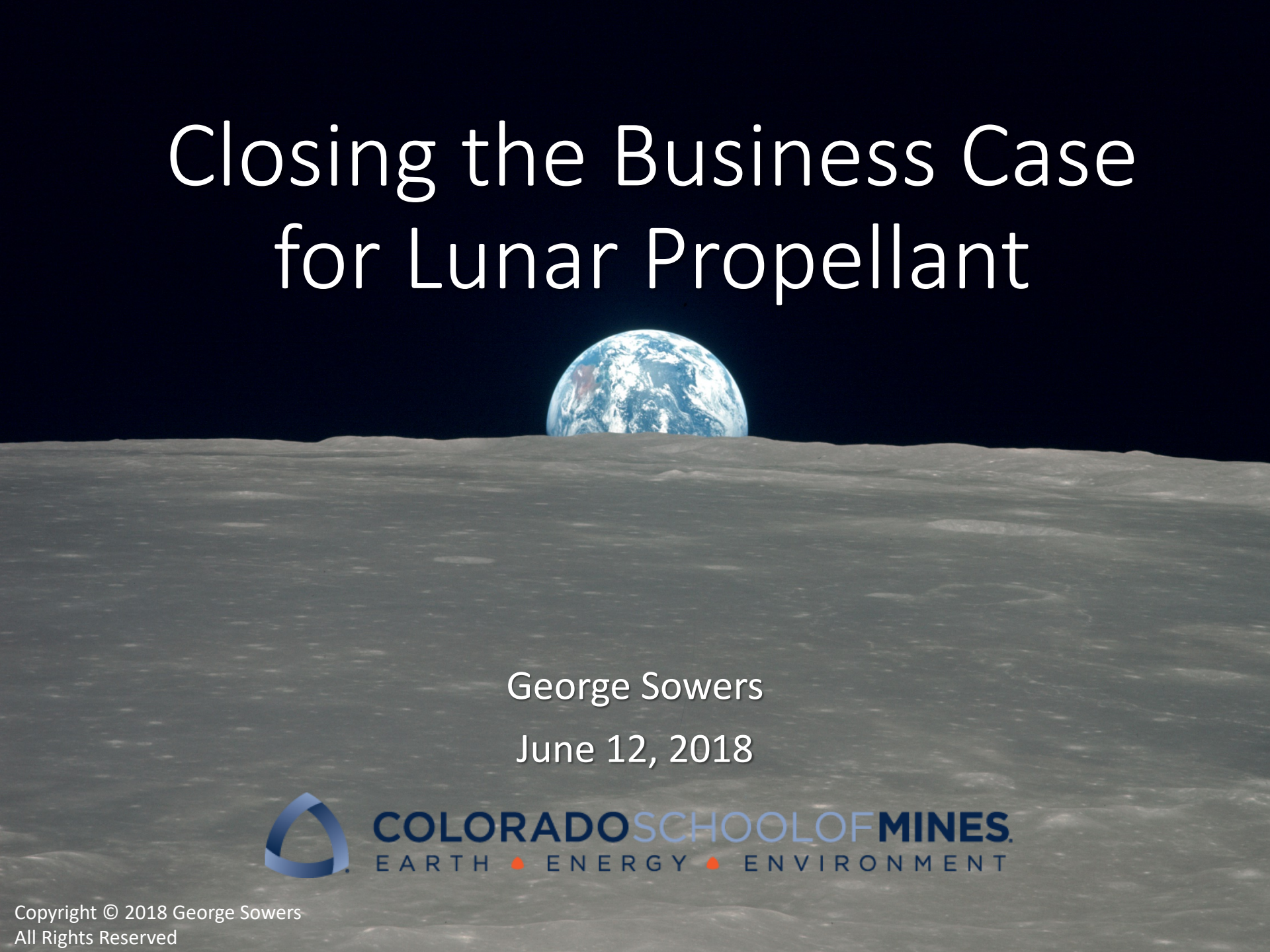
Closing the Business Case for Lunar Propellant



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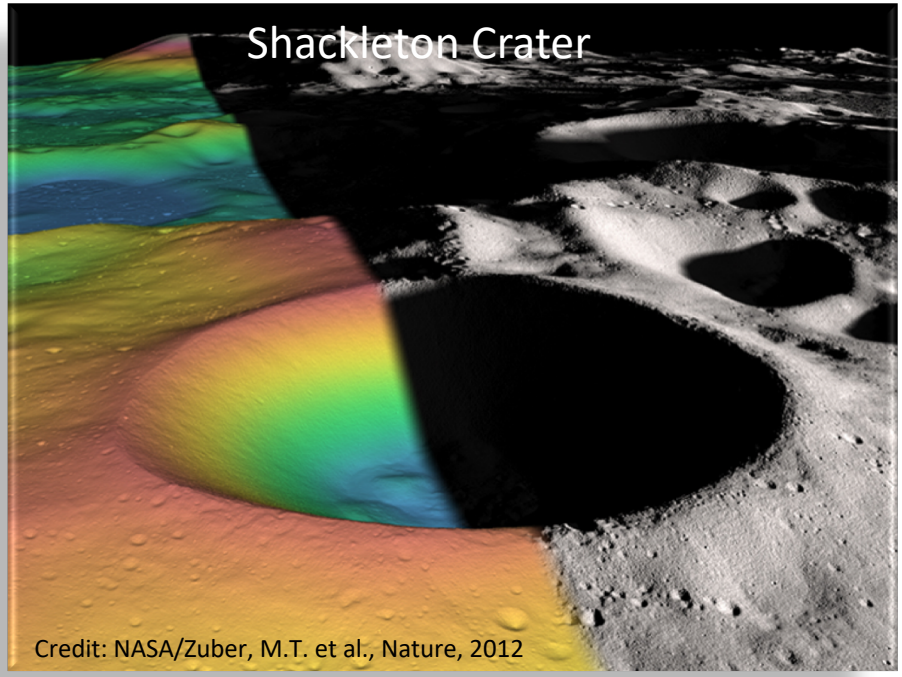
Space-sourced Propellant

- One of the first economically viable uses of space resources will be propellant from water
  - Water is ubiquitous in the inner solar system
  - Water can be electrolyzed into Hydrogen and Oxygen, then liquified into LO2/LH2 propellants
- Use of lunar or asteroid sourced propellant can:
  - Reduce the cost to transport a satellite to GEO
  - Reduce to the cost to launch to the lunar surface by 3X
  - Reduce the cost of a Mars mission by 2-3X
  - Enable a very low cost in-space transportation system



We believe water ice exists in the permanently shadowed regions near the lunar poles

Propellant Business Case

- In 2016, United Launch Alliance (ULA) developed a business case for purchasing LO2/LH2 propellant in cislunar space
  - Based entirely on lowering the cost to launch satellites to GEO
- ULA set prices at various points in cislunar space based on the cost to transport propellant from the point of origin to the point of use (sale)
- To close this business case, **1100 mT** of propellant must be produced on the Moon for **$500/kg** or less

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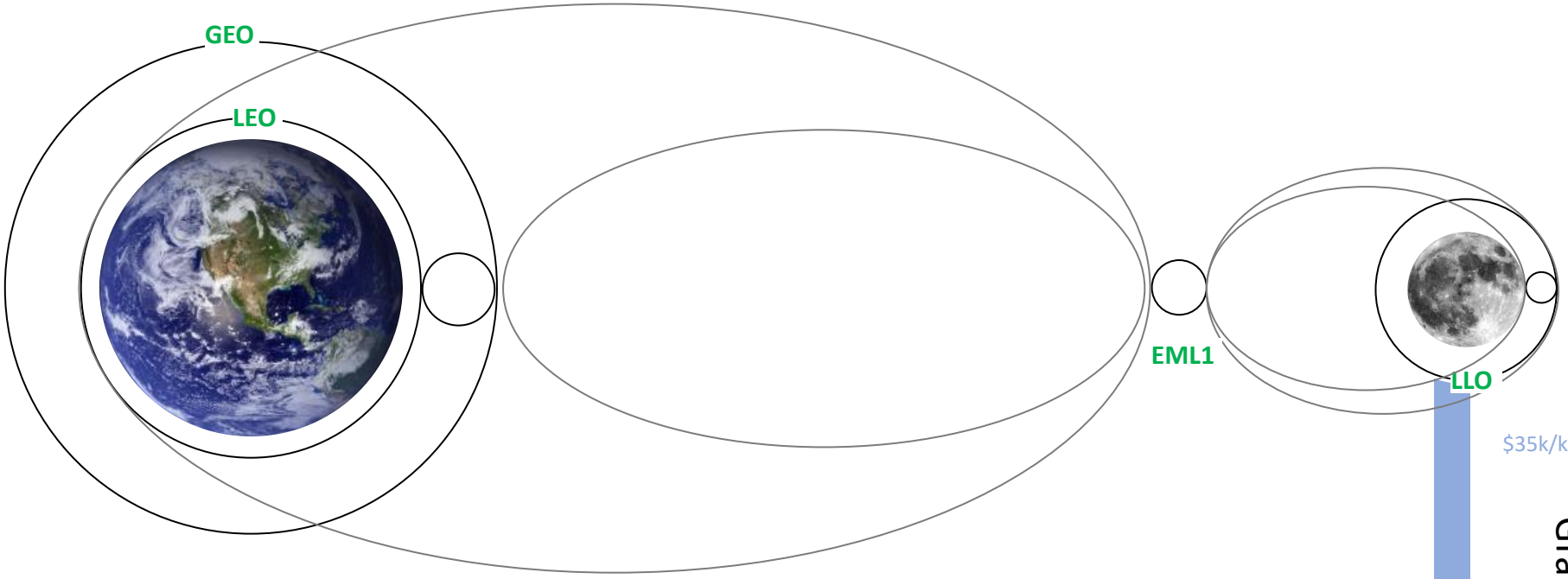
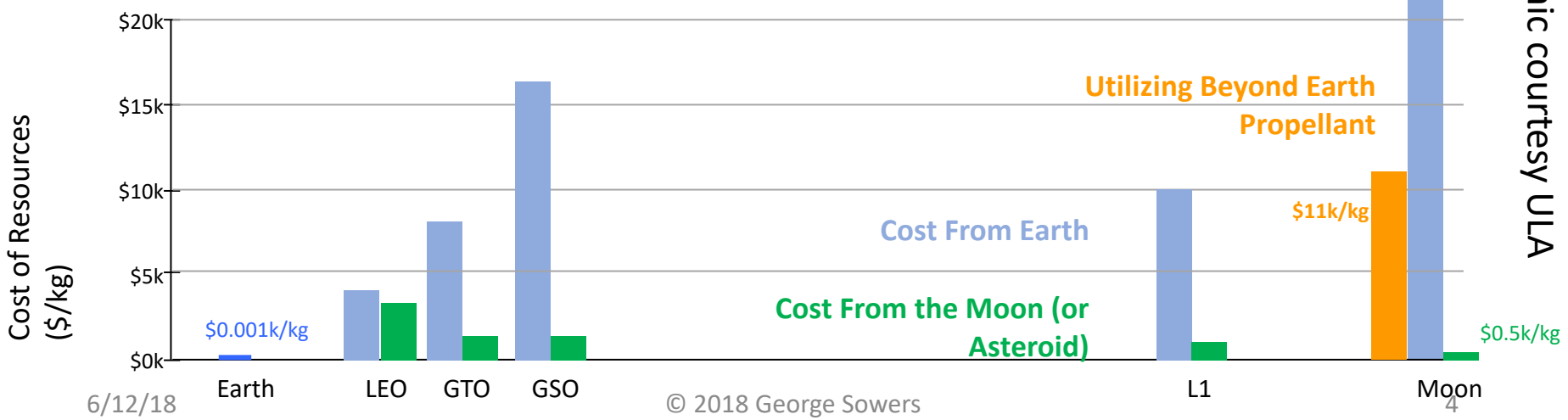
Costs of Propellant in Cislunar Space





Graphic courtesy ULA

Lunar Mining

- Colorado School of Mines lunar propellant mining architecture study (2017) showed that meeting both the price and quantity requirements is **feasible**:

Parameter	Requirement	Thermal Mining
Mass (kg)	40,500 kg	29,000 kg
Development cost ($)	$3.5B	$2.5B
Production rate	1100 mT/yr	1100 mT/yr
Availability/ Maintainability	10 year life	High
Risk		Medium

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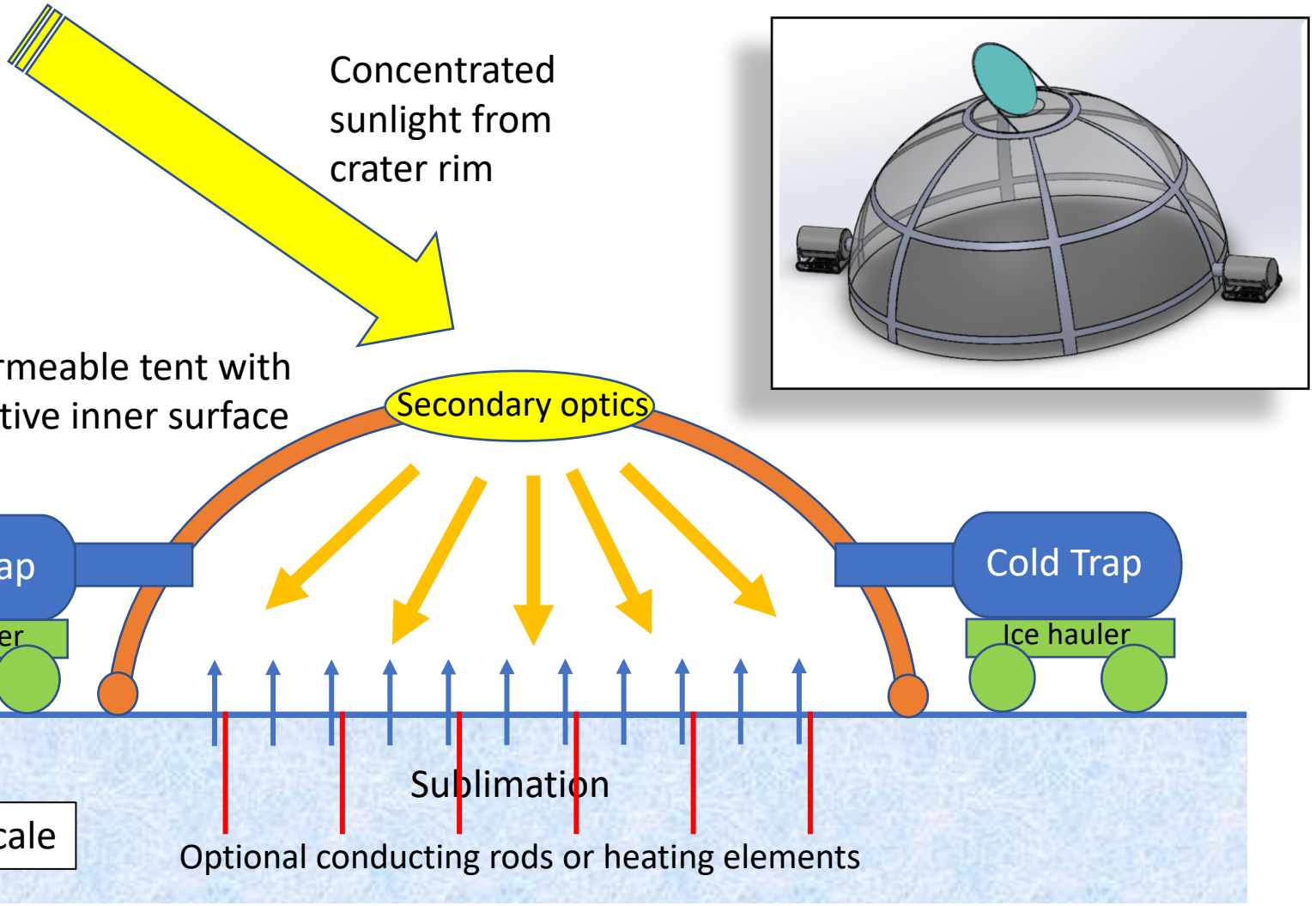
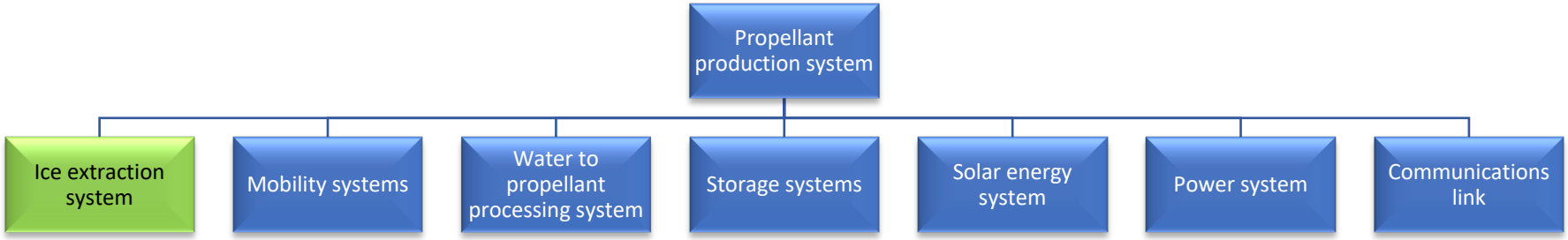
Lunar Propellant Mine Overview

Credit: ULA

Capture Tent Concept



First Level Product Tree

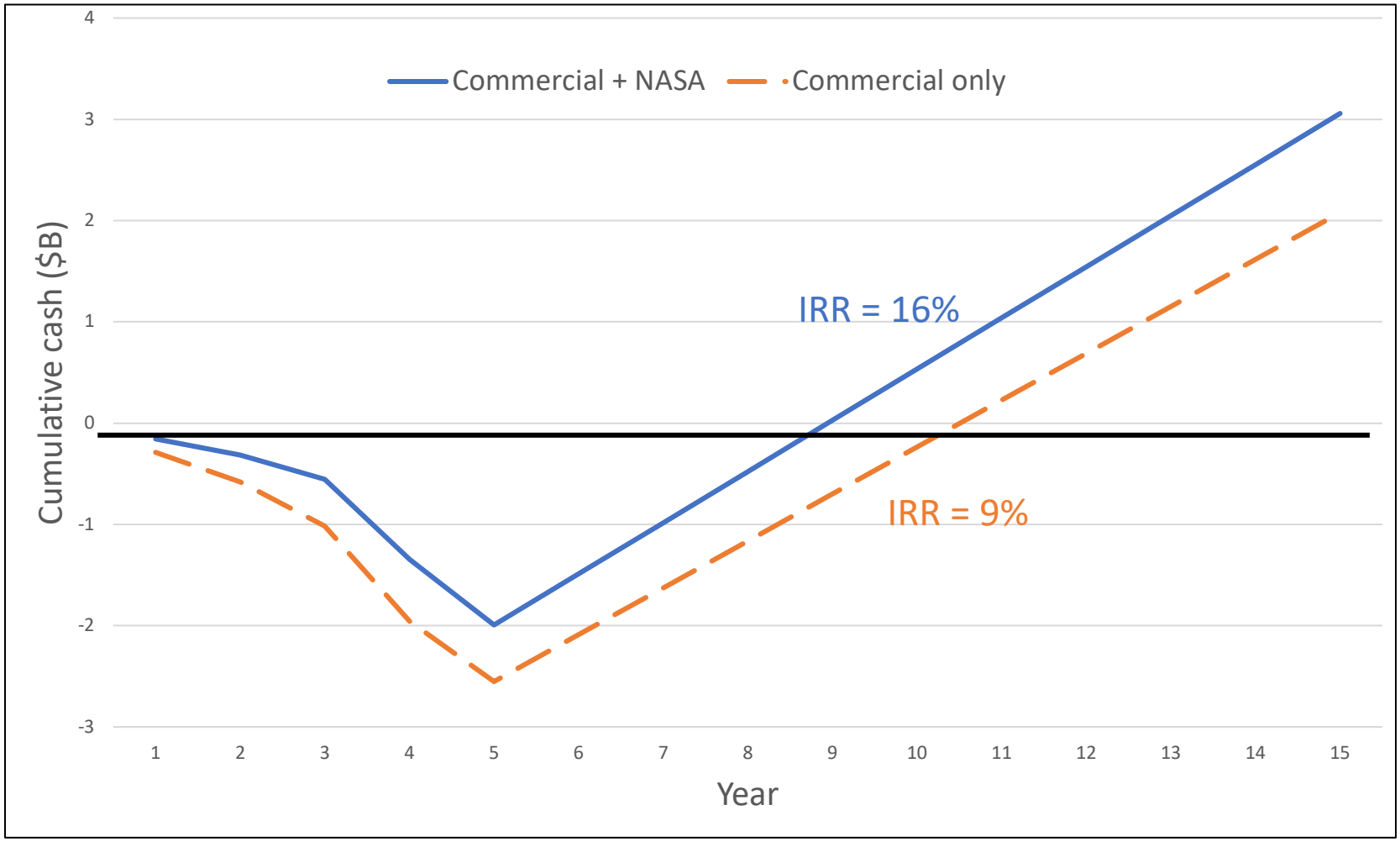


- The trade study focus was on concepts to extract ice from the regolith (in green)
- Other elements were assumed nearly common (in blue)
  - Common concept developed
  - Mass and power requirements were estimated
  - Differences in power consumption due to different ice extraction methods were captured

Business Case Analysis

Parameter	Commercial Only	Commercial + NASA
Propellant production rate	1100 mT/yr	1200 mT/yr
Price (on Moon)	$500/kg	$500/kg
HW Development & production cost	$1.5B	$1.6B
Transportation cost	$1.0B	$1.1B
Annual ops & maintenance cost	$87M/yr	$95M/yr
Annual revenue	$550M/yr	$600M/yr
NASA cost share	$0M	$800M
IRR	9%	16%

Mining Company Cash Flow



NASA Benefit

- NASA identified a need for LO2/LH2 propellants on the surface of the Moon
  - 100 mT/yr for lander ascent (reference 2017 ISRU BAA)
- Cost to deliver that propellant from Earth
  - $3.5B/yr
- Public Private Partnership
  - NASA invests $800M in the development of the mining operation
  - NASA purchases 100mT propellant per year for $500/kg
    - $50M/yr
- NASA savings
  - Year 1: $2.45B
  - Year 2-10: $3.45B/yr

Public Private Partnership

- A Public Private Partnership between NASA and a commercial mining company provides dramatic benefits to **both** parties
- NASA saves more than $3B per year
- The Internal Rate of Return (IRR) for the company increases from 9% to 16%
- Propellant production is easily scaled to meet additional demands
  - Lowers the cost to transport goods to the lunar surface by 3 times
  - Dramatically reduces the cost of a Mars mission (by a factor of 2-3)

Conclusion

- Commercial and NASA demand for propellant exists in cislunar space
- A lunar propellant mining and production architecture can meet the demand at the price required
- A simple public-private partnership model dramatically improves the business case for a commercial production company and reduces costs for NASA