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Commercialization

Encouraging Private Sector Investment into Lunar Surface Capabilities. Thomas J. Colvin, Keith Crane, Rachel Lindbergh, Rina Zhang. IDA Science and Technology Policy Institute (STPI). 1701 Pennsylvania Avenue NW. Suite 500. Washington, DC 20006. Corresponding author: tcolvin@ida.org

Introduction:

NASA plans to return American astronauts to the lunar surface in the 2020s, after which it well seek to establish a sustainable presence on the Moon. One aspect of creating a sustainable lunar presence is for private sector participants to be able to provide capabilities needed for lunar exploration. Over the past decade, the private space sector has played a more prominent independent role in developing space technologies, often with great success. NASA seeks to be able to develop new capabilities needed for lunar surface operations by fostering partnerships with private sector participants.

NASA's Space Technology Mission Directorate (STMD) has identified six broad lunar surface capability areas necessary for sustainable lunar missions: excavation and construction, in situ resource production and utilization, lunar surface power, ability to access extreme locations, dust mitigation, and the ability to survive the extremes of the lunar environment for long durations. The purpose of this study is to describe the value proposition for potential non-Federal investors to co-invest in these six areas and to suggest policy and programmatic options that NASA can adopt to catalyze this co-investment.

Methodology:

The analysis relies heavily on non-attributional interviews conducted with 40 experts, mostly venture and angel investors, aerospace companies, and non-aerospace companies that have expressed some form of interest in the Moon. In addition, we reviewed over 100 interviews with potential investors and lunar-focused companies conducted during previous STPI analyses. Based on these interviews, we describe the reasons why a firm would invest private capital into lunar surface capabilities, identify the barriers to such investment, and assess the recommendations for overcoming these barriers given by interviewees. We also draw on NASA program documents, program evaluations, the public finance literature, the business and investment literature on space companies, and articles from the space press for our analysis. We supplement our analysis with projections of potential future levels of demand for lunar goods and services out to the mid-2030s. Drawing on this analysis and a review of NASA and STMD programs and policy instruments, we conclude with recommendations that NASA and STMD could adopt to catalyze private investment, including specific actions tailored to the six lunar capability areas.

Value Proposition for Investing in Lunar Surface Technologies

By definition, investors invest to generate a return and investors in lunar technologies are no exception. Although many investors have an abiding interest in space, they underlined that any investment in surface lunar technologies would have to have strong prospects of becoming profitable. Investors in lunar technologies are banking on the emergence of a lunar economy or on sufficient demand from NASA and its partners to make their product profitable. Potential investors emphasized that their assessments of the prospects for profitability depend on the potential market for the technology.

Although large space companies will invest substantial funds to bid on large one-off NASA contracts, employees of venture capital firms and other financial institutions said that markets with repeat business like lunar landers, spacesuits, and water are much more attractive because of the potential for repeated business and multiple customers. Employees from non-space venture capital firms said they keep investments in early stage technologies small; larger investments have to wait until the technology nears commercial viability. Investors in lunar technologies were more amenable to investing in R&D because they have confidence that technological challenges can be overcome, if the company has a promising product. Investors specializing in space often take a longer view than non-space venture capitalists. Traditional venture capitalists pursue investment horizons of 7 to 10 years; 15-year horizons can be acceptable among some space investors.

The importance of the future potential market for investors has implications for NASA, especially STMD. From the lens of encouraging private sector investment, NASA should view its funding mechanisms as an avenue for reducing the financial risk of companies and as opportunities to demonstrate potential future markets.

Barriers to Investing in Lunar Technologies

Through our interviews with investors and companies for this project and from our previous research, we identified nine of the greatest barriers to investing in lunar surface capabilities.

NASA's commitment to the Moon is uncertain and possibly insufficient. Investors fear that Congress or the White House may cancel or abbreviate the Artemis program. These fears are exacerbated by the perception that some decision makers within NASA want to pivot to Mars and will not adequately advocate upwards for a sustainable lunar presence. NASA's currently described plans for surface exploration may also be insufficient to attract private investment.

NASA may compete against industry. Investors believe that NASA will leverage commercial partnerships to a point, but that ultimately NASA will try to develop lunar surface capabilities in-house. The two capability areas of highest concern are space nuclear power and ISRU, despite private sector interest in their development.

Lack of private customers for lunar goods and services. Investors largely agree that government demand for lunar goods and services is nascent, but private sector demand will be negligible for the near future. There must be a customer before investors will commit.

NASA's publicly articulated planning for lunar exploration is too vague. Investors need more detail to support their investment decisions, especially about potential future levels of demand for their products.

Support for commercial R&D appears uncoordinated. NASA's anticipated support for commercial R&D into lunar surface capabilities is unclear. Investors note that NASA appears to engage in ad-hoc technology maturation rather than pursuing a coherent plan.

Unclear Opportunities for near-term revenue beyond NASA. Investors believe that some lunar surface capabilities could be adapted to serve terrestrial or Earth-orbit markets, but this potential for revenue is still speculative.

Investors find it difficult to navigate the opportunities NASA offers. Where NASA does have publicly advertised plans or R&D opportunities, investors and companies new to NASA sometimes struggle to take advantage of them. Although public interfaces are much more user-friendly, NASA still lacks a comprehensive, easy-to-use resource that companies and investors can use to engage with NASA and identify opportunities.

Non-space companies struggle to identify business opportunities related to the Moon. Non-space companies with substantial R&D budgets need help to understand the opportunities for collaborative R&D with NASA and space companies.

Recommendations for NASA

We summarize our recommendations for overarching actions that NASA, and potentially the broader U.S. Government, should take to address barriers to private investment for lunar surface capabilities. Contained in the report, but omitted here for brevity, we also provide considerations and further recommendations to guide NASA's implementation of the overarching recommendations listed below.

- The most significant action to encourage substantial private sector investment in lunar surface capabilities would be for the United States Government to increase its demand for lunar goods and services by committing to longer duration surface stays for crew.
- In conjunction with industry and other stakeholders, NASA should draw up an architecture for a sustainable presence on the Moon. As part of this effort, STMD should develop an R&D roadmap that clearly communicate its priorities among and within the six categories of lunar surface capabilities, milestones that lead to a flight demonstration for priority technologies, and estimated annual funding for each capability area over the next five years.
- NASA should clearly state the categories of goods and services that it will buy commercially and those that it will develop in-house. Investors are uncertain which goods and services NASA will develop internally.
- NASA should estimate its desired times, quantities, prices, and locations of delivery for lunar goods and services.
- NASA should support stepping-stones to the Moon, such as two commercial HLS providers, buying CLPS landers in bundles, in-space refueling, and commercial LEO habitats that feed-forward to lunar surface habitats and in-space refueling.
- NASA should provide access to lunar infrastructure for private sector activities. NASA should make available lunar infrastructure and services to the private sector for some compensation, although not necessarily full cost recovery. NASA should provide access to high rate communications, PNT, power, surface mobility, and a method to survive for an extended duration.
- STMD should provide contract options for awardees to sequentially progress through NASA's R&D support mechanisms. By drawing clearer paths between entry points to NASA awards and the potential for larger amounts of future NASA support, the perceived value of smaller rewards increases for participants.
- STMD should help build bridges between terrestrial/LEO markets and lunar markets. Near-term revenue opportunities for companies developing lunar surface capabilities are likely to be from terrestrial customers with overlapping needs.

Lockheed Martin's Vision for the Lunar Water Economy

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Abstract: Lockheed Martin Space is a strong proponent of the lunar water economy with a long heritage of ISRU technology development, from prospecting and extraction to resource processing. Recent awards like the Cryogenic Demonstration Mission (CDM) and Lunar Vertical Solar Array Technology (LVSAT) underscore our continued investment in and commitment to helping develop this vision. Across the space industry meanwhile, progress in mobility, power, transportation, and other ISRU-enabling infrastructure are bringing lunar resource development closer to reality than ever.

Our vision is that tens of metric tons of water and propellant will flow yearly through a sprawling cislunar network of mines, refineries, storage depots, lunar landers, and even large interplanetary transports like Mars Base Camp, while construction and metallurgy using lunar-sourced material will bring us closer to building structures in-situ. NASA Human Landing System missions will generate significant demand for lunar LOX/LH2 propellant to achieve fully sustainable exploration and development once the program's initial goal of landing the first woman and next man on the Moon is complete. Handling hydrogen propellant is extremely difficult as well, and Lockheed Martin's investments in cryogenic fluid management and storage will help the industry take advantage of the ubiquity, sustainability, and chemical potency of water and liquid hydrogen and oxygen.

While our belief in and support for the lunar water economy is comprehensive, achieving this shared vision requires far more than one company's involvement. An integrated, whole-of-industry approach is needed. Our role in this approach is to provide our view of the heuristics, identifying segments of the value chain where our own efforts are best invested, but also enthusiastically endorsing collaboration opportunities between established as well as nontraditional partners to strengthen all segments of the space resources value chain. By bringing down the barriers to entry, we aim to make it possible for a broader-than-ever range of scientists and innovators to focus their energy where it is needed most—on creating technologies that help unlock the Moon's resource potential and develop a robust, sustainable cislunar economy.

Abstract Joe Hinzer WGM

Canada’s Advantage for Administering Space Resources Exploration and Extraction

Canada is a globally recognized leader in Mineral Exploration and Development. The PDAC (Prospectors and Developers Association of Canada) is a well known and recognized model of a self-regulating industry association that has successfully advocating with government for members and has participated in the development of globally accepted safety and sustainable exploration and development practices. Collectively Federal and provincial mines ministries have developed world class administrative systems to manage the recording and tracking of mineral exploration holdings including the location, extent, and data collection and management of data availability, including production statistics for operational entities.

We believe the Model developed by Canadian governments of fostering industry self-regulation and working with industry associations to find the most effective administrative procedures can readily be modified and adapted for off world exploration and development.

Post, initial State exploration and exploitation activities, standardized reporting of mineral exploration information will be crucial for project risk assessment and financing activities including accessing public stock markets. While current data reporting and disclosure requirements are an excellent basis for reporting on such extra-terrestrial resource projects, the agreement on modification to existing standards and definitions and adoption of suitable data verification procedures still need to be agreed.

Abstract for PTMSS – Jeff Plate, Interstellar Resources

Integrated Lunar Prospecting and Exploration Methods by Commercial Operators

Interstellar Mining Inc. ("IM") as a commercial lunar prospecting, exploration and mining company is focused on applying several key prospecting methodologies to fulfil the most basic requirements of any mining company which is to find the ore. Although scientific missions by nation states have confirmed the existence of water, IM is focused on increased resolution of specific exploration targets via the use of private orbital data, impactors for ground truthing, and AI/Machine learning systems to target scare exploration assets to the most probabilistic areas for exploration and development. The prospecting methodology is commercially focused and designed to be cost effective which his a key issue for investors.

The Business Case for Lunar Ice Mining

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The key to human expansion into space and space development, in general, is developing space activities that deliver value in an economic sense. In other words, the key to space development is making money in space, i.e. profit. However, the search for money making space activities has proved elusive. We present a business case for a commercial company to mine lunar ice and process the ice into rocket propellant. We discuss the existing and future markets for propellant and an architecture for mining and processing propellant and the associated costs. We then examine three scenarios, one commercial stand alone and two involving a public private partnership (PPP) model with NASA. We provide a comparison with other similar analyses. Business returns are positive for all three scenarios, though the PPP models provide increased returns and share risk with the government. Once established, lunar sourced propellant will dramatically reduce the cost of all beyond LEO space activities and potentially enable other profitable commercial ventures to emerge.

Resource Assessment Methods, Application for Terrestrial and Lunar Assessments. J. A. Coyan[1], Department of the Interior, US Geological Survey, 904 West Riverside Ave, Suite 202, Spokane, WA 99201, jcoyan@usgs.gov

Introduction: The U.S. Geological Survey has been conducting resource assessments for "locatable" minerals (i.e., generally minable hard rock minerals limited to lands with reserved status, e.g., gold, silver, copper), "leasable" minerals (i.e., locatable minerals on land that has acquired status and include other types of commodities, e.g., coal, oil, phosphate, geothermal), and "salable" minerals (i.e., common minerals of low value per volume that can be sold under a mineral material contract, e.g., sand, gravel, decorative stones, cinders) for decades [1]. Depending on the amount of available data, the time constraints, the deadline, intended end users, and which methods are chosen, the estimate of uncertainty and the results will vary. Assessments conducted by the USGS fit into three, broad categories, 1) Summary Assessments, 2) Qualitative Assessments, and 3) Quantitative Assessments. Within the qualitative resource assessment category are traditional Qualitative Assessments, and Mineral Prospectivity Mapping. Within the quantitative assessment category are the Three-Part Form of Assessment, Probabilistic Estimates, and Three-Dimensional Modeling studies (Figure 1). Qualitative resource assessments commonly produce maps with mineralized areas ranked as high-medium-low and are useful in areas that have insufficient data to conduct a fully quantitative assessment [2]. Quantitative resource assessments commonly produce maps that delineate areas that are permissive for mineral deposits and provide a distribution of the probable contained commodity being assessed.

Summary Assessments: Summary Assessments are a rapid way to inform government officials of known deposits (i.e., mineralized area with a known grade and tonnage estimate, delineated in three-dimensions), prospects, (i.e., areas with known mineralization, possible grade information and past production, but no full resource delineation), and occurrences (i.e., mineralized areas are identified but typically not developed with little other information available). In many ways, this is equivalent to a literature review of known mineralization. A Summary Assessment provides no guidance for predicting undiscovered deposits or uncalculated reserves or resources.

Qualitative Assessments: Traditional Qualitative Assessments are very similar to Summary Assessments in which a mineral inventory is produced, but then economic geologists, experts in the commodity being studied, estimate a high, moderate, or low probability for additional potential of the commodity present. Uncertainty in these types of assessments may be high to moderate depending on the abundance of direct and indirect evidence. In some cases, the uncertainty may be captured and used as an additional parameter to rank the areas being assessed (Figure 2).

With additional data (e.g., location of known deposits, geophysics, geochemistry, location of geologic structures), Mineral Prospectivity Mapping can be used for predicting prospective areas. Multiple evidence layers are constructed from geophysical, geological, or geochemical data (e.g., a fault proximity map) [4]. Weights are assigned to each evidence layer depending on how well or poorly it is correlated to the deposit type. The multiple evidence layers are then combined to create a single ranked prospectivity map.

Quantitative Assessments: Quantitative mineral resource assessments are less subjective than qualitative assessments, are produced from concrete data, and have computable results. The Three-Part Method is a USGS-developed method of estimating undiscovered resources. The Three-Part Method has been successfully applied at the local and global scale to numerous commodities (see minerals.usgs.gov/science/assessments.html). The Three-Part Method relies on deposit models that describe a deposit type rather than a single deposit and include information such as mineralogy, alteration, geochemical, and geophysical anomalies [5]. The deposit model provides guidance for two of the three parts: 1) what geology is permissible for mineralization and 2) what grade and tonnage data are acceptable to create analogue databases. The third part of this method is a collection of expert estimates of undiscovered deposits. The grade, tonnage and expert-estimate distributions are then combined using Monte Carlo Simulation to produce a final distribution of material.

Probabilistic estimation is a form of stochastic simulation which uses borehole data to create a distribution of true measurement. A random sample of the distribution is taken and added to a grid containing the borehole data. The process repeats until the model is complete. The amount of commodity for the system is recorded and the process is repeated until enough data is gathered (usually several hundred times). The distribution of the model outputs shows the most probable estimates as well as the expectations of the range the values are likely to fall in, thereby capturing the uncertainty.

Three-dimensional modeling is more akin to what terrestrial mining companies produce. These models use a grid with axes in the X, Y, and Z directions. Each grid cell is assigned a value of concentration of the commodity or commodities of interest (grade). Assignment of the value to the grid is supported by dense drilling, sampling, and assaying of the cuttings to delineate the deposit in all three-dimensions, thereby providing an estimate for the total endowment.

Conclusions: With the current repository of data collected on the moon, the lunar community is at the level of performing Traditional Qualitative Assessments and coarse Mineral Prospectivity Maps. As our understanding of the type, form, and distribution of lunar volatiles increases, it is imperative that as a community we adopt other assessment methods moving toward Quantitative Assessment capabilities.

References: [1] U.S. Forest Service. 2009. Minerals Suitability Classification Process. [2] Zientek, et al. (2014) Geological Survey SIR 2010-5090-T. [3] Carranza, Emmanuel John Muico. 2008. Geochemical anomaly and mineral prospectivity mapping in GIS (Elsevier). [4] Singer, D., and Menzie, W. D. 2010. Quantitative mineral resource assessments: An integrated approach (Oxford University Press).

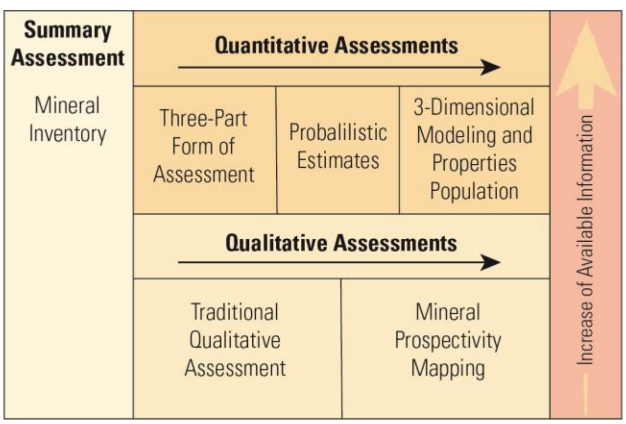

Figure 1. Relationship of the types of assessments the USGS conducts.

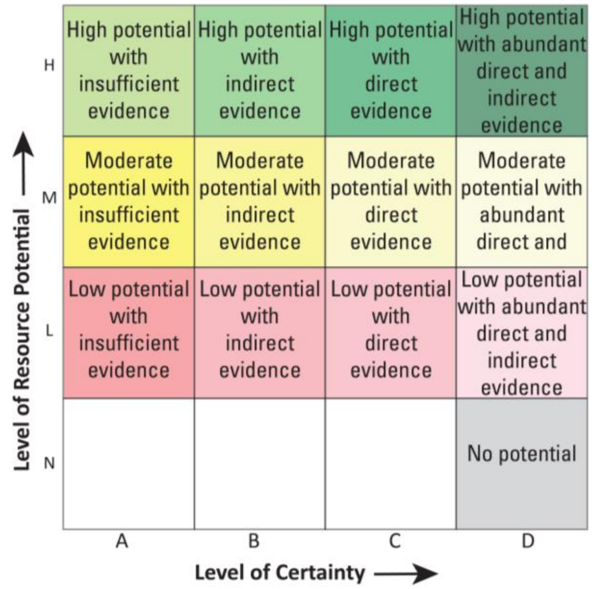

Figure 2. Qualitative Resource Assessment ranking matrix combining level of certainty and resource potential.

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CEMI’s ‘Innovation for Mining’ Network for Extreme Conditions.

Doug Morrison, CEMI

Space is an extreme environment, and explorers look for opportunities to find the resources they need along the way, since bringing everything from Earth is prohibitively costly. Space also does as many things as possible autonomously - limiting human involvement to the need for creativity or dexterity. Cost and autonomy are Frontiers that mining must cross very soon - so soon that we are now adopting innovations from other sectors to solve our problems in the time we have. Mining already operates in extreme environments, conditions that most people would find unacceptable – well beyond +/- 30° C. More difficult heat, humidity and logistic conditions have to be managed autonomously, at lower cost.

The difference is that systems for space are highly specialised - very few actors and very few events. Mining is multiple projects and lots of people. Space is the ‘haute couture’ of science and engineering; mining today is ‘bargain basement’ by comparison. Mining’s future is many more projects at lower cost - to enable the Green Transition by 2030-35. Many more mines, fewer people and autonomous systems. CEMI’s clients are hundreds of SMEs that can merge their expertise with your highly sophisticated techniques to make them work at scale and maintain the essential functionality we need to meet our conditions. If the fashion industry can pivot to the middle ground, we can too. Mining has begun the journey to the prêt-a-porter model for technology in extreme environments - we could use your help.