MAJOR TAKEAWAYS of the MINING SPACE SUMMIT 2018

By the Luxembourg Space Agency [1]

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The Mining Space Summit 2018 was a one-day workshop organized to foster the increasingly vibrant dialogue around the development of the space resources utilization (SRU) sector. As global investment in SRU companies and capabilities increases and new sources of demand for space resources materialize, outstanding challenges remain. Two challenges in particular will be key in enabling the success of the SRU sector: (1) the viability of SRU business models and (2) the development of critical technologies and operations.

To address these challenges, engagement between the terrestrial mining industry, those industrial entities currently mining on Earth, and the space mining community is key. To facilitate a productive dialogue on these points, stakeholders from across terrestrial and in-space mining, financial, and government communities participated in the Summit. Over the course of the day, participants identified and discussed the opportunities, challenges, as well as the similarities and differences related to their business models and, critical technologies and operations.

I. INTRODUCTION

On 28th of September 2018, the Luxembourg Space Agency (LSA) organized the first Mining Space Summit at the Abbey Neumunster in Luxembourg City. More than 140 participants from over 17 countries working in different industries (e.g. oil and gas, terrestrial mining, space, finance, and government) joined this one-day workshop. The participation in the event was free of charge and the following four sponsors, Eurasian Resources Group, PWC, Offworld, and LSA, covered all the costs.

The workshop consisted of a plenary session in the morning, designed to provide attendees the opportunity to learn during eight keynote presentations about SRU business models, technological approaches, and operations, followed by six topic-specific parallel breakout sessions in the afternoon for participants to engage directly on how the space and Earth mining communities can collaborate or learn from one another. A concluding plenary in the afternoon and a closing reception in the evening rounded out the event.

The breakouts focused on two broad themes: (1) business models and (2) critical technologies and operations. The business models' topics included; market and dynamics, investment and financial planning (e.g. analyzing future demand), and the role of government and regulators. The critical technology and operations topics included; prospecting – providing value, extraction – creating value, and enablers – optimizing value.

II. THE PLENARY SESSION

The following presentations provided a general overview to the audience:

The Luxembourg SpaceResources.lu Initiative
Mathias Link, Luxembourg Space Agency
Introduction to Space Resources
Angel Abbud-Madrid, Colorado School of Mines
Future Potential Market and Value Chain of SRU
Yann Perrot & Luigi Scatteia, PWC

[1] Michael Grasso, Bob Lamboray, Cedric Letsch, Mathias Link, Gary Martin, Joseph Mousel

Importance of Interaction between Space and Non-Space Communities
Jean-Jacques Dordain, SpaceResources.lu Advisor
Lunar Propellant Helping to Enable ULA's Cislunar 1000 Vision
Bernard Kutter, United Launch Alliance
The First Step - Prospecting and Mining on the Moon
Kyle Acierno and Carlos Espejel, ispace
Gas & Cryogenics, an Enabler for your Space Mining Journey
Bertrand Baratte and Benoit Chidaine, Airliquide
Space Resources Activities at the European Space Agency
James Carpenter, European Space Agency

III. BREAKOUT SESSIONS

In the afternoon, the participants actively engaged in six different parallel breakout sessions and provided their feedback. In each session, short presentations were given along with a set of questions to stimulate discussion. The outcome of each session was then presented to the full audience in the late afternoon.

The three business oriented sessions discussed multiple areas of interest including:

Market and Dynamics; understanding space resources supply and demand dynamics by considering their use-cases, prices, associated costs, and other factors.

Investment and Financial Planning; financing space mining projects and ventures and understanding potential financing models for projects in an innovative and high-risk frontier field.

Role of Government and Regulators; enabling the growth of a nascent industry through public policy and regulatory actions.

In parallel, discussions in the three concurrent technical sessions covered:

Prospecting – Proving Value; finding, identifying and analyzing resources to prove their value and justify mining operations.

Extraction – Creating Value; establishing and operating mines in extreme and remote conditions and generating value from a mine in space in a sustainable way.

Enablers – Optimizing Value; increasing mine efficiency by leveraging critical support services, technologies and processes, such as logistics, communication services and power distribution.

Market and Dynamics

Understanding space resources supply and demand dynamics by considering their use-cases, prices, associated costs, and other factors.

This breakout group had representatives from space resources companies, terrestrial mining, investment community, and government. It focused on understanding the current market situation and how it might change over time. The group identified possible next steps to meet the challenges that were identified.

Key Questions:

- What are the current demand drivers for space resources, how will they evolve in the future?
- Who are the future customers?
- Which space-based resources are most in-demand now? How is demand quantified?
- What are the use-cases of these resources?
- How to think about cost drivers in this sector are there any rules of thumb?
- What is needed to take a decision to engage in a mining project?
- What is the value proposition of prospecting missions?

Major Takeaways:

Current Situation: The group expects the market to evolve over time and they attempted to make near-term (3-10 years) and mid-term (+10 years) forecast in order to develop a set of recommended actions.

Government space missions that will need extraterrestrial water for fuel and life support will drive early markets in the near-term. However, there is still a need to generate money for developing new ventures and new customers to reach a critical mass for sustaining the sector. The space mining sector needs to develop business models, applications, and conduct research that will develop technologies for markets on Earth in the near-term, while preparing for their in-space activities in the mid-term.

For the mid-term, they predicted to see in-space manufacturing along with in-space construction of facilities. Industries will move off the planet and in-space manufacturing will increase. The long-term result is that more and more people and industries will leave the planet as time moves forward creating an increasing economic sector in space.

Challenges. The group identified challenges highlighting the need for collaboration between the two industries.

They stressed the importance of having both terrestrial and space mining companies increase interaction with their customers in order to develop stronger business cases. To build strong mining economic sectors more companies and a larger customer base is needed for increased sustainability.

The space mining sector needs commitments from governments as anchor customers, because there is currently too much risk and the profitable markets are expected to develop too far into the future for most investors.

It is also challenging to convince new investors to enter the sector. There are two types of investors: visionary and conservatives. In contrast with space mining the traditional terrestrial mining industry is a "slow dinosaur" that avoids risky decisions. In addition, the space mining industry needs to evolve from technology push to market pull.

Enabling Activities: The breakout discussion resulted in four important recommendations for the community.

- Develop a stable customer base by creating a need for products made in space, (e.g. private and/or public outposts on the Moon) and involve the customers in market research and product development. This will in turn create an important alliance of customers needed for long-term sustainability.

- Develop a stable commitment from governments by encouraging them to be anchor customers and guaranteeing to buy resources at a fixed price at a given time.

- Develop a stable legal and regulatory framework to bring down risk for investors and promote the development of more companies in the space mining sector.

- Develop a critical mass of investments needed for sustaining the sector. Big companies may play an important role in backing small space players (at least initially).

Investment and Financial Planning

Financing space mining projects and ventures and understanding potential financing models for projects in an innovative and high-risk frontier field.

This breakout group considered how space mining projects and ventures could secure financing. The participants included thought leaders from space startups, large mining and oil & gas companies, aerospace firms, governments, investment banks and other financial institutions. The participants discussed the current and future state of investment in space resources utilization activities. To kick-start the discussion, the moderators presented on financing trends in the terrestrial mining and space and satellite telecommunications industries.

Key Questions:

- How are space and terrestrial mining activities financed today?
- How could space mining and space resources utilization projects be financed and which forms are most applicable?
- What are the potential enablers to "kick-start" and sustain investment in the sector?
- How can space, mining, and finance communities support each other to make it happen?

Major Takeaways:

Current Situation: Despite the fact that the space industry is undergoing profound evolution, investment in space mining projects and ventures has been limited. The nature of space-sector financing has evolved significantly over the last five years. Low cost access to space coupled with small spacecraft architectures has invited new breeds of investors into the sector. Investors, particularly business angels and venture capitalists, are financing companies across the value and supply chains of the industry. Despite the increase in financing, investment in space resources utilization has mostly been limited to government grants.

Strategic and financial investors highlight risk factors that constrain their investment appetite. The long-time horizons associated with space mining challenge its attractiveness to angel and VC investors. Strategic investors, such as large mining companies, which are used to managing projects with long-term time horizons, cite the lack of "anchor customers" for

resources mined from space. According to mining sector participants, prospective customers have either not been entirely engaged or have not elaborated on their interests in sufficient detail.

Lenders shared this concern and highlighted the fact that space-mining projects have not been successful in securing debt. This is unsurprising, as few terrestrial mining projects in "extreme environments" (e.g. deep-sea) have secured debt financing, driven by economic rationale uncertainties and operational/technical risks. In today's environment, investor considerations regarding the sector's long-term time horizons, uncertainty in the business case, and concerns regarding the operational risks have resulted in relatively modest levels of investment.

Future Situation: Grants, equity, and government funding in various forms are likely to be most relevant to kick-start space resources ventures. Space mining ventures that focus on developing capabilities with near-term revenue generating potential with broad, multi-sector applicability could attract interest from angel investors and VCs.

Governments could be interested in offering research grants to space mining entities that target the development of specific capabilities or technologies with applicability beyond space. Governments are also interested in "strategic returns" in the form of economic development, which could be measured by job creation, IP generation, exports, turnover, or some other metric. For both governmental grants and equity, investors will consider the strength of the business case, soundness of the technical approach, quality of the team, and fundraising plan. Moreover, while some investors may be interested in the long-term vision of space resources utilization, most will be interested in business plans that employ "step-by-step" approaches with various and clear exit opportunities.

Enabling Activities: To enable increased investment in the sector, investors and prospective customers of resources mined from space could consider a series of actions for governments and intergovernmental organizations to seriously consider their roles as customers of space mining ventures. To this end, governments could incorporate space resources utilization into their space exploration and science architectures.

Additionally, governments could also be providers of "guarantees" as an initial stimulant. While government-based revenue could mitigate some investor concerns, many financiers are likely to be less interested in ventures in which the government is the *only* customer. Government R&D funding should target areas of the space resources utilization value chain that are incomplete and have "enabling" technical characteristics. To mitigate risk and improve attractiveness to private financiers, investors, particularly angels and VCs could leverage government grants as co-investments in financing rounds.

Coupling government R&D funding and equity could help to reduce technical risks, strengthen the overall investment due-diligence process, and attract a diverse pool of prospective investors. Lastly, inspiration capital (enabled by entrepreneurs, celebrities, government officials, etc.) could be key to ensuring continued support and even unlocking additional investment.

Role of Government and Regulators

Enabling the growth of a nascent industry through public policy and regulatory actions.

This breakout group had participants from both space and terrestrial mining, government, and finance. The discussion focused on issues concerning the Outer Space Treaty and how governments can work to clarify the policy issues.

Key Questions:

- What government policy options might best encourage the sustainable development of space resources markets?
- What role can public institutions play in order to accelerate the development of this industry?
- What policy options might encourage increased private sector participation in the sector?
- How important is the role of a government as a risk taker or early anchor customer?
- How do legal, tax, environmental, and other forms of regulations affect the ability to finance space mining projects?
- How are terrestrial mining rights licensed, (e.g. those in deep sea), and how can such a model be applied to space?

Major Takeaways:

Current Situation: There is no clear regulatory framework for space mining and little relevant international law. Under the Outer Space Treaty,

national appropriation of celestial bodies is not allowed, but it is not clear how this principle applies to space resources. The Committee on the Peaceful Uses of Outer Space (COPUOS) is having challenges in clarifying regulatory situation in this area in a timely manner, while some countries have stepped forward with national legal frameworks. In the meantime, soft law could be created as a start, such as establishing guidelines and standards.

Investment decisions are difficult since there is no clear assurance of property rights. The situation is not critical today but might become critical in the future, such as, on the lunar peaks of eternal light where there may be prime locations for space resources activities.

Governments can do many other things to nurture this industry by supporting research, providing funding, and developing standards. Current hurdles can be considered more of an issue of industrial policy than of regulations.

It is worth considering that terrestrial and in-space mining industries manage information in different ways. For terrestrial mining, geological information is made public, explorers need to share it, and in exchange, they get the right to mine. In space mining explorers want to keep information for themselves, they consider it proprietary (as it was in the terrestrial industry at the start) but they might benefit more if the data was shared.

Ideal Situation: Governments should act as a facilitator and involve the industry in defining what are the right regulations for market sustainability. They can learn from the commercial satellite servicing industry, especially their self-regulation practices allowing to set up industry standards and best practices to reduce risk of space debris.

Governments and space agencies can play important roles in creating standards, especially if there is an external need. The industry should establish an international authority for delivering concession and property rights. This approach is an analogy to the International Telecommunication Union (ITU) where it allocates frequency and orbital positions on first come first served basis. Using the analogy of International Sea Bed Authority would not be very successful due to strong requirements on benefit sharing.

Enabling Activities: The group recommended to develop a clear policy statement on what should be allowed in space, giving appropriate legitimacy internationally. It will be important to translate policy into appropriate regulations. This is where the space industry can learn a lot from the terrestrial systems.

Other discussion forums involving industry are needed such as the Hague Working Group. Industry should work out how to behave among themselves, but need guidance from states. A “Space mining industry association”, representing the industry, should be created to discuss policy and regulations with governments around the world.

Bringing together terrestrial mining and space communities more often would be beneficial for both communities. They should create an “inter-industry” association. Events like the “Mining Space Summit” are a good first step.

Determining who are the beneficiaries and how they should benefit is an important activity. Those taking the risks should also be rewarded as in the mining industry.

The space mining industry should work on sharing of benefits, most importantly sharing information, so that everyone can have it (especially the scientists). Space companies will benefit from exchange of informationand of best practices.

A tax-credit scheme for space mining investors similar to the flow-through share system in terrestrial mining should be worked out, encouraging investors to put out speculative money.

Prospecting - Proving Value

Finding, identifying and analyzing resources to prove their value and justify a mining operation.

This group was made up of researchers, and representatives from government, financial and both terrestrial and space mining. The session looked at the first link in the space resources and mining value chains – finding the valuable resources.

Key Questions:

- Currently in terrestrial mining, what level of details is required before engaging in a mining operation?
- What technologies are needed to achieve this level in space?
- What technologies and approaches could best serve space prospecting operations and how could they help terrestrial prospecting?

Major Takeaways:

This session was about prospecting and started with the discussion on the initial "ore" of interest, and the existing knowledge on its location. A case was made for water and for oxygen. An argument for the latter was that it could already be discovered remotely, in the form of Ilmenite ($FeTiO_3$), while exact data for water is not available. A point that also needs to be considered in the selection of the first mining product is the extraction technology, where the advantage also seemed to be on the side of oxygen.

Consequently, the idea was to create momentum for the industry to utilize a phased strategy, starting with low risk undertakings, consisting of a mission for oxygen from Ilmenite on the Moon. According to some participants, this mission is already feasible today, from mining to processing. Real samples exist and the geological context is reasonably well known.

A significant problem faced on the Moon, but even more on asteroids, is the lack of ground truth. Even if possible deposits are identified and located through orbital spectroscopy, the lack of capabilities to assess the tonnage, the grade and the physical properties of the resource, as well as the lack of understanding of the geological context of the permanently shadowed region of the Moon make the raising of investment even for pilot-scale extraction and processing operations difficult. This makes the acquisition of ground truth data unavoidable.

To cover this demand for ground truth data the group discussed; mobile vs. static landers as vehicles, as well as drilling vs. trenching as sub-surface access methods technique. While mobile landers and trenching allow covering greater areas and thus collecting more data, static landers and drilling allow deeper exploration.

The group identified and discussed the used terminology in terrestrial and space mining and the ownership regime as additional challenges needing attention.

Although the terms currently used in terrestrial and space mining are the same, both communities seem to use them differently. To bring both communities together, the terms used in space need to be clearly defined. Therefore, a team to define the terminology and the standards for reporting data was suggested.

Additionally, a clear ownership regime for space exploration data needs to be established, as no claims to territories can be made. As an example, the current terrestrial practice is that whoever pays for the data owns it. Governmental-funded low-resolution data is openly accessible, while privately funded high-resolution data is generally kept private.

Extraction - Creating Value

Establishing and operating a mine in extreme and remote conditions and generating value in a sustainable way.

Terrestrial mining and space mining are facing very different technological challenges but there are areas where each industry can learn from the other. This breakout session discussed these differences and made observations that should lead to follow-up activities in both industries.

Key Questions:

- What are the challenges of operating in extreme conditions, with limited or no support of human operators?
- What is the role of robotics and artificial intelligence in remote mining operations?

Major Takeaways:

Current Situation: Mining on Earth is a very old industry that will significantly evolve over the next decades as resources are becoming more and more difficult to access and mines tend to become deeper in order to find the resources in the required quality and quantity. This creates new challenges and the traditional mining industry will have to innovate in order to make these deep mines sustainable and financially interesting. Even though there is a clear trend to automate terrestrial mining operations in order to improve efficiency and increase safety for operators in mines, only isolated tasks have so far been automated and mines still depend a lot on human operators putting them in tough and sometimes

dangerous situations. The mine of the future will certainly be more automated and operators will be less exposed to these extreme situations.

On the other hand, space mining is in its infancy and many questions still need to be answered. So far, many different space-mining concepts have been developed and depending on their location, they may differ substantially, but no architecture has been operationally proven. Because of a lack of in situ information, there is no clarity on the form of the resource in space, and in the next years, more ground truth is needed to answer these fundamental questions.

Enabling Activities: In general, more automation and autonomous systems are needed to operate in extreme conditions, be it on the Moon's surface, in deep-sea operation, or in deep terrestrial mines. Swarm architectures, where many small robots collaborate in one operation, could be one of the key enabling technologies for both industries to operate in extreme conditions and to leverage mass automation advantages as well as move people from harm's way.

Future Activities: In the next years, both industries can support each other by developing baseline technologies on Earth and reutilize later as validated technology in space. The participants of this breakout session identified the following areas of interest for possible future collaboration; robust sensors in combination with machine learning and artificial intelligence techniques, waterless operations, fuel cells, robots and autonomous systems in general.

Enablers – Optimizing Value

Increasing mine efficiency by leveraging critical support services, technologies and processes, such as logistics, communication services and power distribution.

The discussion centred on how to increase terrestrial mining efficiency by leveraging critical support services developed for the space industry such as, technologies and processes used for logistics, communication, and power distribution. The participants included both terrestrial mining and space experts. The results of the discussion can be grouped into three main areas; the current state of terrestrial mining, how to increase collaboration between the two industries, and recommendations for future activities.

Key Questions:

- What are the critical technologies and processes that support mining projects in extreme conditions?
- What supporting services are required to make a mining project efficient?
- How do these services apply to space?

Major Takeaways:

Current Situation: Terrestrial mining is big business with large profits therefore, space mining will need to have an attractive value proposition to be of interest to the terrestrial mining industry. Terrestrial mining has a very long history and is generally conservative in the introduction of new technology. In addition, it is always seeking to minimize investment risk and may inhibit collaboration between the two areas.

Areas of Collaboration: To facilitate collaboration it is important to improve communication between terrestrial mining and space industries. The group felt that the two communities should develop common terminology and that there should be a space-terrestrial mining dictionary. Possible areas of collaboration from the space industry include automation, robotics, and big data. Areas identified from the terrestrial mining side included conventional mining methods e.g. micro tunnelling, strip mining, in-situ leaching (chemical mining), and fundamental rock breakage technologies including laser cutting.

Future Activities: Recommendations for future activities include the space mining industry learning more about the terrestrial mining industry by attending mining conferences, which occur on regular schedules such as, the Future of Mining Conference, the Society for Mining, Metallurgy & Exploration Conference, and the Conference on. Sustainable Development in the Minerals Industry. It was identified that mining equipment companies should be targeted by space miners for collaboration instead of targeting the actual terrestrial mining companies themselves since the mining equipment companies are where innovation is taking place for terrestrial mining. Government co-funding is key to enable research and can facilitate enabling startups and mining companies to work together. Lastly, a good catalyst for collaboration would be a DARPA-like competition supported by teaming together terrestrial mining and space mining companies.

IV. CONCLUSION

The first Mining Space Summit was a great success. It represents an important step forward towards establishing a meaningful connection between two industrial sectors; terrestrial resources and space resources. With the attendance of 140 experts, the summit exceeded expectations. One important metric was the participant representation - 60% from space, including start-ups and global players, with 40% from mining, oil and gas industries, finance, and government sectors.

The Summit focused on two challenges that are key in enabling the success of the space resources sector: the viability of their business models and the development of critical technologies and operations. This summary paper has provided the major results of those discussions and has set the foundation for future work. The 2018 summit was only the beginning of a long-term process to identify areas of collaboration between the two industrial sectors. Future summits will build on these results.