America's Ride to Space

On Orbit Refueling: Supporting a Robust Cislunar Space Economy

3 April 2017

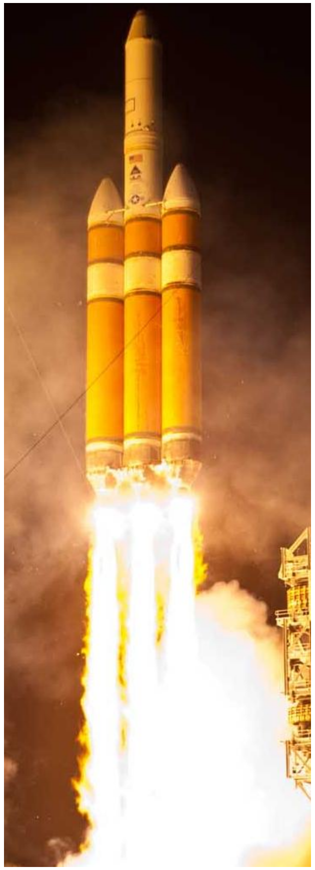
Launch History

ULA's Vision: Unleashing Mankind's Potential in Space

ULA is developing the enabling transportation system for a Self Sustaining Space Economy

Atlas V

Delta IV



United Launch Alliance

Customers

National Security Space

Global Positioning System (GPS)

Intelligence, Surveillance and Reconnaissance

Commercial Space

Earth Imagery

Commercial Communication

Civil Space

Robotic Exploration and Science

Mars Science Laboratory

Pluto New Horizons

Increasing Our Knowledge of the Earth and Its Climate

Geostationary Operational Environmental Satellite (GOES)

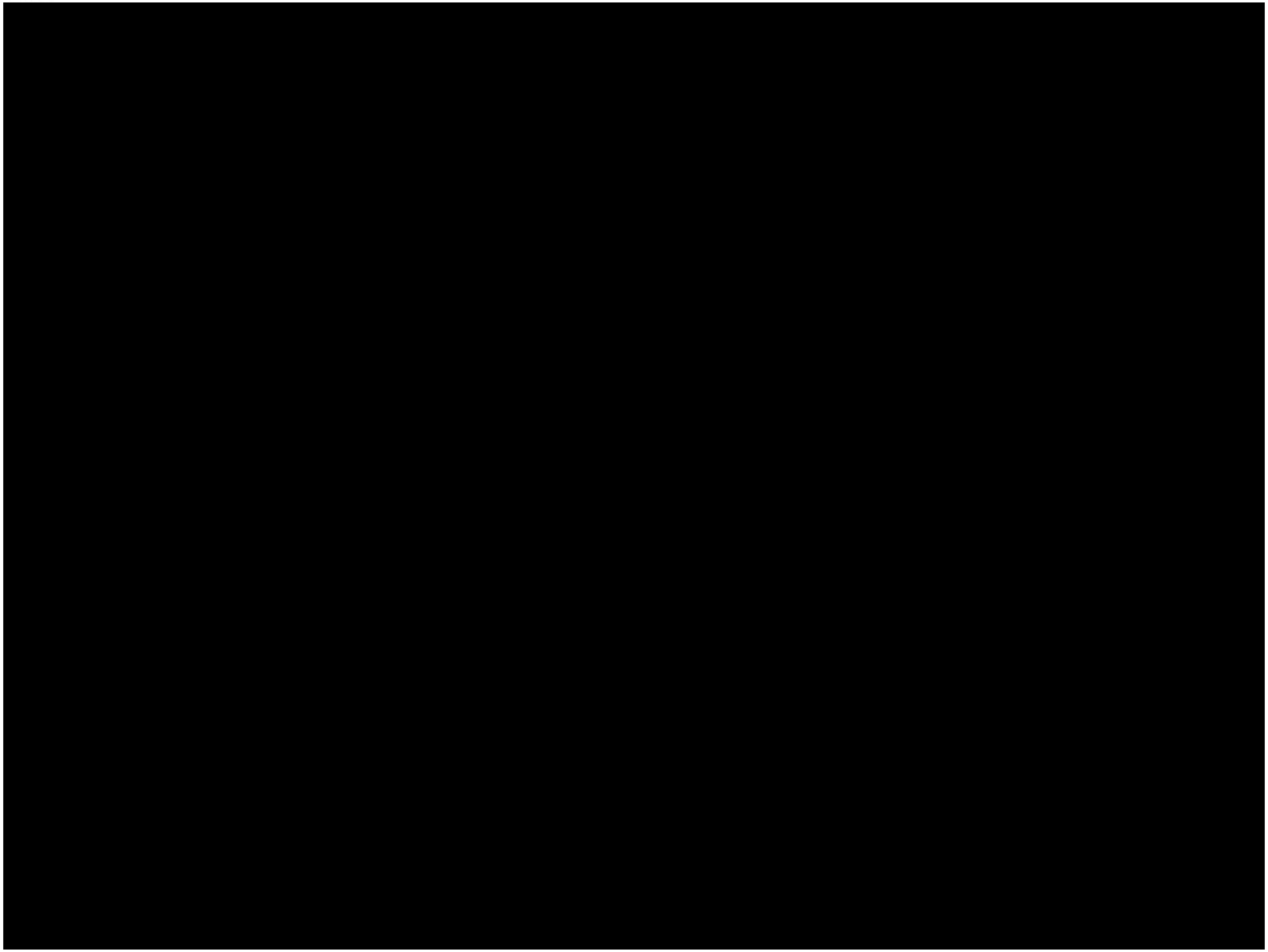
Cloudsat

Human Launch

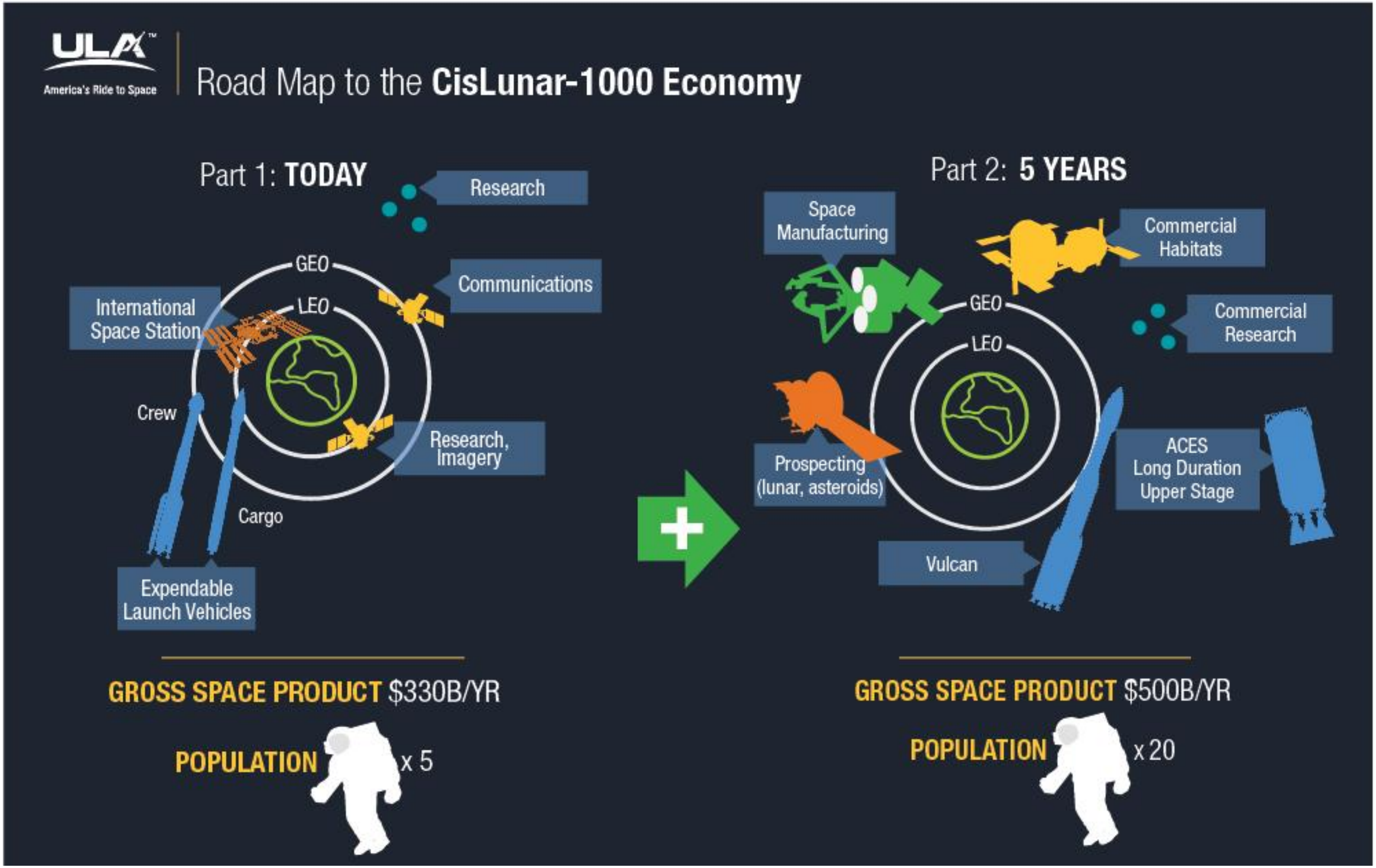
Cargo

Crew

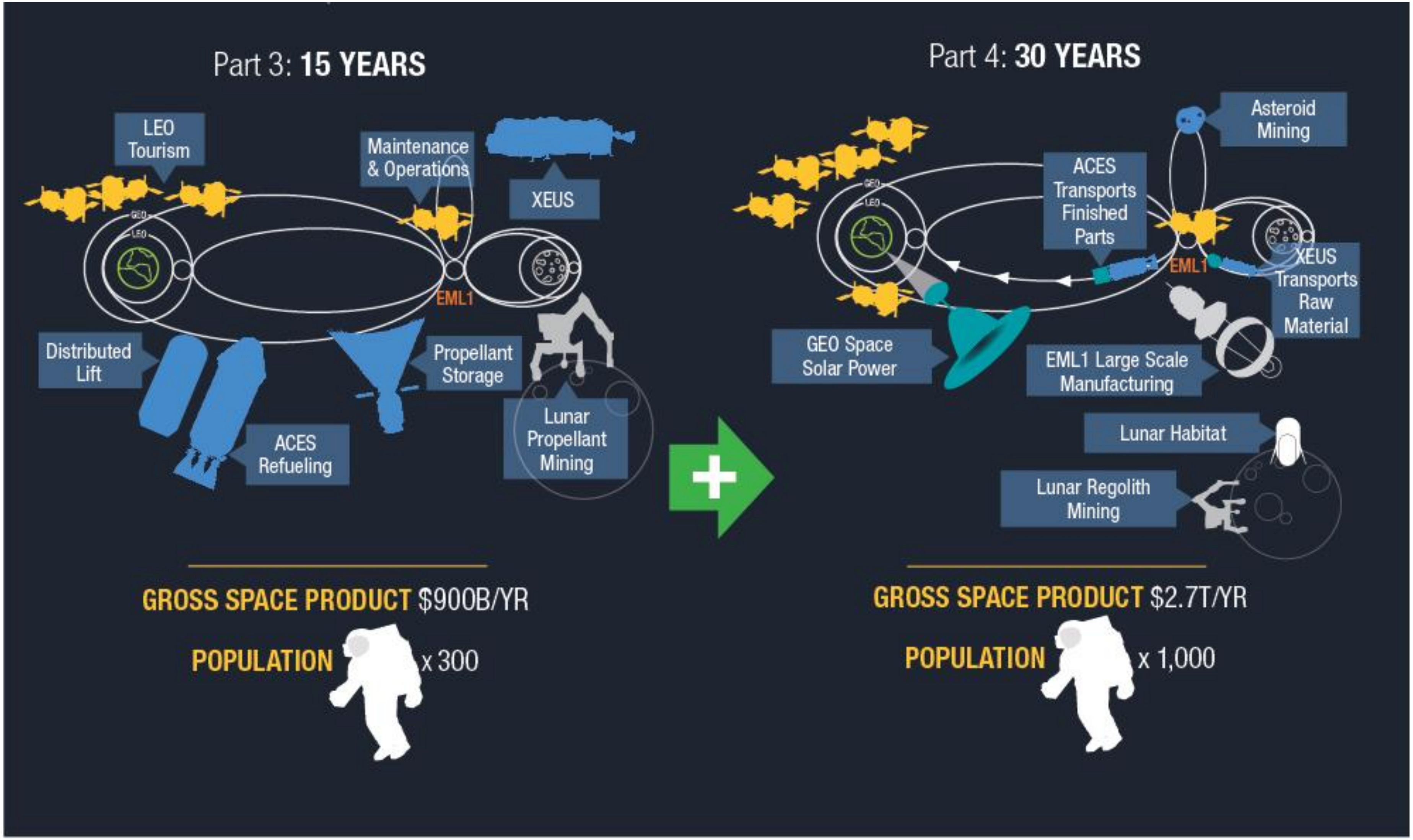
2016 ULA Launches



Cislunar 1000 Vision

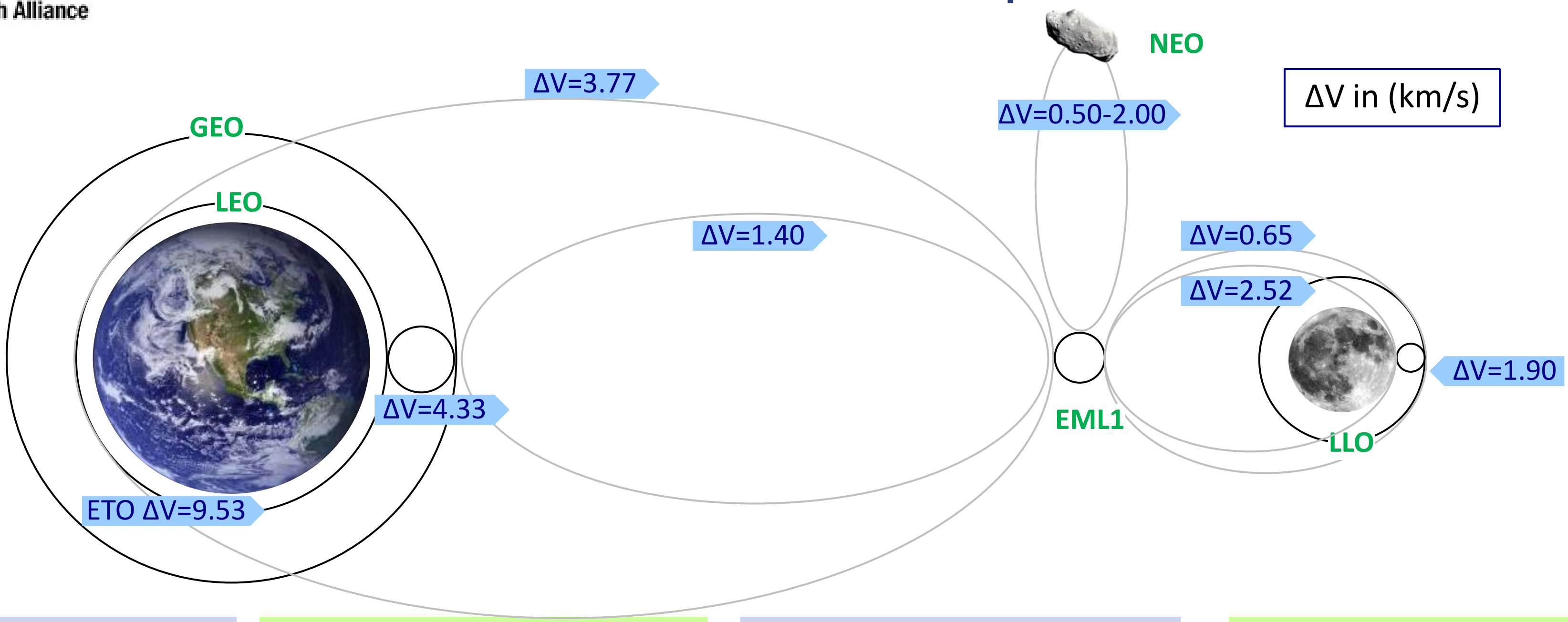


Cislunar 1000 Vision



United Launch Alliance

Cislunar Econosphere



LEO
ISS
Remote Sensing
Commercial Station
Communication
Space Control
Debris mitigation
Science
R&D
Tourism
Manufacturing
Propellant Transfer
Data Servers

GEO
Observation
Communication
Space Control
Debris Mitigation
Space Solar Power
Repair Station
Satellite Life extension
Harvesting

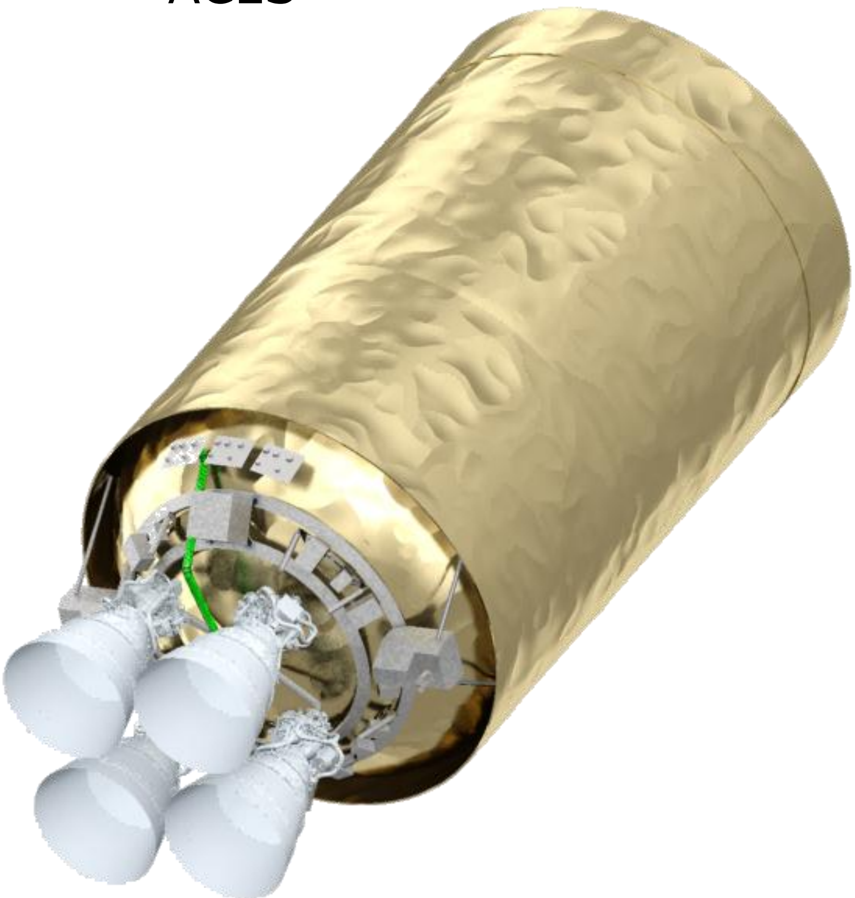
High Earth Orbit
Science / Astronomy
Communication Link
Way Station
Propellant Depots
Repair Station
Lunar Solar Power Sat
Manufacturing
Planetary Defense

Lunar Surface
Science/ Astronomy
•Lunar
•Observatory
Human Outpost
Tourism
Mining
•Oxygen/Water
•Regolith
•Rare Earth Elements
•HE3
Manufacturing
Fuel Depots
Solar Power to Earth

Existing market / Emerging market \ Future market

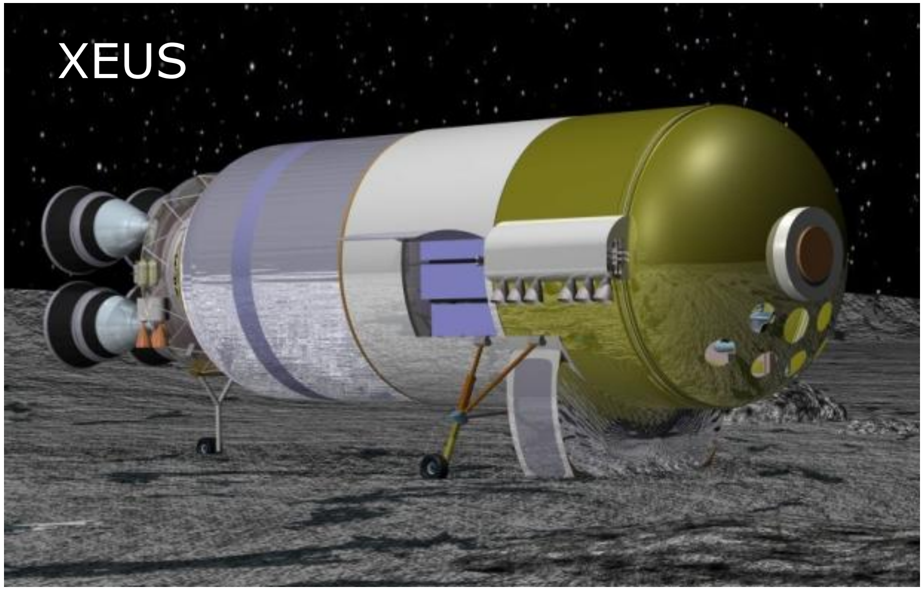
Cislunar Transportation System

ACES



Fueled with LO2 and LH2 propellant provided from:

- Earth
- Moon
- Asteroids

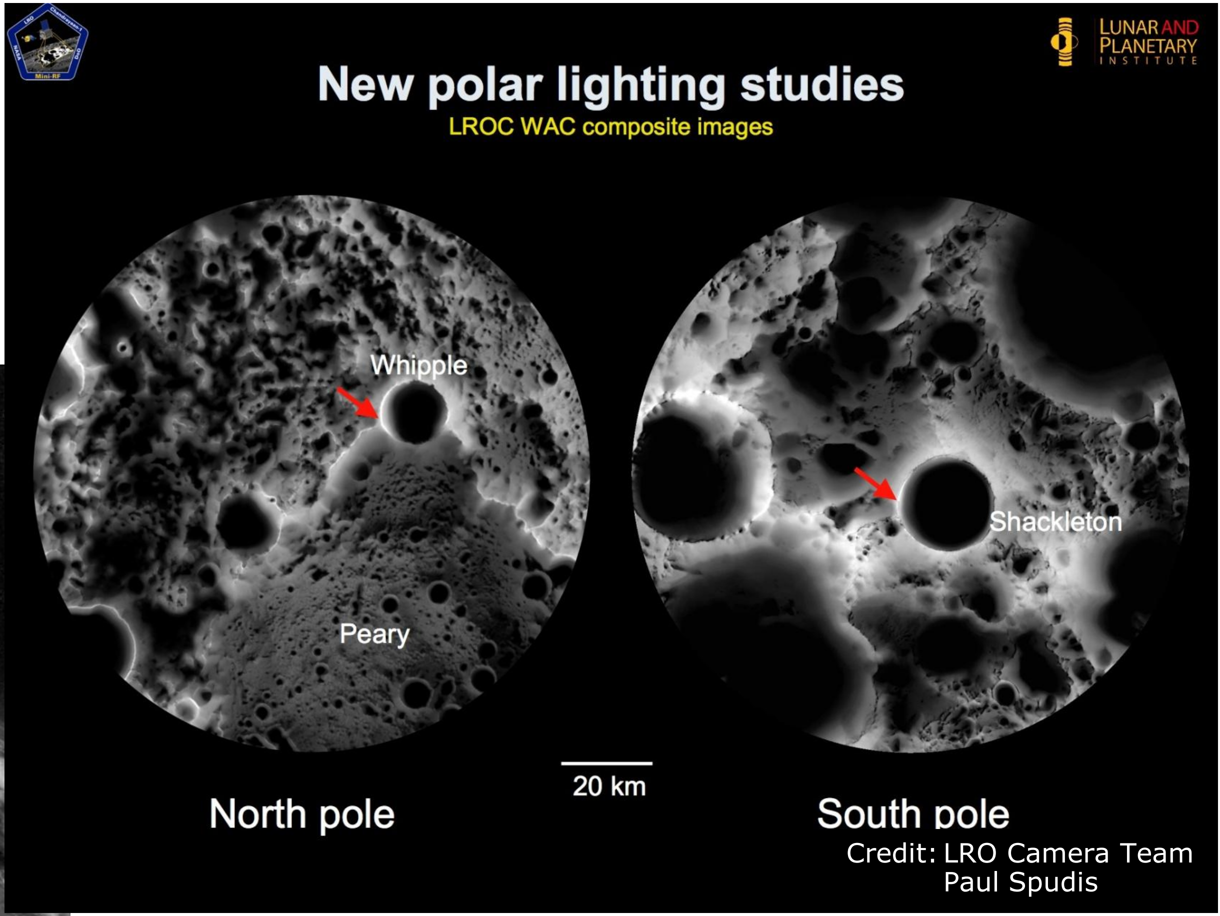


Reusable Transportation Avoids Earth’s Deep Gravity Well

United Launch Alliance

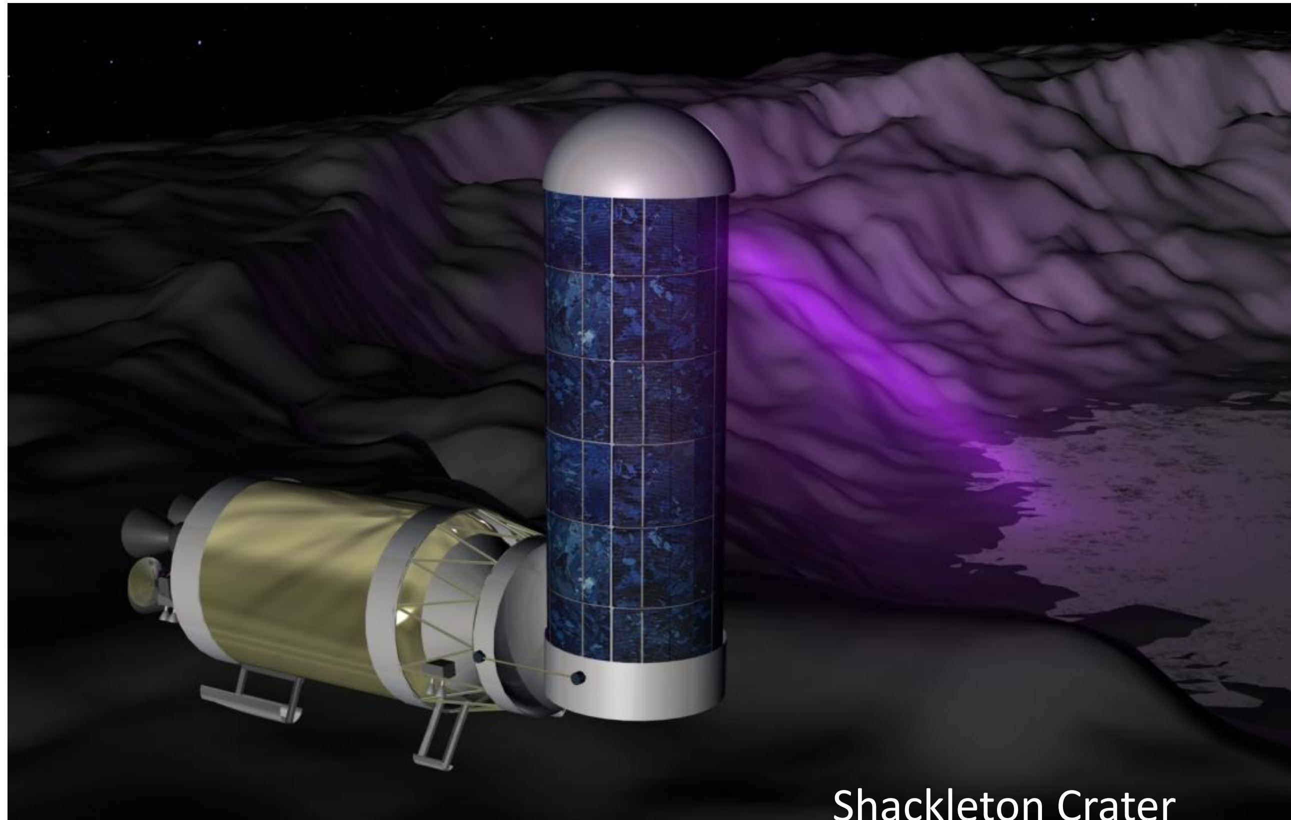
Lunar Water

- Water at Lunar poles
  - –Cold Traps in Craters
  - –~10B mT per pole
- Fuel, Water, Oxygen

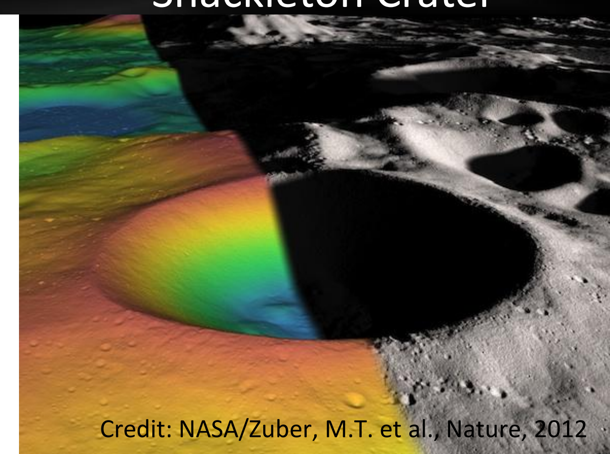


Lunar Water Extraction

- Power Tower on Crater Rim
  - Beam power to crater floor
- Sublimate ICE
  - Collect and liquefy
- Electrolyze water
  - Liquefy and store LH2 & LO2

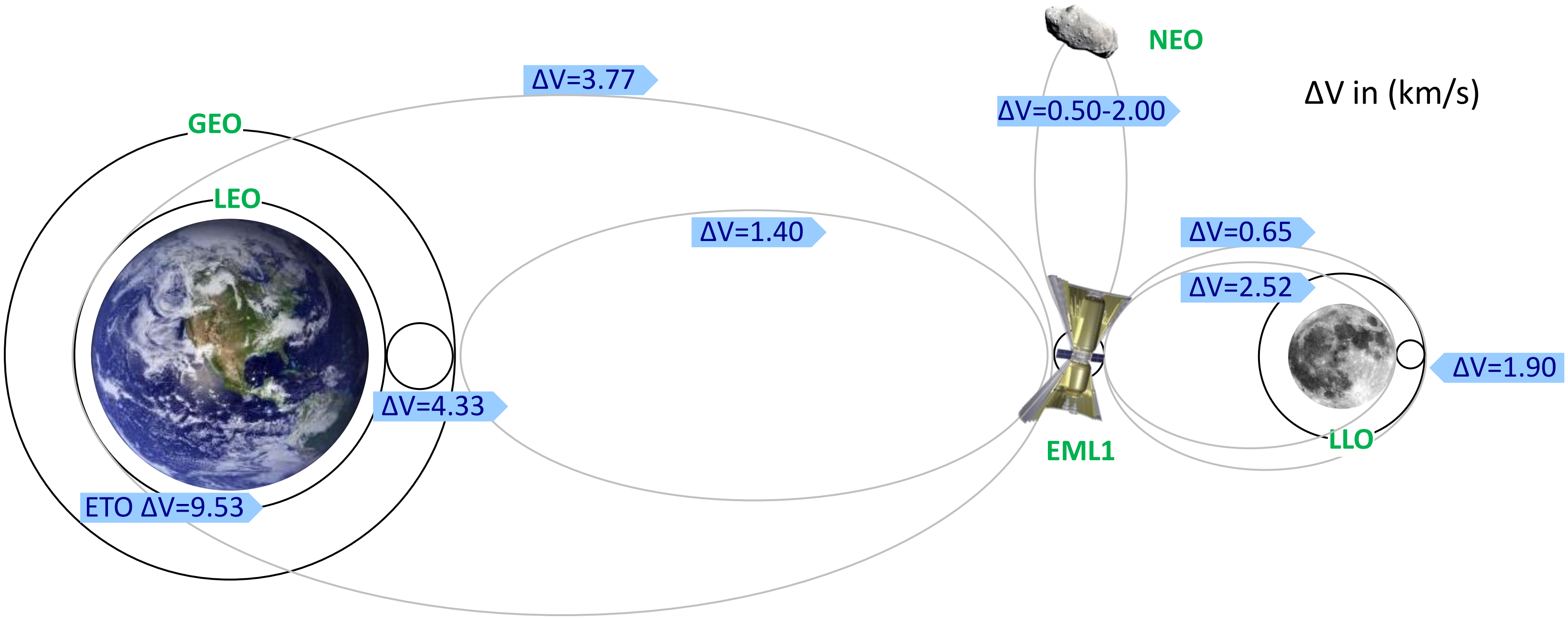


Shackleton Crater



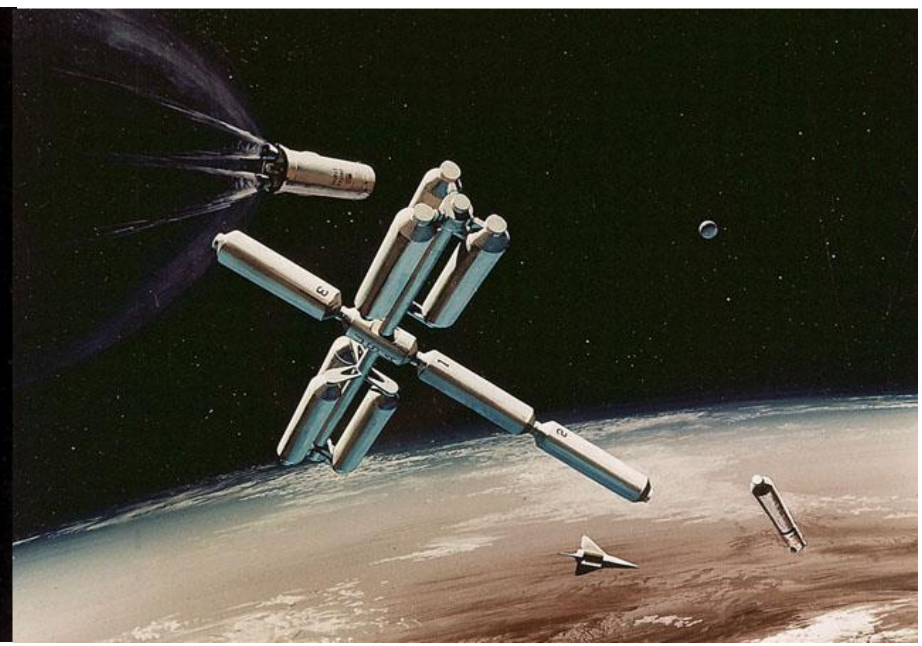
Transportation Refueling Nodes

- L1 Provides logical propellant staging node
  - Assessable from NEO's and lunar surface
  - Can distribute propellant to any Earth orbit
  - Good staging location for distant missions
- Lunar surface
  - Make propellant for ascent transportation



Historic On-Orbit Refueling Paradigm

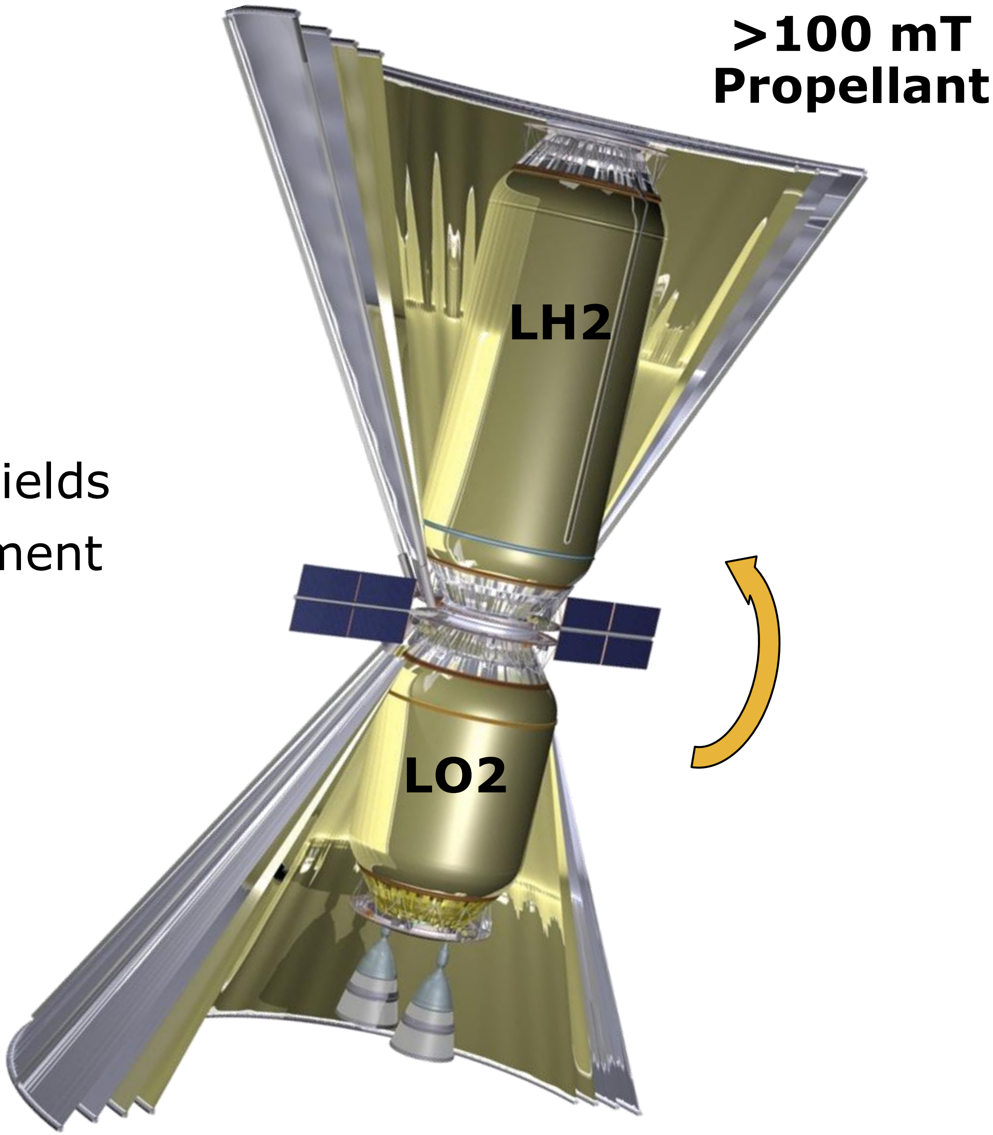
- On-orbit refueling is historically associated with:
  - Large scale, permanent propellant depots
  - Zero-G cryo fluid management
  - Zero Boil off Storage



Historic Refueling Architectures Present Insurmountable Barriers

Simple On-Orbit Refueling Node

- Produce LO2 & LH2
  - Electrolyze water
  - Liquefy GO2 and GH2
- Store LO2 and LH2
  - Thermally Isolate & Sun Shields
  - Settled propellant management
- Distribute LO2 & LH2
  - Pressure fed transfer
  - No-vent-fill

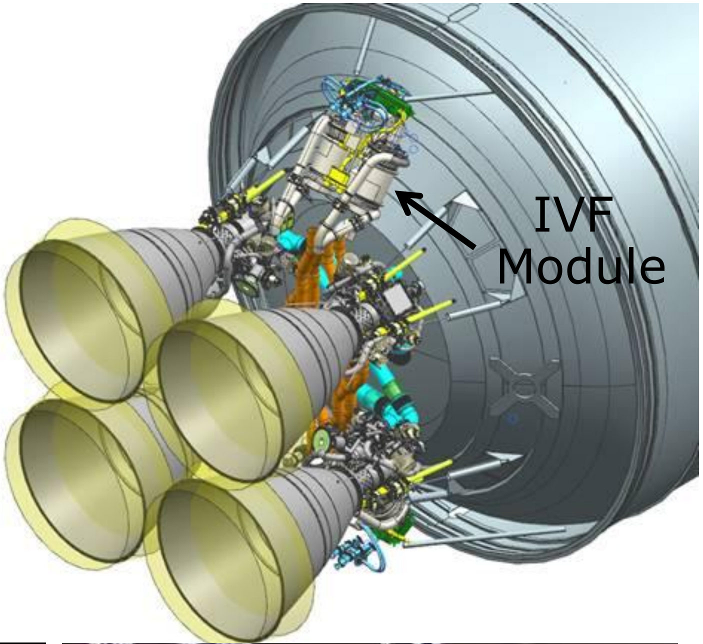


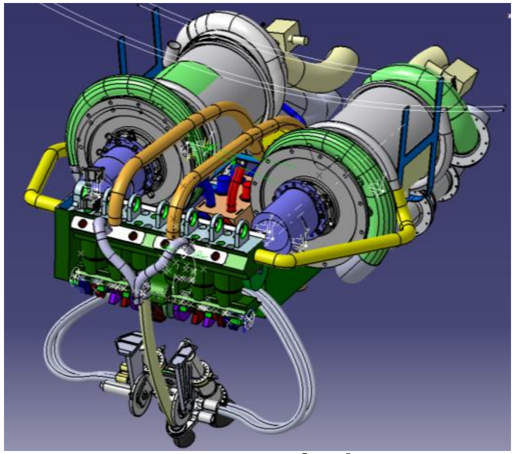
Single Launch Emplacement

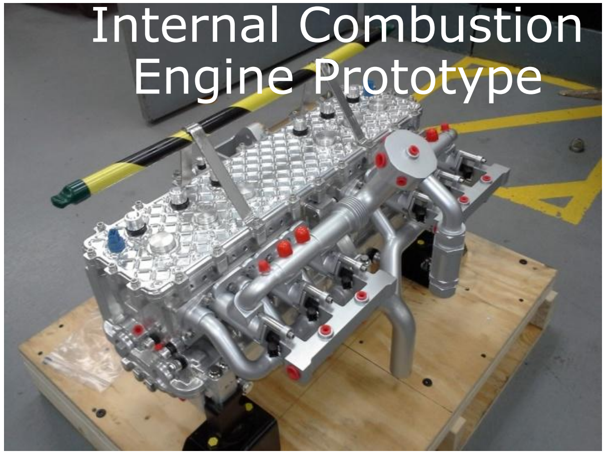
Transportation Enabling Technologies
Integrated Vehicle Fluids

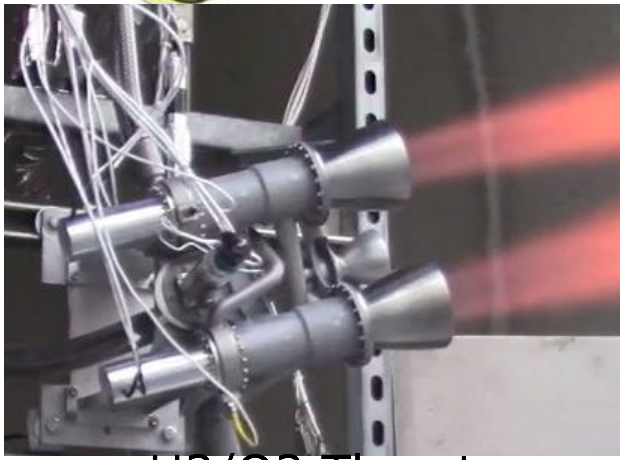
- Integrated Vehicle Fluids & Cryogenics
  - Power —> No Main batteries
  - Reaction control —> No Hydrazine
  - Pressurization —> No Helium

- Enables
  - Service Module Flexibility
  - On Orbit Refueling
  - Reusable ACES throughout cislunar space



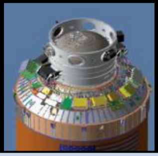
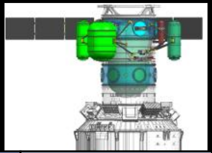

IVF Module


Internal Combustion Engine Prototype


H2/O2 Thrusters

On-Orbit Refueling Reduced to LO2 and LH2

Transportation Enabling Technologies: Cryo Fluid Management

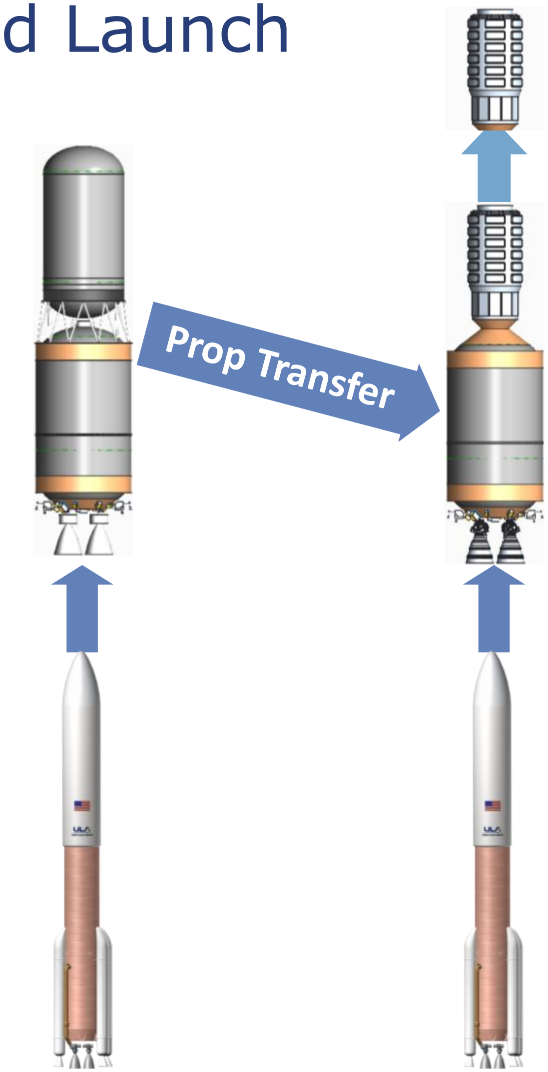



2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Initiate CRYOTE		CRYOTE 1 built		CRYOTE 1 LN2 Test		CRYOTE 3 Tank Delivery		CRYOTE 3 IVF Test	
	CRYOTE Light		CRYOTE Grande		CRYOTE No Vent Fill		CRYOTE 3 Cryo Test		CRYOTE 3 Long Duration



Distributed Launch

Vulcan	Earth Escape	GSO or Lunar Orbit	Lunar Surface
Delta HLV	11 mT	7.4 mT	-
Single Launch	14 mT	10 mT	3.8 mT
Distributed Launch	30 mT	24 mT	12 mT



Propellant Launch

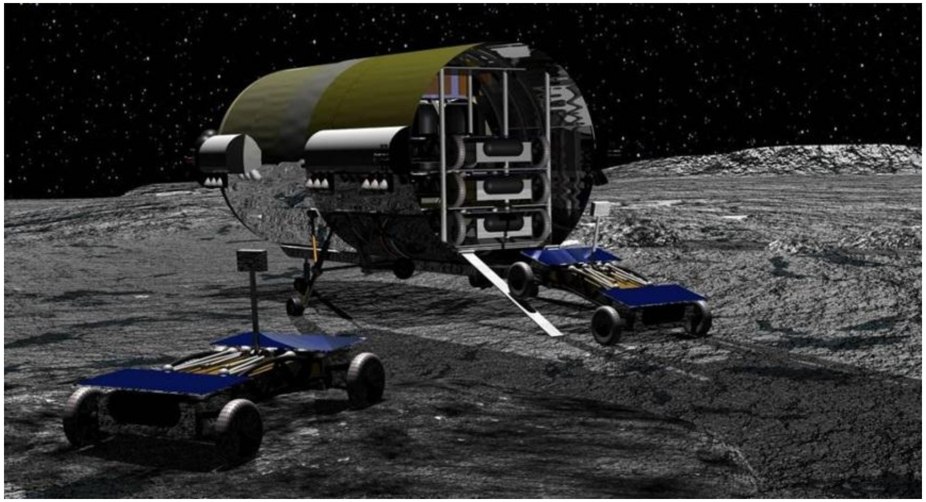
Payload Launch

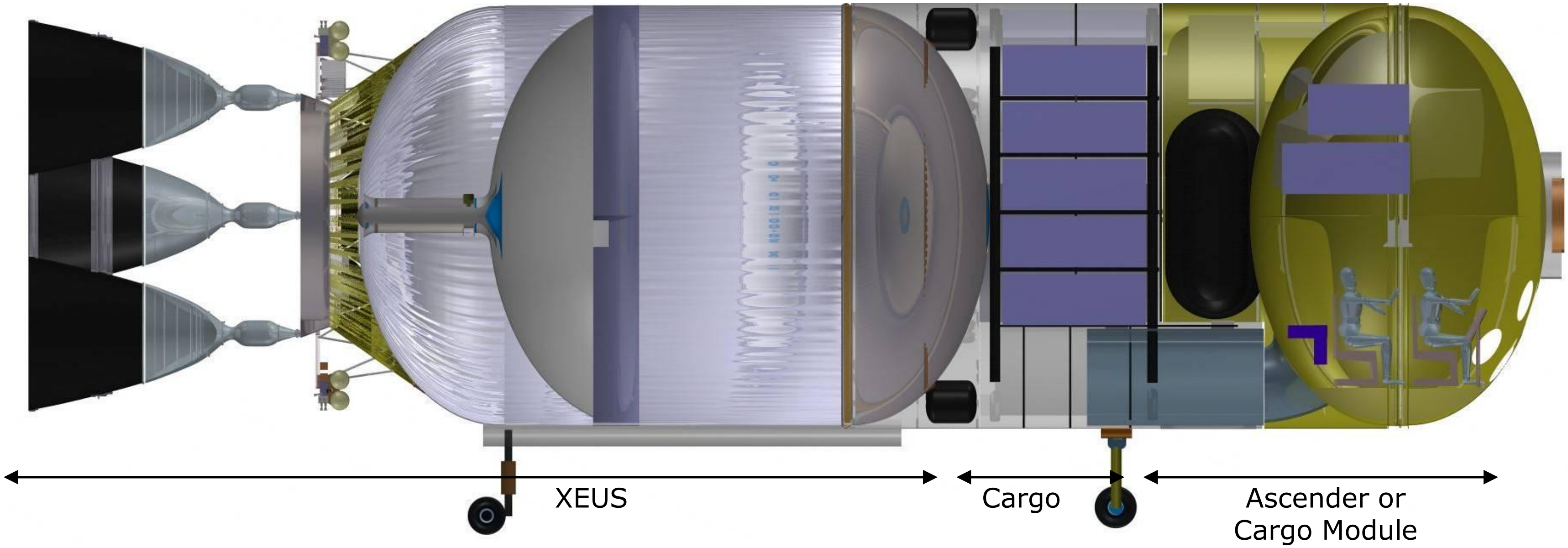
Initial Step to Upper Stage Reuse

ULA
United Launch Alliance

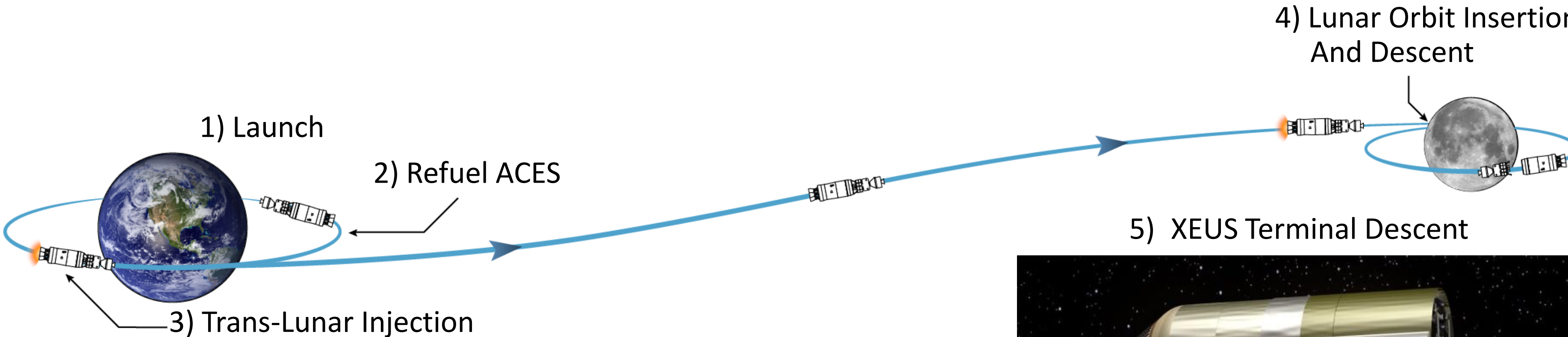
XEUS

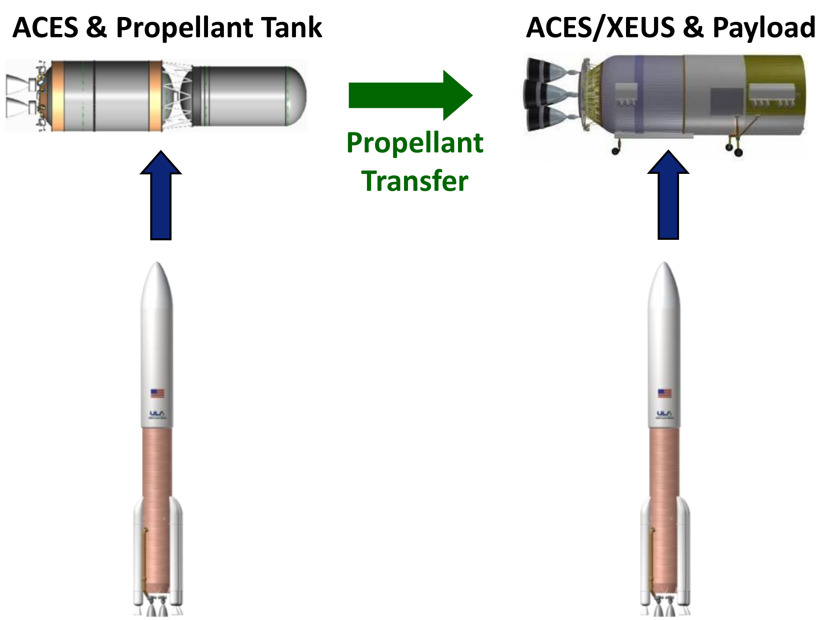
- ACES + Mission Kit
  - Electric LH2 & LO2 pumps
  - LH2/LO2 Thruster
  - Landing GN&C
  - Landing struts

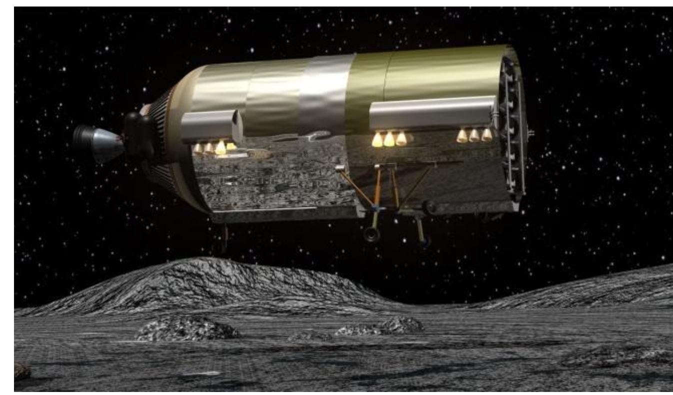




Lunar Surface Cargo Mission

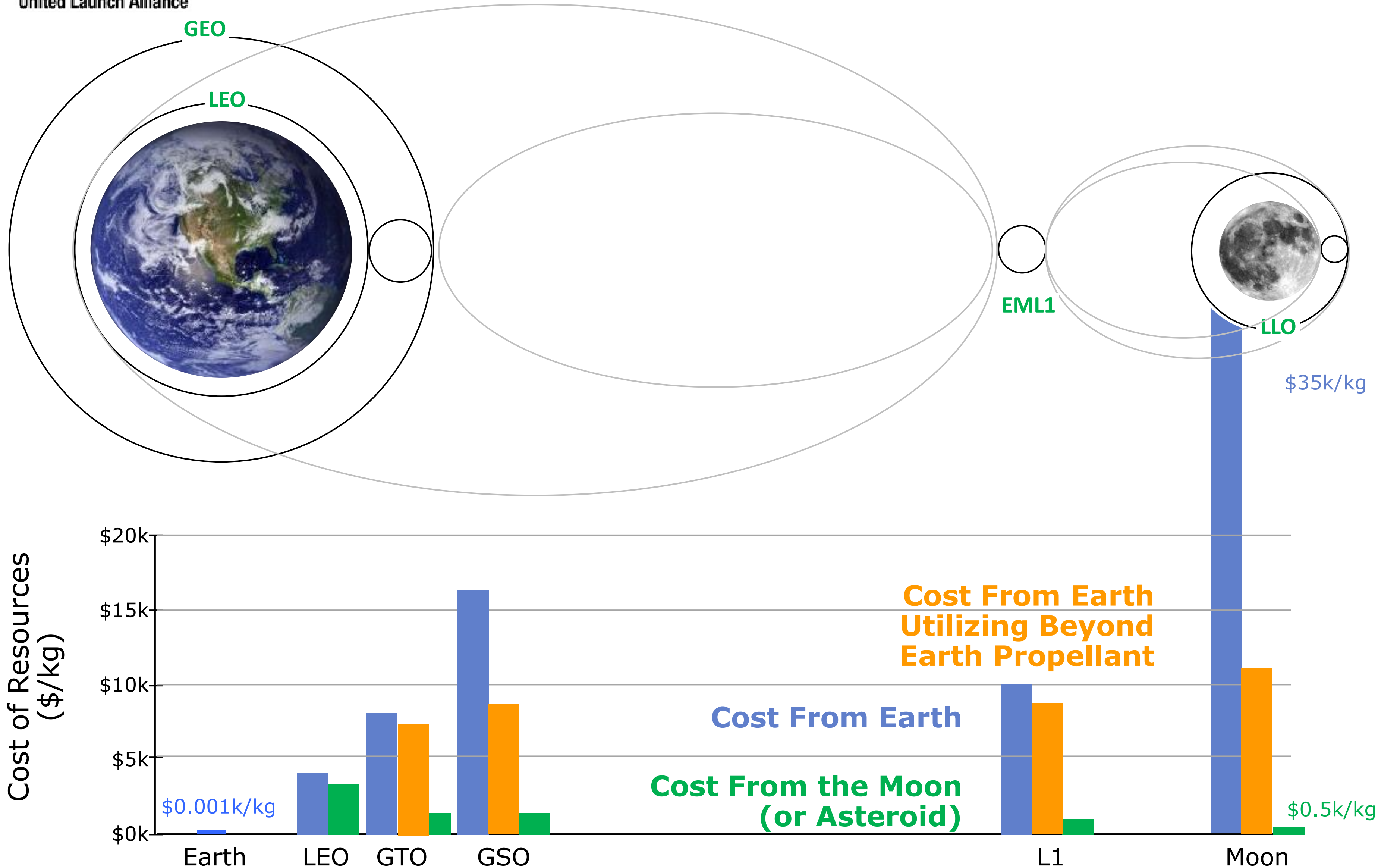






- Enables Large Scale Lunar Infrastructure
  - Science
  - Propellant production
  - Manufacturing
  - Habitation

Costs of Resource in Cislunar Space



Standing on the Threshold of Robust Cislunar Economy