America's Ride to Space

Transportation Architecture for Cislunar Space

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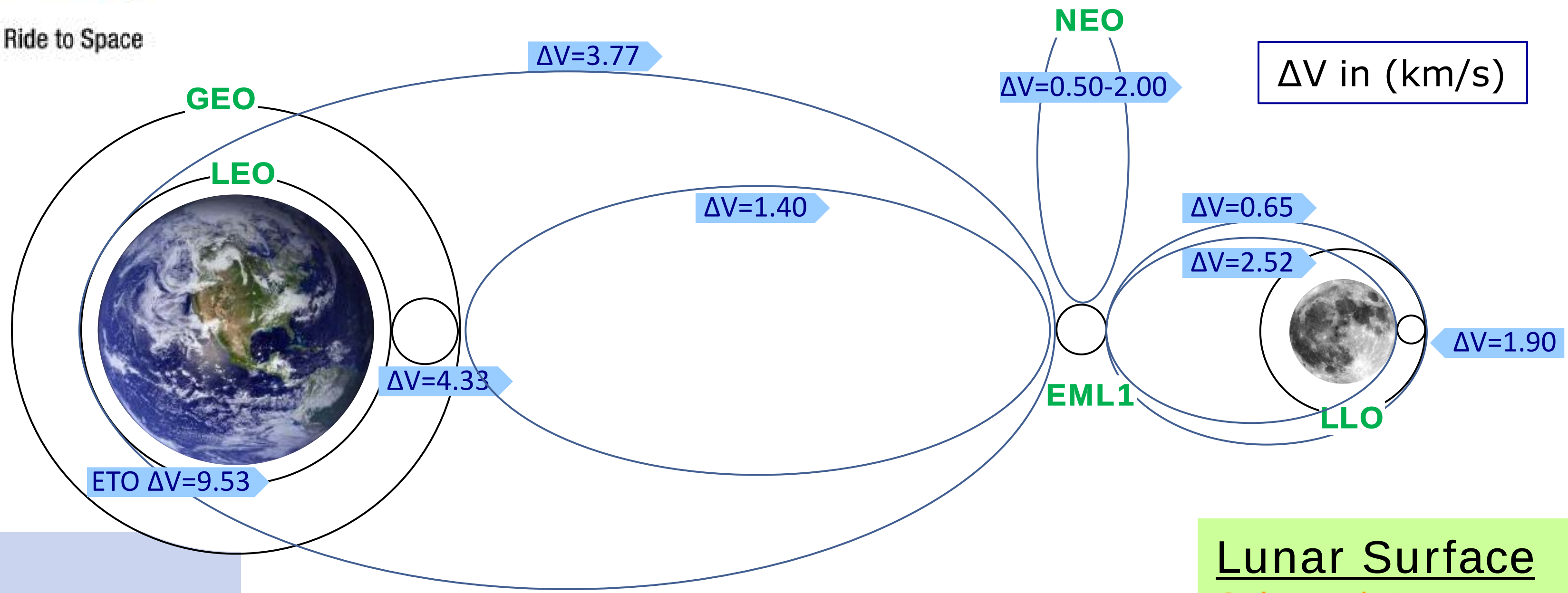
The Challenge

- The key to closing the business case for space solar power is dramatically lower transportation costs
  - Historical costs to GEO are $40,000/kg
  - Next generation launch vehicles may reduce cost to <$20,000/kg
  - Cost to launch 12,000mT solar power satellite from earth = $240B
- Reusable rockets not the answer
  - Limited savings possible
- Launch rate helps, but is it enough?

But… a self sustaining economy in cislunar space can reduce transportation cost by orders of magnitude

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
Comm 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

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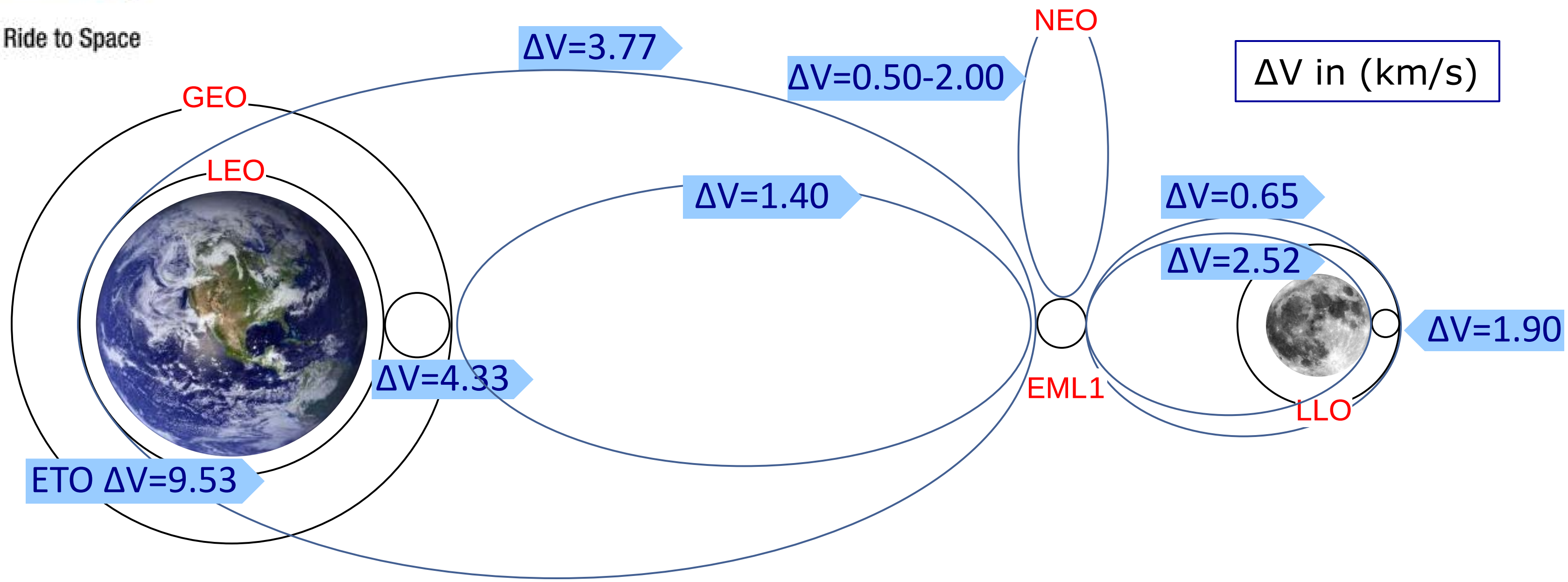
Cislunar Econosphere



	Δ V	Δ V^2
Earth to GEO	13.9 km/s	192 $(km/s)^2$
Moon to GEO	3.92 km/s	15.3 $(km/s)^2$
Earth to L1	13.3 km/s	177 $(km/s)^2$
Moon to L1	2.52 km/s	6.4 $(km/s)^2$

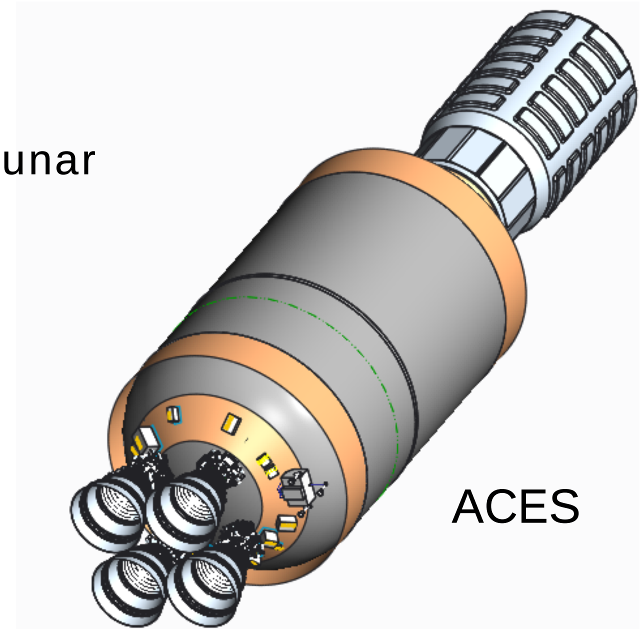
Getting to GEO takes 8% the energy from the Moon as from Earth
Getting to L1 takes 3.6% the energy from the Moon as from Earth

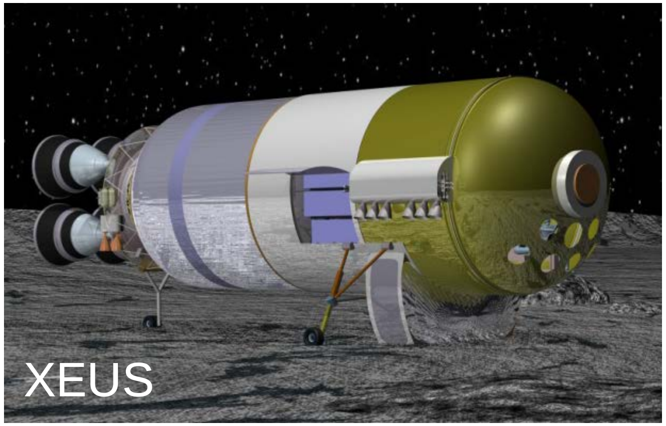
America's Ride to Space

Transportation System

- Based on LO2/LH2
  - High energy, well understood, available on lunar surface & asteroids

- Transportation Infrastructure
  - Lunar Surface
    - Propellant extraction & refining
    - Propellant storage & transfer
  - NEO/Asteroid
    - Propellant extraction
  - EML1/2
    - Propellant storage & transfer
  - LEO
    - Propellant storage & transfer (uphill only)

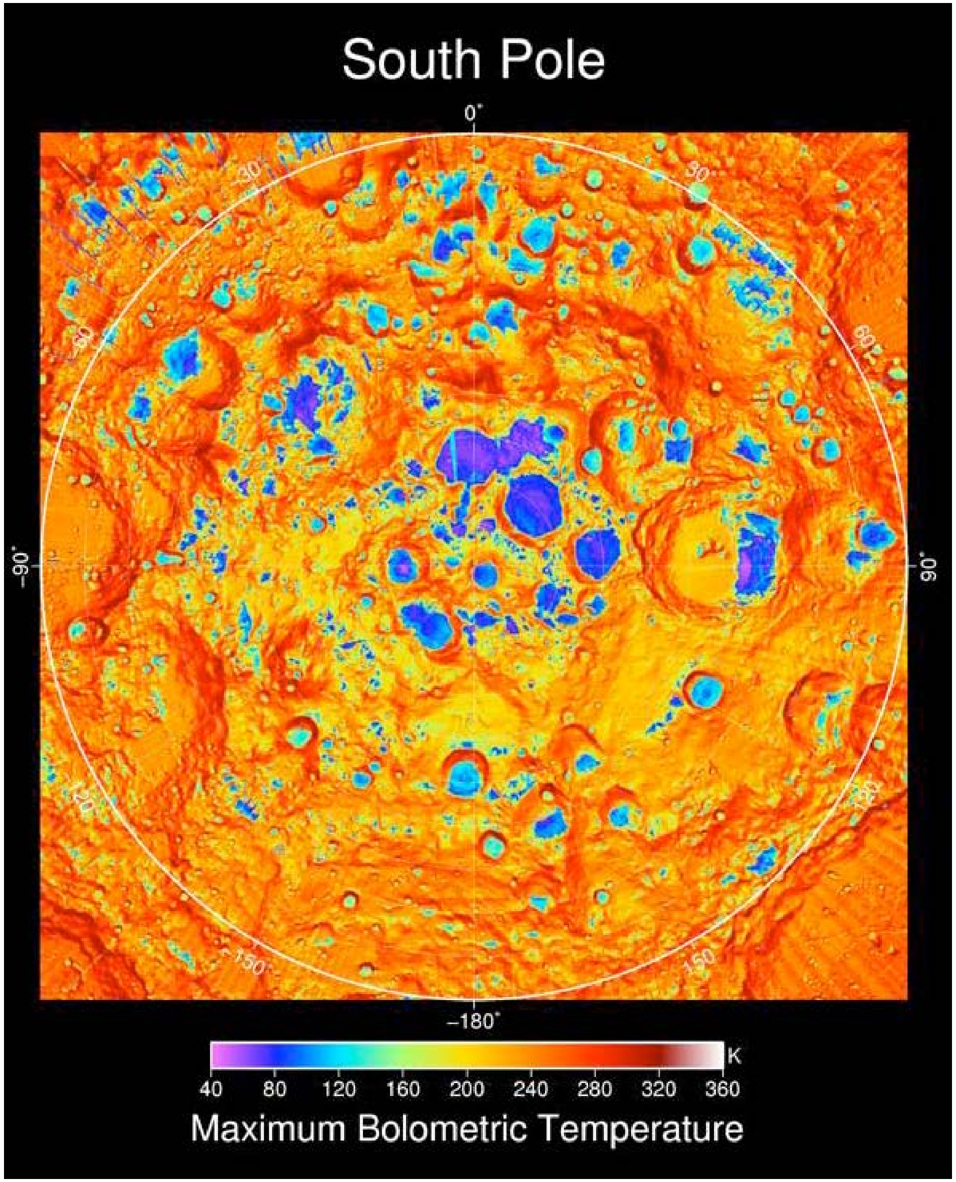




- Transportation elements
  - Currently in development
  - ACES: ELM1/2 to GEO & NEO/Asteroid
  - XEUS: Lunar surface to EML1/2

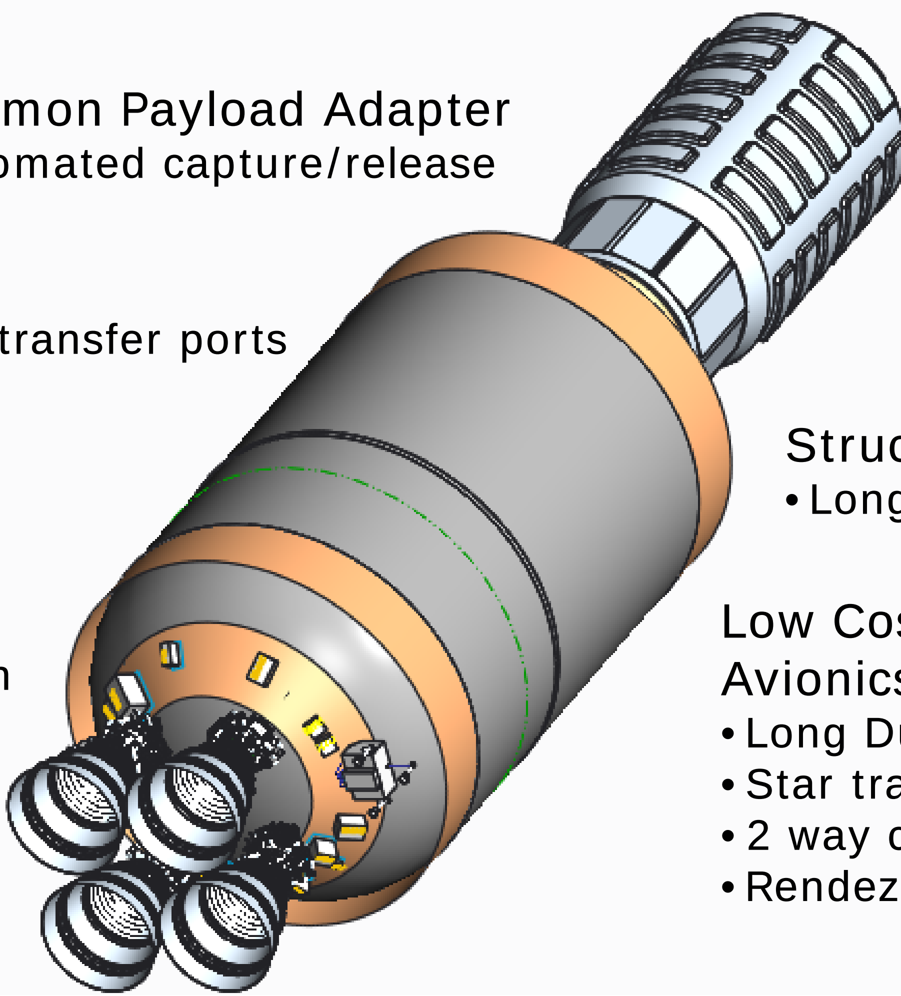
Lunar Propellant Mining

- Substantial water near the lunar poles
  - Hidden in cold traps in craters near the poles
  - ~600M mT per pole
- Provides fuel for ACES/XEUS



ULA America's Ride to Space

Reusable ACES Enabling Technologies



Common Payload Adapter
- Automated capture/release

Refuelable
- LO2 & LH2 transfer ports

Integrated Vehicle Fluids
- Power
- Pressurization
- RCS with translation

Low Cost Propulsion
- RL10C+, XCOR 8H21, BE3U
- Robust, long lived

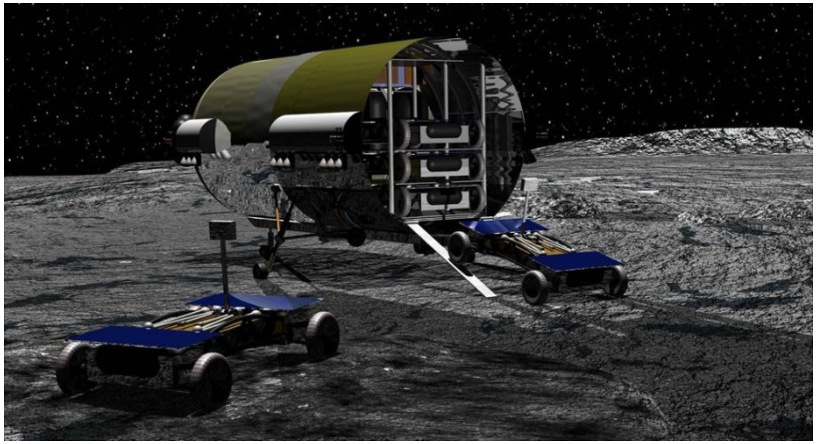
Structural MLI
- Long Duration

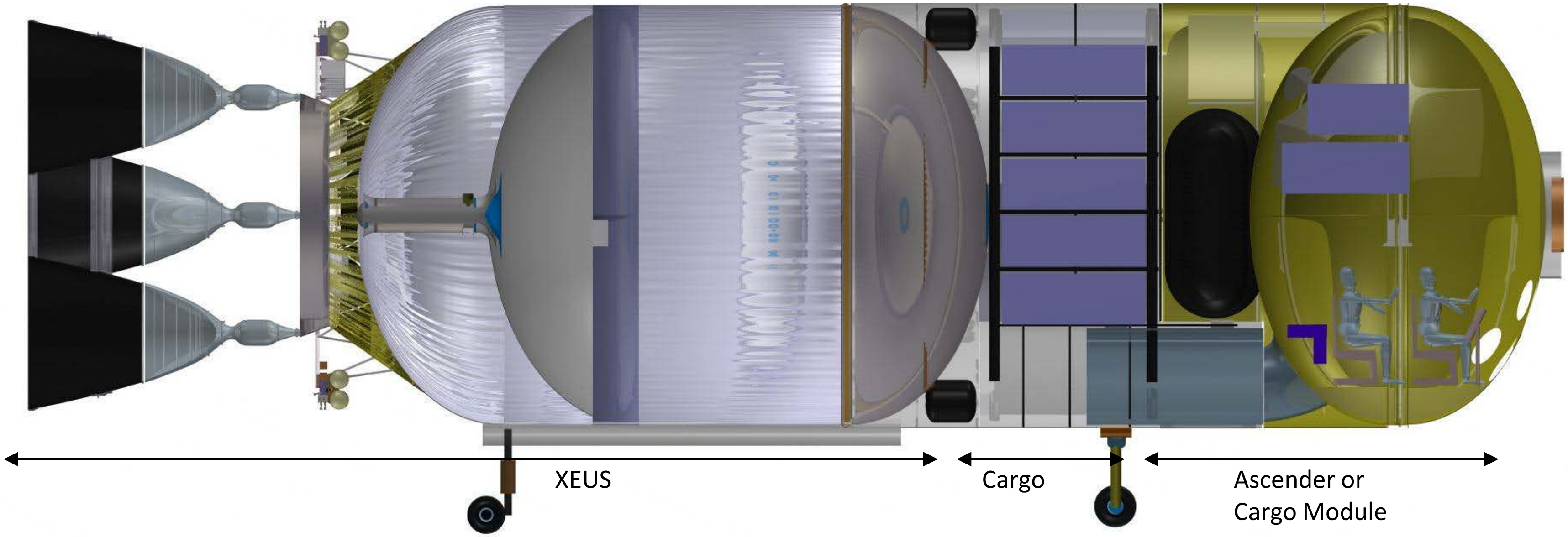
Low Cost Advanced Avionics
- Long Duration
- Star tracker
- 2 way com
- Rendezvous

ACES: Fully reusable, high performance space truck

XEUS

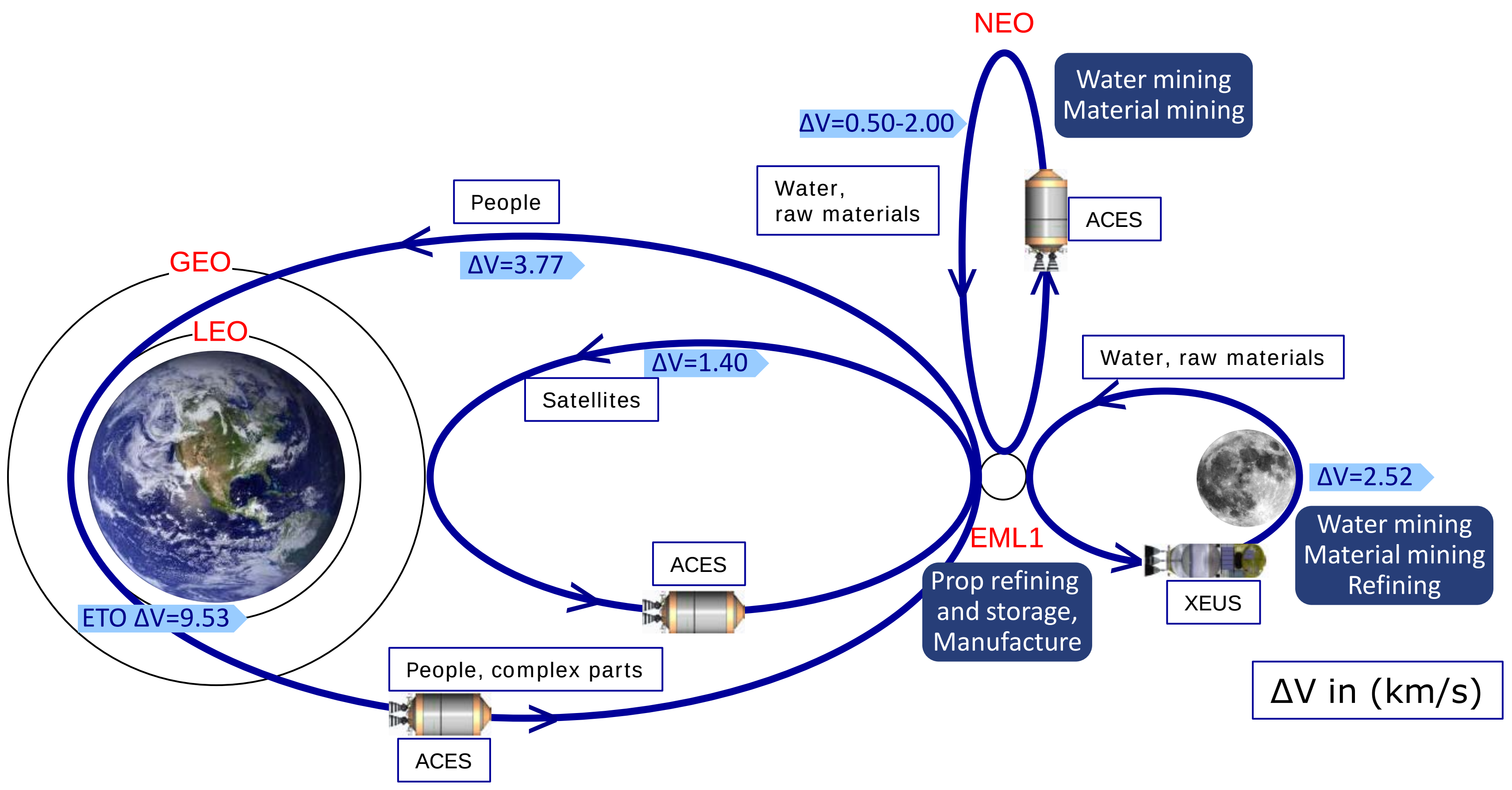
- Lunar surface missions
  - Prospecting, mining, manufacturing, science
- ACES Mission Kit:
  - Electric LH2 & LO2 pumps
  - LH2/LO2 Thrusters
  - Landing GN&C & Landing struts





XEUS: Fully reusable, 2 way surface transportation

Trade Routes



Space-based Solar Power (SSP) Business Case

- Scenario
  - Mine raw material on lunar surface
  - XEUS transfer to EML1
  - Manufacture Solar Power Satellite Components at EML1
  - ACES transfer from EML1 to GEO
  - Satellite assembly in GEO

- Business case assumptions
  - Solar power satellite mass (if manufactured in space)
    = 1/2 Solar power satellite mass (if launched from Earth)
  - 10% additional material delivered from lunar surface to EML1
  - ACES and XEUS HW are free
    - Used initially to deliver goods/people to L1 or lunar surface
    - Nearly unlimited reuses
  - $2M operations cost for each ACES/XEUS trip
  - Cost of propellant on moon same as on earth
    - LH2: $5.94/kg
    - LO2: $0.09/kg

SSP Business Case, Cont'd

- Analysis
  - ACES can deliver 160mT from EML1 to GEO and return to EML1
  - XEUS can deliver 70mT of propellant (a full ACES load) or raw materials from lunar surface to EML1 and return
  - **Total transportation cost for 6000mT satellite = $350M**
    - Includes cost to transport raw materials to L1 and finished goods to GEO

- Open questions
  - Cost & feasibility to mine ice (propellants) on lunar surface or NEO
  - Cost and feasibility to mine SSP raw materials on lunar surface or NEO
  - Cost and feasibility to manufacture SSP satellites in space

Transportation cost to GEO reduced by factor of 680