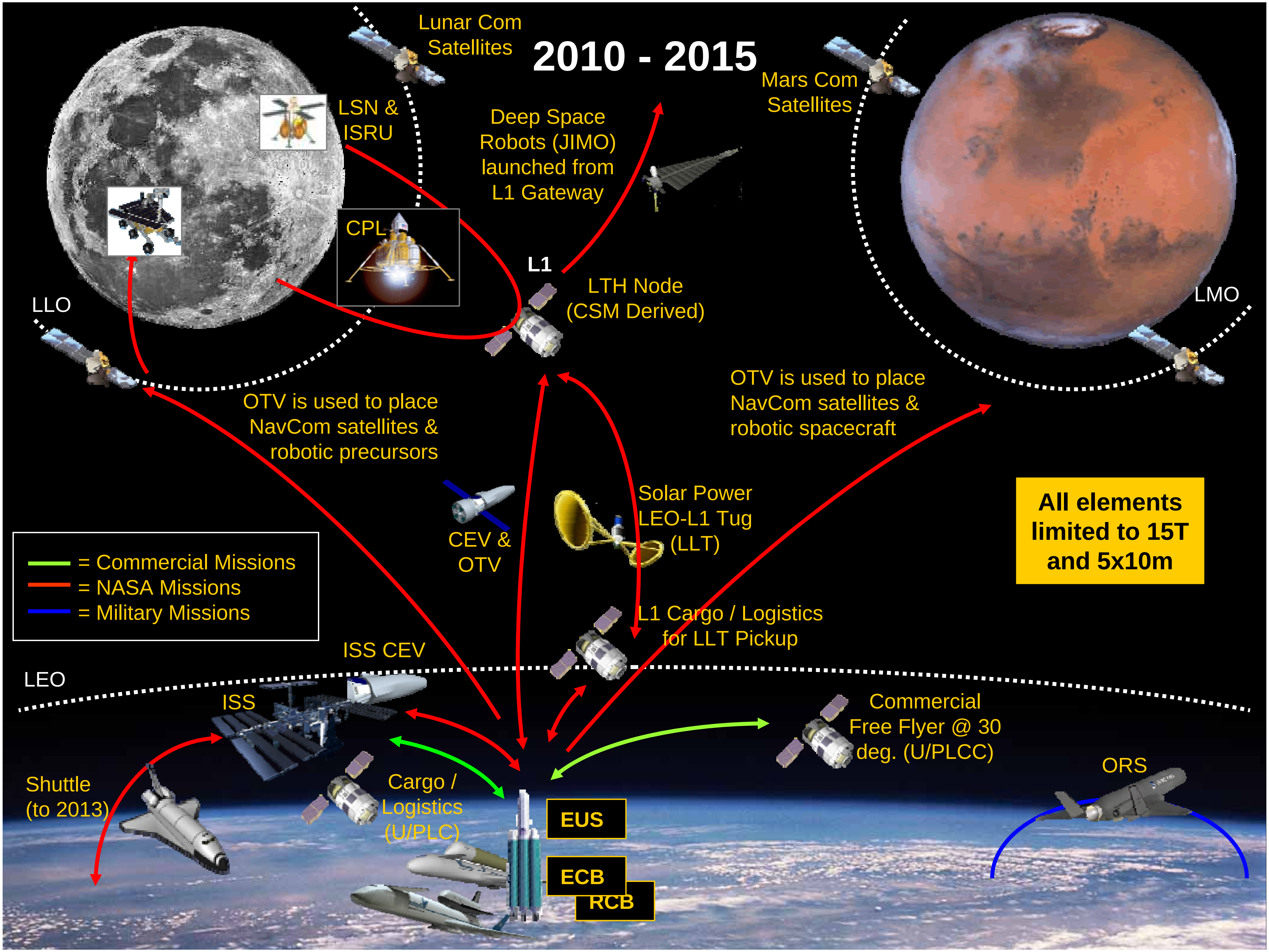
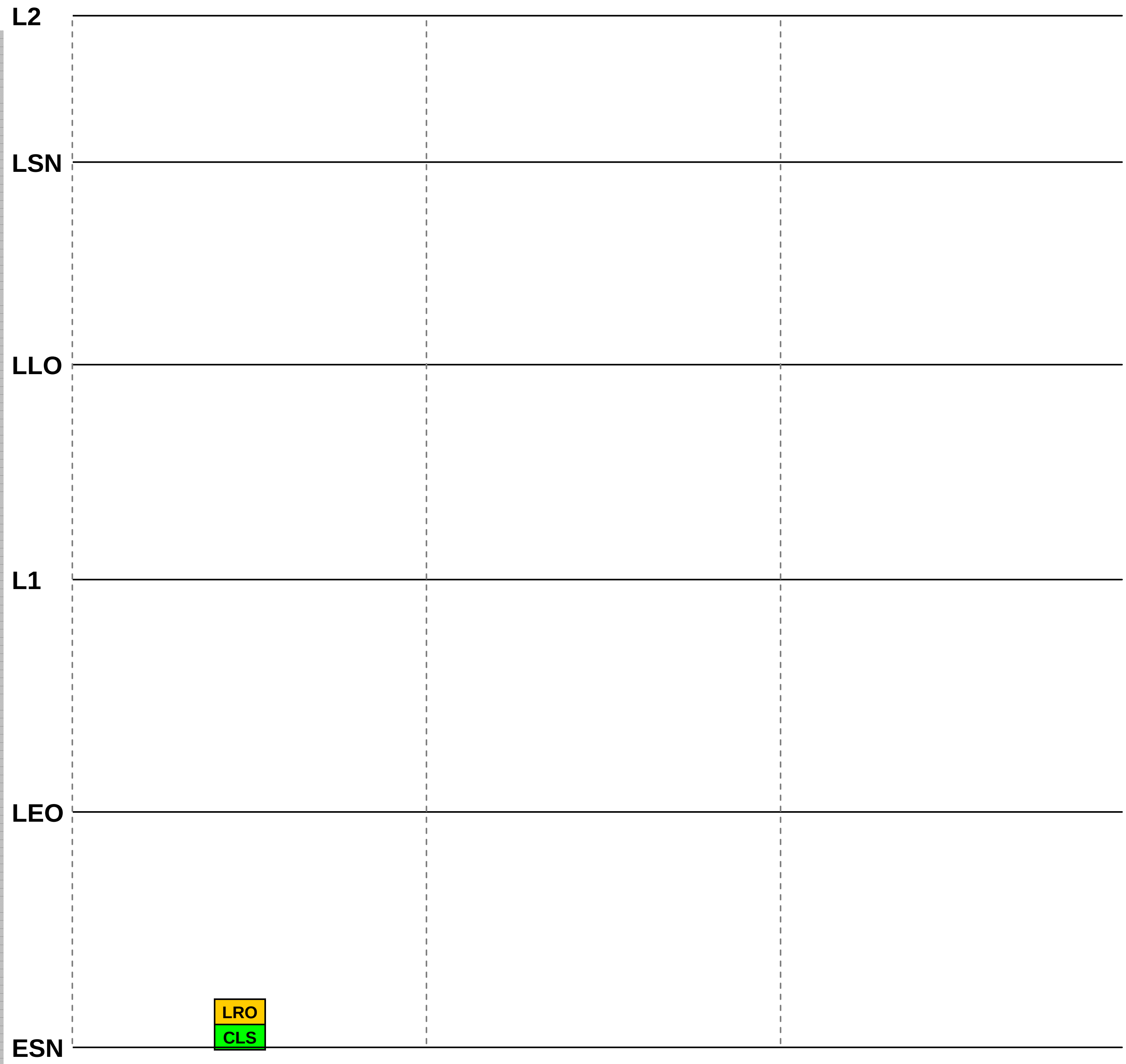

2010 - 2015
Lunar Com Satellites
LSN & ISRU
CPL
LLO
Deep Space Robots (JIMO) launched from L1 Gateway
L1
LTH Node (CSM Derived)
Mars Com Satellites
LMO
OTV is used to place NavCom satellites & robotic precursors
OTV is used to place NavCom satellites & robotic spacecraft
CEV & OTV
Solar Power LEO-L1 Tug (LLT)
All elements limited to 15T and 5x10m
= Commercial Missions
= NASA Missions
= Military Missions
L1 Cargo / Logistics for LLT Pickup
ISS CEV
LEO
ISS
Commercial Free Flyer @ 30 deg. (U/PLCC)
ORS
Shuttle (to 2013)
Cargo / Logistics (U/PLC)
EUS
ECB
RCB

VISTA Sequence

- Each column is a snapshot in time
- Time Steps are not homogenous

Launch 1

- Existing L/V
- Lunar Reconnaissance Orbiter (LRO)

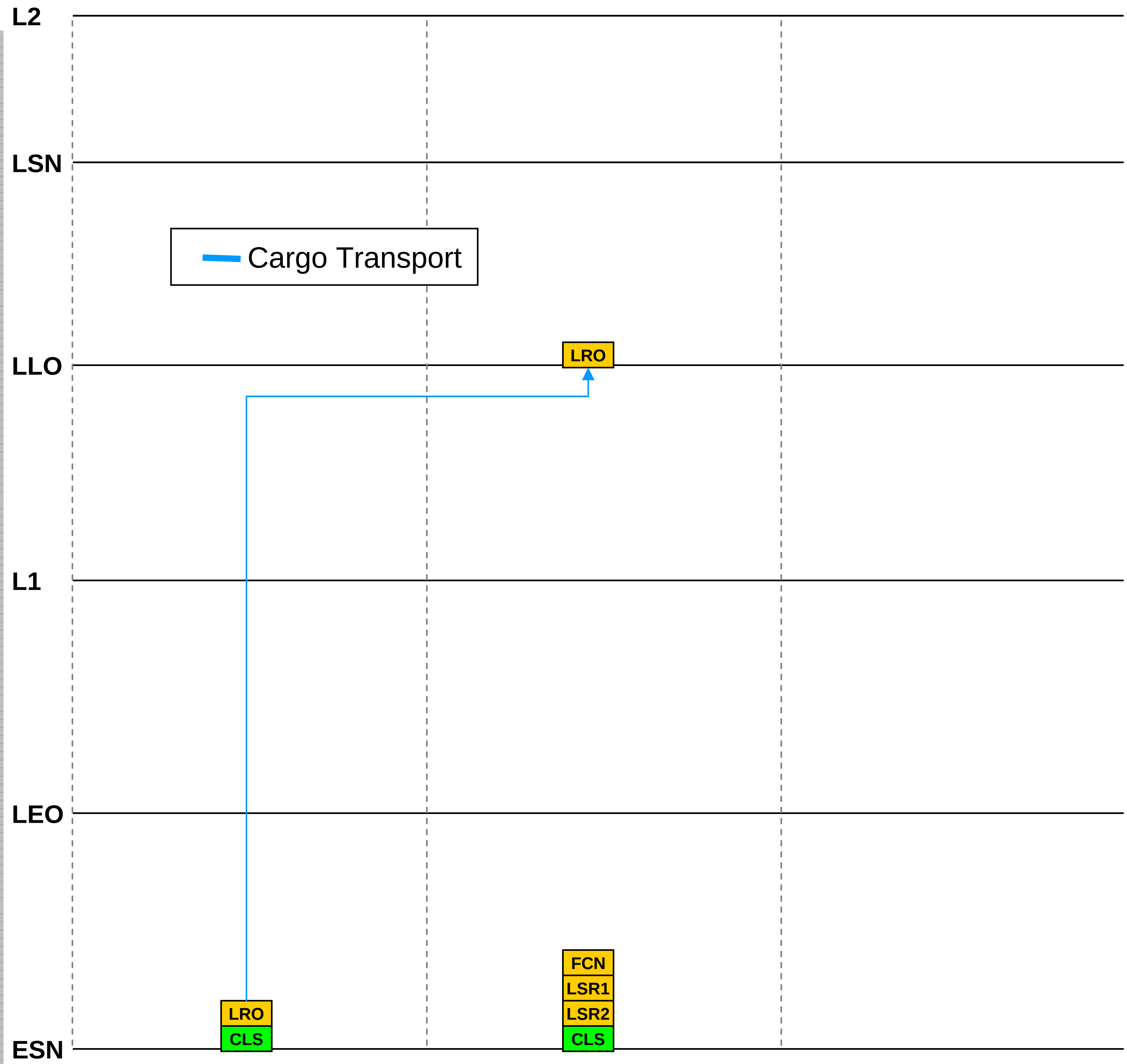


LRO

- Arrives in Low Lunar Orbit

Launch 2

- Existing L/V
- Farside Communications Node (FCN)
- Nearside Lunar Science Rover Lunar (LSR1)
- Farside Lunar Science Rover (LSR2)



LSR / FCN

- Lunar Science Rover 1 arrives at Lunar Nearside
- Lunar Science Rover 2 arrives at Lunar Farside
- Farside Communications Node (FCN) arrives at L2 Halo Orbit

Launch 3

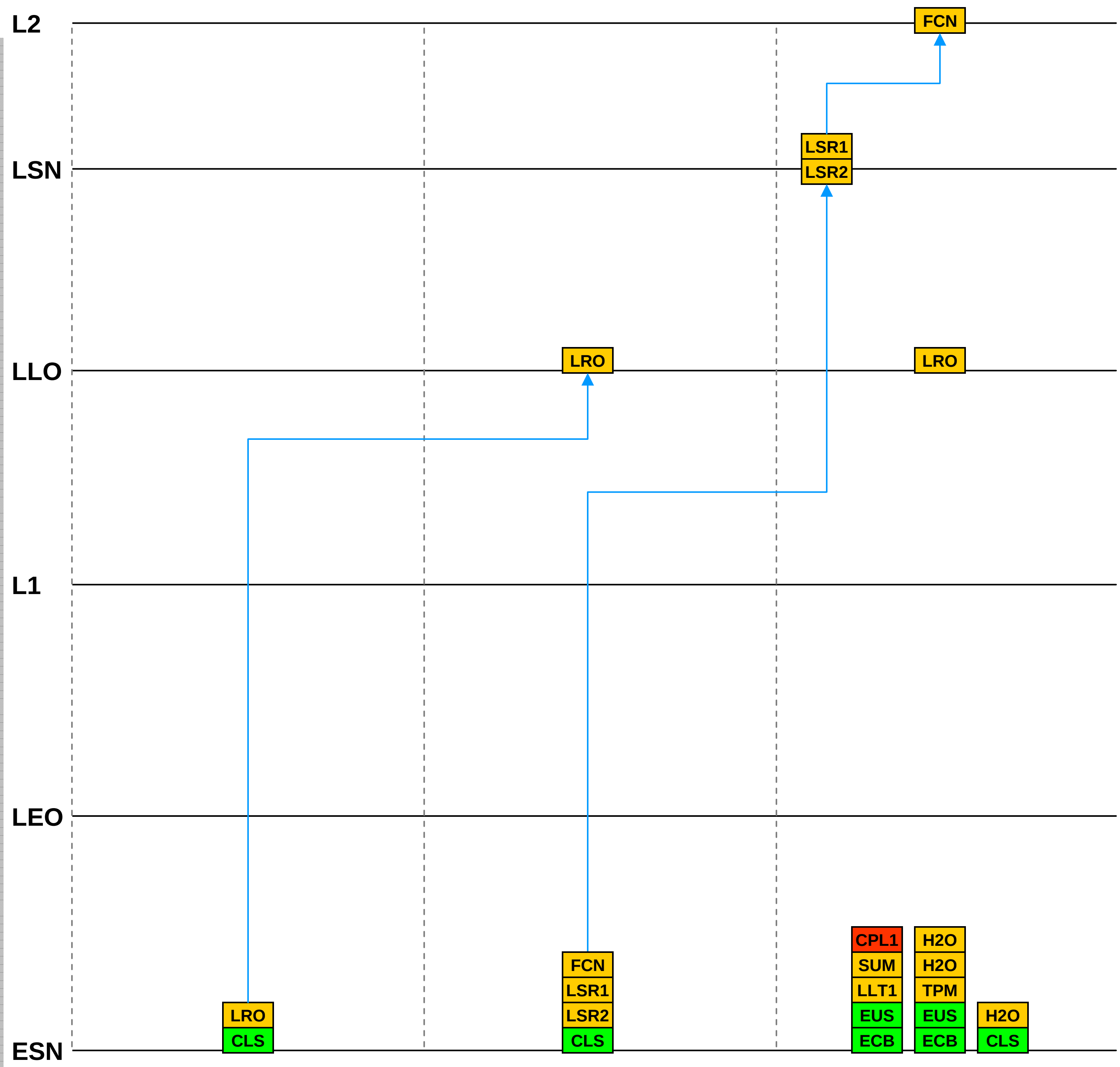
- Common Planetary Lander 1 (CPL1)
- LEO L1 Tug 1 (LLT1)
- Space Utility Module (SUM), include arm, airlock, H2O splitter, storm shelter

Launch 4

- Tug Propellant Module (TPM) with Xenon
- Water (H2O)

Service

- Commercial Launch Service (H2O)

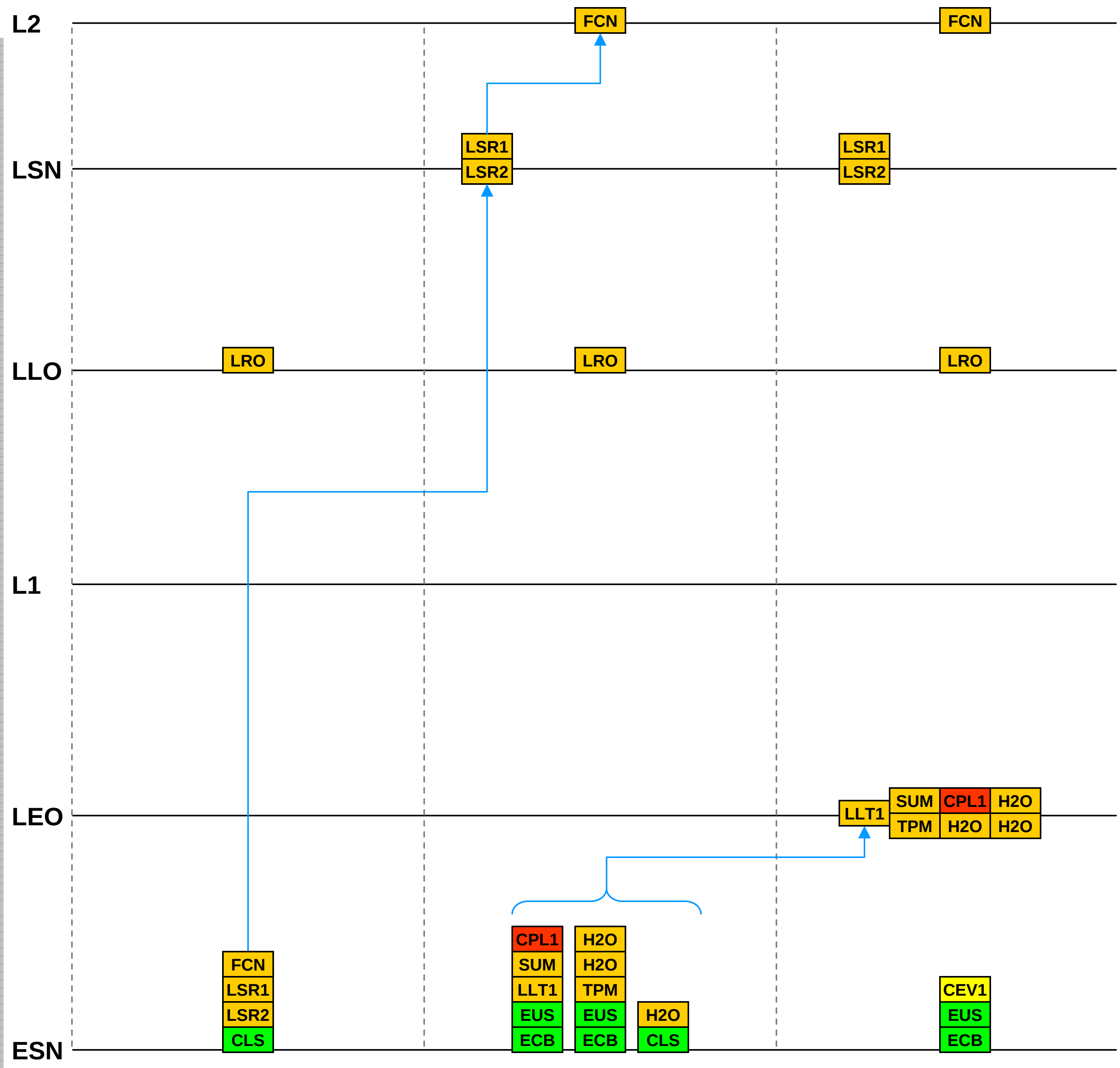


LLT Assembly

- LEO L1 Tug is assembled in LEO

Launch 5

- CEV unmanned test flight



L1 Station

- Tug (LLT1) becomes the core of L1 station and starts propellant production from H2O
- Lander (CPL1) tanks are used for cryo propellant storage

Launch 6

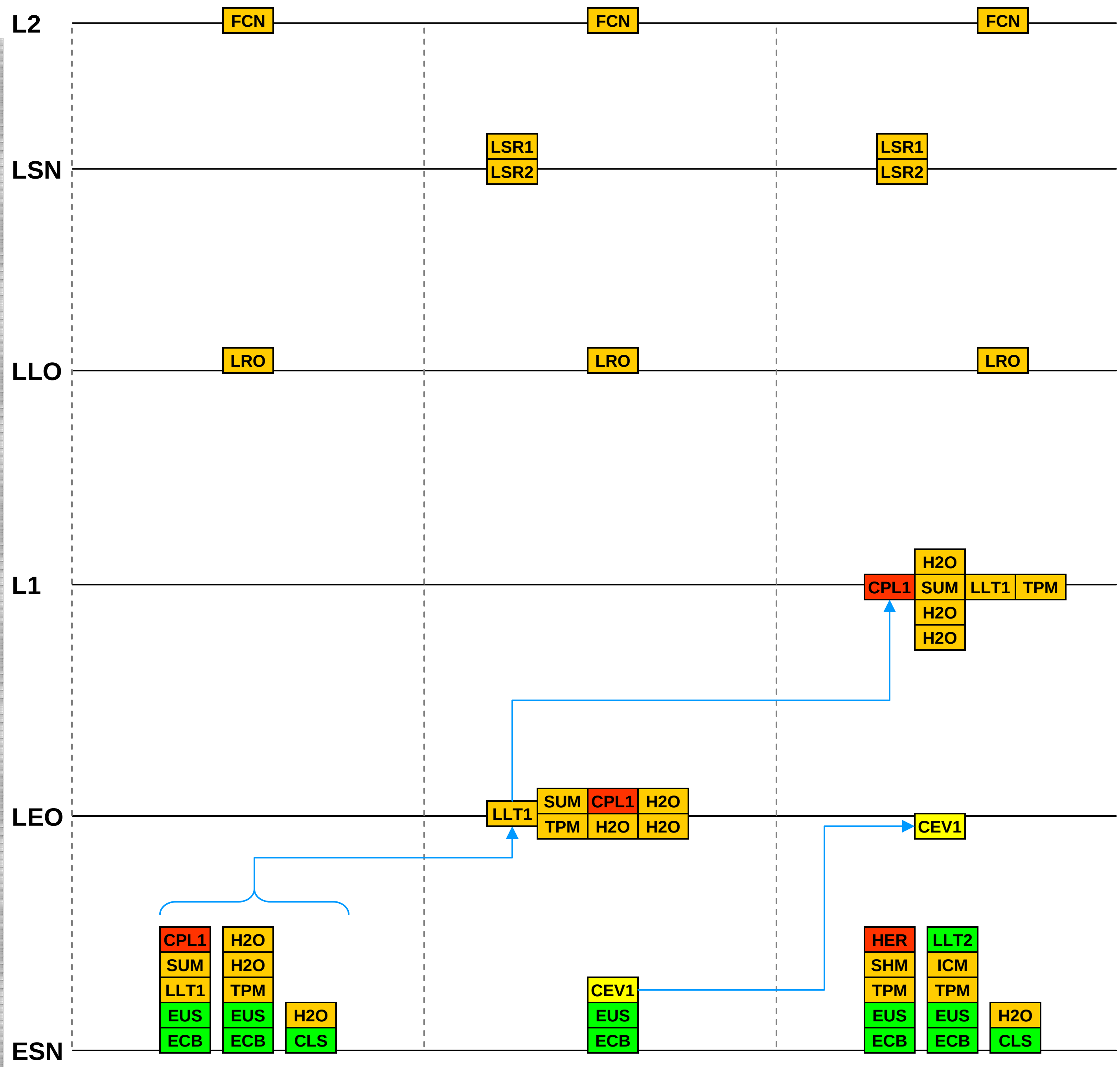
- Human Exploration Rover (HER)
- Space Habitation Module (SHM)
- Tug Propellant Module (TPM)

Launch 7

- LEO L1 Tug 2 (LLT2)
- Inter Connect Module (ICM)
- Tug Propellant Module (TPM)

Service

- Commercial Launch Service (H2O)

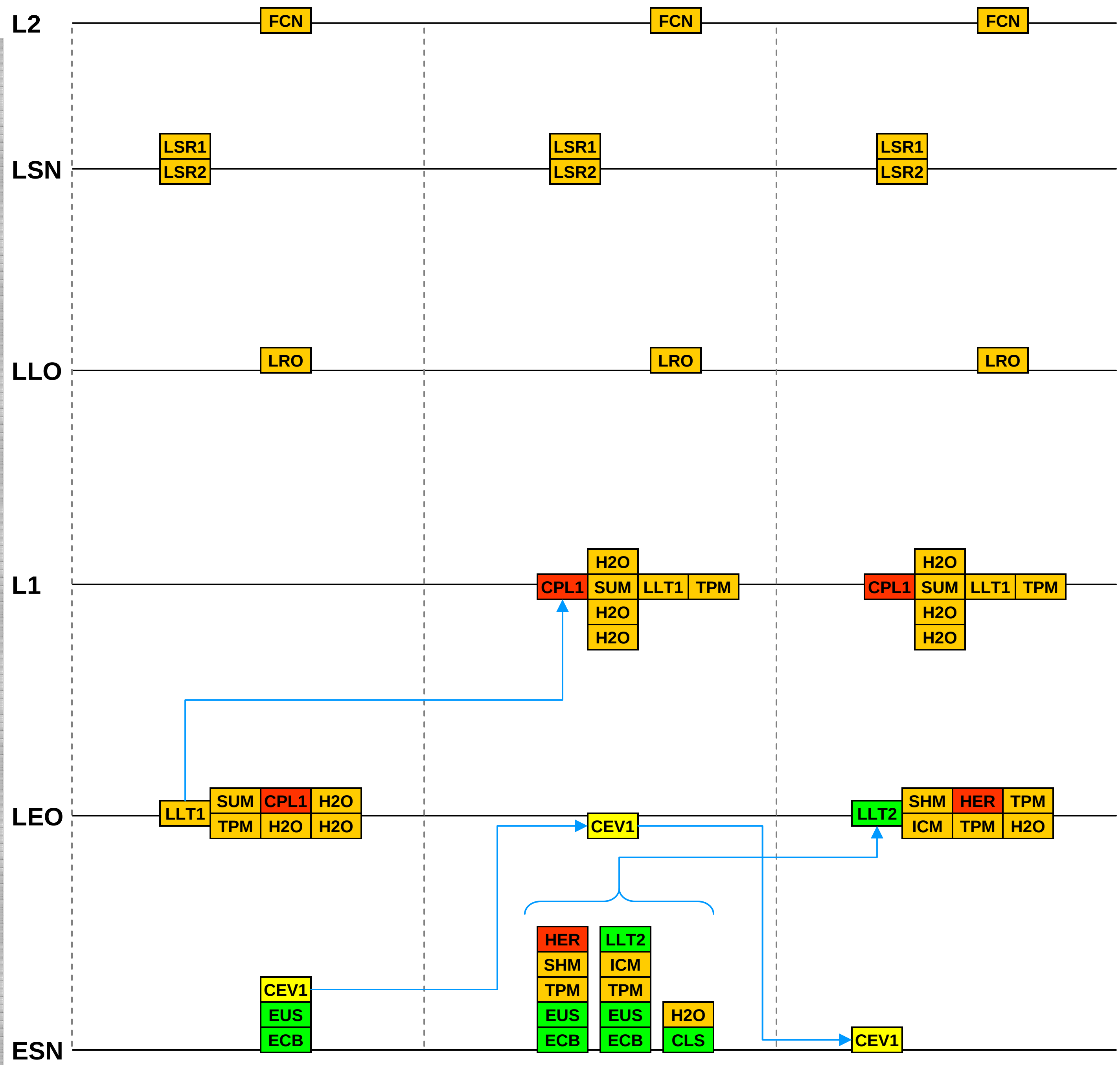


LLT2 Assembly

- LEO L1 Tug 2 is assembled in LEO

CEV Testflight

- CEV test article returns to Earth



L1 Expansion

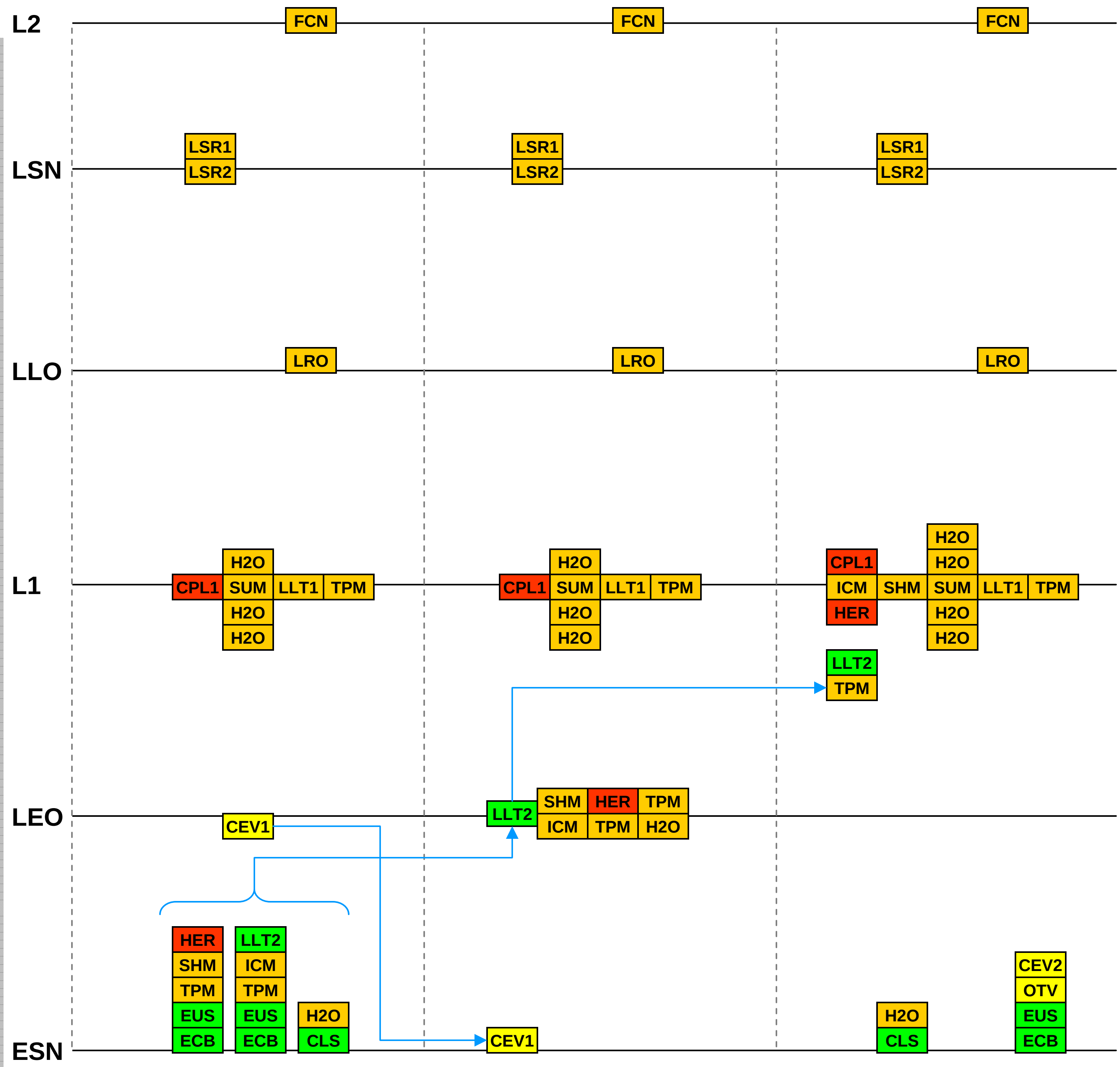
- Space Habitat Module (SHM)
- Inter Connect Module (ICM)
- H_2O tanks

Launch 8

- CEV with crew
- Orbital Transfer Vehicle (OTV)
- L1 Mission for CEV shakedown and assembly

Service

- Commercial Launch Service (H_2O)

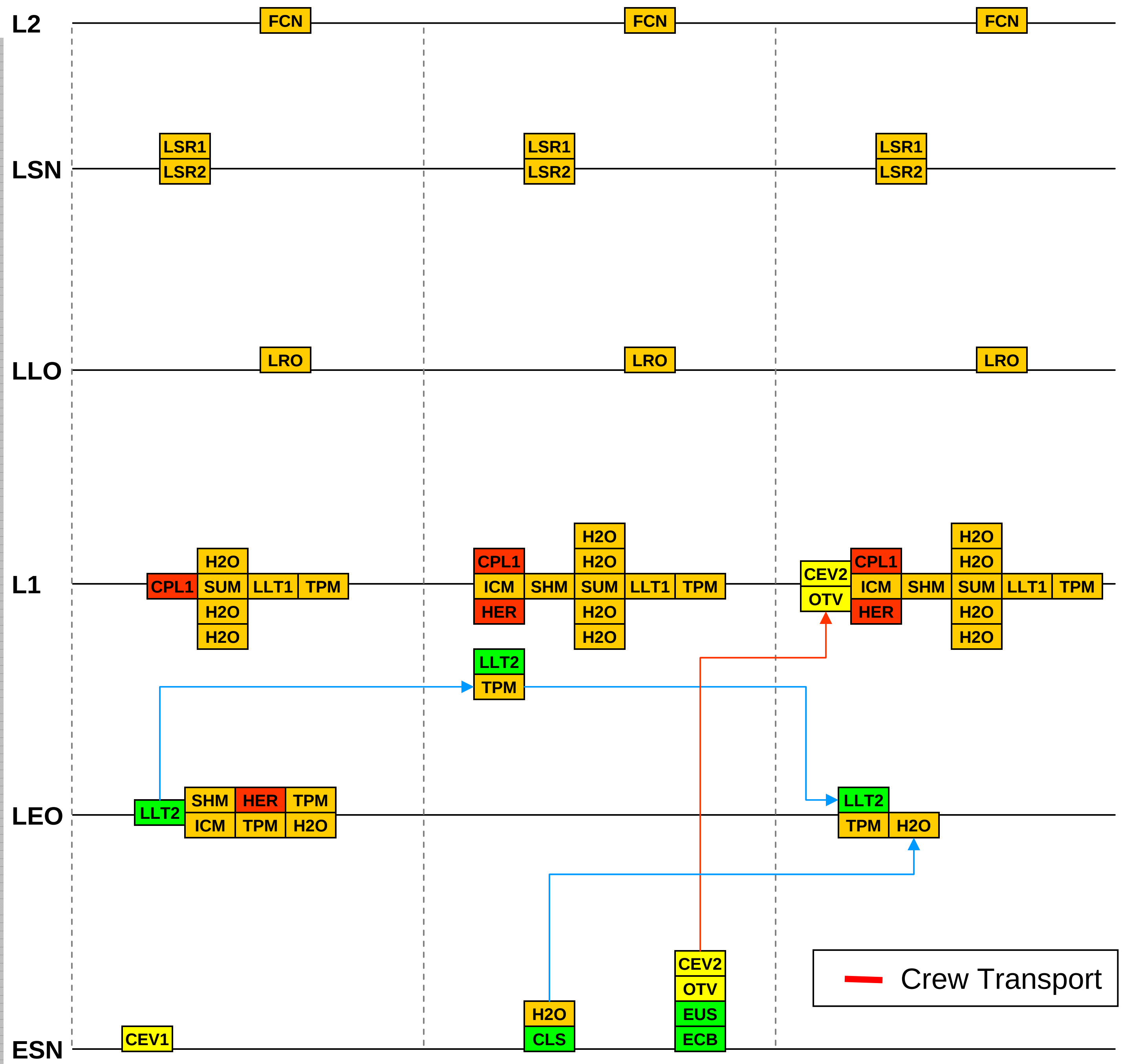


CEV

- Arrival at L1 Station

Tug 2

- Arrival at LEO
- H2O payload berths

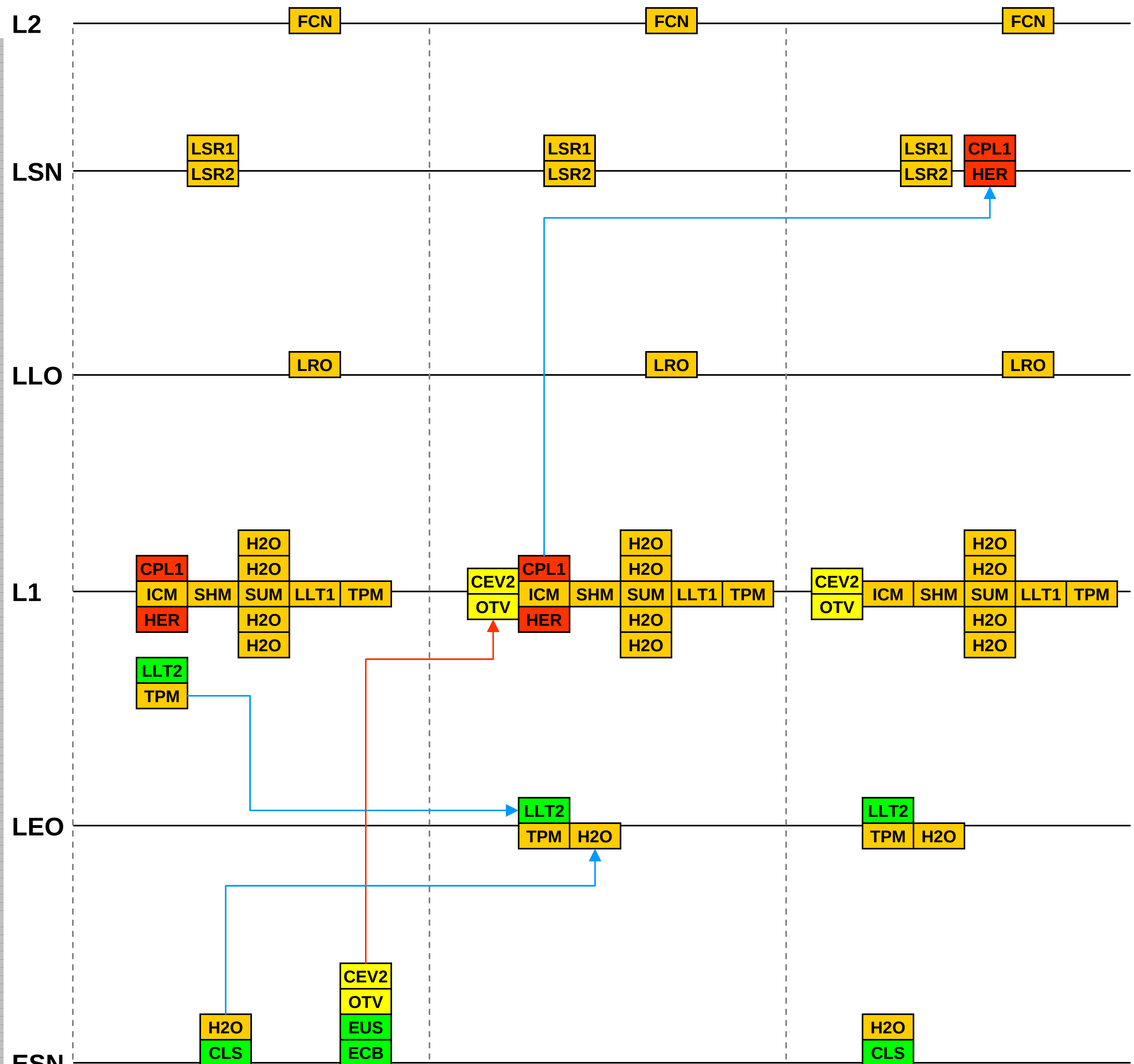


Lander 1

- Teleop landing on Lunar Surface
- Crew controls from L1 Station
- Human Exploration Rover (HER) delivered to Moon for teleops mission

Service

- Commercial Launch Service (H2O)



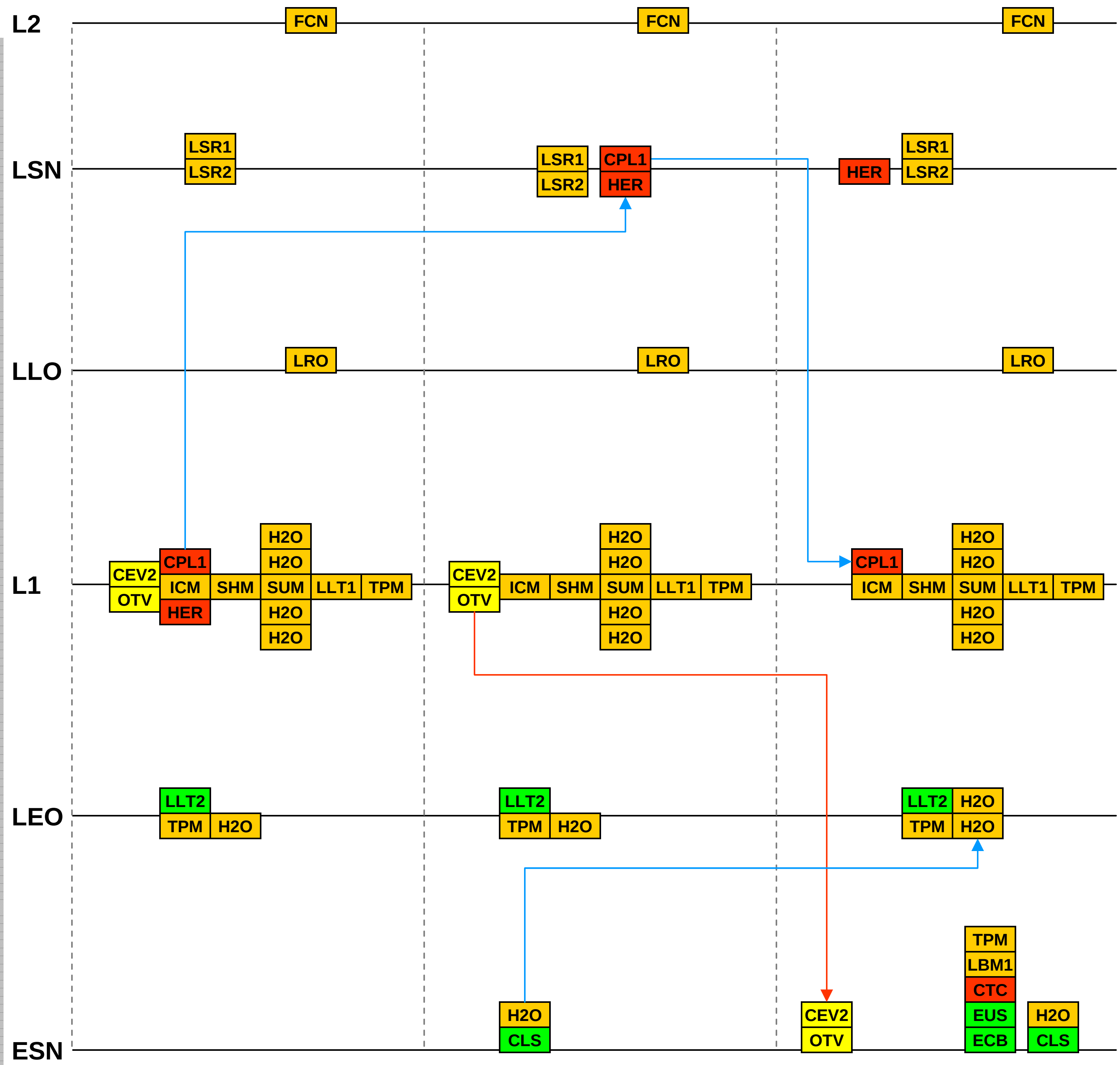
Lander 1
- Returns to L1 Station empty

CEV 2
- Returns crew back to Earth

Tug 2
- Tug captures H2O module

Launch 9
- Tug Propellant Module (TPM)
- Lunar Base Module 1 (LBM1)
- Crew Transfer Carrier (CTC), works with lander to transfer crew to lunar surface

Service
- Commercial Launch Service (H2O)

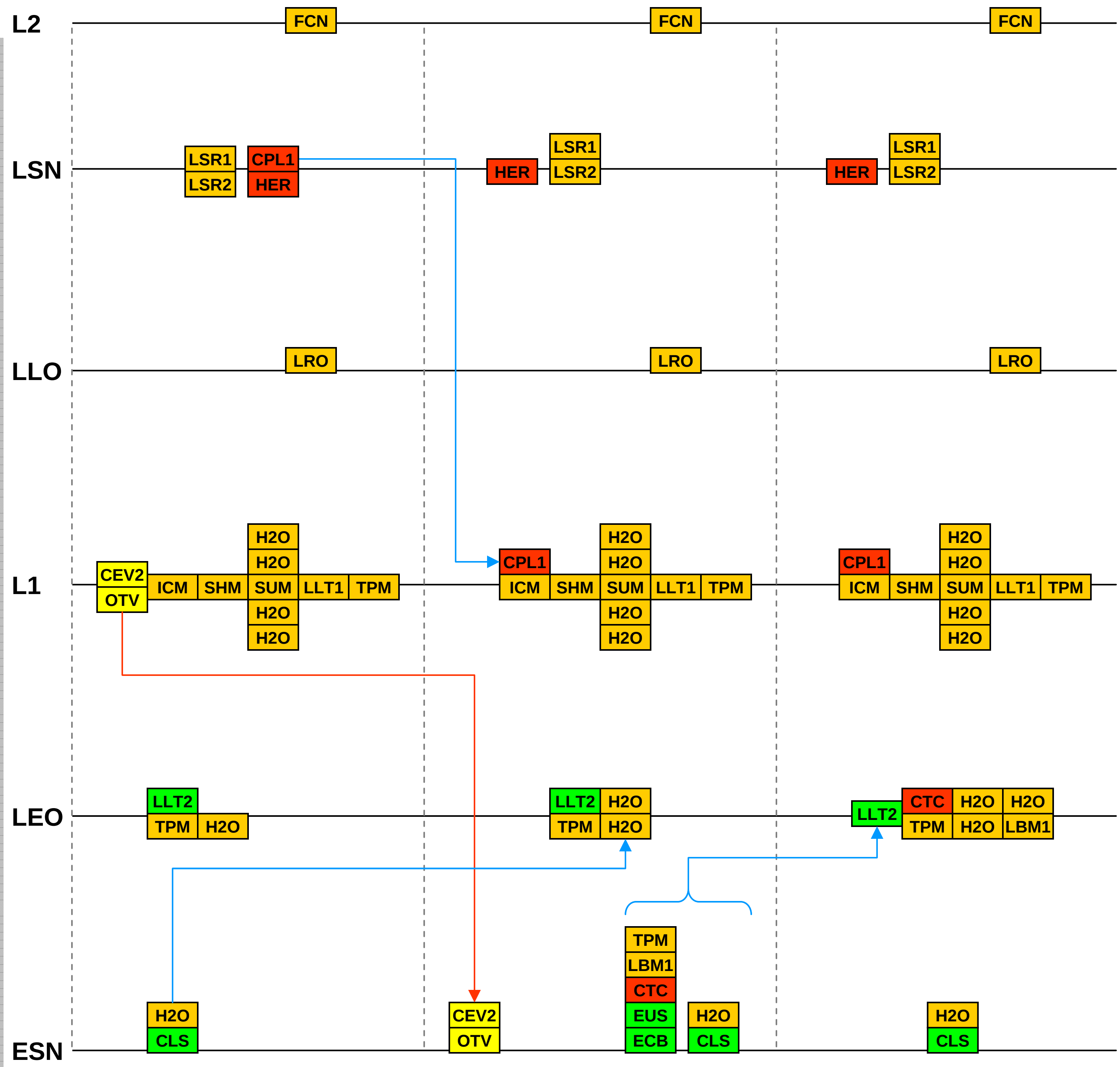


LLT2 Assembly

- LEO L1 Tug 2 (LLT2) is assembled in LEO

Service

- Commercial Launch Service (H2O)

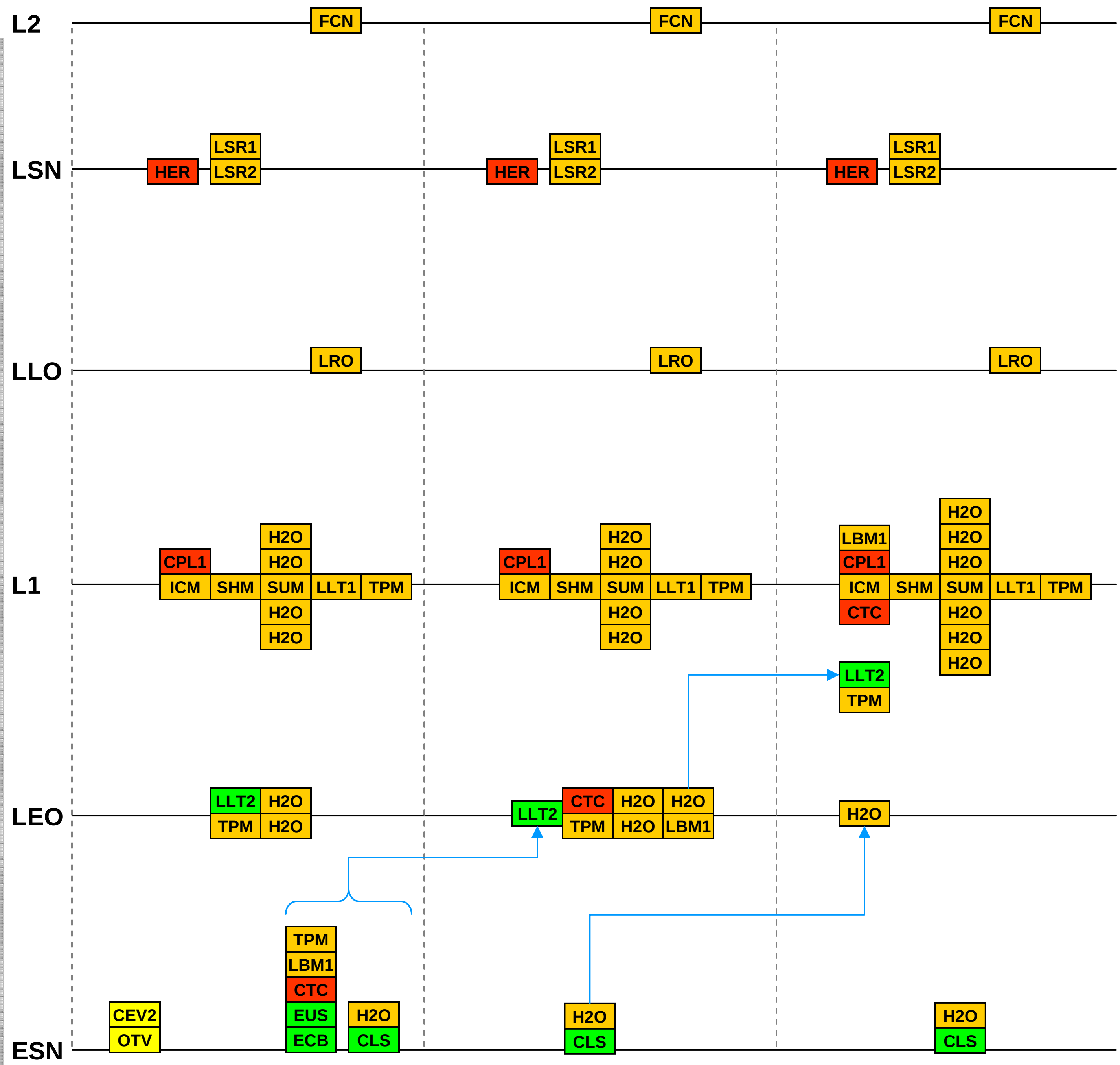


Tug 2 @ L1

- Lunar Base Module 1 (LBM1)
- Crew Transfer Carrier (CTC)
- Water (H2O)

Service

- Commercial Launch Service (H2O)



Lander 1

- Lunar Base Module (LBM) is delivered to lunar surface

Tug 2 @ LEO

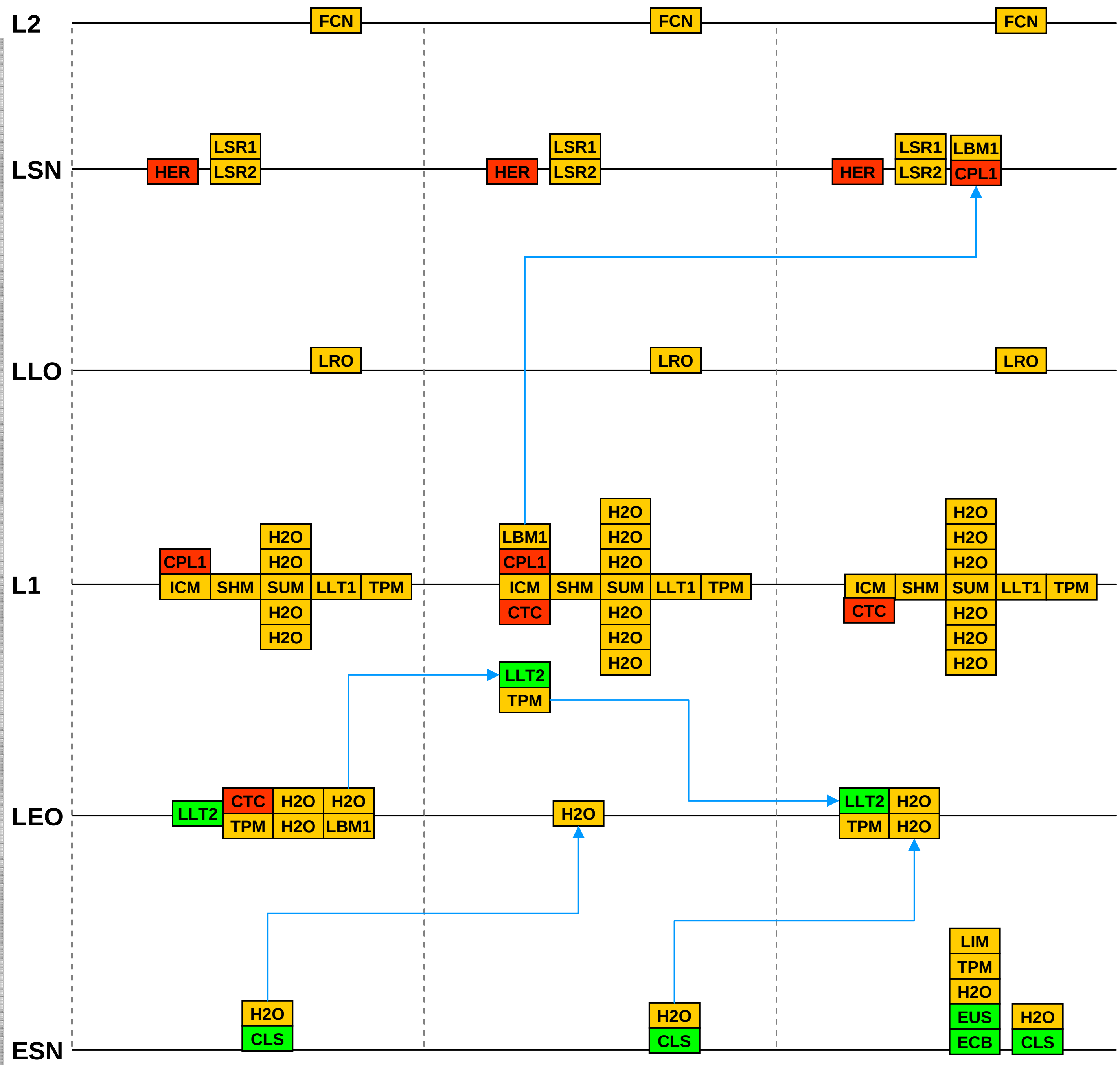
- Tug returns to LEO
- Captures H2O placed in LEO

Launch 10

- Tug Propellant Module (TPM)
- Lunar ISRU Module (LIM)
- Water (H2O)

Service

- Commercial Launch Service (H2O)

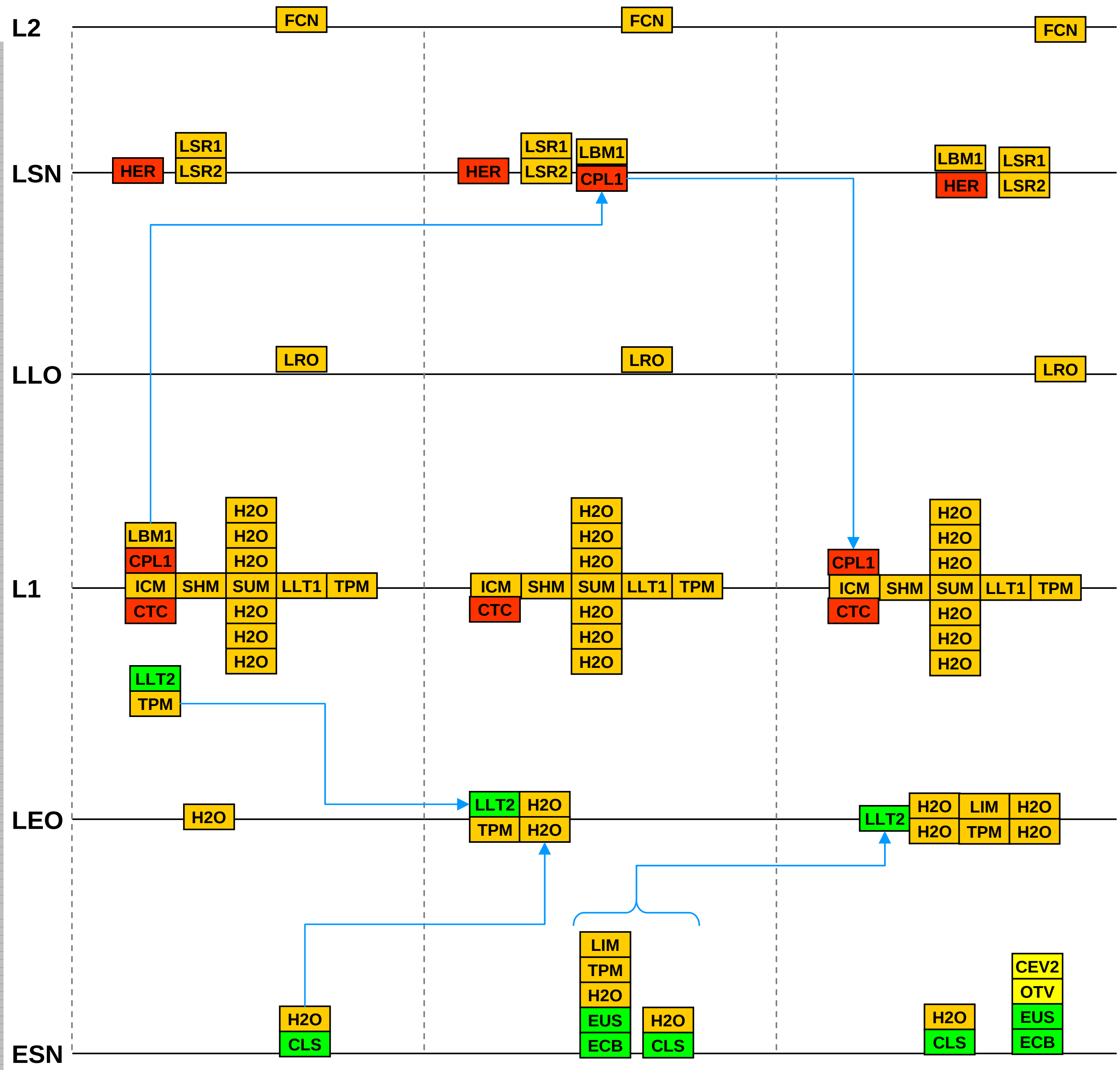


Lander 1
- Returns to L1 Station

LLT2 @ LEO
- Tug 2 is reloaded in LEO

Launch 11
- CEV + OTV
- Crewed Lunar Excursion Mission 1

Service
- Commercial Launch Service (H2O)



CEV @ L1

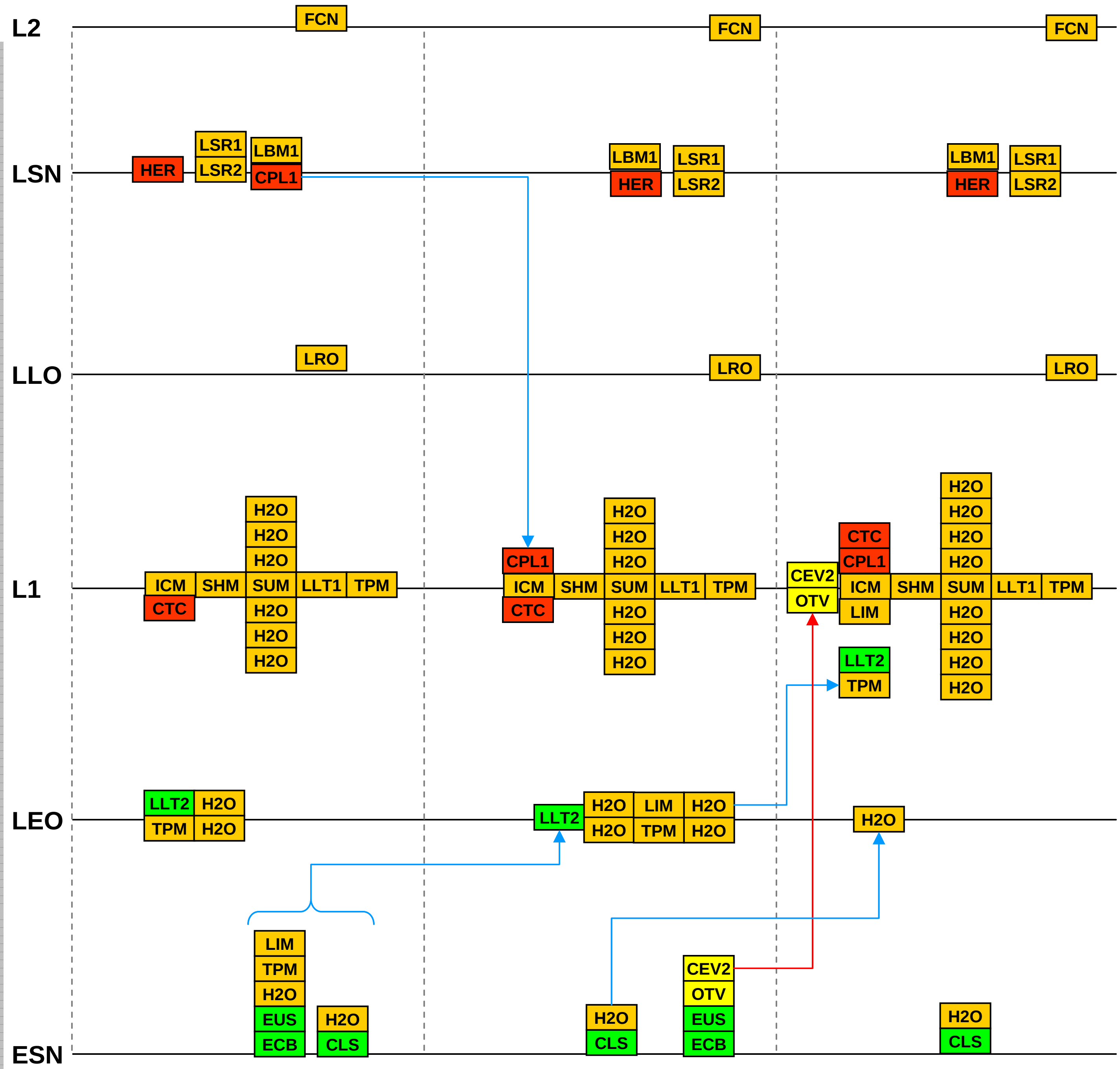
- CEV arrives at L1 station with Crew
- Crew supervises lander and crew carrier assembly

LLT2 @ L1

- Tug 2 arrives at L1 station with Lunar ISRU Module / H2O

Service

- Commercial Launch Service (H2O)



Lander 1

- Arrives on Lunar surface with crew
- Crew uses Human Exploration Rover (HER) to setup Lunar Base Module (LBM) with regolith shielding for shelter

LLT2 @ LEO

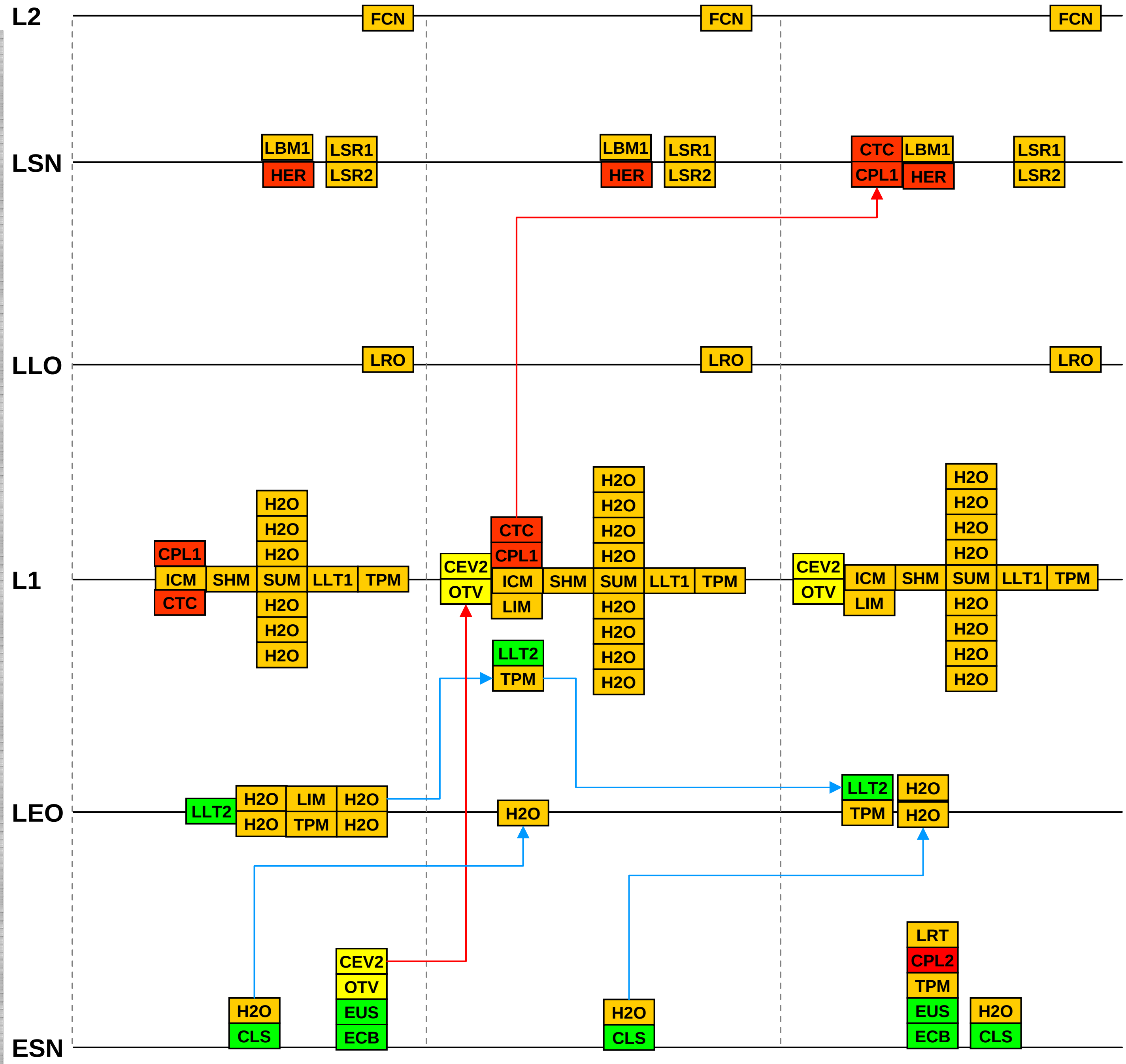
- Tug 2 returns to LEO and collects H2O modules

Launch 12

- Lunar Rover Tanker (LRT) propellant delivery vehicle
- Common Planetary Lander 2 (CPL2)
- Tug Propellant Module (TPM)

Service

- Commercial Launch Service (H2O)

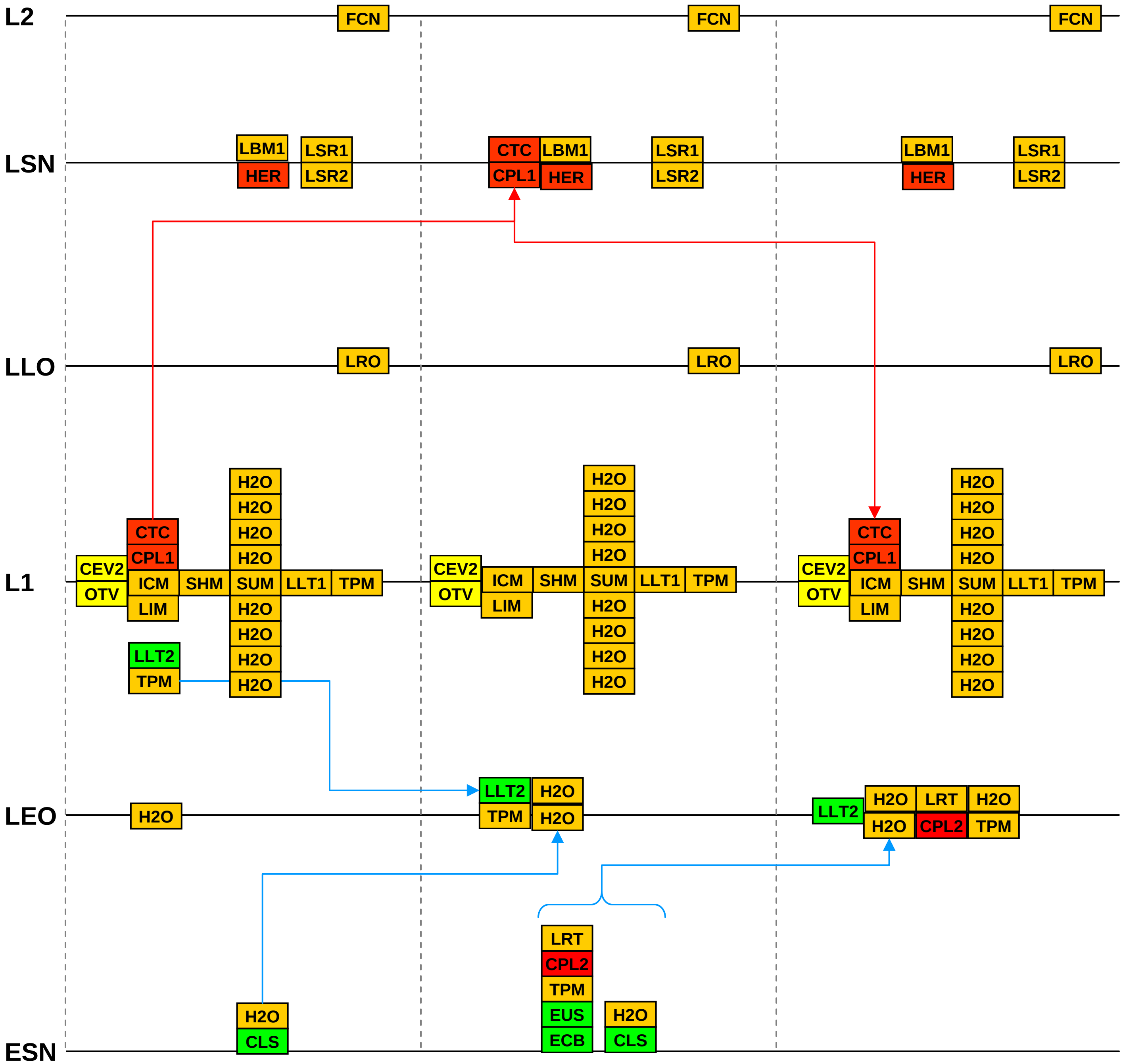


Lander 1 @ L1

- Crew returns to L1 station
- Transfers to CEV

LLT2 @ LEO

- Tug 2 is fully assembled in LEO



LLT2 @ L1

- Lander 2
- Lunar Tanker Rover
- H2O

CEV

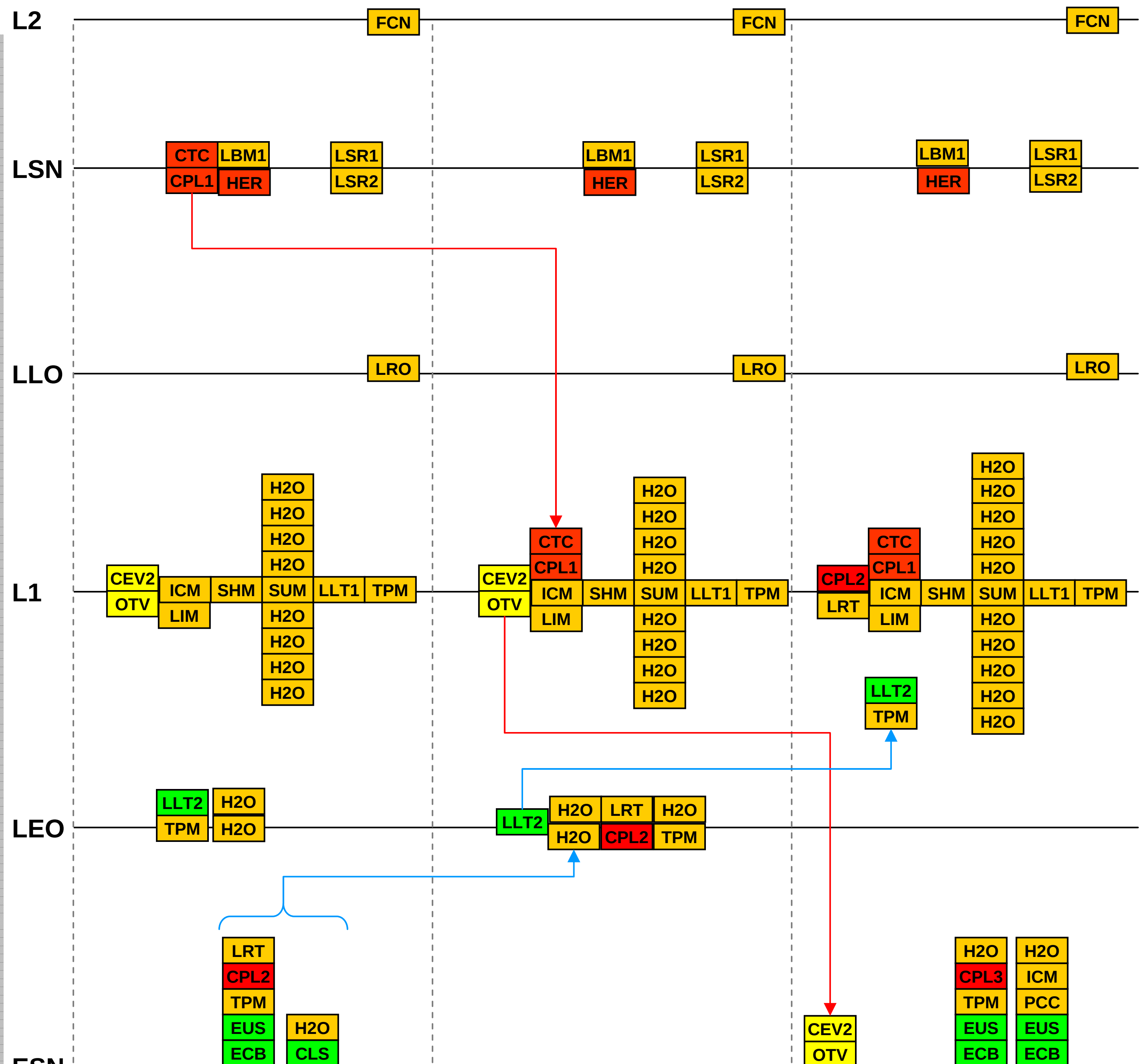
- returns crew to Earth

Launch 13

- Tug Propellant Module (TPM)
- Water (H2O)
- Lander 3 (CPL3)

Launch 14

- Water (H2O)
- Inter Connect Module (ICM) for lunar base
- Pressurized Cargo Carrier (PCC) logistics module for lunar base



Lander 1

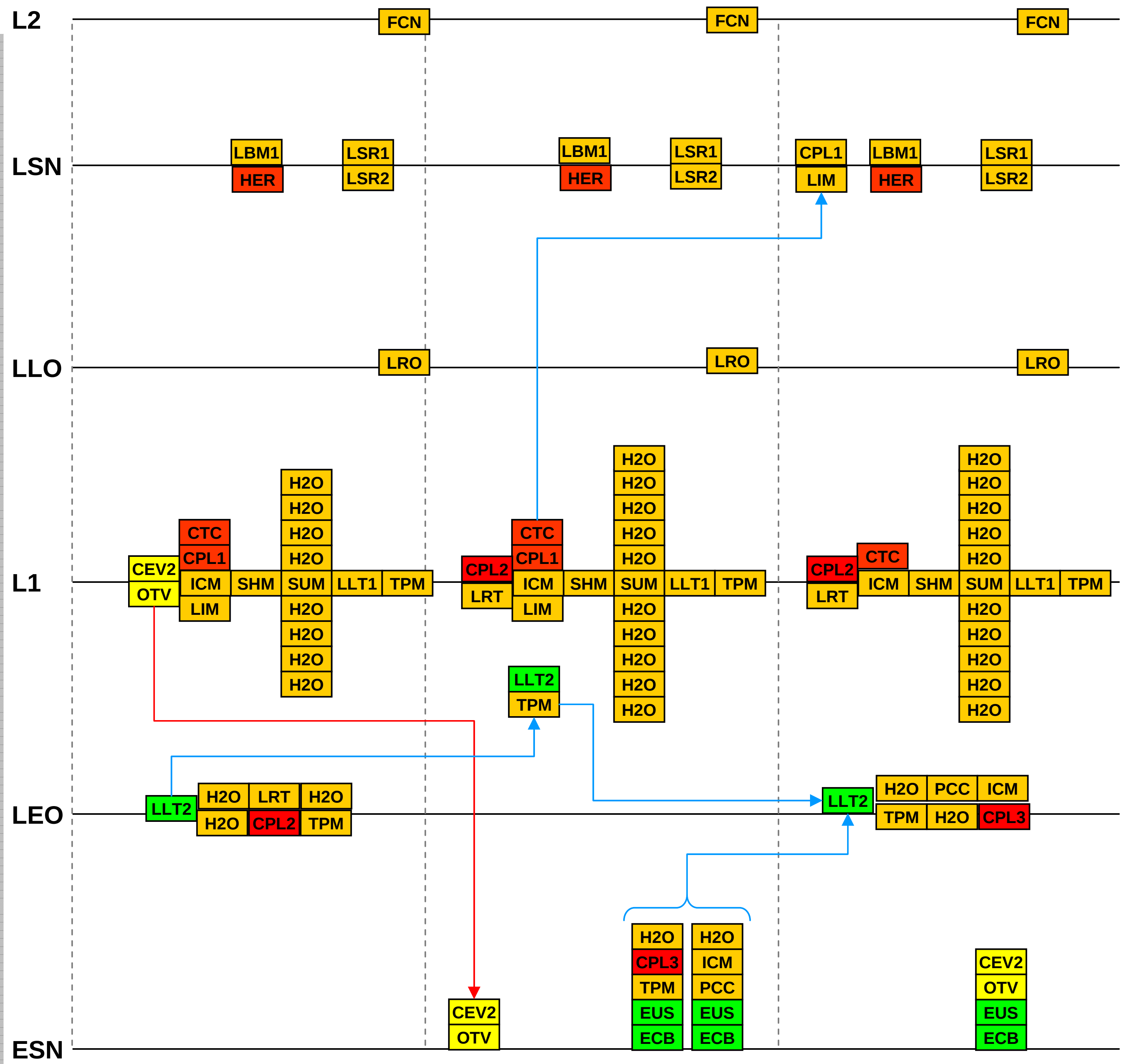
- Lunar ISRU Module (LIM) to surface
- Lander remains as cryo storage facility

LLT2 @ LEO

- Tug 2 is assembled and refuled in LEO
- Pressurized Cargo Carrier (PCC)
- Inter Connect Module (ICM)
- Lander 3 (CPL3)
- Water (H2O)

Launch 15

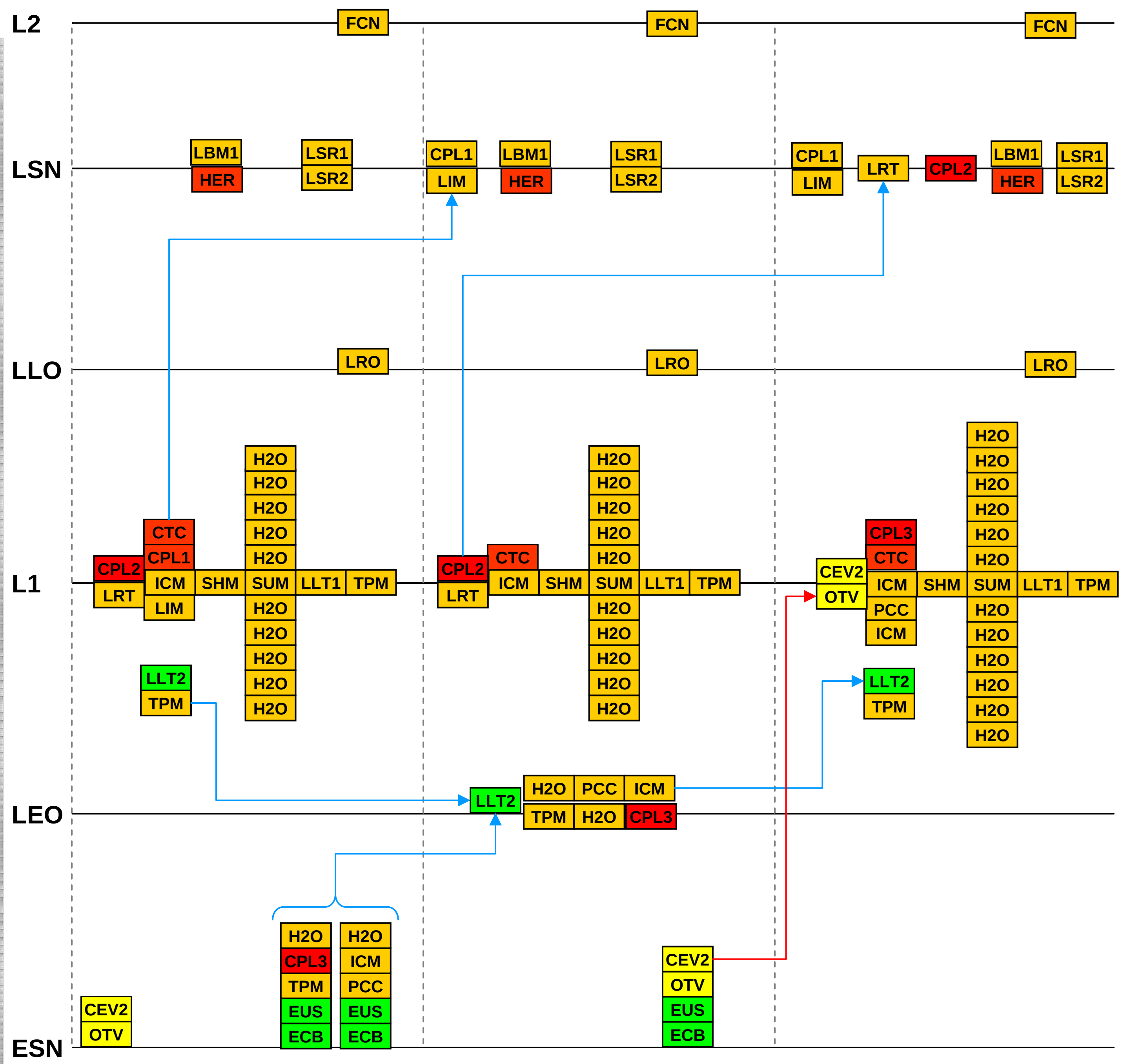
- CEV2 with crew for lunar excursion mission 2



Lander 2
- Delivers Lunar Resource Tanker (LRT) to surface
- Remains until refueled via ISRU

CEV 2
- Arrives at L1
- Crew transfers to Lander 3 and crew transfer carrier (CTC)

LLT2 @ L1
- Lander 3 (CPL3)
- Inter Connect Module (ICM) for lunar base
- Logistics module (PCC) for lunar base
- Water (H2O)



Tug Swap

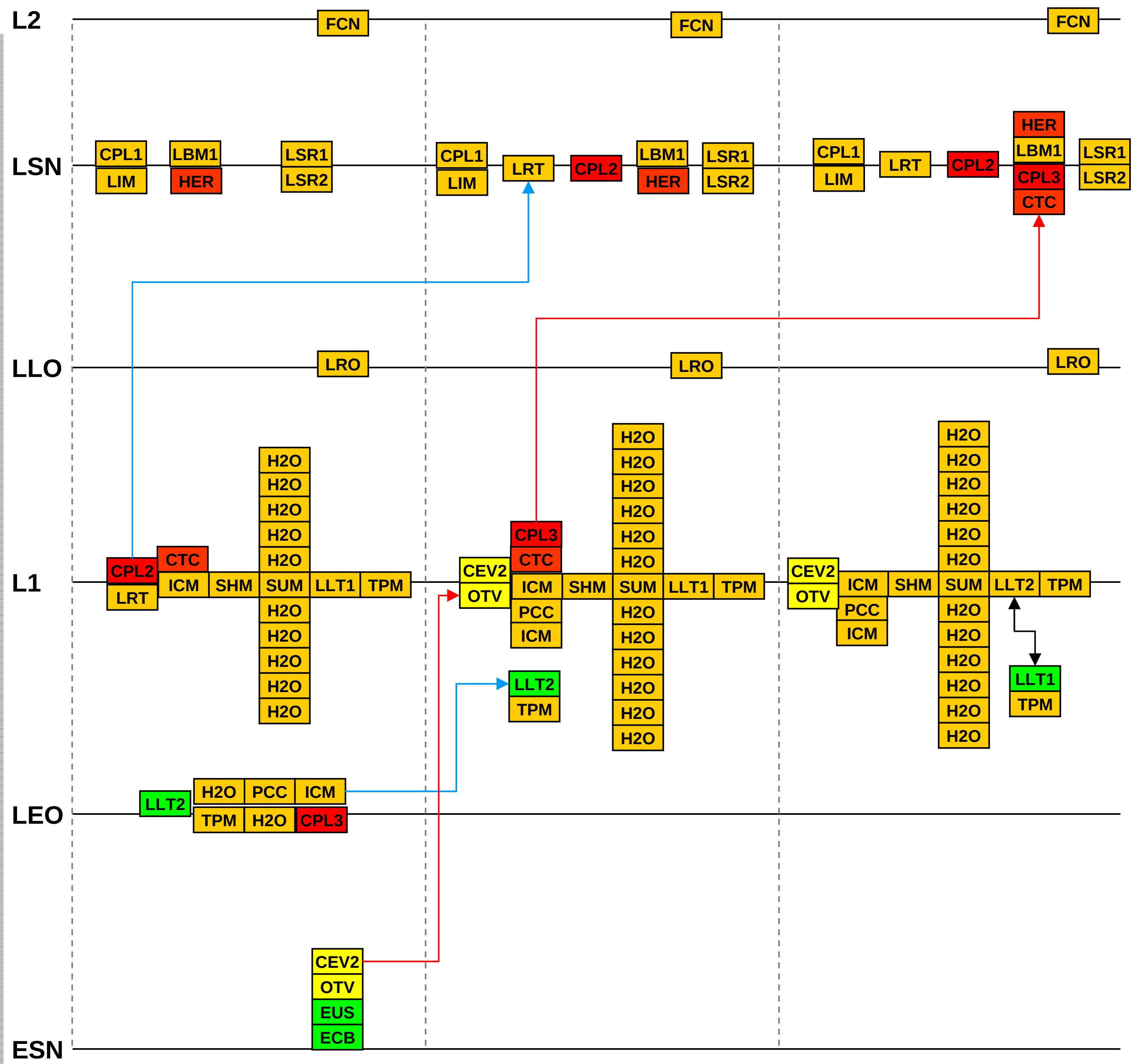
- Tug 2 remains as L1 station core
- Tug 1 returns to LEO for further cargo use

Lander 3

- Transports crew to lunar surface for excursion mission 2 (base assembly & ISRU maintenance)

Lander 2

- Fully fueled on lunar surface prior to crew departing L1

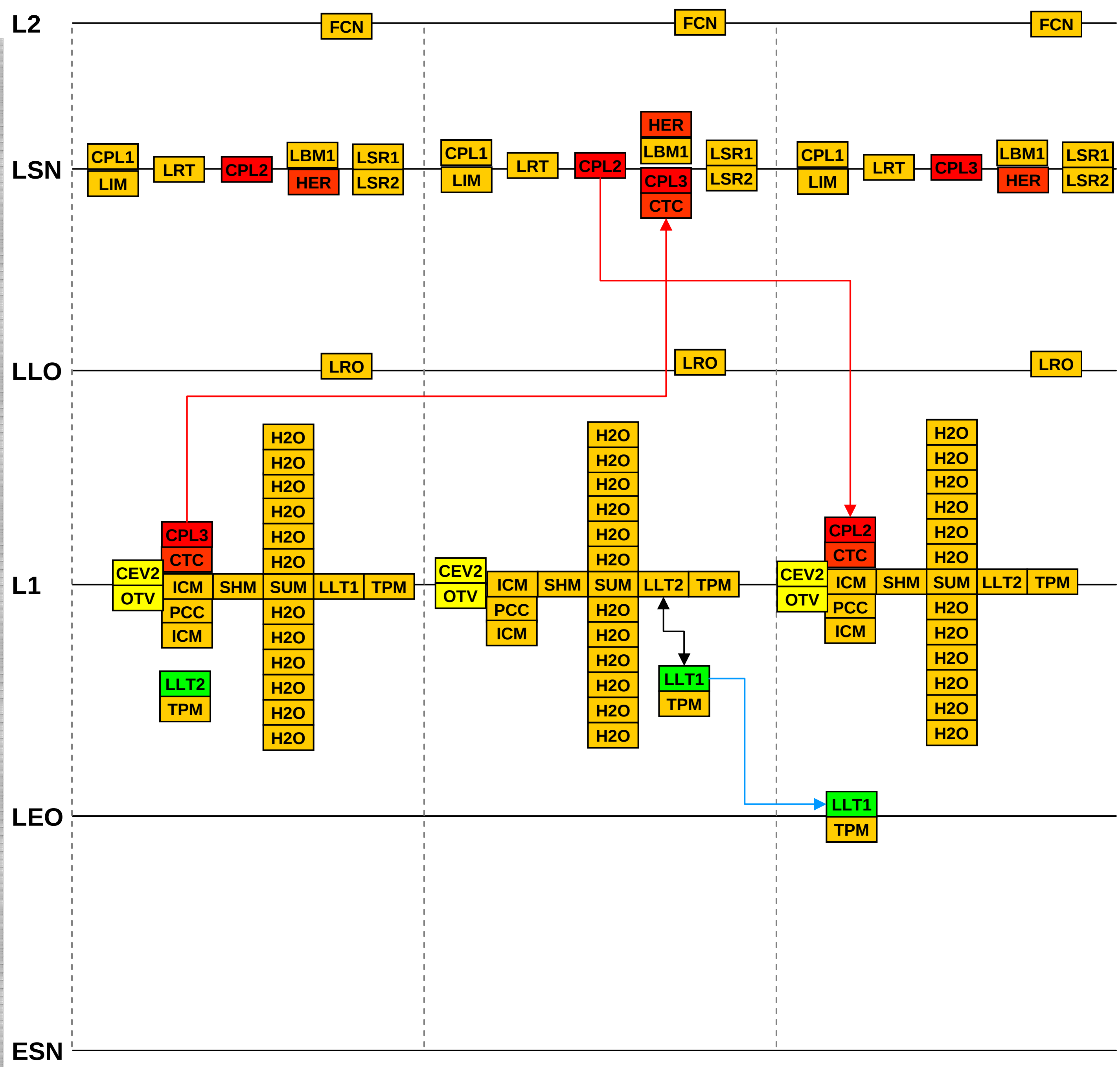


Lander 2

- Returns crew to L1 station
- Fully fueled for return trip to surface

LLT 1 @ LEO

- Tug 1 arrives in LEO ready for next cargo run



Lander 2

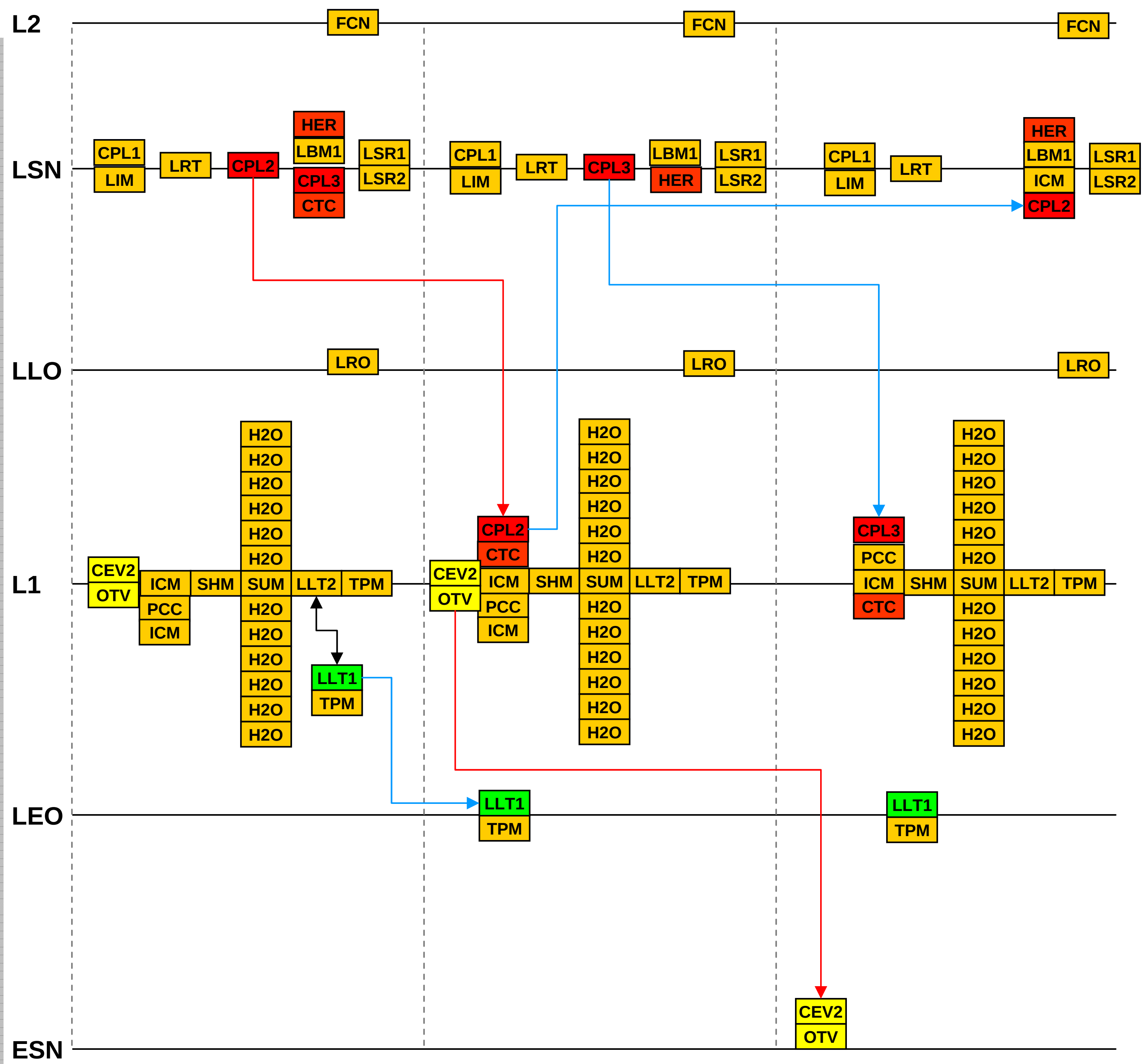
- Returns to lunar surface with Inter Connect Module (ICM)

Lander 3

- Flys to L1 station to pick up logistics module

CEV

- Returns crew to Earth

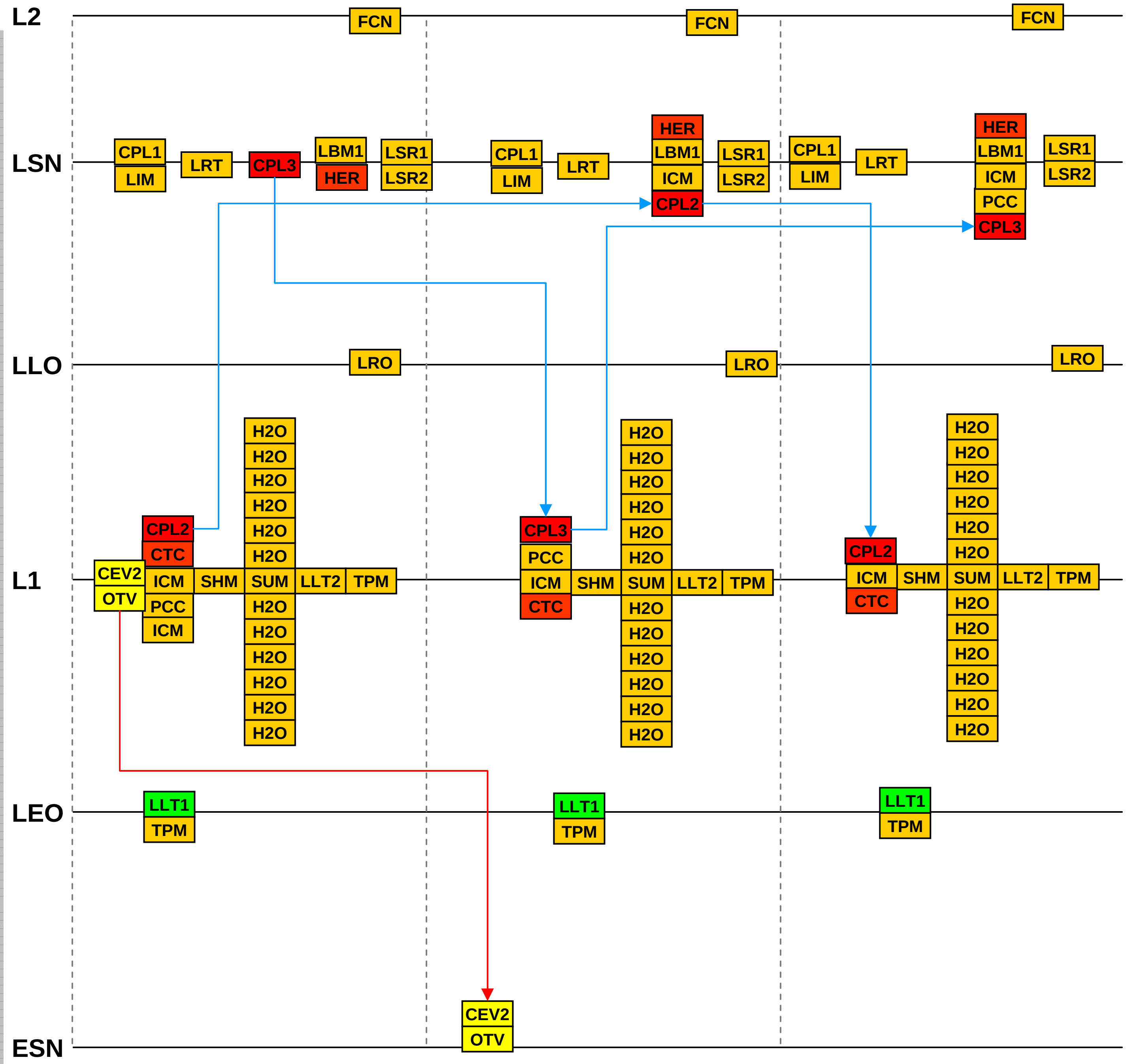


Lander 3
- Delivers logistics module (PCC) to lunar surface

Lander 2
- Returns to L1 station fully fueled standing by for next crew transfer

Tug 2
- In LEO ready for next cargo transfer

- **Completed Logistics Train for permanent lunar base**
- **Fully functional & sustainable Lunar Outpost**
- **Fully functional & sustainable L1 gateway for further exploration**



VISTA Deployment Summary

- 15 Launches from 2007 to 2015 (~2 launches per year)
- ~150T of water to LEO (19T/year) via commercial launch services
- 2 Space Tugs
- 3 Planetary Landers

- Commercial H2O to LEO service incubates other commercial LEO markets
- L1 Gateway enables highly efficient outer solar system exploration
- Lunar ISRU significantly reduces exploration launch mass requirements
- Water commerce acts as fallback if ISRU is not realized
- Ability to return significant quantities of material from the Moon (up to 15 T)

VISTA's step wise modular approach enables synergy with other stakeholders and encourages the placement of permanent human outposts for sustained program extensibility.

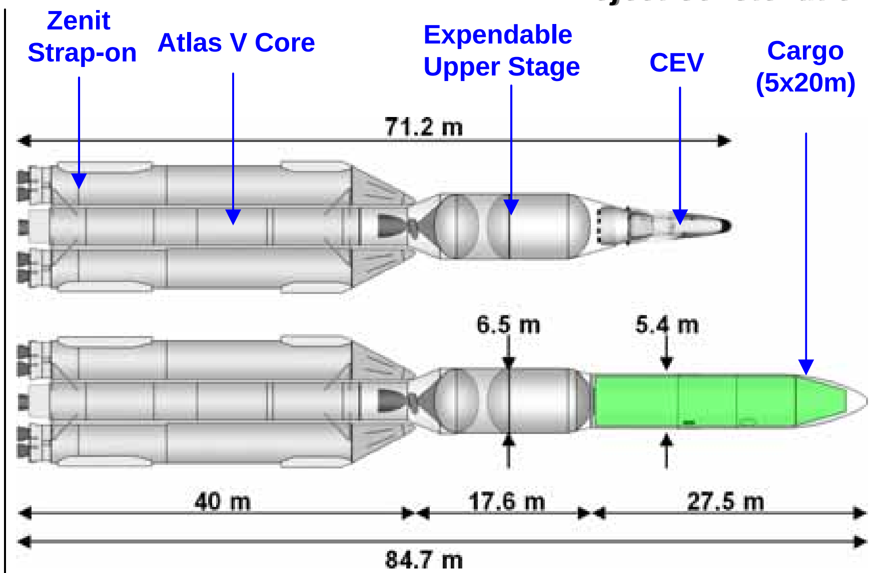
Baseline ESS: ETO Segment

Project Constellation

DRM-1: 22,000 kg to TLI (no fairing)
DRM-2: 40,000 kg to LEO (5x20m fairing)

Expendable Common Booster:
Atlas V Core + 2x Zenit

Expendable Upper Stage:
New Development, RLX Engine



Weight Statement	DRM 1		DRM 2	
	kg	lbm	kg	lbm
Payload	22,041	48,591	40,000	88,185
EUS @ MECO2	14,402	31,750	14,402	31,750
EUS reserves	1,992	4,391	2,209	4,869
EUS TLI propellant	37,831	83,402	0	0
EUS LEO propellant	82,372	181,598	99,216	218,734
LES / Fairing	2,236	4,930	6,124	13,500
Core at separation	28,210	62,193	28,210	62,193
Core Propellant	286,795	632,275	220,474	486,061
Boosters at separation	57,750	127,316	57,750	127,316
Booster Propellant	679,990	1,499,120	397,566	876,483
Gross Liftoff Mass	1,213,618	2,675,566	865,950	1,909,090

- Cost Summary
  - TBD Development Cost
  - TBD Production Cost
  - $240 M per Launch
- Reliability Summary

PLC	PLP	PLM	PLS
TBD	TBD	TBD	TBD

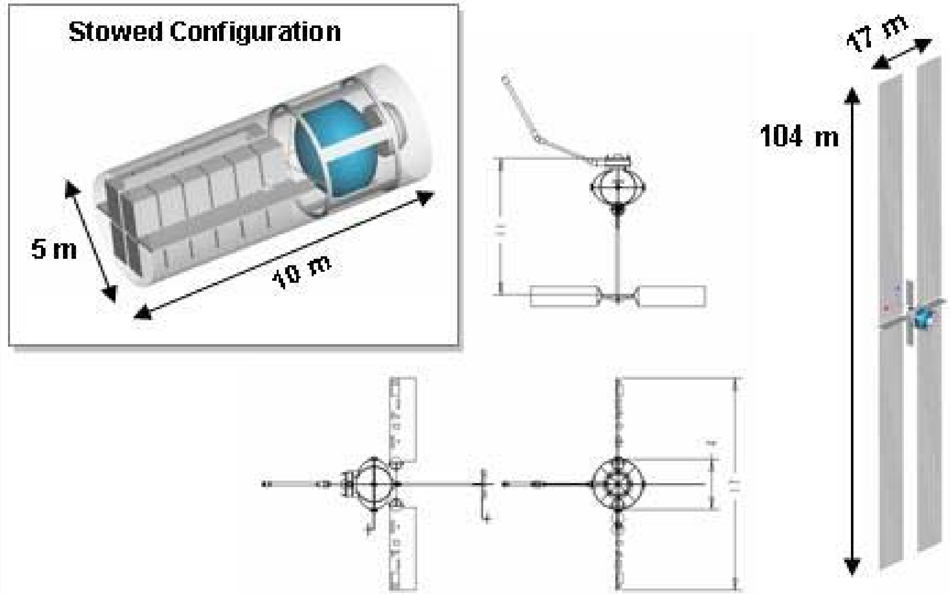
- Critical Technology Needs
  - RLX LOX/LH Engine

ANDREWS SPACE

Baseline ESS: LEO L1 Tug

DRM-1: 60,000 kg LEO to L1
DRM-2: 15,000 kg L1 to LEO

- Stowed envelope of 5x10m
- Solar Electric (Hall or Ion), Xenon Propellant
- Reusable (propellant launched with payload in LEO)
- 300kW array, acts as communications relay
- Manipulator arm for payload berthing
- 300 days transfer time using conventional orbital mechanics, or 180 days using n-body trajectory at identical power levels



Baseline LEO L1 Tug Sizing

Transfer Time, days			***300***
Ideal ΔV, km/sec			***3.4***
Specific Power, kW/kg	α	"= Pa/Mpp"	***0.0971***
IMLEO	kg		***95,000***
Initial Isp, seconds	Isp		***3,850.0***
Thruster/PPU Efficiency	η		***0.75***
Ave Acceleration, m/sec2			0.000131
Mass Fraction		"=M0/M1"	1.09
Thrust, N			11.90
Busbar Power, kW			299.5
Powerplant Mass, kg			3,084.9
Propellant plus Tank Mass, kg			12,260.3
SEP Mass	kg		4,456
P/L + Propellant Launch Mass	kg		91,452
Useful Payload	kg		78,284

- Cost Summary
  - 28,700 M-Yr Development
  - 1012 M-Yr Production
  - TBD Per transfer / operations cost (one-way)
- Reliability Summary

PLC	PLP	PLM	PLS
TBD	TBD	TBD	TBD

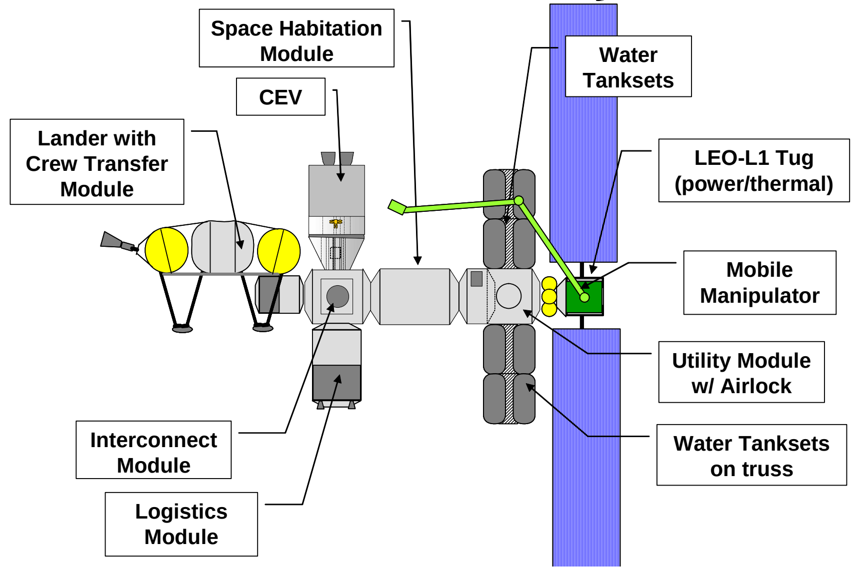
- Critical Technology Needs
  - 100+ kW Electric Thrusters
  - Highly packagable solar array / concentrators
  - Low cost hardened solar cells

ANDREWS SPACE

Baseline ESS: L1 Transfer Hub (LTH)

Project Constellation

- Crew Support
  - 8 for 5 days (crew handover), 3 day storm shelter
  - 4 for 14 days (L1 housekeeping)
- Docking Ports
  - 2x CEV, 2x Lander, extensible logistics module
  - Up to 18 H2O tanks
- Functions
  - Lander reconfiguration / assembly
  - Propellant production from H2O
  - Communications Relay
  - EVA support, Storm shelter (safe haven)



Element	Abbreviation	Qty	Length [m]	Diameter [m]	Press. Volume [m3]	Habitat Volume [m3]	Dry Mass [kg]	Equipment [kg]	Propellant / Fluids [kg]	IMLEO [kg]
LEO L1 Tug - 1 (at L1 node)	LLT1	1	10	4.5	-	-	7,500	-	430	7930
Manipulator Arm	-	1	2	4.5	-	-	4,500	-	-	4,500
Space Utility Module (Prop production)	SUM	1	7.8	4.5	85	28	16,150	-	580	16,730
Space Habitation Module	SHM	1	7.8	4.5	85	28	8,140	3,600	1,900	13,640
Interconnect Module - L1	ICM	1	6.3	4.5	42.5	30	5,800	-	-	5,800
Water Tank Sets	H2O	1	3.9	4.5	40.1		1,800	-	-	1,800
L1 Transfer Hub	**LTH**	**-**	**-**	**-**	**252.6**	**86**	**43,890**	**3,600**	**2,910**	**50,400**

- Cost Summary
  - 94,700 M-Yr Development
  - 5838 M-Yr Production
  - TBD Operations
- Reliability Summary

PLC	PLP	PLM	PLS
TBD	0.000	TBD	TBD

- Critical Technology Needs
  - TBA

Baseline ESS: Common Planetary Lander (CPL)

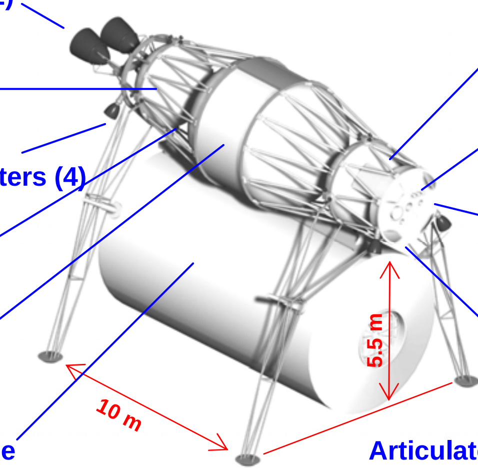
DRM-1: 15 T from L1 to Moon
DRM-2: 10 T from L1 to Moon and back

5x10 m Payload Modules

Dual LOX/LH Main Engine (RL-10)
Underslung Payload Attachment
GOX/GH ACS

Initially based at L1, propellant from H_2O

Later based on Moon, prop from ISRU



Mass Budget [kg]	
Structure/Thermal	4,770
Propulsion	1,690
Equipment	970
Margin	1,115
Dry Mass	8,545
Propellant / Fluids	33,300
Payload	15,000
Launch Mass	56,845

- Cost Summary
  - 16,800 M-Yr Development
  - 1150 M-Yr Production
  - TBD Operations

- Reliability Summary

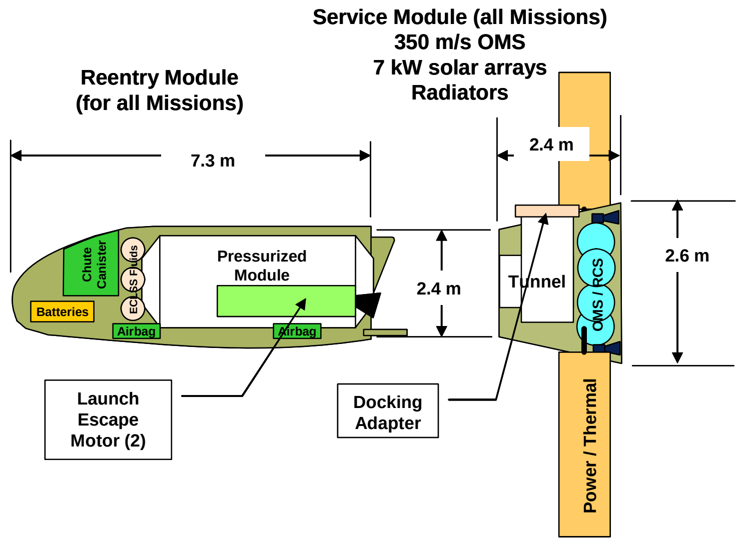
PLC	PLP	PLM	PLS
TBD	0.00	TBD	TBD

- Critical Technology Needs
  - GOX/GH ACS Thrusters
  - Long duration / low boiloff cryo tanks
  - Automatic Landing (GN&C)

Baseline ESS: Crew Exploration Vehicle (CEV)

- Transfer up to 4 crew between Earth and L1
- Transfer up to 6 crew between Earth and LEO
- Optionally piloted (remote / teleops capability)

- Reusable Medium L/D Reentry Module (RM)
- Expendable Service Module (SM)
- Combines with Orbital Transfer Vehicle (OTV) for lunar missions



Mass [kg]	Reentry Module (RM)	Service Module (SM)
Structure/Thermal	3,276	804
Propulsion	76	141
Equipment	3,262	297
Margin	1,324	236
Dry Mass	7,938	1,478
Propellant / Fluids	105	115
Payload	1,000	0
Launch Mass	9,043	1,593

- Cost Summary
  - 29,400 M-Yr Development
  - 1289 M-Yr Production
  - TBD per Launch

- Reliability Summary

PLC	PLP	PLM	PLS

- Critical Technology Needs
  - TBA

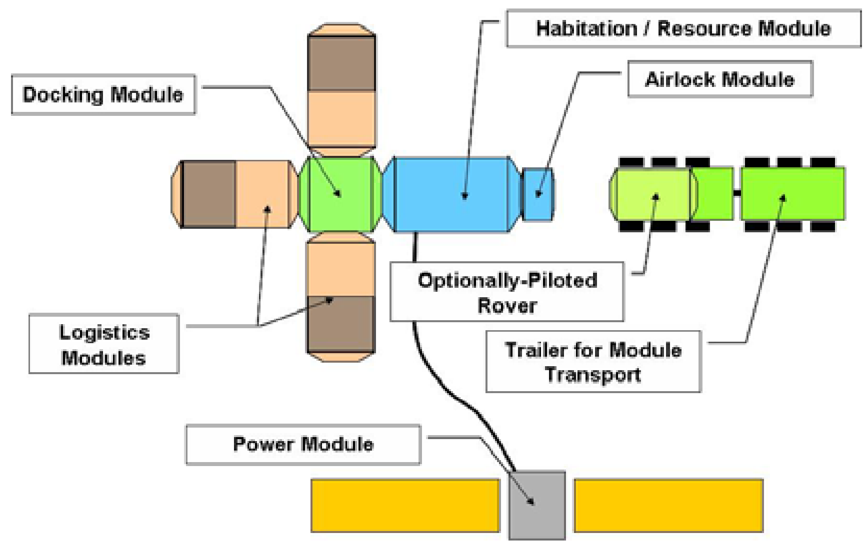
ANDREWS SPACE

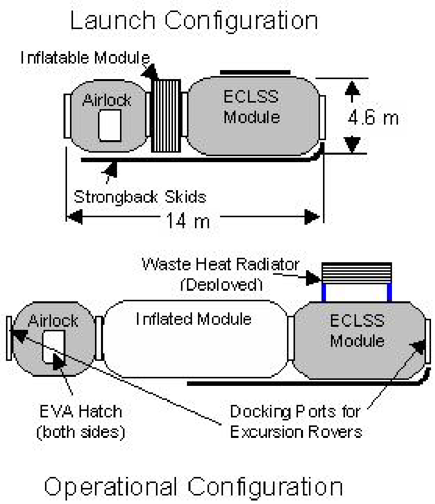
Baseline ESS: Lunar Surface Node (LSN)

Project Constellation

- Support 4 crew in 6 month rotation
- 30 m^3 per person
- Regolith shielding (buried) module as storm shelter
- Standard docking port, EVA support

- Modular constructed outpost
- Each element constrained to standard payload size, mass
- Water based ISRU capability from separate plant, rover tanker module used for propellant transport





Contents	[kg]
ECLSS	1,716
Logistics	1,010
Work Stations	486
Crew Systems	786
Structure	6,184
EMU (EVA Suit Spares)	204
Equipment in ECLSS	3,172
Inflatable Module	1,541
LAUNCH MASS	14,894

- Cost Summary
  - 37,600 M-Yr Development
  - 2940 M-Yr Construction
  - TBD Operations Cost

- Reliability Summary

PLC	PLP	PLM	PLS
TBD	0.00	TBD	TBD

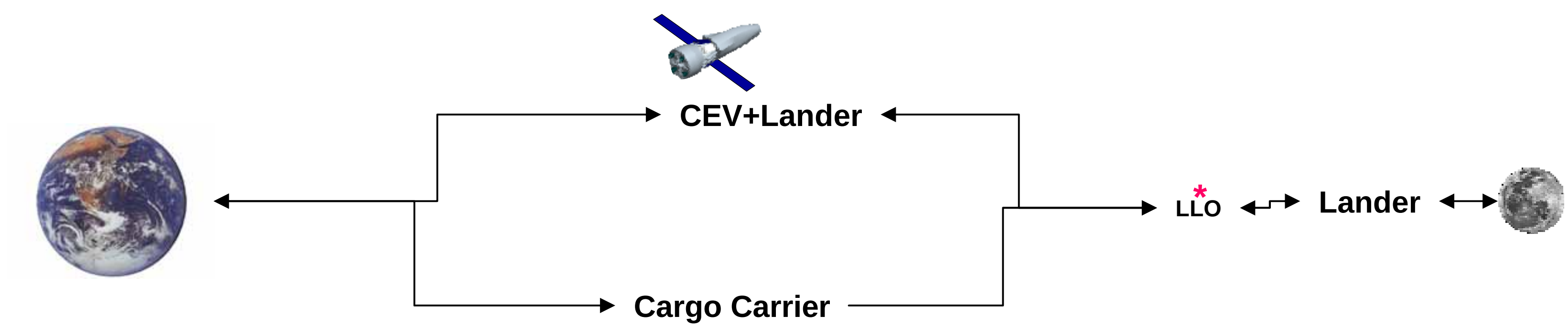
- Critical Technology Needs
  - TBA

ANDREWS SPACE

Node 1 Location Trade - Option 2 : Earth / LLO / Moon

- **Concept Description**
  - Both CEV and an expendable lander are launched to LLO together.
  - Lander descents to Moon, returns to LLO, remains there for refuel/reuse for cargo.
  - Cargo is launched to LLO, rendezvous with lander and refuels it for descent.
  - Lander remains on lunar surface after cargo use.

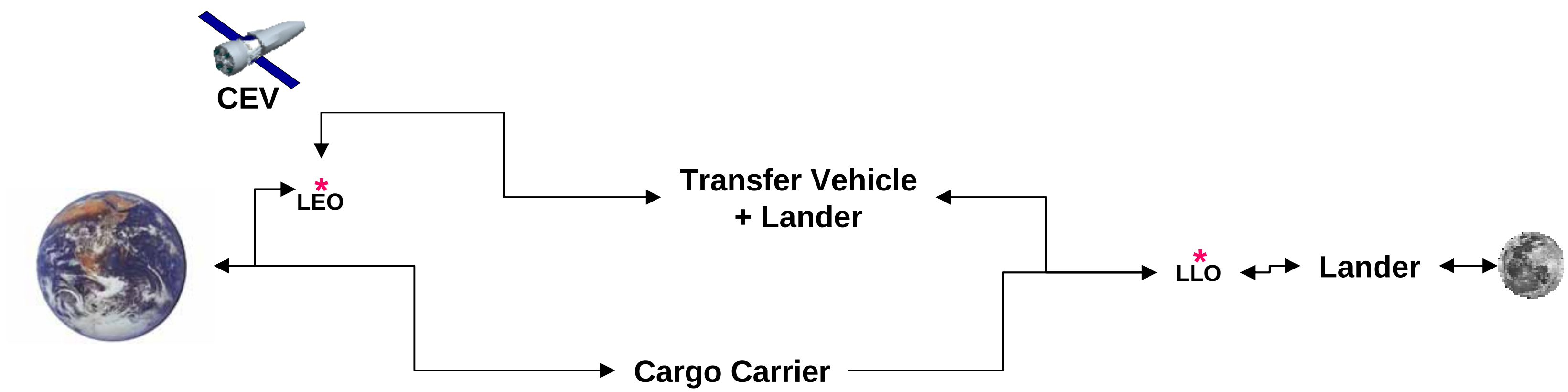
Safety / Mission Success	**Low number of systems** **CEV always carries a new Lander**
Effectiveness	**Efficient Lunar Cargo Transfer**
Extensibility	**Mission model extensible to Mars**
Affordability	**No in-space Infrastructure** **Partial reuse of lunar lander**
Sustainability	**Low cost**



Node 1 Location Trade - Option 3 : Earth / LEO / LLO / Moon

- **Concept Description**
  - As option 2, but reentry portion of CEV remains in LEO, rendezvous on the return leg

Safety / Mission Success	**Reentry system remains in LEO environment**
Effectiveness	**Efficient Lunar Cargo Transfer**
Extensibility	**CEV can be sized for LEO commercial applications**
Affordability	**Partial reuse of components**
Sustainability	**CEV matches multiple stakeholders**

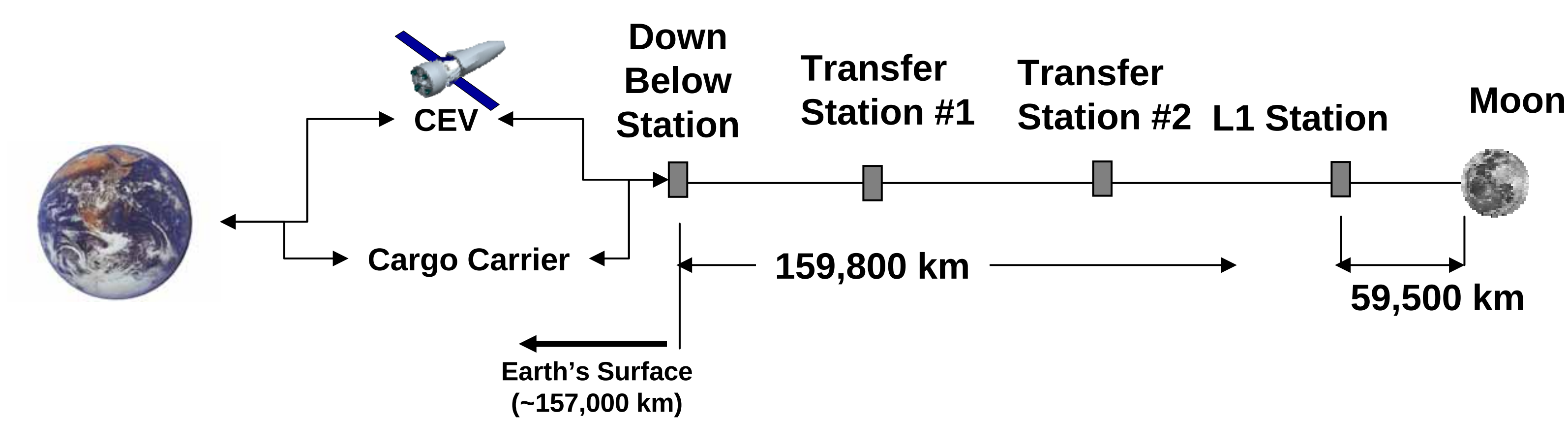


Node 1 Location Trade - Option 4 : Earth / L1 Elevator / Moon

Project Constellation

- **Concept Description**
  - "Space Elevator" anchored at L1
  - CEV services Earth to "Down Below" Station
  - Elevator takes crew / cargo to lunar surface
  - Objects released at "Down Below" Station can be aerocaptured into Earth orbit
  - Transfer Stations limit ribbon length required and allow multiple payloads to move at once.

Safety / Mission Success	**Increased "Time-to-Safety"** **Reduced number of systems**
Effectiveness	**Extremely efficient cislunar transport**
Extensibility	**Many uses for non-exploration applications**
Affordability	**High initial technology hurdle**
Sustainability	**Great ISRU / settlement potential**

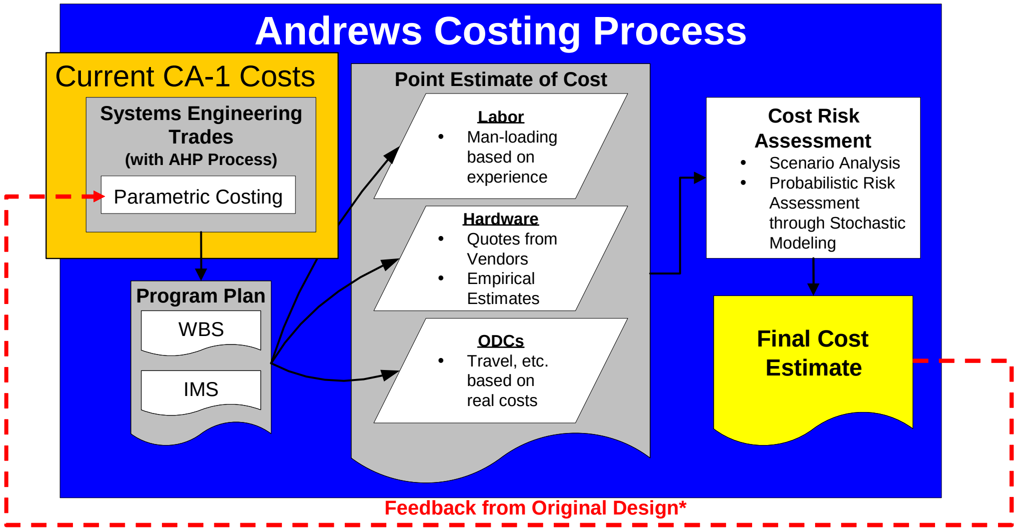


Architecture Overview / Definition

- Introduction
  - *Overview (Agenda)*
  - *CA-1 Roadmap*
- Exploration Objectives
  - *Decomposition & Maturation*
  - *Relationship to Architecture*
- Architecture Overview / Definition
  - **Assumption & Groundrules**
  - **Mission Definition**
  - **System Updates**
  - **CONOPS Definition**
  - **Top Level Development Timelines**
  - **Alternatives to be traded**
- **Trades & Analyses for ESS & CEV**
  - *Definition*
  - *Connection with Architecture*
  - *Outcomes/Expected Results*
  - *Surprises*
- **Technology Requirements**
  - *Relationships to Architecture*
  - *Development Plans*
- **Exploration Program / Tech Risk**
  - *Significant Risk Definition*
  - *Architecture Specific*
  - *Mitigation Approaches*

Andrews Cost Estimation Process

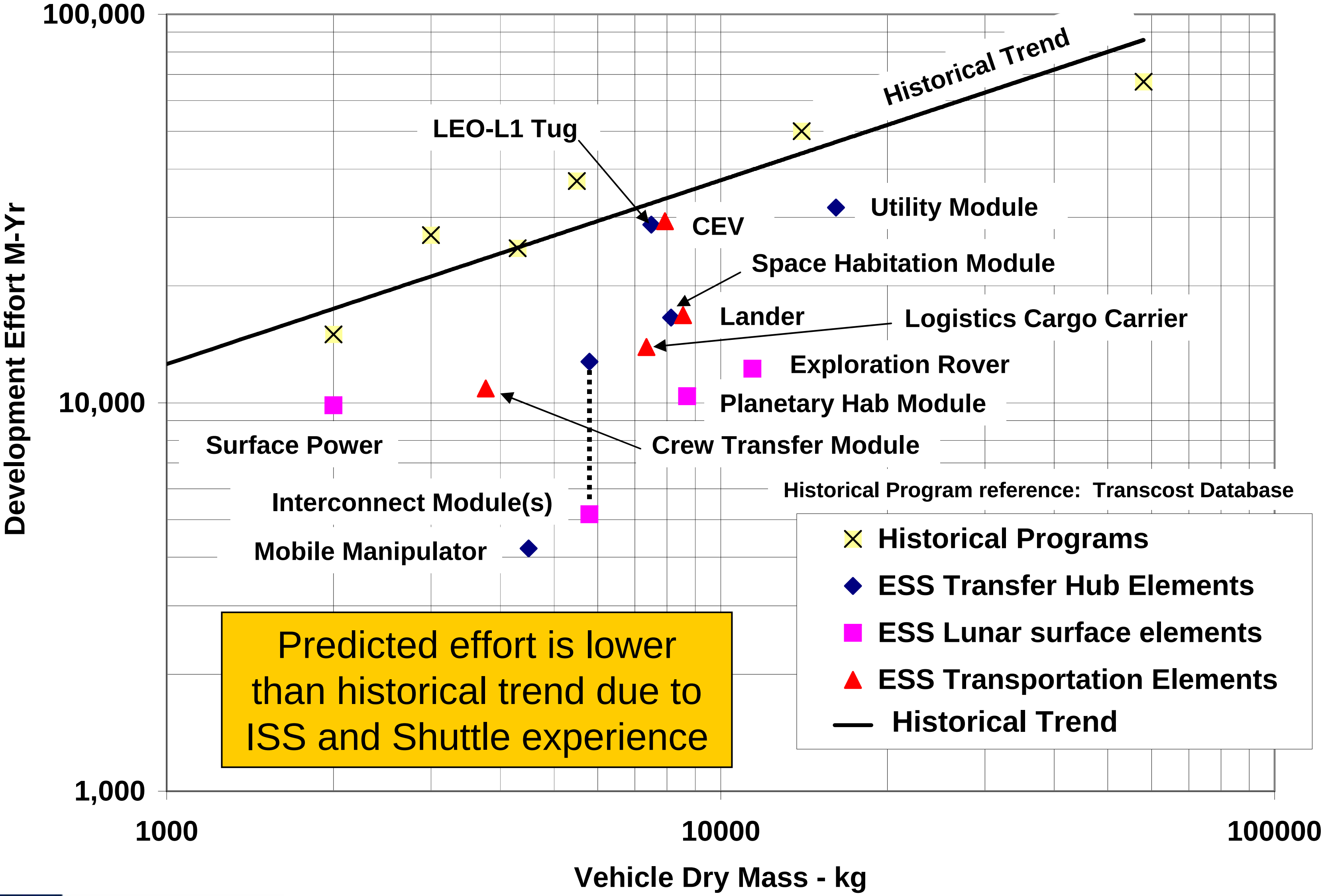
- Two step costing process is used:
  - Early engineering trades uses TRANSCOST to support configuration trades
  - Detailed costing done using detailed WBS and bottoms-up estimate
- Relative Costs predicted for VISTA elements to-date
  - Development Effort
  - First Unit Production Effort
  - Launch Costs



- Super-system element trade option costs will be predicted to support trades
  - Alternate node scenarios
  - Alternate lunar base scenarios
- Operations costs will be developed to support Super-system trades
  - Launch operations
  - Element operations
  - Mission operations
  - Fixed and annual costs

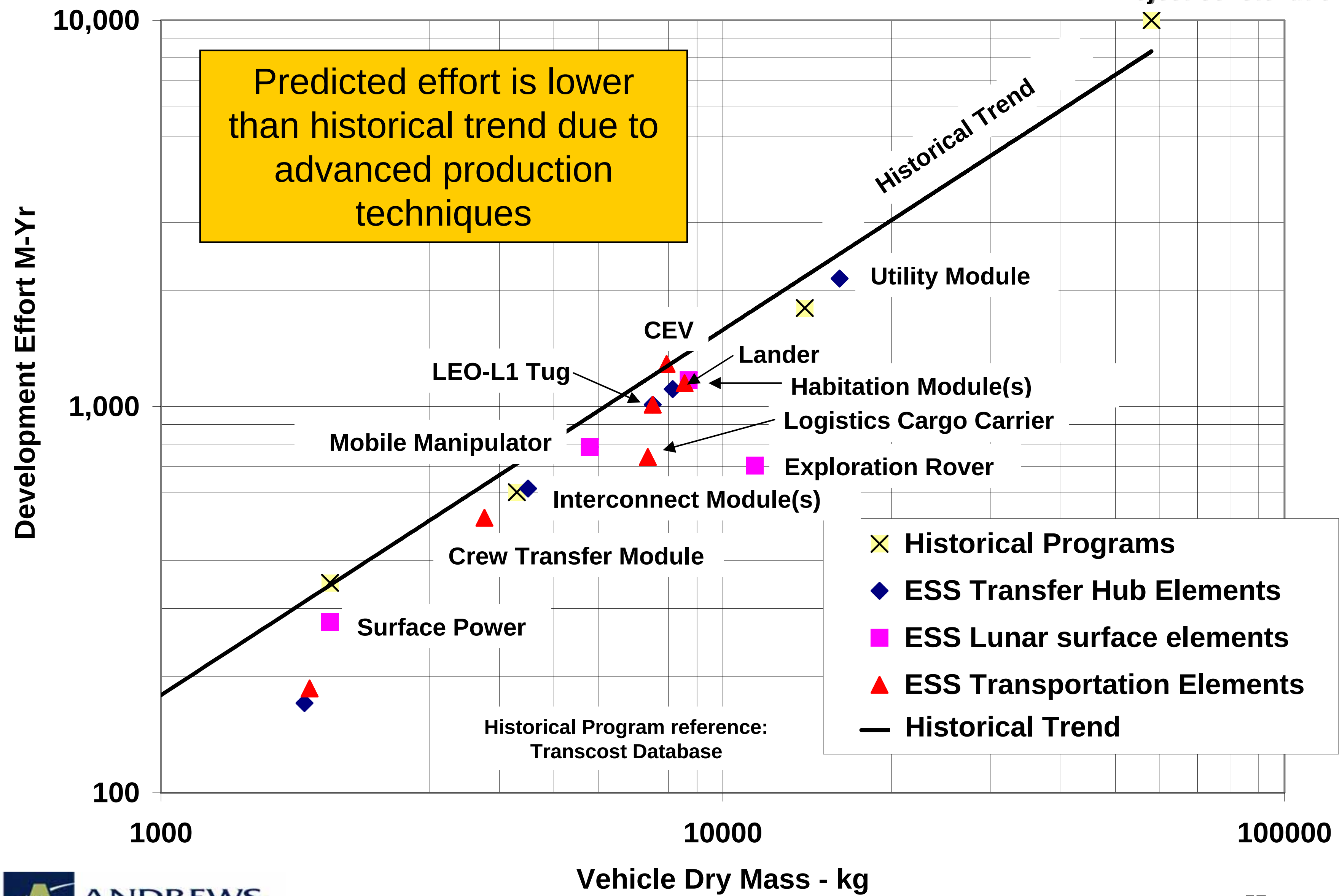
VISTA Exploration Super-System Element Development Effort

Project Constellation



VISTA Element Unit Production Effort

Project Constellation



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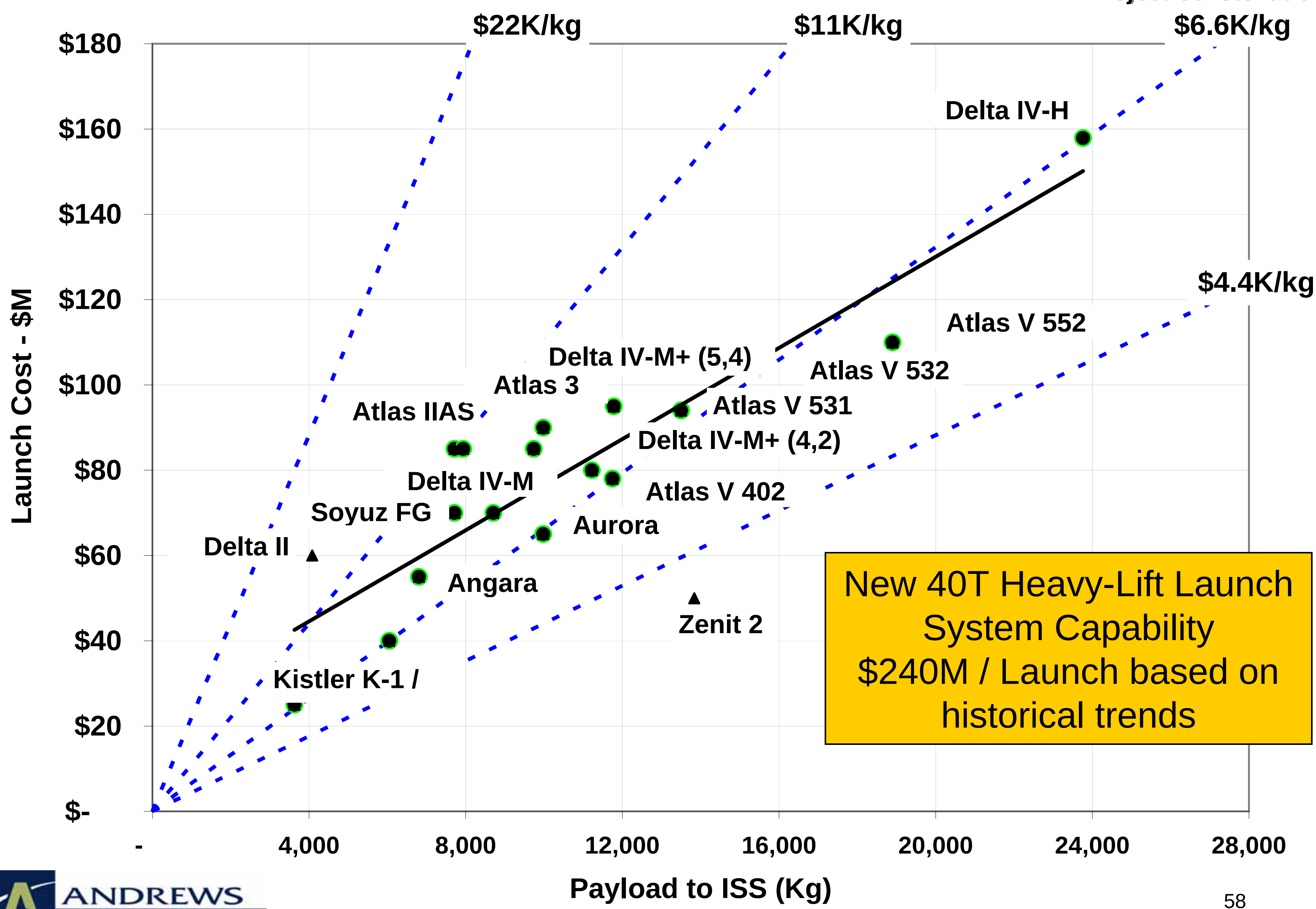
VISTA Launch Costs Based on Historical Trends

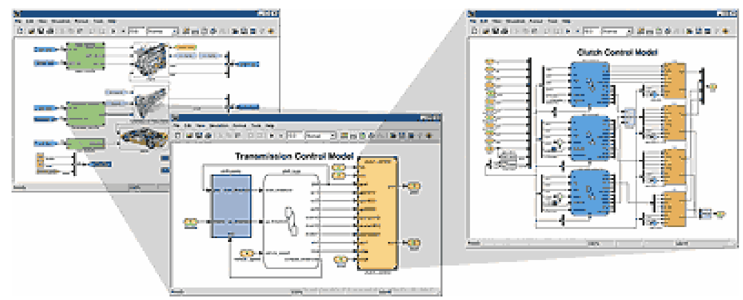
Project Constellation



ANDREWS SPACE

Integrated SuperSystem Model

- **Objective: evaluate integrated SuperSystem FOMs**
  - **Segment Capture**
  - **Crew Throughput**
  - **Cargo Throughput**
  - **Rate of Non-Nominal Events**
  - **Milestone Frequency**
  - **Cost Profile**



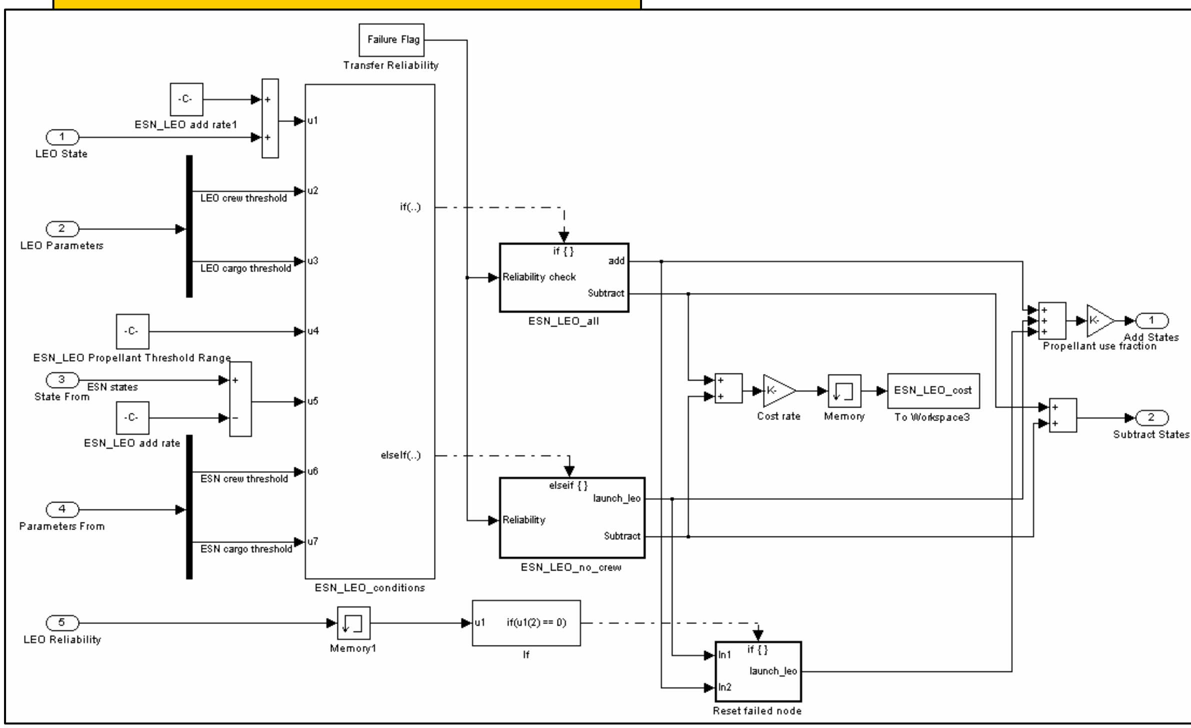
- **Tool Platform: MATLAB / Simulink**

Model inputs	• Initial state values • Node Locations / Transfer Paths	
Model states	• Crew • Cargo • Propellant	
Model parameters	• Send rates (crew/cargo sent at each transfer) • Propellant use (per transfer) • Cost (cost per unit throughput) • Reliability (likelihood of failure for each throughput) • Transfer Time	Transfer Blocks
	• Thresholds (min/max required to function or supported) • Cost (per unit time) • Reliability (likelihood of failure per unit time) • Cargo use (as consumables or for propellant, per unit time) • Time between crew change-out	Node Blocks
Model outputs	• Overall crew / cargo / propellant transport (throughput) as a function of time • Overall cost as a function of time • Rate of Non-Nominal events	

Simulink Model Representation: Transfer Block

- **Transfer blocks connect only to Node Blocks**
- **Transfer initiation depends on a number of conditions**
  - **Departure Node: sufficient crew/cargo/propellant**
  - **Destination Node: needed crew/cargo**
  - **No transfer failure**
  - **Time since previous transfer**

ESN to LEO transfer block



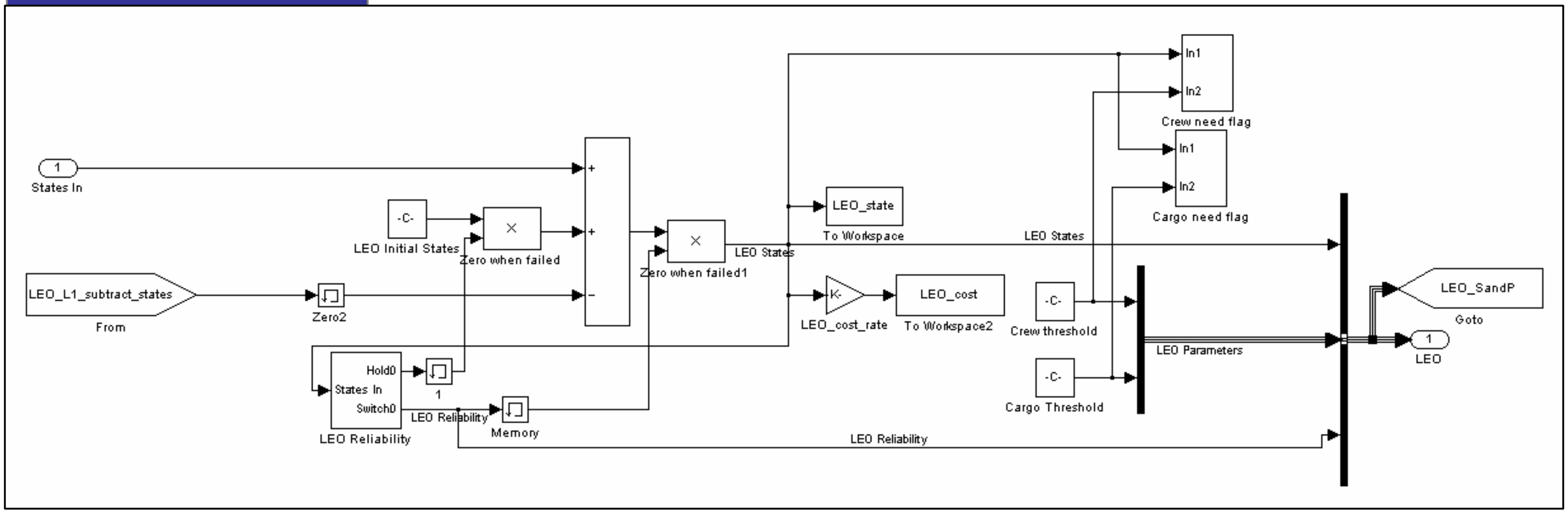
Transfer Conditions	
If	**Action**
"To" crew upper limit ≠ 0 **&** "To" crew + crew send rate + crew in transit <= upper "To" crew limit **&** "From" crew - crew send rate >= lower "From" crew threshold **&** "To" cargo + cargo in transit that will arrive before crew >= lower cargo threshold **&** LEO crew need = true **&** Time since last transfer >= minimum time between transfers **&** "From" propellant - Transfer propellant use >= lower "From propellant threshold*	Send crew and use propellant
"To" cargo + cargo send rate + cargo in transit <= upper "To" cargo limit **&** "From" cargo - cargo send rate >= lower "From" cargo threshold **&** "To" cargo need = true **&** Time since last transfer >= minimum time between transfers **&** "From" propellant - Transfer propellant use >= lower "From" propellant threshold*	Send cargo and use propellant
Transfer failure = true	Zero out current states in transfer
Node failure = true	Reset states at node to zero

*Condition exists only for the L1_Moon transfer due to L1 and the Moon being the only propellant-tracking nodes.

Simulink Model Representation: Node Block

- Node Blocks connect only to transfer blocks
- Node update accounts for various events
  - Initial States (crew, cargo, propellant)
  - States transferred to node
  - States transferred from node
  - Conversion of states at node
  - Use of states for node sustainability (crew consumables)
  - Node failures

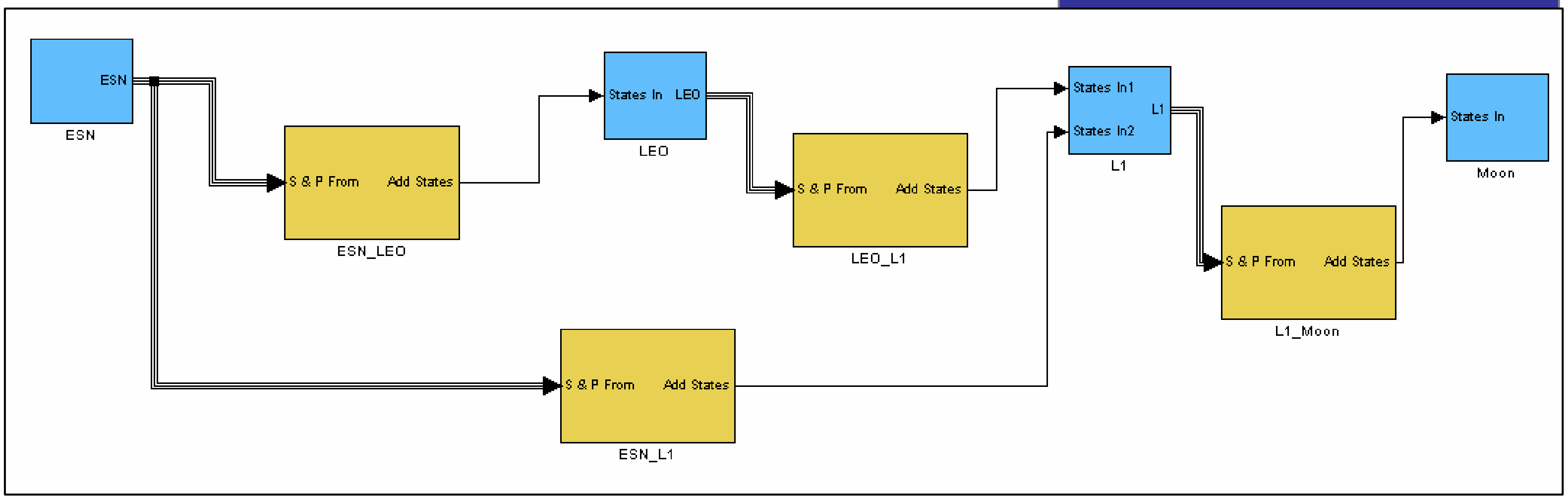
LEO node block



VISTA Model Summary

- Baseline nodes: ESN, LEO, L1 and Moon
- Baseline transfers:
  - ESN to LEO (cargo only)
  - LEO to L1 (cargo only)
  - ESN to L1 (crew only)
  - L1 to Moon (crew or cargo)
- Modeled to show:
  - Initial build-up of states
  - Initial build-up costs
  - Effect of node and transfer failures on build-up time

Top-level VISTA model



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ETO and L1 Station Parameters Example

Project Constellation

Supersystem Model Transfer Parameters						
	Send Rates (units/transfer)		Reliability	Cost rate	Transfer time	Turn-around time between transfers
Transfer	Crew	Cargo (tons)	(%)	($/transfer)	(hours)	(hours)
ESN_LEO	0	40	0.9		1	336

Transfer block parameters:

- **Send rates - number of crew or tons of cargo to send for each transfer**
- **Reliability - percentage of transfers for which there is no transfer failure**
- **Cost rate - cost per state per transfer**
- **Transfer time - amount of time the states spend in transit between nodes**
- **Turn-around time between transfers - time between subsequent transfers from a given node**

Supersystem Model Node Parameters													
	Initial States		Crew Threshold		Cargo Threshold (tons)		Propellant Threshold (tons)		Operating Cost ($/time)		Reliability	Cargo Use	Cargo to Prop. Rate
Node	Crew	Cargo (tons)	Min.	Max.	Min.	Max.	Min.	Max.	Crew	Cargo	(%)	(tons/crew/hour)	(tons/hour)
L1	0	0	0	8	45	200	0	35			0.9	1.79E-04	1.62E-02

Node block parameters:

- **Initial states - crew and cargo present at the given node at time = 0**
- **Crew threshold - minimum and maximum number of crew allowed at the node at any time step**
- **Cargo threshold - minimum and maximum tons of cargo allowed at the node at any time step**
- **Propellant threshold - minimum and maximum propellant allowed at that node at any time step**
- **Operating cost - cost per state per time step at the given node**
- **Reliability - percentage of time steps for which there is no failure at the given node**
- **Cargo use - rate of cargo consumed by the crew at the given node**
- **Cargo to propellant rate - rate at which water (cargo) is converted to propellant at the given node**

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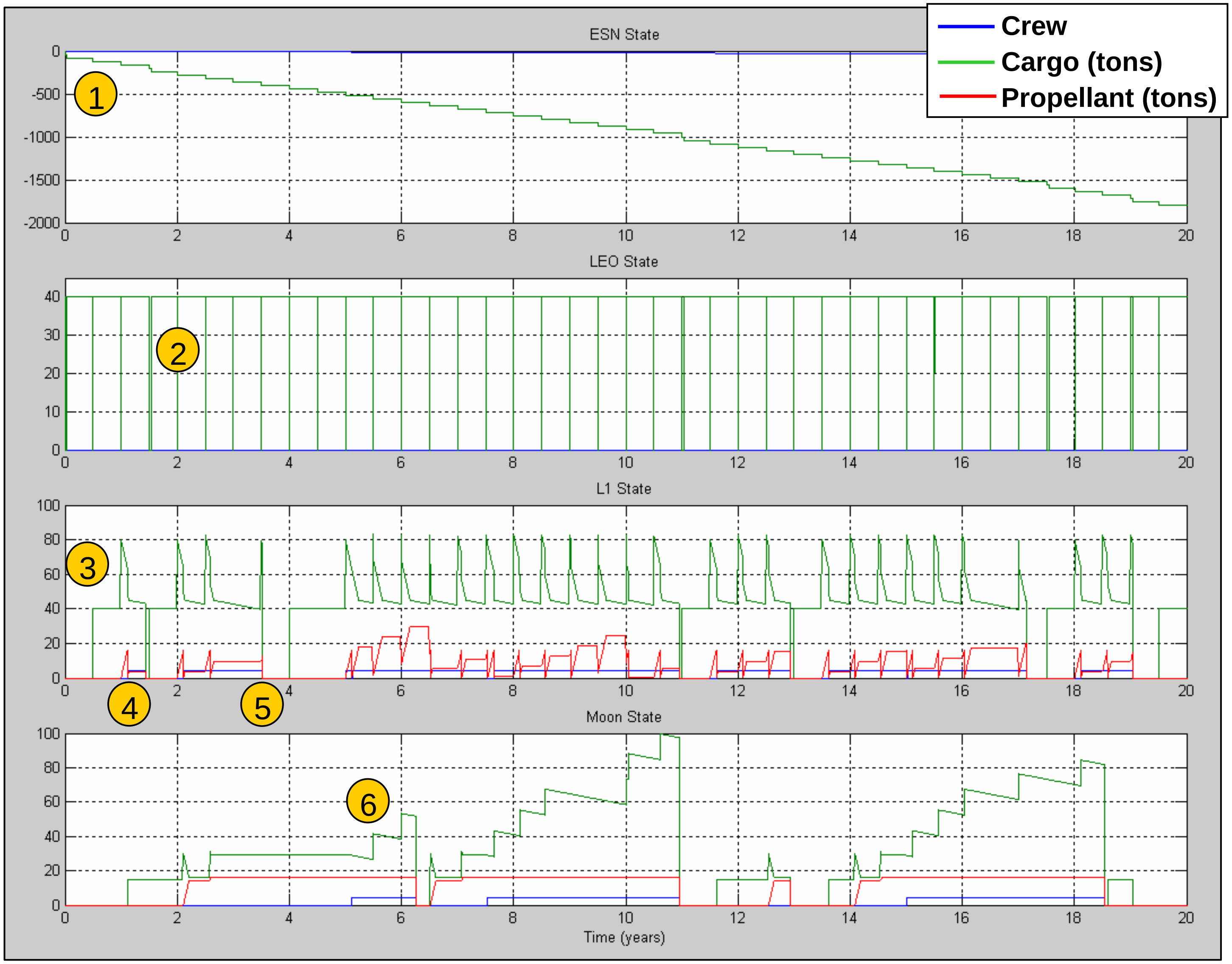
VISTA Model Results: Node states



1. Earth Surface Node states are initialized at zero to capture output

2. Cargo is the only state to travel through the LEO node

3. Cargo at L1 reaches its minimum threshold before propellant is created and crew arrives

4. Transfer from L1 to the Moon is triggered by adequate propellant at L1

5. Node failures cause all states to go to zero

6. Cargo at the Moon is used for crew consumables

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Architecture Overview / Definition

- Introduction
  - *Overview (Agenda)*
  - *CA-1 Roadmap*
- Exploration Objectives
  - *Decomposition & Maturation*
  - *Relationship to Architecture*
- Architecture Overview / Definition
  - Assumption & Groundrules
  - Mission Definition
  - System Updates
  - CONOPS Definition
  - Top Level Development Timelines
  - Alternatives to be traded
- Trades & Analyses for ESS & CEV
  - Definition
  - Connection with Architecture
  - Outcomes/Expected Results
  - Surprises
- **Technology Requirements**
  - *Relationships to Architecture*
  - *Development Plans*
- **Exploration Program / Tech Risk**
  - *Significant Risk Definition*
  - *Architecture Specific*
  - *Mitigation Approaches*

VISTA Technology Needs (PoD)

- Propulsion Technology
  - RLX class LOX/LH Rocket Engine (Restartable w/ Improved Reliability)
  - RL-10 class Space-Based Engine (IVHM-based Auto-checkout)
  - 5 klbf class Space-Based LOX/LH Highly-Throttlable Lander Engine (might be pressure-fed)
  - 100+ kW Electric Thrusters (Hall or Ion acceptable – must be long-lived)
  - Water to Propellant in-space factory (Electrolyzer w/ Liquefaction)
  - ISRU Propellant Factory (Mining, Separation, Electrolyzer, plus Liquefaction)
- Power Technology
  - Improved RTGs (25% efficient)
  - Highly Packagable Solar Array Concentrators
  - Low cost, hardened solar cells
  - 50 kWe Regenerative Fuel Cell (supports pressurized rovers)
  - 250 kWe Fission Surface Powerplant (Supports ISRU)
- Robotics Technologies
  - Extended Duration Rovers
  - Enhanced Mobility Rovers (Rough Terrain Capable)
  - Visual Reality Tele-operation
- Human Exploration Technologies
  - Improved Lunar/Mars EVA suit (Back access from habitat to avoid dust contamination problem?)
  - Inflatable Living Space
- Automation / Avionics
  - ARPO
  - Adaptive / Autonomous GN&C
- Aerodynamics
  - Ballute or deployable lifting brake (Option for Aerobraking back into LEO)
- Thermal Control
  - Deployable radiators for moon/Mars surface applications

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VISTA Risks & Mitigation Strategies

- **Risk is categorized into programmatic and technological / conceptual**
- **Programmatic Risks**
  - **Schedule**
  - **Cost**
  - **Stakeholder Interest**
- **Technological / Conceptual Risk**
  - **Low TRL for enabling technologies**
  - **Single technology dependency**

Technology	Element Use	TRL	Fallback
LOX/LH Rocket Propulsion	Expendable Upper Stage Common Planetary Lander	4-9	Some specific technology applications (e.g. lander engines) are yet to be developed.
Storable Rocket Propulsion	Orbital Transfer Vehicle (LEO-L1) CEV and derivative vehicles	4-9	
Electric Propulsion	LEO-L1 Tug L1 Phobos Tug Exploration Spacecraft (JIMO)	7	Solar Thermal Storable (LEO / L1) LOX/LH (L1 / Phobos)
Inflatable Habitats	Long Duration Habitat - at L1 Node - for L1 – Phobos Crew Transfer	4	Hard Shell Modules derived from Common Space Module (CSM)
ISRU	Martian & Lunar ISRU (water to LOX/LH)	4	Commercial water transport from Earth
Life Support Systems	Permanent Outposts (L1, Moon, Phobos, Mars)	4	Partially Closed Life Support + ISRU

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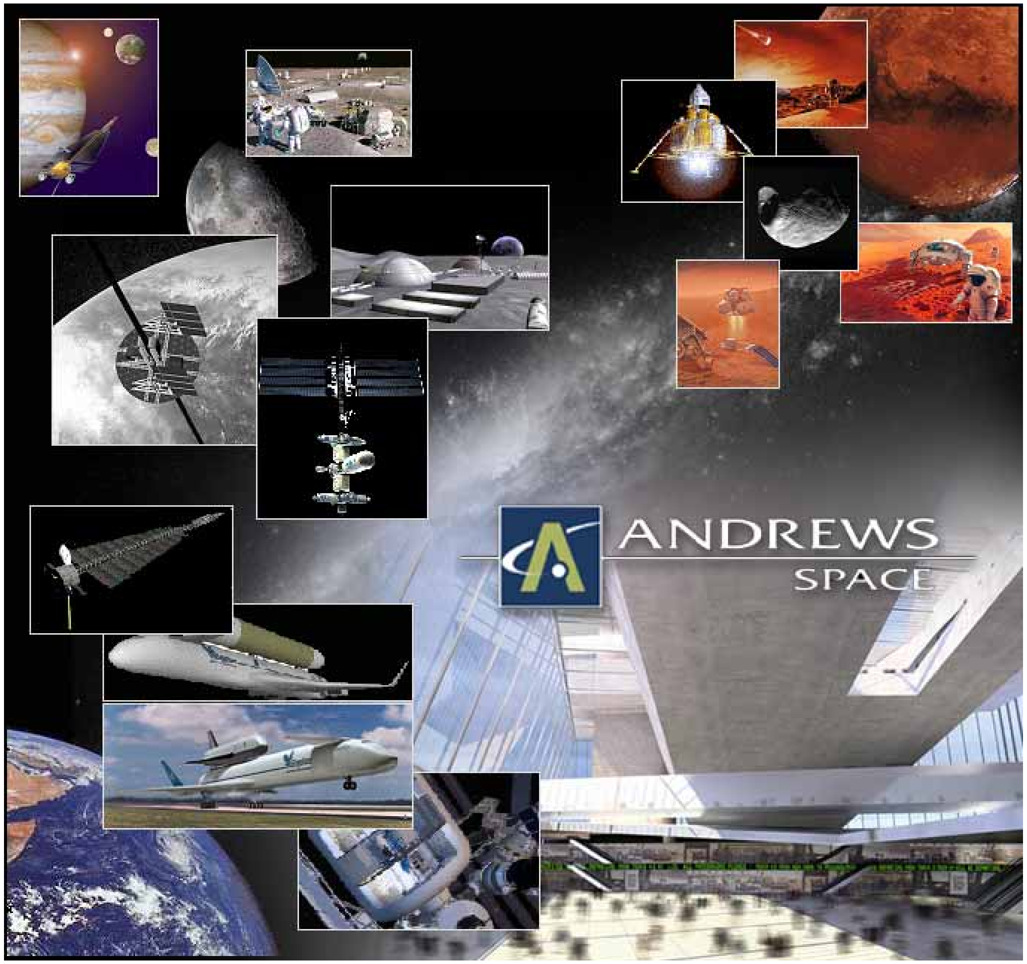
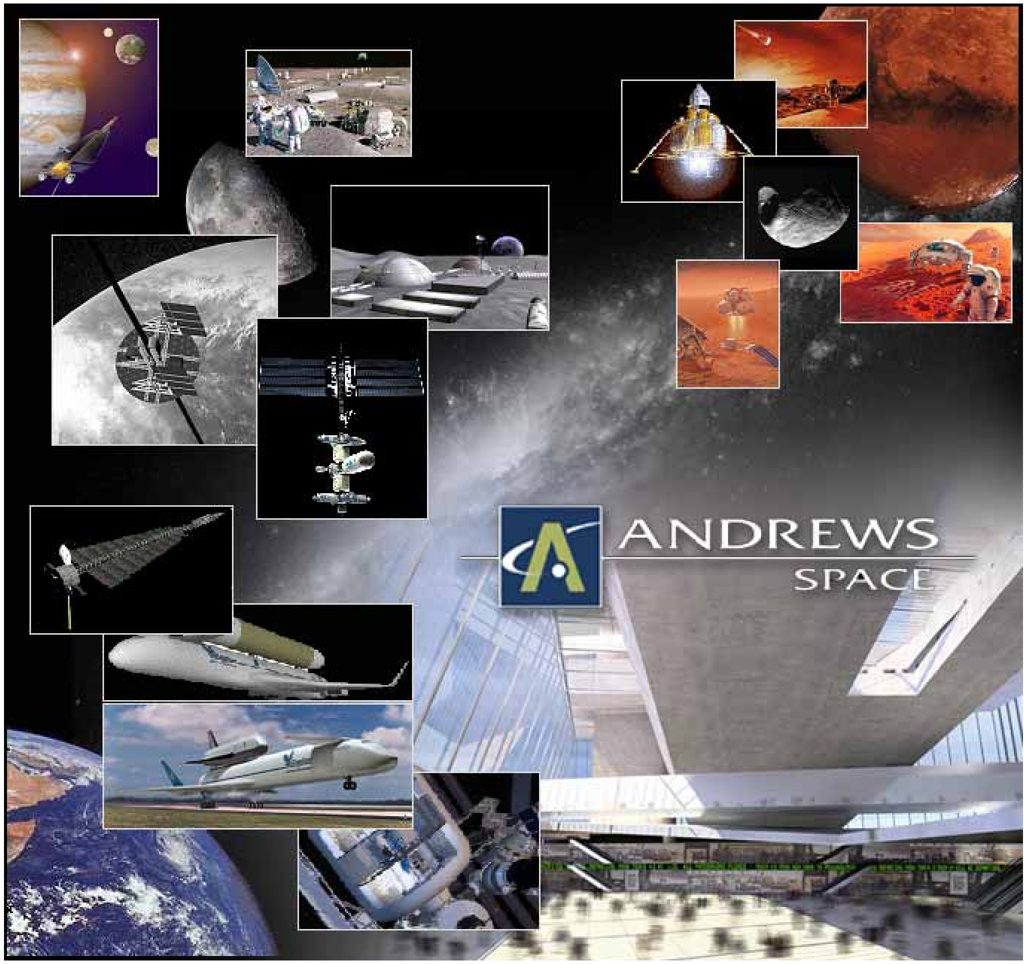
Issues/Concerns



- If stakeholders other than NASA are not adequately represented in the FOMS, the resultant architecture will be Apollo updated.
- It is difficult to impossible to complete architecture trades without some launch vehicle requirements/interaction.
- Disruptive technology breakthroughs have the greatest potential impact on architectures with the least representation in technology planning.
  - Electric Tugs
  - ISRU Propellants
  - Space Elevator
  - Lunar Catapults

Summary / Questions



- A consistent set of DRC and FOMs was defined to enable objective trade study evaluations
- Definition and analysis of a baseline ESS is nearing completion
- The trade space has been delineated and a number of promising trade options have been identified
- Analysis methodologies have been developed and applied to the baseline system
- Technology needs have been identified for enabling and enhancing technologies
- Systematic investigation of the trade tree will be used to refine the baseline and identify the most suitable ESS solution