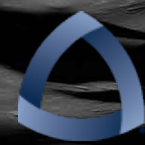




# Mining Ice on the Moon

George Sowers

October 2019

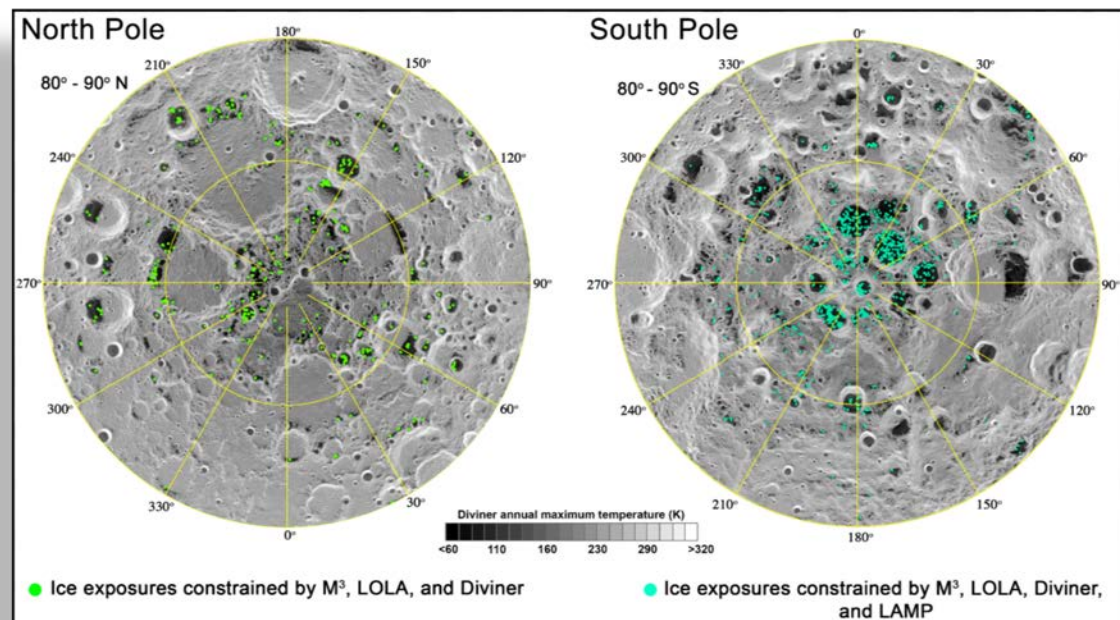


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# Lunar Propellant Production

- Mounting evidence for water ice near the lunar poles
- Water is critical for sustainable exploration & development of Space
  - Essential for all life; oxygen for breathing air; radiation shielding
  - Water based propulsion
  - **LO<sub>2</sub>/LH<sub>2</sub> rocket propellant**

Surface ice indications of up to 30wt%

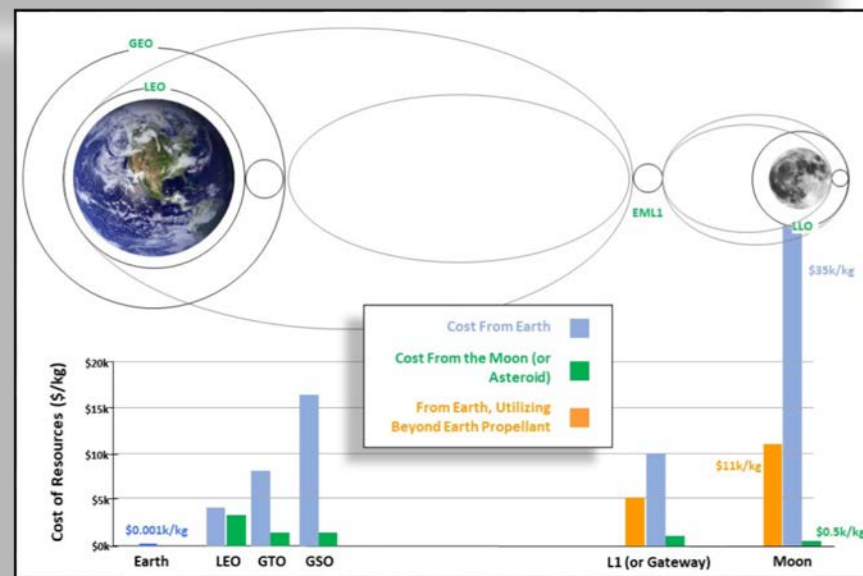
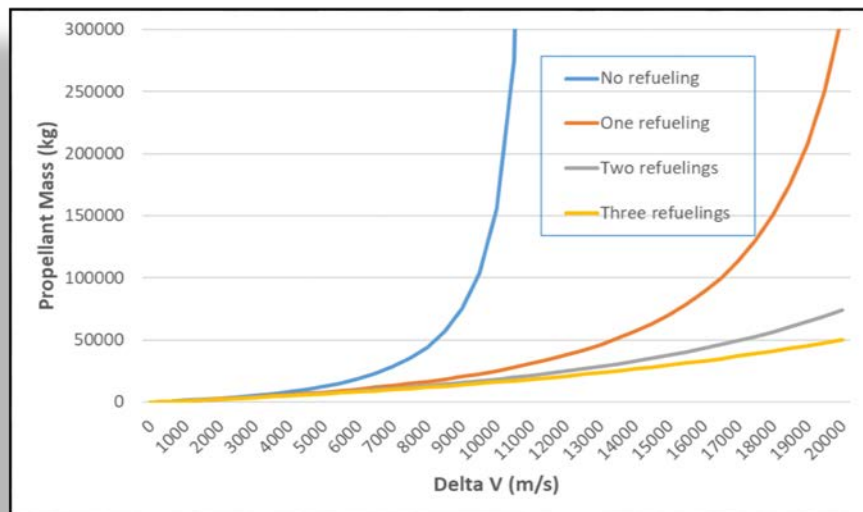


Li, S, Lucey, P.G., Milliken, R.E., Hayne, P.O., Fisher, E., Williams, J.P., Hurley, D.M., Elphic, R.C., Direct evidence of surface exposed water ice in the lunar polar regions. PNAS (2018).  
<https://doi.org/10.1073/pnas.1802345115>

Space Sourced Propellant Changes Everything

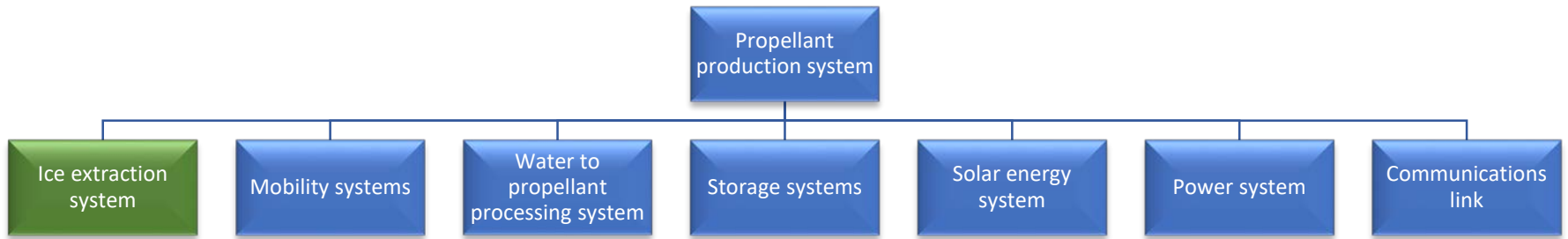
# Physics and Economics

- **All** beyond LEO missions benefit from lunar propellant (via refueling)
  - NASA
  - Military
  - Commercial
  - International
- Eventual transition to water based propulsion (steam, plasma,  $\text{LO}_2/\text{LH}_2$ )
  - Upper stages
  - Satellites
  - In-space stages



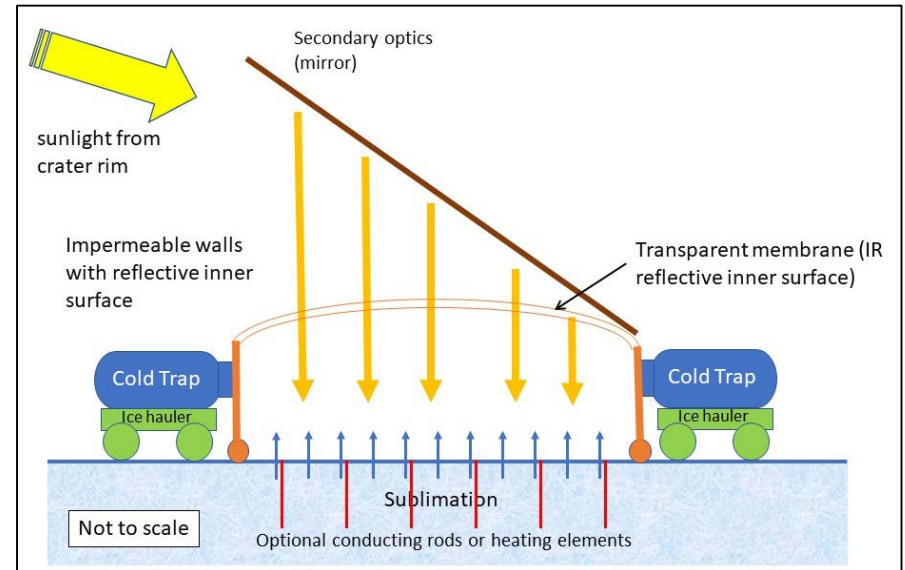


# Propellant Production System Elements

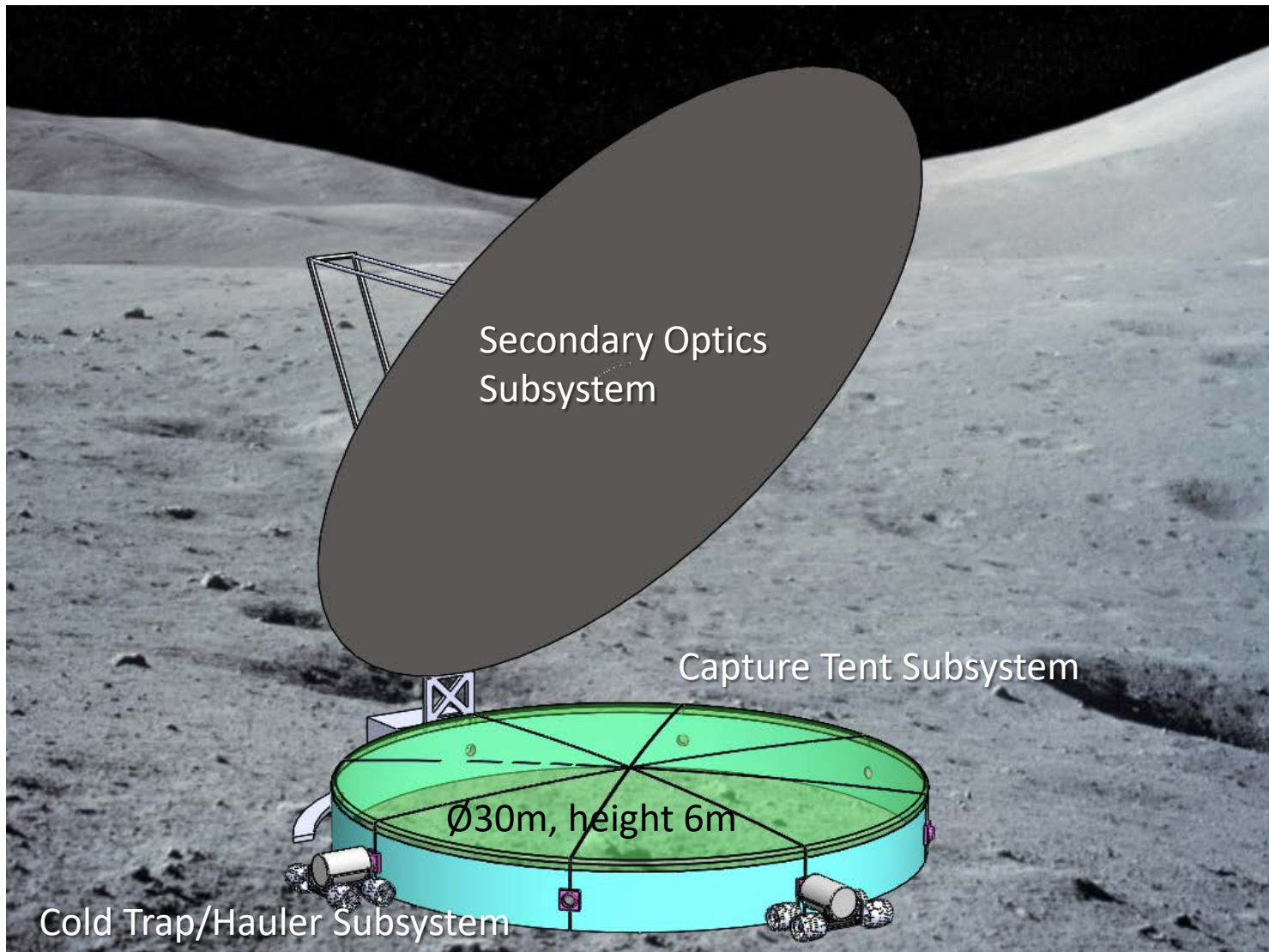


# Ice Extraction Options

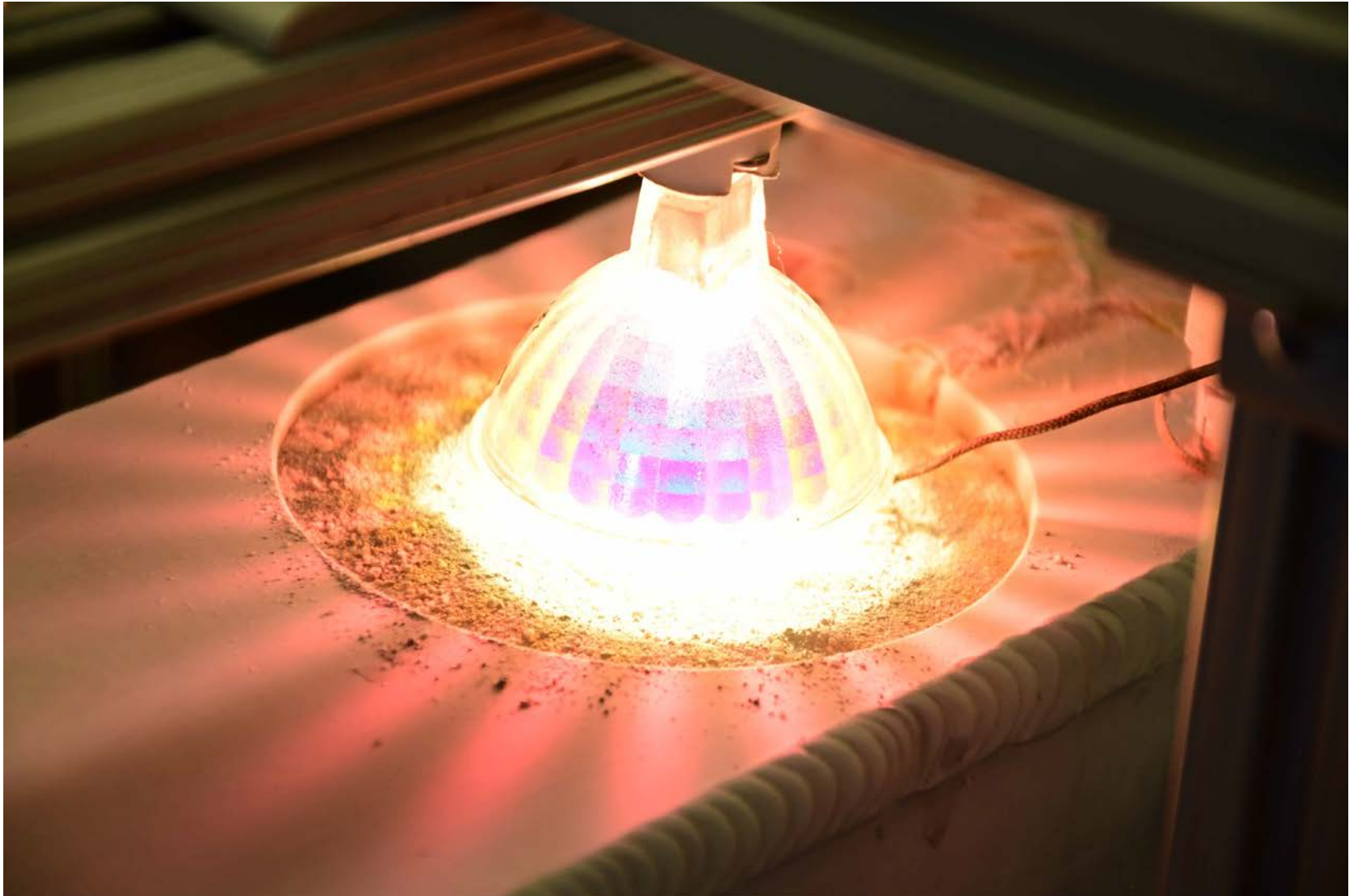
- Direct surface heating
  - Sunlight
  - Microwaves
- Subsurface heating
  - In conjunction with surface heating
  - Conducting rods/straws
  - Heating elements
- Excavation
  - Material heated in oven



# Surface Heating System



# Surface Heating of Icy Regolith Simulant

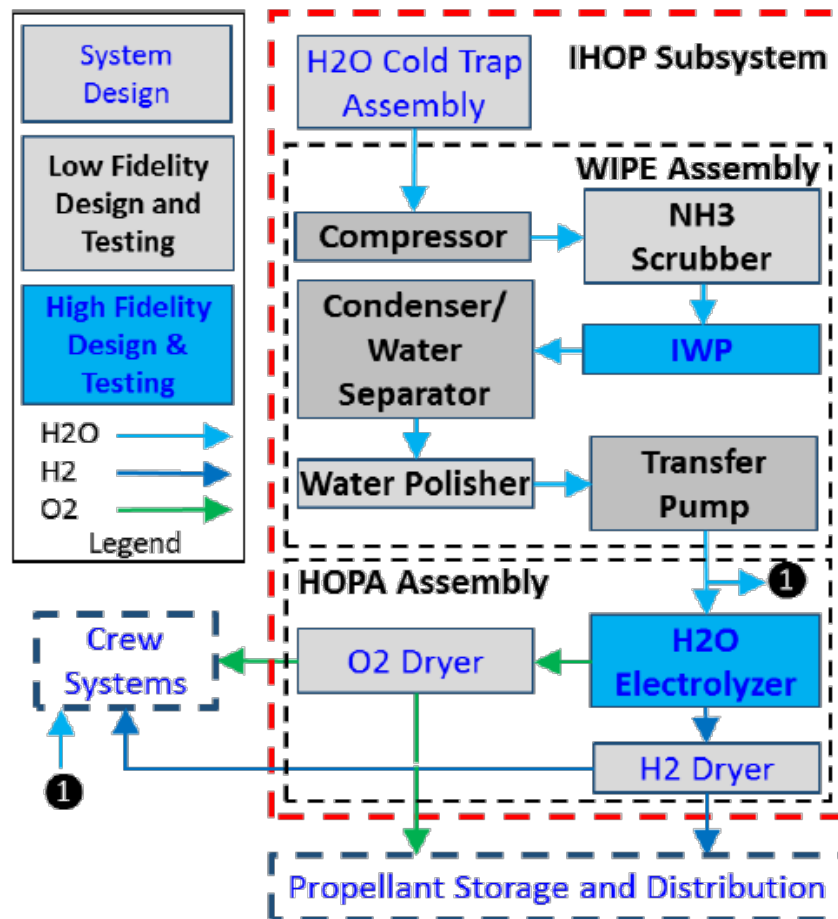




# Other Elements

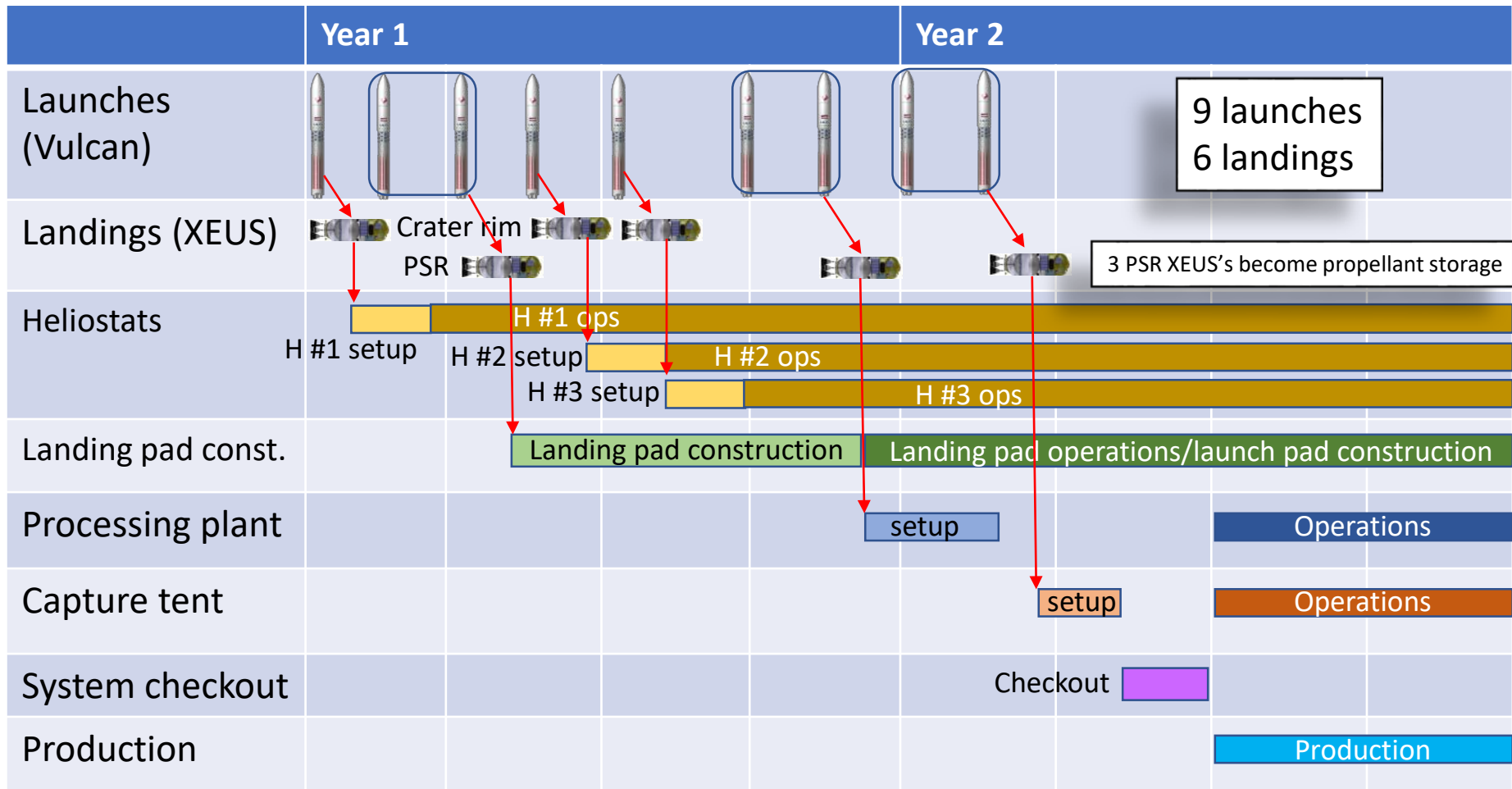
- **Mobility Systems**
  - General purpose robotic vehicle(s) for assembly maintenance, and emplacing optional conducting rods/heating elements
  - Haulers for ice and relocating ice extraction system
- **Propellant processing**
  - Purification, electrolysis and liquefaction
- **Propellant storage**
  - Assumed to be provided by spent landers used for deployment

Propellant Processing System Schematic





# Deployment & Setup Timeline



18 month timeline: 1<sup>st</sup> launch to production

# Summary/Conclusions

- The Moon is rich in water ice resources
- Low cost methods are in development to extract economically useful quantities of ice
- A propellant production architecture for lunar ice mining and propellant production has been defined
- Lunar propellant will dramatically lower the cost of space exploration and underpin the growth of the cislunar economy

Overarching Goal is Industrial Scale Propellant  
Production in 10 Years