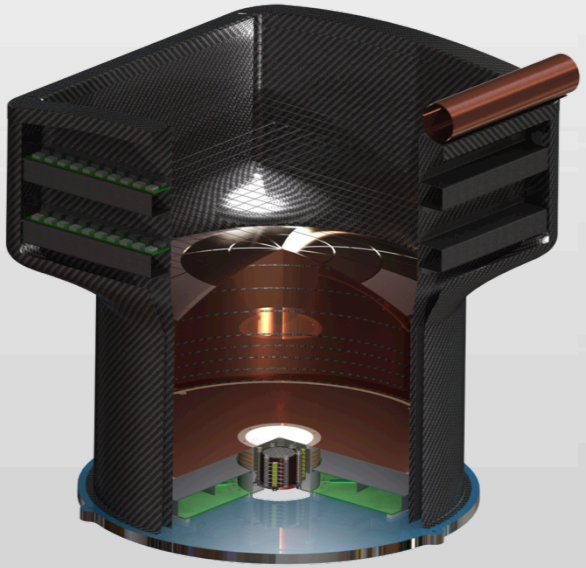
Analysis and Economics of Emerging Space Industry: Lunar Resource Extraction

Space Resources Roundtable
Seventh Joint Meeting
June 8, 2016
Colorado School of Mines
Golden, CO

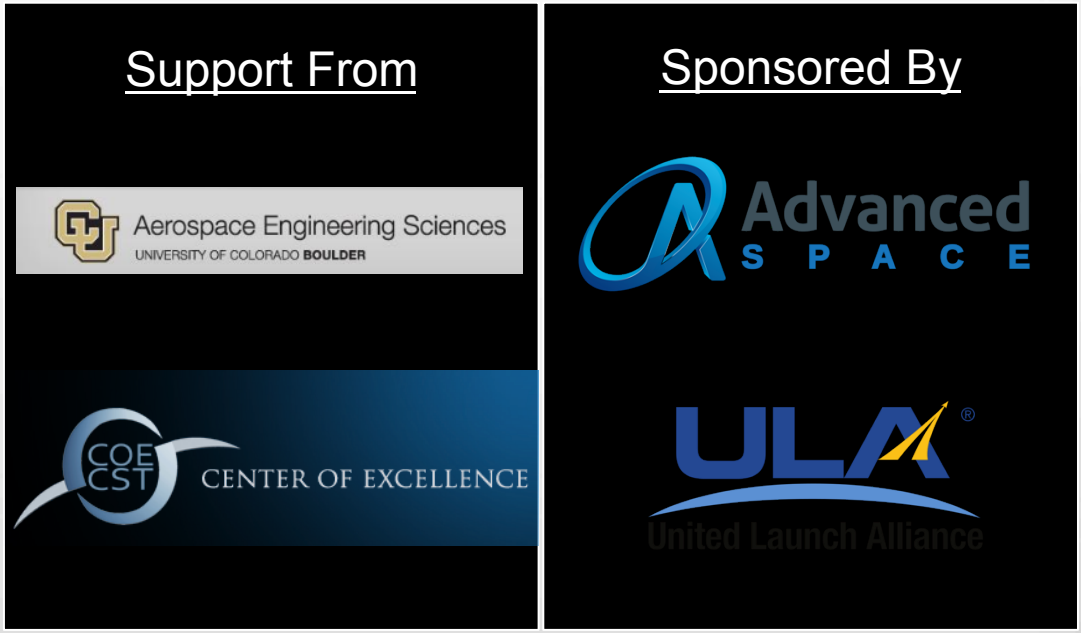
Introduction

- LASP – Laboratory for Atmospheric and Space Physics
- CAS – Center for Aerospace Structures
- IMPACT - Institute for Modeling Plasma, Atmospheres, and Cosmic Dust
- HyperDust - lunar, interplanetary, interstellar dust
- Lunar Science!



ESIL-08: Emerging Space Industry Leaders Workshop

- Emerging Space Industry Leaders
- Objectives:
  - Inform - perspective, background, context
  - Perform - group analysis on identified market
  - Network - internal and external to industry
- ESIL-01 through ESIL-09 available at ESIL.space

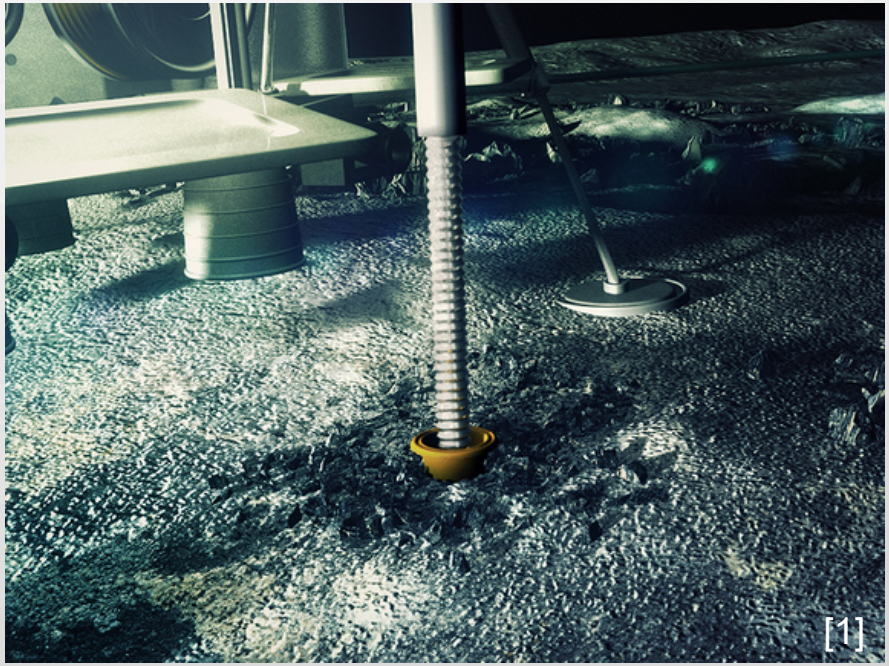


ESIL-08: Emerging Space Industry Leaders workshop

- Participants
  - Trevor Bennet *CU*
  - Charles Cain *CU*
  - Nicholas Campbell *CU*
  - AJ Gemer *CU*
  - Thomas Green *CU*
  - Bernard Kutter *ULA*
  - Tobias Niederwieser *CU*
  - Brandon Seifert *Advanced Space*
  - Scot Szatkowski *ULA*
  - James Thomas *Advanced Space*
  - Eric Threet *ULA*
- Guest Speakers
  - Mohamed Ragab *ULA*
  - George Sowers *ULA*
  - Brad Cheetham *Advanced Space*
  - Jon Goff *Altius Space Machines*
  - Sean Mahoney *Masten Space Systems*
  - Dylan Taylor *Space Angels Network*

Industry Sector (Scope)

- Industry is <u>sustainable</u> extraction of lunar resources
  - Primarily water, other materials considered
  - Including prospecting, mining, and processing
  - Initial goal is to sell/deliver on the surface
  - Assume: Initial activity is primarily robotic
  - Global market reach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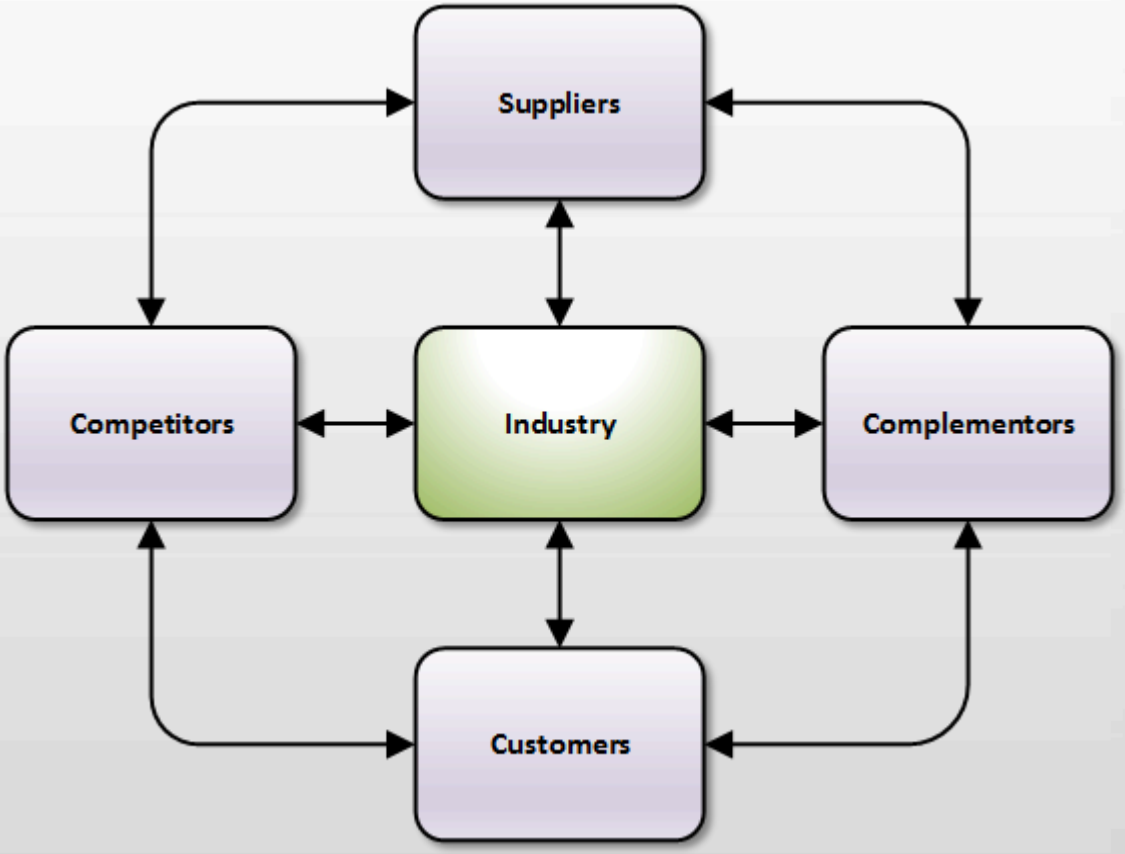
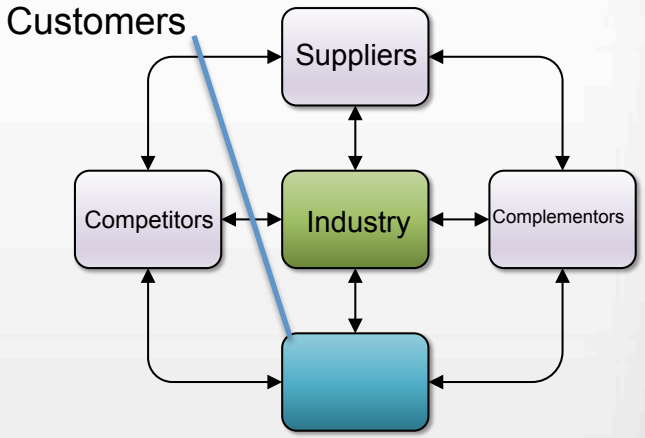
PARTS Value Net Framework

- Players
- Added Value
- Rules
- Tactics
- Scope

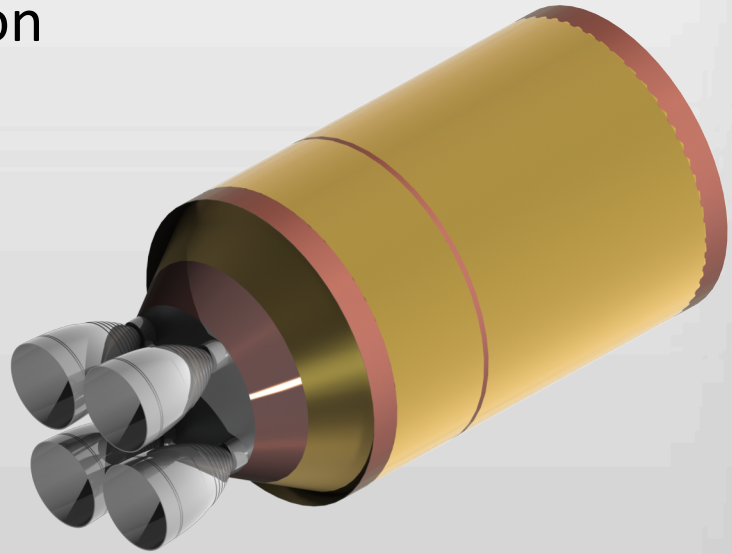


Credit: Brandenburger & Nalebuff (1996)

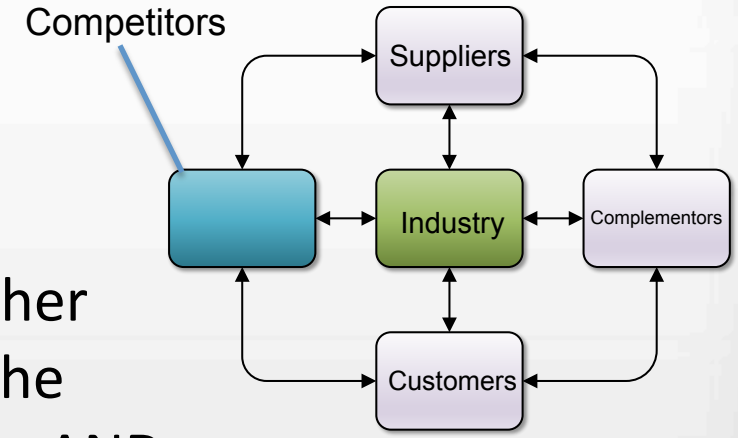
PARTS: Players



- Customers
  - Users of LOX and/or LH2 upper stages willing to invest in refueling tech
    - ULA Advanced Cryogenic Evolved Stage (ACES)
  - Lunar Village - people, plants, radiation protection, etc.
  - Water to ISS, Bigelow, other space/ surface stations
  - Mars exploration
  - Government customers for data products to support science/research

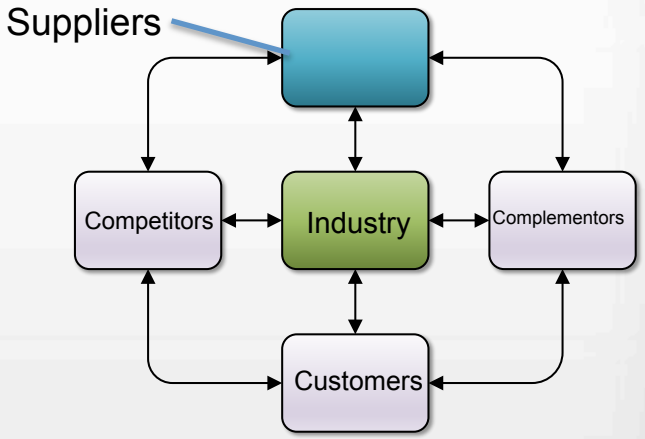


PARTS: Players

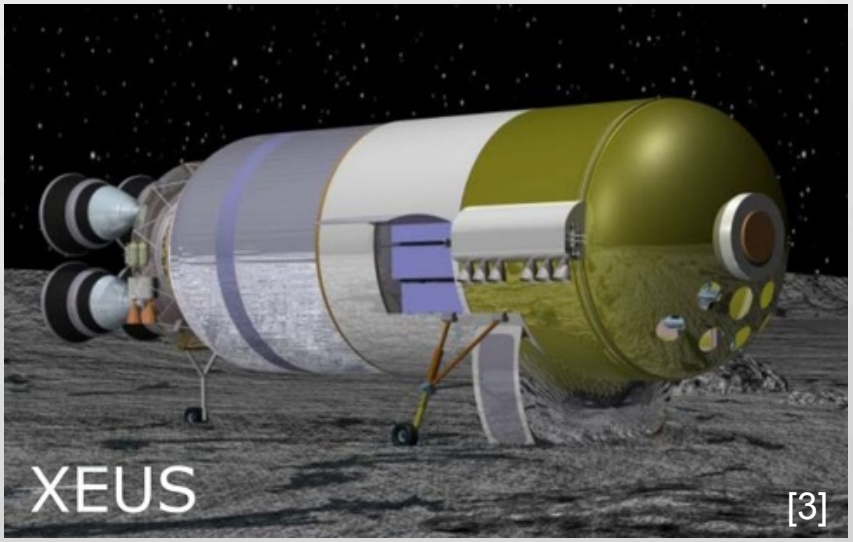


- Competitors
  - Earth-sourced suppliers
    - Important trend: Reusable and other launch improvements will lower the cost of infrastructure on the Moon AND simultaneously lower the added value of lunar resources to Earth orbits
  - Non-LOX-based in-space propulsion developments (electric, fusion, etc.)
  - Government provider of resources on the surface
  - Near-Earth Object supplied resources

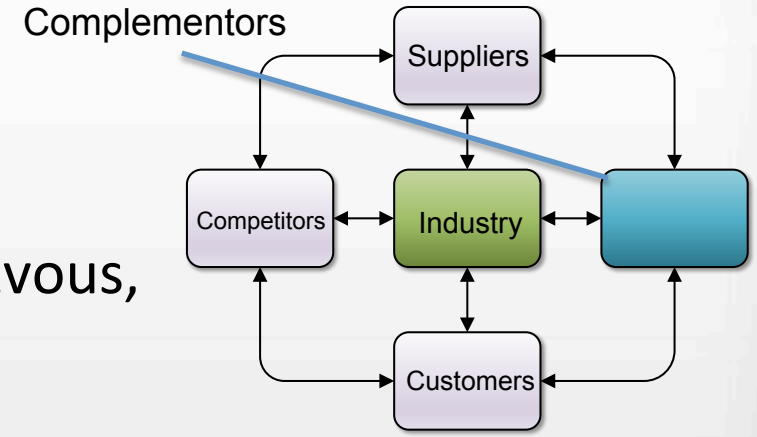
PARTS: Players



- Suppliers
  - Data collection/remote sensing
  - Communications infrastructure
  - Launch service & in-space transportation provider
  - Lander/hardware provider for surface ops
    - Masten Space Systems XEUS large lunar lander systems



PARTS: Players



- Complementors
  - Refueling tech - fuel transfer, rendezvous, docking systems
  - Distributed lift, advanced in-space transportation
  - Other lunar surface activities: mining, tourism, research/science
  - Mars exploration/transportation
  - In-space manufacturing

PARTS: Added Value

- Capability-based incentive to develop supporting technologies
  - Flexible, applicable to wide range of missions
  - Resource-dependent activities (Moon, Mars)
  - Enable NEOs and rest of solar system
- Changes equation on human spaceflight, exploration of Moon and Mars
  - Reduce cost of cargo launch to Mars; Colonization becomes possible
  - Tourism & entertainment
- Enables other cis-lunar activities & infrastructure
  - Large arrays, structures, habitats, space solar power, etc
  - In-space manufacturing
- Planetary & Space Science
  - Propellant to support/enhance scientific missions
  - Increased access, decreased cost
  - Sample return

PARTS: Rules

- Fair market access is critical
  - Avoid restrictions on who can be a customer
  - Avoid dumping of propellant in an anti-competitive way
- Need a jurisdiction to establish standard rules of business, likely international coalition
  - Who has authority to make rules and enforce them?
  - Who can own resources, and how do you claim something?
- Collaborations between policy makers, commercial aerospace, and ISRU community
- Standardization: fuel transfer mechanics, etc.

PARTS: Tactics

- Emerging market = distributed launch/fuel transfer as independent activity which is enhanced by lunar resources
  - Early adopters are transportation providers, but they need to accept more risk than with Earth-based distributed launch
- Non-economic incentive to promote industry development
  - Policy to reduce risks, barriers to entry, etc.
- Parallel independent tracks with different price points, timelines, and risk
  - GSO, Lunar, Mars

Industry Potential

- Lunar water extraction serves as a low-hanging fruit to kick-start a sustainable, in-space economy
- Quantify demand from identified customers, costs from suppliers
- Establish, model, and analyze interdependencies and sensitivities of this economy

Current Challenges & Risks

- Amortize initial investment to reduce unit cost to reasonable price
  - Need technology development roadmap to reduce variance on cost predictions
- Technology development timelines/funding influence viability and timeline of industry
  - Market stability - changing customer priority, policies
  - Timing is key!
- Key technical challenges:
  - High-resolution prospecting
  - Machinery lifespan in lunar environment
  - Operation, energy access in permanently-shadowed regions
  - Collection, processing, and storage
- Shift to distributed lift capabilities, reusable/refuelable upper stages
- Shifting rules/regulations
- Uncertainty over ownership

Conclusions

Extraction of lunar water has the potential to significantly impact the future of space development

There are potential near-term markets for lunar propellant which result in a potential path to market

Prospecting, accessing, and utilizing this water is a important step to creating new space capabilities

Lunar water extraction will spur technological, operational, and policy development

Questions?

Thank you!

References

1. Lunar Drill Image: http://www.space.com/27807-private-moon-mission-lunar-one.html
2. Spudis, P. D., & Lavoie, A. R. (2011). Using the resources of the Moon to create a permanent, cislunar space faring system. AIAA SPACE 2011 Conference & Exposition, (September), 1–24. doi:doi:10.2514/6.2011-7185
3. XEUS Image: http://www.ulalaunch.com/uploads/docs/Published_Papers/Upper_Stages/ACES-Stage_Concept-AIAASpace_2015.pdf