Analysis and Economics of Emerging Space Industry: Lunar Resource Extraction

Space Resources Roundtable
Seventh Joint Meeting
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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

Although the FAA has sponsored this project, it neither endorses nor rejects the findings of this research. The presentation of this information is in the interest of invoking technical community comment on the results and conclusions of the research.
ESIL-08: Emerging Space Industry Leaders workshop

**Participants**
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- Bernard Kutter *ULA*
- Tobias Niederwieser *CU*
- Brandon Seifert *Advanced Space*
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- 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 **sustainable** 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

[1]
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:  


3. XEUS Image:  