

MAJOR TAKEAWAYS of the MINING SPACE SUMMIT 2019

By the Luxembourg Space Agency ⁽¹⁾

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The second edition of the Mining Space Summit was a one-day workshop organized by the Luxembourg Space Agency (LSA) as part of Space Resources Week (www.spaceresourcesweek.lu), a space-resources-centered series of events organized in Luxembourg between the 7th and 11th October 2019. Additional events included a Professional Course on Space Resources, organized in collaboration with the International Space University (ISU) and the Colorado School of Mines, as well as an In-situ Resource Utilisation (ISRU) Workshop organized in partnership with the European Space Agency (ESA).

The Mining Space Summit 2019 built on the results of the previous year's event, focusing again, on the two main challenges that will be key in enabling the success of the space resources utilization sector: (1) the viability of SRU business models and (2) the development of critical technologies and operations.

To address these challenges, engagement between the space resources community and terrestrial industries, including mining and oil & gas, is essential. To facilitate a productive dialogue on these points, stakeholders from across terrestrial and space resources industries, financial, and government communities took part in the Summit.

Over the course of the day, participants identified and discussed the opportunities and challenges faced by the space resources industry. They also considered the similarities and differences between their business models, critical technologies and operations.



I. INTRODUCTION

On the 9th October 2019, the Luxembourg Space Agency (LSA) organized the second Mining Space Summit at Luxexpo The Box, in Luxembourg City.

Taking part in the Summit were more than 180 participants, representing entities from 24 countries, working in fields as diverse as oil & gas, terrestrial mining, space, finance, and government.

Four sponsors supported the LSA in covering the event's costs: Eurasian Resources Group (ERG)¹, Arendt & Medernach², KPMG³ and ispace Europe⁴. This made it possible to offer the participation free of charge.

The workshop started with a plenary session in the morning, where participants learned about the latest SRU developments, obtained some theoretical background on the topic, and discovered different approaches on how space and terrestrial use cases can be combined to the benefit of both.

¹ <https://www.eurasianresources.lu/>

² <https://www.arendt.com/>

³ <https://www.kpmg.lu>

⁴ <https://ispace-inc.com/>

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After the lunch break, the day continued with six topic-specific parallel breakout sessions in the afternoon, for participants to engage directly on how the space and terrestrial resources communities can collaborate or learn from one another. The breakouts focused on two broad themes: (1) business models and (2) critical technologies and operations. Both were building upon the results of the 2018 Summit.

A concluding plenary in the afternoon, summarized the breakout sessions for all participants. A closing reception in the evening, open to all participants of the Space Resources Week, rounded out the event.

II. THE PLENARY SESSION

The following presentations during the morning plenary session provided a general overview to the audience:

- **The Luxembourg SpaceResources.lu Initiative – Update**
Mathias Link, Luxembourg Space Agency
- **Lunar and Asteroid Geology for Space Miners**
Daniel Britt, University of Central Florida
- **Lunar Ore Reserves Standard (LORS)**
Carlos Espejel, ispace Europe
- **Lunar Resource Mapping: Data Fusion and AI-driven Anomaly Detection**
Jérôme Burelbach, Frontier Development Lab
- **METIS : Seismic 4.0 for Earth Exploration and Beyond ..?**
Bruno Pagliccia, Total
- **Space Resources Research at UNSW**
Andrew Dempster & Serkan Saydam, University of New South Wales
- **Developing Technologies for Space by First Developing a Terrestrial Business Case**
Joost van Oorschot, Maana Electric
- **The ESA Space Resources Strategy**
James Carpenter, European Space Agency

III. BREAKOUT SESSIONS

In the second part of the event, the participants actively engaged in six different, parallel breakout

sessions. 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 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 resources 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 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.

The results of the discussions were as follows:

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, the investment community, and government. It was chaired by Jim Keravala (CEO at Off-World, Inc.). The session focused on understanding the current market and how this might change over time. The

group developed possible next steps to meet the challenges that were identified.

Reminder: Key Findings 2018

- Develop a stable customer base – by creating a need for products made in space.
- Develop a stable commitment from governments – as anchor customers guaranteeing to buy resources at a fixed price at a given time.
- Develop a stable legal and regulatory framework - bring down risk for investors.
- Develop a critical mass of investments - for sustaining the sector.

Key Questions

- What are the current demand drivers for space resources, how will they evolve in the future?
- Which factors will drive the ability to finance space resources projects and ventures?
- What factors could drive the valuation for space resources ventures?
- What government policy options might best encourage the sustainable development of space resources markets?
- Is there any progress notable over the last year?
- What actions need to be taken to achieve future goals?
- How can the two industries support each other to make it happen?

The two last questions aim to develop and present actionable recommendations.

Major Takeaways

Current Situation (or What are the current demand drivers for space resources, how will they evolve in the future?):

The group of experts recognized that the market is looking for a driving catalyst, acknowledging that, beyond GEO, the market is in a development stage equivalent to the early Internet. Currently, governments and space agencies are the main customers. One point was highlighted regarding the lack of coordination between different elements of the value chain and that there is a gap of communication between the space community, customers and investors. Finally, the group stressed that the present commercial space services may sustain the

development of a future commercial space resources market. Additionally, the group agreed that propellant is one of the key products for the short-term market.

Challenges (or What would be the ideal situation):

The group identified challenges, highlighting the need for collaboration between terrestrial and space industries. They stressed the importance of having both terrestrial and space resources companies increase interaction with their customers in order to develop stronger business cases. These challenges are short, mid and long-term. The group of experts highlighted the following challenges to achieve an ideal situation:

- Off-world outposts and colonies may trigger the development of a space resources market
- The space-to-Earth short term and space-to-space long term pathways
- Space laboratory facilities may use space resources to generate high-value products and specialized research for Earth customers
- Moon facilities or tourism will trigger space resource generation.

To build space resources into a strong, sustainable economic sector, more companies and a larger customer base is needed.

The space resources sector needs commitments from governments as anchor customers, as current risk levels are too high and a profitable market is only expected to develop far in the future too far for most investors.

It is also difficult to convince new investors to enter the sector. There exist two types of investors: visionary and conservative. In contrast to space resources, the traditional terrestrial mining industry is a “slow-moving dinosaur” that avoids risky decisions. For its part, the space resources industry needs to evolve from ‘technology push’ to ‘market pull’.

The breakout discussion resulted in six important principles for the community:

1. Elaborate stakeholder communication guidelines (customers, investors, regulators).
2. Develop the integration of end-to-end service solutions.
3. Focus on risk reduction, starting already in the early stage (integration, standardization...).

4. Work on the meaning of resources e.g. Moon, gravity, ...
5. Consolidate the international legal framework and regulations.
6. Have a cultural upgrade, including robust assumptions and a customer pull as well an investor push.

Finally, geopolitical, strategic stakeholders are one of the key customers in the short-term (!).

Recommendations

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, for example, private and/or public outposts on the Moon. Involve potential 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, 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 entry of more companies into the space resources sector.
- Develop a critical mass of investments needed to sustain the sector. Big companies may play an important role in backing small space players (at least initially).

Investment and Financial Planning

Identifying and understanding the risks and criteria for investing in mid-term space mining projects and ventures.

The objective of this breakout group was to identify the challenges for space mining projects and ventures to secure investments from traditional or established sources. The participants included thought leaders from space resources companies, aerospace firms, governments, investment banks, venture capitalists and business angels, and other financial institutions. Shiva Dustdar, the Innovation Financial Lead at the European Investment Bank (EIB), and Richard Aked, the Managing Director of Space Application Services, hosted the session.

To kick-start the discussion, the hosts presented an overview of the mid-term space mining business and investment opportunities and the criteria used by long-term investment tools, such as for mining projects, at the EIB.

Reminder: Key Findings 2018

- Governments should incorporate space resources utilization into their space exploration and science architectures.
- 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.

Key Questions

- What are the current risks and challenges of investing in space mining?
- What are the recommendations for space mining companies and Government to de-risk?

Major Takeaways

Current Situation:

The expected space resources use cases in the near future are based on extracting water from the Moon. However, at this point, the potential commercial customers for these upcoming use cases are non-existent. This leads to current uncertainties regarding customer needs, profitable business models, and market size. These uncertainties make space resources, as yet, an unattractive industry to invest in.

Challenges:

Strategic and financial investors highlight risk factors limiting their willingness to invest. Currently, market demand is still lacking and it is unclear for most companies who customers are in Space. It is therefore difficult for investors to evaluate a space company. Moreover, there is no concrete price tag for space resources, leading to a blurred market value.

Most investors have a short investment horizon and expect a return on investment within a maximum of 5 years. Valuation and revenue generation with space resources, on the other hand, has a time horizon of *at least* 10 years. This discourages conventional investors.

Participants expressed their concern about the lack of a legal framework to legitimize the commercial use of space resources on the Moon, asteroids and other planets, which is another source of uncertainty, and therefore reluctance among investors.

Recommendations

In order to enable increased investment in the space sector, investors and space companies recommend governments to continue to implement the legal frameworks necessary to define schemes and partnerships for space missions.

In general, the media only really report on large private space projects such as SpaceX and Blue Origin. As a result, traditional investors perceive these types of companies as representative of the commercial space industry. Participants would like to see the media carrying stronger messages on the benefits and business opportunities of space in general and a move away from the obvious players who require lots of investment and spend a lot of time on R&D development before commercialisation. Inevitably, it will require some effort to educate investors about the potential of space resources and the importance of certain resources in the near future.

At present, there are no concrete price tags for space resources, nor is the exact availability of resources known. It has been discussed and recommended that a regulated Space Resources Commodity Exchange be set up to generate price tags for space resources. In addition, we should focus on water and oxygen as a first step as they have potential business models in the near future. Estimating prices and quantities of these space resources will help add value to the market today.

The lack of current demand means that space resource companies should try to focus on ‘dual use’ projects, which work on Earth and in space. There is no market in space yet. Therefore, participants agree that companies must find terrestrial markets and applications for space assets and offer their space technologies or services on Earth. In these cases, the space company is often obliged to stop presenting itself as a space company and concentrate exclusively on its capabilities and services for the terrestrial markets. This is the only way for space resource companies to generate short-term revenues.

ESA, the European Commission and European countries should be more aggressive and announce ambitious space missions that boost demand. NASA

leads the way here, communicating major missions and seeking solutions from the private sector. Perhaps other countries can benefit from their international alliances and join or help to shape such major missions.

Overall, the space resources sector is a risky regulatory environment and requires the right financial mechanisms, which are not yet available. These need to be investigated and developed.

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, industry, space agencies, government, and academia. The discussion was chaired by Bob Calmes (Arendt & Medernach) and Gerald Sanders (NASA). Conversation focused on how to find the right balance between an enabling state policy / regulatory environment and the building of a new commercial market.

Reminder: Key Findings 2018

- The group recommended the development of a clear policy statement on what should be allowed in space, giving appropriate legitimacy internationally.
- Governments should act as a facilitator and involve industry in defining what are the right regulations for market sustainability - allowing the industry to set up standards and best practices.
- Determine beneficiaries and how they should benefit. Those taking the risks should be rewarded, as in the mining industry.
- Create a “space resources industry association” or “inter-industry association”, to discuss policy and regulations with governments.
- Work on the ‘sharing of benefits’, such as information.
- Bring together the terrestrial mining and space communities more often.
- A tax-credit scheme for space resources investors should be worked out, encouraging investors to make speculative money available.

Key Questions

- What government policy options might best encourage the sustainable development of space resources markets?
- What role can public institutions play in accelerating the development of this industry?
- What policy options might encourage increased private sector participation in the sector?
- How important is the role of 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 resources 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 neither a production capacity nor market for space resources. The panellists addressed the main barriers to sustainable and commercially viable space resources activities.

First, resources are surrounded by uncertainty, as exploration and estimation of reserves are still in an early developmental stage. Second, mining technology readiness still has to be tested and demonstrated. Third, the users have to be identified and a market has to be developed. We also need to think about realistic market growth potential. Fourth, future space resources activities have to set a high sustainability of operations standard from a transportation, logistics, maintenance and infrastructure standpoint. Fifth, there is uncertainty related to the regulatory aspects such as the required legal framework, property rights, standards and taxation.

Governments are able to, and should, play a key role in reducing the existing barriers. However, government initiatives should not overwhelm the efforts of the private sector.

Challenges:

Some participants raised the question of what role the government should play: facilitator or regulator. This calls for a very balanced approach that would allow governments to assure proper administrative function *and* manage the related risks.

Commercial viability is an important driver for space resources technology advancement and spin off to Earth solutions. There remains the pressing question of environmental issues and the needs of the Earth vs purely economic interests.

Lack of state-unified policies and uneven advancement on-Earth activities and minerals policies is a very real challenge.

Ethical considerations are very often raised by society: why should we expect people to behave better in space than on Earth?

Recommendations

The core question remains: how do we reach a sustainable industry and how do we manage the “impossible balancing act” with basic space treaty principles and humankind’s interests.

The splinter session participants suggested the adoption of an open and inclusive approach to government’s involvement. Administrative functions should be considered along with the regulatory framework. The terrestrial system could be easily transferred to the space sector. Such an approach could rely either on a national authority or an international body, both with their advantages and disadvantages. Governments from all development levels should be properly involved.

The panel concluded that discussions in international forums such as UNCOPUOS⁵ need to continue. On a national level, governments should evaluate existing administrative requirements and consider how current barriers can be reduced.

There is a need for governmental funds to be invested in a sustainable and responsible manner. Governments should continue to invest in their limited capacity (directly, indirectly – tax credits equal to investments). Governmental investment should also

⁵ United Nations Committee on the Peaceful Uses of Outer Space

significantly contribute to resolving pressing problems on Earth.

The good safety and reputation of mining activities along with social responsibility should be prerequisite: terrestrial applications could significantly benefit from technologies coming from space exploration.

Industry associations, non-political in nature, are needed to support governments in creating future policies and frameworks.

Finally, governments should think about creating a dispute resolution body.

Prospecting - Proving Value

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

This breakout session was composed of almost 40 professionals from space and terrestrial resources companies, academia, research institutes and government. It was chaired by Steve Hunt (Chairman of JORC⁶ and Chief Advisor Resources and Reserves at Rio Tinto) and Clive Neal (Professor at the University of Notre Dame). To start the discussions, Carlos Espejel (ispace Europe) gave an introductory presentation on the Lunar Ore Reserves Standard (LORS).

Reminder: Key Findings 2018

- Need for ground truth data - mobile vs. static landers as vehicles and drilling vs. trenching as sub-surface access methods and techniques.
- Develop better communication between the terrestrial and space mining communities. Currently, both use the same terms, but use them differently - the terms used in space need to be clearly defined.

⁶ Joint Ore Reserves Committee, <http://jorc.org/>

⁷ Committee for Mineral Reserves International Reporting Standards, <http://crirSCO.com/>

⁸ Petroleum Resources Management System, <https://www.spe.org/en/industry/petroleum-resources-management-system-2018/>

Key Questions

- Currently, in terrestrial mining, what level of detail is required before engaging in a mining operation?
- What technologies are needed to achieve this level in space?
- When can we talk about ore/reserve/resource in a space context?
- What does already exist in terms of reporting standard?
- What needs to be included in a space resources standard?
- Who should be involved in the definition of such a standard?

Major Takeaways

Current Situation:

The group of experts noted that, for iron and titanium, prospecting on the Moon is already sufficient. On the other hand, for water related to the unknown cold traps, probably the first mining product, it is not. The spatial resolution of prospecting is currently low, and is only done in 2D, not in depth.

Additionally, current prospecting does not address extractability, although the efficiency of extraction is critical. Current TRLs (Technology Readiness Levels) for the needed extraction technologies are in the range of 3-4 (out of 9), thus maturation is necessary.

Current prospecting missions are publicly funded, the work of space agencies right now is comparable to pre-competitive work of geological surveys. A good example of a lesson learnt was mentioned in the form of publicly funded prospecting of uranium reserves, which proved valuable only at a later stage.

Concerning existing terrestrial reporting standards, there are several that can be used for inspiration, such as JORC⁵ and CRIRSCO⁷ in mining. In oil & gas, the main code is the PRMS⁸ by the Society of Petroleum Engineers, while the UNFC-2009⁹ combines both worlds.

⁹ United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources, https://www.unece.org/energy/se/unfc_2009.html

Challenges:

The participants noted that prospecting is a campaign, and not a single mission. Getting the best results will require on one hand, accessibility with robotics. On the other hand, the right processes are needed: How deep do we drill? What is the spacing of the drill holes? Therefore, depth and continuity information is needed, e.g. with radar and neutron data.

All participants agree that big risks exist, both in the market and the technology, and that these risks need to be reduced. Concerning technical risks, the opinion of the group was that risk reduction needs to be done in parallel fashion (extraction, processing, manufacturing...) instead of serial, as the process will otherwise take too long. Additionally, uncertainties need to be mapped to efficiently direct investments.

On the market side, more data is needed to allow business plans to be put together with enough credibility to attract investors. The question here is: who owns the lease? NASA's data is publicly available, in the same way as the USGS on Earth, but they get their return on invest by selling the lease. This will currently not work on the Moon. So, who will pay for these prospecting missions? On Earth, geological surveys do it. Could space agencies be the equivalent in space?

If prospecting is to be economically viable, a customer or customer base needs to be defined, else prospecting is not needed. However, prospecting missions could provide data that proves the usability of a resource, and thus provide customers.

To attract investors, you need to know the product demand early on and to understand at what stage of ISRU you are in.

Finally, is there a need for a descriptive framework (reporting code) for off-world resources? Most costs, such as for extraction and processing, have not been defined yet, so the complete costs of using resources is unknown. This makes getting investments difficult. Just going from "exploration target" to "inferred resources" will not be sufficient to attract investors. Therefore, the group agreed that such a code is needed, as using space resources has never been done before.

¹⁰ NASA Commercial Lunar Payload Services, <https://www.nasa.gov/content/commercial-lunar-payload-services>

In conjunction, a new economic model for space mining may be needed.

Recommendations

Summarizing the discussion, the following recommendations were given by the group:

- **Ownership** needs to be clear: you only have value if you have the rights to extract. This is core in terms of being able to use space resources.
- **Risk reduction** must happen across the board: in extraction technology, exploration target ground truth and so on. This will establish the viability of mining operations, secure next stage funding and create a market. Better understanding of the entire discipline will enable risk determination. Alternatively, space agencies can contribute to risk reduction in several dimensions, including market and technology development. This can be achieved, for example, through strategic governmental investment.
- Have partners from **other industries**, such as terrestrial mining, with instruments that can be easily adapted or with instrument ideas, to test them on the Moon through CLPS¹⁰-like programmes. This could be part of the funding solution.
- Create a **virtual market**, trade space resources without actually mining them yet. You will still need to know that there is potential, through prospecting and 'exploration target' stages. Alternatively, create virtual clients, represented by space agencies for instance.
- Develop a **reporting framework** to qualify and quantify the resources for investors.

Extraction - Creating Value

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

This technical session, addressing everything from extracting a resource to processing it, was chaired by Françoise Allain, a Mining & Mineral Process Expert at TechnipFMC, a global supplier to the terrestrial oil and gas industry, and by Professor Angel Abbud-

Madrid, Director of the Center for Space Resources at the Colorado School of Mines.

Reminder: Key Findings 2018

- From an operational point of view, automation and autonomous systems are considered critical for operating a mining operation in extreme conditions
- Both terrestrial and non-terrestrial industries can support each other by developing baseline technologies on Earth and reutilizing them later as validated technology in space. This applies to the following areas: robust sensors in combination with machine learning and artificial intelligence techniques, waterless operations, fuel cells, robots and autonomous systems in general.

Major Takeaways

The participants of this session agreed that the topic is very broad and in order to have a fruitful discussion between the terrestrial and space industry, it would be best to choose a specific use case. The terrestrial mining and oil & gas industries have developed many technologies that could potentially be reused in space. However, in order to identify a specific technology, it is important to have clear requirements.

The participants decided to focus their discussion on the production of oxygen from regolith, as, compared to the trapped volatiles in the permanently shadowed regions (PSR), there are less uncertainties around regolith, which is widely available on the Moon. Furthermore, this will be a relevant use case, as oxygen will certainly play a major role in the first years of lunar ISRU developments. The following processes with regard to oxygen production on the Moon were briefly presented and discussed: hydrogen reduction, carbothermal reduction, molten salt reduction (FFC).

Some participants pointed out that beneficiation is an important stage that allows improving the efficiency of the process. Magnetic and electrostatic separation, crushing and sieving technologies are available for terrestrial processes and could be adapted for use in space. In order to select the most suitable, the mining industry needs to know the basis of design for a lunar operation. They need to know the characteristics of the material in order to define technical requirements for the equipment and processing plant.

Collaboration between the terrestrial and the space industry will be essential and the terrestrial industry acknowledged that they can support the ISRU community through their general expertise in handling and processing resources. Collaborating with smaller mining companies and advanced equipment providers seemed to be the most promising route. In order to make this a win for both sides, it is also important to identify technologies from space that could be reused in a terrestrial mine.

In line with this idea, the participants identified several areas with possible synergies. Smaller automated plants and rovers to be operated in extreme environments, in combination with swarm technologies, are areas where both sides could potentially benefit in the years to come. Both industries could also collaborate in developing new, more efficient and environmentally friendly processes, in line with the concept of a waterless mine or carbon-neutral steel production.

A last point addressed in this session was the need for ground based testing. Some people argued that, as it is impossible to recreate the exact lunar environment on Earth, any process and technology will have to be validated on the Moon. Testing on Earth should therefore be limited to the minimum and the community should learn from experiments on the Moon.

Recommendations

In order to progress and bring the discussion on In-situ Space Resource Utilisation to the next level, the participants agreed that it is important to demonstrate in the near future that the use of space resources is possible. In line with the focus chosen at the beginning of the session, they recommended to have, as early as possible, a small ISRU demonstration mission on the Moon that is capable of producing oxygen from lunar resources. Such a demonstrator could be delivered to the Moon's surface with a commercial provider, possibly in the frame of NASA's CLPS program. Some participants suggested burning a candle on the moon with this oxygen in order to engage with the public.

Enablers – Optimizing Value

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

This breakout group had representatives from space resources companies, terrestrial mining, academia and government. It was chaired by Serkan Saydam (Professor at the University of New South Wales) and Chad Hargrave (Research Team Leader at the Commonwealth Scientific and Industrial Research Organization). The breakout focused on identifying the critical technologies and processes that support mining projects in extreme conditions and identified actionable recommendations to move the two communities toward increased collaboration.

Reminder: Key Findings 2018

- Possible areas of collaboration from space to terrestrial mining include automation, robotics, and big data analysis.
- Possible areas of collaboration from terrestrial to space resources included conventional mining methods e.g. micro tunnelling, strip mining, in-situ leaching (chemical mining), and fundamental rock breakage technologies (including laser cutting).
- Recommendations for future activities included the note that space miners can learn more about the terrestrial mining industry by attending established mining conferences.
- A good catalyst for collaboration could be a DARPA-like competition supported by teaming terrestrial mining and space resources companies.

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 (or What can terrestrial mining do for space resources, and vice-versa?):

During the discussion there were many areas identified where current terrestrial mining could inform and support the emerging space resources industry.

Terrestrial mining companies are adopting a modular design architecture that can be more easily modified and tailored to fit the changing realities they face as mines mature – making it more difficult to retrieve the ore. They must go deeper and chase smaller seams, which is more demanding on their equipment and resources. One current trend is to have small mining vs. mass mining approaches.

- Terrestrial miners have a deep understanding of production and processing. This knowledge can help space miners understand what approaches could be profitable.
- There are benefits to be had from creating a market for knowledge transfer terrestrial miners to their space cousins. This would feature technologies such as:
 - Nanobots/small robots, micro-tunnelling and swarm robotics
 - Remote sensing technologies
 - Communications – dealing with latency and availability
 - Reliability in communications, pose estimation, and automation

Challenges (or What issues should be addressed now):

As was discussed at the 2018 Summit, the group identified the need for increased collaboration between the two industries and the potential benefits of knowledge transfer traveling in both directions.

In addition, the following challenges were identified for the space resources industry, with the recommendation that working together could provide solutions that may benefit both groups.

- **Energy** requirements are enabler resources and there are innovative solutions in development such as power beaming.
- **Drilling** technologies for space should look at the new techniques being used in terrestrial mining and adapt them to the space environment.

- **No current market** for mining industries in space, and the challenge is – what needs to be done to create a market in space in the next 20 years?
- **Market stability** - if launch costs are reduced, is there a LEO market for water for propulsion? Like any market, this one may evolve over time, especially if there is human settlement in space.

Recommendations

The breakout discussion focused on a recurrent recommendation from last year - how can we inspire space and mining companies to work together? They proposed three actionable activities:

- To help space and terrestrial mining companies collaborate, there could be a global competition using the Google Lunar XPRIZE model to require teams to have both space and terrestrial mining companies as members. Major mining companies have expressed interest in creating such an activity. The focus of the prize would be on important mining industry driver other than just money. These drivers could focus on the environment, safety, social acceptance and new knowledge outcomes.
- Continue to identify common areas for collaboration where the two industries can work together, such as, on safety and on environment.
- Continue to discuss and identify dual-use technologies for space and terrestrial mining.

IV. CONCLUSION

The second Mining Space Summit was a great success, as was the whole Space Resources Week. By attracting more representatives from the terrestrial resources industry, it represents an important step forward towards establishing a meaningful connection between two industrial sectors, terrestrial resources and space resources.

With the attendance of more than 180 experts, we had a significant increase of participants, only limited by the size of the breakout session groups. One important metric was the participant representation - 58% from space, including start-ups and global players, and 42% from mining, oil and gas industries, finance, and (non-space) 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 the discussions, and will help to set the foundation for future work.

The 2019 summit was only an intermediate step of a long-term process to identify areas of collaboration between the two industrial sectors. Space Resources Week 2020, announced at the end of the ESA ISRU Workshop, will happen between the 5th and 9th October and will build on these results.