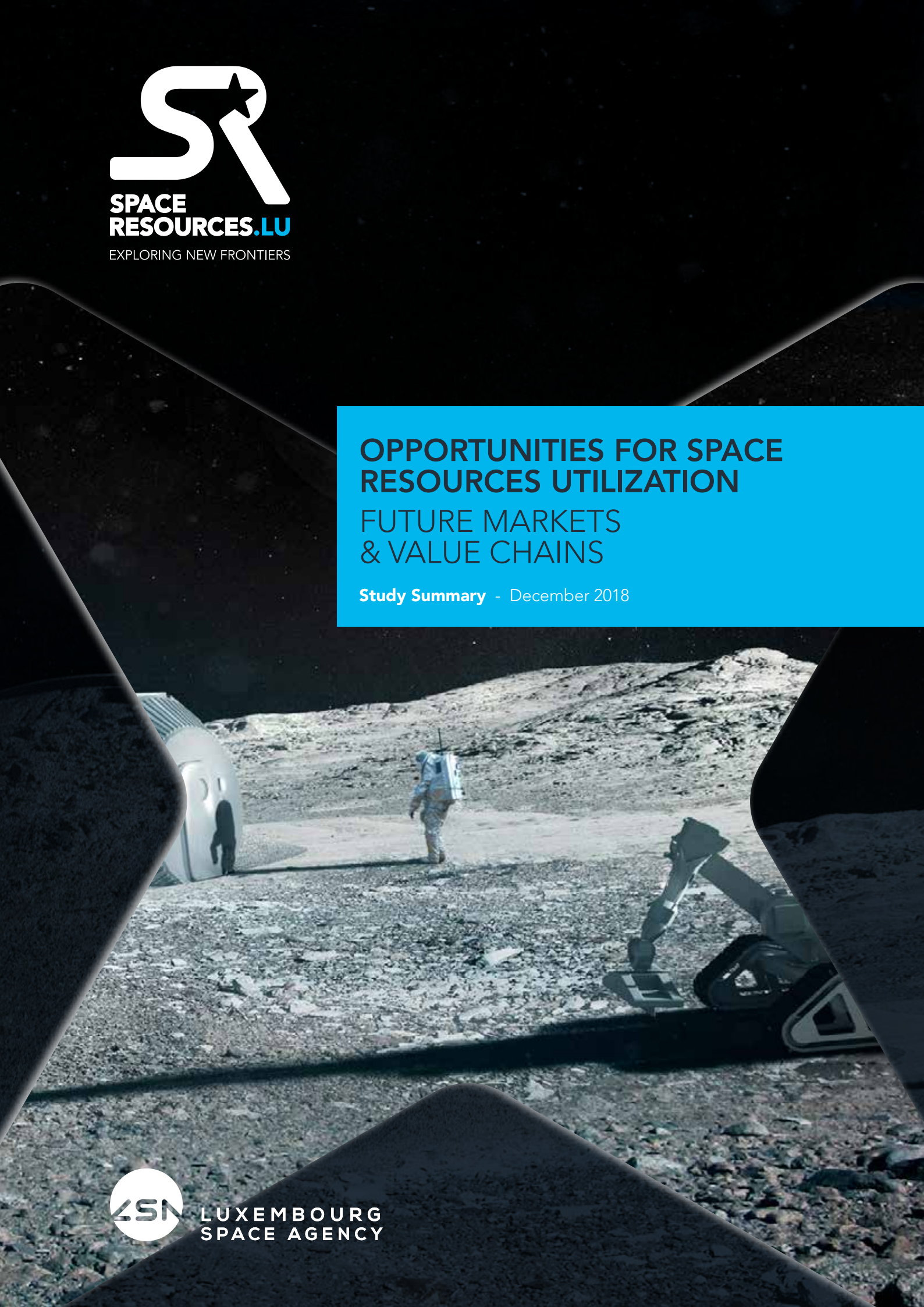
SPACE RESOURCES.LU

EXPLORING NEW FRONTIERS

OPPORTUNITIES FOR SPACE RESOURCES UTILIZATION

FUTURE MARKETS & VALUE CHAINS

Study Summary - December 2018



LUXEMBOURG SPACE AGENCY

INTRODUCTION

The vision of the SpaceResources.lu initiative, launched by the Luxembourg Government is to contribute to the peaceful exploration and sustainable utilization of space resources for the benefit of humankind. The focus for achieving this goal is to support and promote the development of a sustainable commercial industry for space resources utilization.

Luxembourg's strategy for pursuing this exciting vision is based on several key points:

- Large quantities of space resources are available in the Solar System;
- Incorporation of space resources into exploration missions will reduce costs and improve their economic viability;
- Space resources will play a foundational role in future in-space economies;
- Space resources technology has multi-sector, near-term commercial value in existing terrestrial markets.

The exploitation of volatiles – mainly water – and other resources such as raw regolith or metals available on celestial bodies requires the establishment of new supply chains for effective utilization. Although the time horizon for the first operational applications are expected to be in the next decade, preparatory steps are being taken today in developing the enabling technologies and obtaining prospecting information on future exploitable space resources. It is in the interest of pioneering space companies, space agencies, and other visionary organizations to ensure they capture early opportunities and anticipate future needs for the space resources utilization value chains to emerge.

ASSESSMENT METHODOLOGY

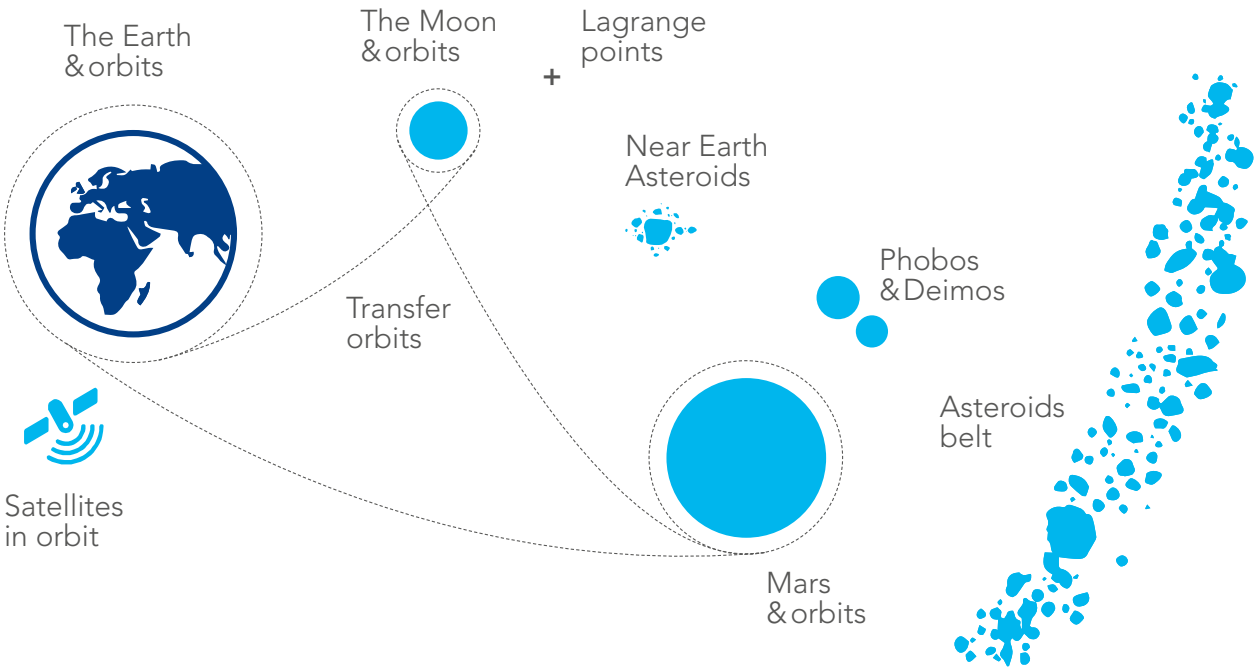
In line with the vision of the SpaceResources.lu initiative, the Government of Luxembourg commissioned a study to identify the potential markets and value chains for using space resources and the opportunities they will create. In addition to an extensive literature review, data was collected from a large number of interviews with community experts in space agencies, private companies, and universities.

This data supported an extensive analysis of the demand side by considering all possible applications of space resources as well as an in-depth look at the supply side and cost-profiles of space resources missions. The analysis assessed the technical aspects and socio-economic benefits of this promising new industrial sector, and confirmed the enormous opportunities that lie in front of us.

SPACE RESOURCES
UTILIZATION VALUE CHAINS

Primary drivers for the establishment of the space resources industrial sector are determined by their effect on the affordability of space missions and their ability to provide autonomy to the missions by enabling them to 'live off the land'.

Many materials are of potential interest for space resources utilization, and they can be prioritized based on a combined examination of the supply side (which resources are available on the celestial bodies of interests) and of the demand side (what applications would benefit from these resources). Analysing the different value chains includes characterizing the amount of required material available at different locations in space, along with the type and location of their uses, then comparing the costs of using space resources to the costs of using materials provided directly from Earth. If space resources are cheaper in the particular case studied then this becomes a potential opportunity for commercialization.



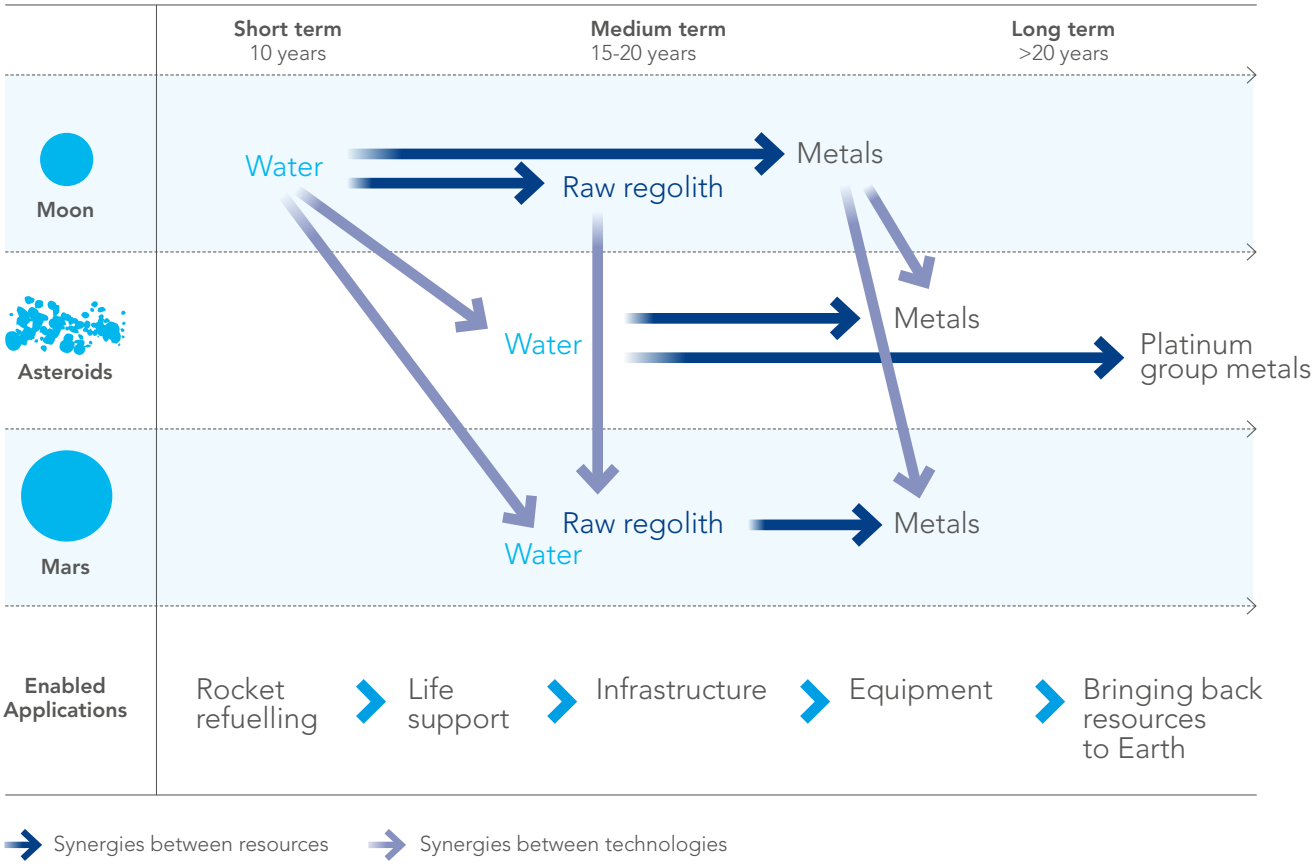
Celestial bodies considered for the assessment of the space resources utilization value chains.

Relevant applications include: life support, rocket propellant, planetary surface construction, in-space manufacturing, radiation shielding, as well as, the return of high-value materials to Earth. Examples of the types of space resources considered include: water, methane, metals, regolith and platinum group metals.

The overall space resources utilization value chain is segmented into the primary building blocks as shown below.

This value chain and its building blocks might lead to different value chains depending on the targeted resource, celestial body and timeframe.

Cross-cutting activities such as launch and logistics, telecommunications, as well as energy provision are also seen as important areas, supporting the whole value chain. The high level roadmap below shows how space resources value chains will develop over time.

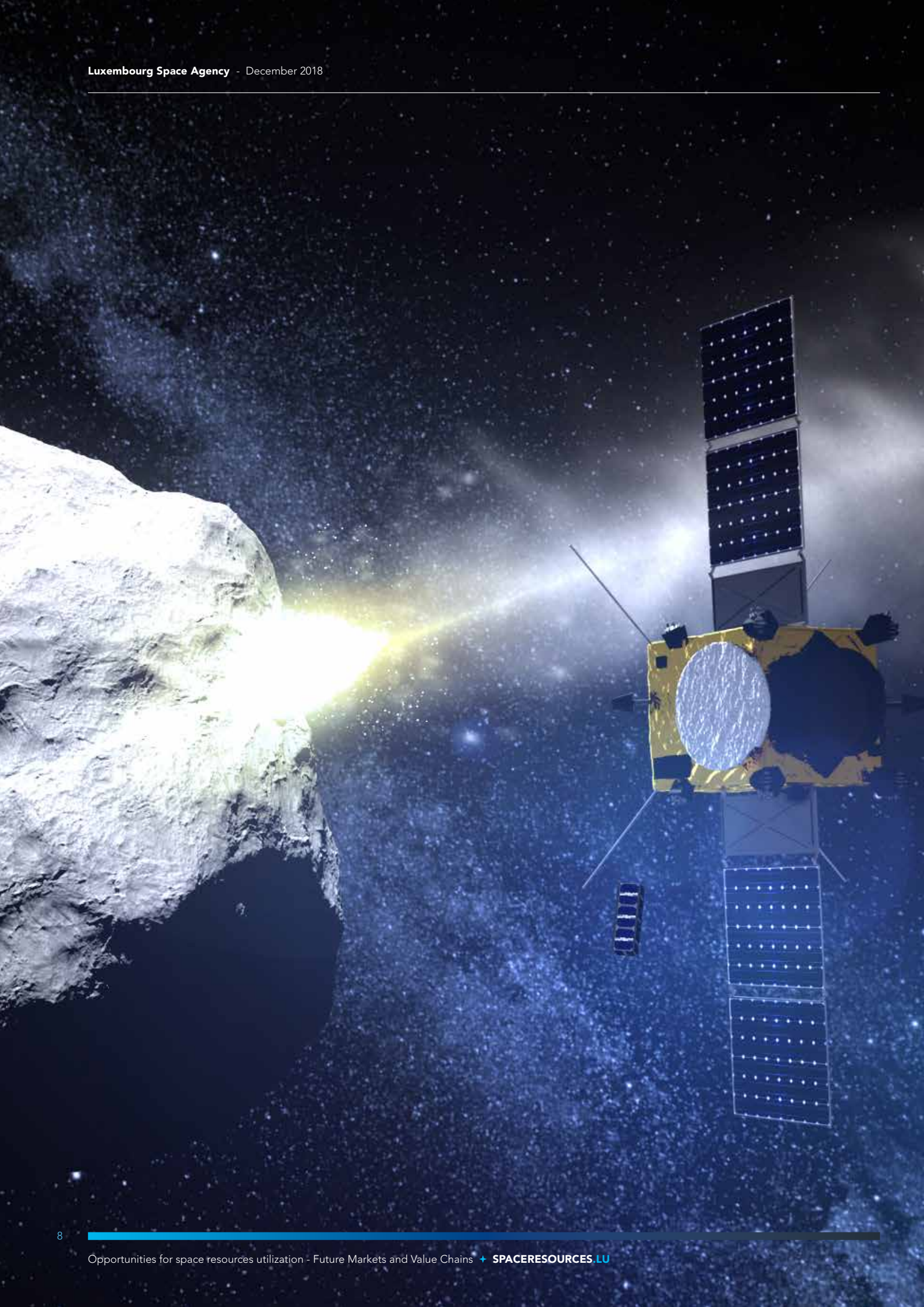


The value chain for rocket propellant offers the most viable business case and best near-term opportunity, because of high confidence in demand and availability of resources (water) on the Moon. The transportation of humans to different celestial objects will drive a major part of the demand for fuel, but in addition, the in-space servicing industry will also be a primary user of fuel such as Methane (CH_4) and Water (H_2O).

For life support, seen as a mid-term business opportunity, human presence in Low-Earth Orbit and on the Moon is expected to follow a smooth progression as experts estimate off-Earth population growth to reach a total of several dozen by 2045. The most aggressive migration of humans to space is given by the estimates for future Mars missions. The process of populating Mars is predicted to evolve very rapidly to many tens of people in the 10 to 15 years after the first settlers arrive.

Other mid-term opportunities include space infrastructure development and in-situ equipment manufacturing. These areas will drive the demand for metals (in particular Iron and Nickel) and regolith. Additionally, the utilization of space resources for these applications will actively contribute to reducing launch costs.

The platinum group metals value chain will only develop in the longer term, primarily due to technical challenges to extract the elements from in-space locations, while remaining competitive with Earth market prices.



SOCIO-ECONOMIC IMPACT

Using space resources is expected to create socio-economic benefits in three major areas:

The first area is the space resources utilization industry itself, which is expected to generate a market revenue of 73 to 170 B€ (Present Value 2018) over the 2018-2045 period, supporting a total of 845,000 to 1.8 million Full Time Employees - Years. Efficiency gains in the form of cost savings for the end-users (i.e. customers of space resources) are estimated at 54 to 135 B€ (Present Value 2018). This figure accounts for fuels (CH_4, H_2O), water (H_2O) for life support, and materials for equipment and infrastructure (regolith and metals).

The second area involves knowledge and technology spillovers represented by technological developments associated with space resources value chains which are expected to encompass several technical domains, such as materials science, manufacturing, additive manufacturing, robotics, and data analytics. It is forecasted that these spillover benefits will be in the order of 2.5 B€ over 50 years (Present Value 2018). Network spillovers, are predicted to have very strong effects from industrial clustering which facilitates the interchange of knowledge and personnel between organizations. There will also be strong effects from the development of standards for the new industrial sector.

Finally, the space resources value chains are expected to contribute to wider effects with a strong contribution to social and strategic benefits by enabling space exploration and development, and with some contributions to environmental benefits by lessening dependence on Earth's finite resources.

NEEDED TECHNOLOGY

The technology for space resources utilization processes exists at a low to medium Technology Readiness Levels. Major steps need to be taken in demonstrating the technologies at an advanced stage on Earth and then raising readiness levels for use in flight. In addition, the technologies need to be flown in space to demonstrate to investors, agencies and other stakeholders that the scenarios deemed economically feasible are also technically possible.

Different kinds of technologies are required across the value chain. The technologies have been classified in the following groups:

Prospecting technologies
Technologies supporting the prospecting and exploration of the resource through geophysical and mineralogical measurements, pinpointing deposits of interest, and obtaining data to support their exploitation.

Mining technologies
Technologies enabling the extraction, local transportation, beneficiation and handling of the bulk material.

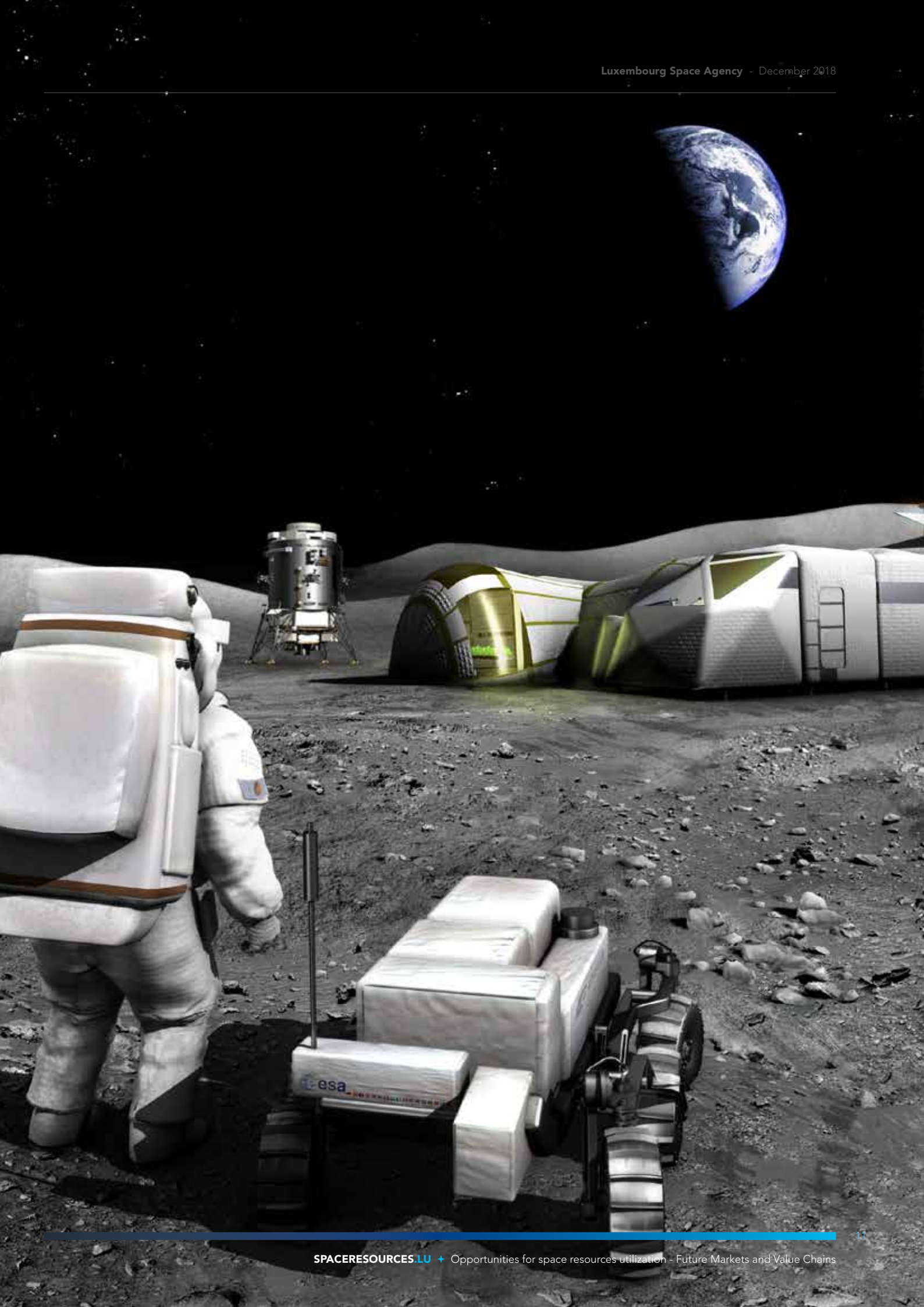
Transport and supply technologies
Technologies enabling the transportation of the resources through space to the point of storage or utilization, and/or back to Earth.

Refinement technologies
Technologies allowing the processing of the material in order to obtain the final products like structural materials in intermediate or final shape.

Manufacturing technologies
In-situ creation of structural elements and fabrication of everyday tools; for example through the use of 3D printing.

Supply (storage) technologies
Technologies to store and transfer the resources, in particular oxidizers and fuel.

Support technologies
Technologies applicable across the whole value chain, and necessary to support space resources utilization operationally, including software, robotics, communications and energy technologies.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CHALLENGES

Realizing the potential benefits of space resources remains challenging and requires global partnerships. There are technical and commercial challenges, but also regulatory and financial ones. Technical capabilities necessary for enabling the entire value chain from prospecting to utilizing space resources must be developed, tested, and matured. Identifying capabilities needed for space mining that also have near-term business potential is required to ensure incremental growth as the market today is nascent and will need time to mature.

International and domestic legal frameworks need to be established to protect entrepreneurs, assure investors, and ensure responsible business activities. Significant investment with long-time horizons must be available to enable private firms to develop and deploy critical systems.

FINAL THOUGHTS

Defining a near-term set of space resources utilization value chains made it possible to estimate future resource markets which in turn informed the development of a strategy to reach towards the visionary goals of the SpaceResources.lu initiative. Although space resources utilization still has some uncertainties requiring planners to make several assumptions, the analysis of the different value chains revealed a number of promising aspects for the future of this important industrial sector.

There are opportunities across all stages of the value chains that can be leveraged to create commercial benefits, in particular, early prioritization of specific space resources and uses were identified along with areas for further technology developments. The collaboration between space actors and the terrestrial mining industry is expected to play a central role in the successful development of space resources by leveraging experience and know-how of mining companies.

Importantly, space resources utilization can generate sizeable socio-economic benefits, including economic impacts, employment, market spillovers, and technology spillovers. Cost savings assessments have demonstrated substantial cost reductions for space missions, revealing viable markets for space resources products.

LUXEMBOURG SPACERESOURCES.LU INITIATIVE

The Luxembourg Government decided to launch the SpaceResources.lu initiative based on its past successes in the space sector. The initiative aims to contribute to the peaceful exploration and sustainable utilization of space resources for the benefit of humankind.

To create the strong foundation required to support and promote the development of a commercial space resources utilization industry the Luxembourg Government is working on a five pillar strategy:

- Ensure national political support and promote international cooperation
- Build clear legal framework and engage internationally
- Promote long-term public support and workforce engagement through education and R&D
- Provide dedicated support for industrial research and development activities
- Develop investment instruments focussed on commercial space

Since its launch in early 2016, the initiative has made considerable progress on all pillars, resulting in the establishment of companies addressing different areas of the space resources utilization value chain.

Luxembourg has signed dedicated bilateral agreements with multiple countries and has stepped-up its engagement on the European and international level. In particular, it supports discussions on the utilization of space resources in forums such as the UN-COPUOS or the Hague International Space Resources Governance Working Group.

In August 2017, the Luxembourg Parliament enacted a law on the exploration and utilization of space resources, making it the second country in the world that recognizes the possibility of resources ownership by private companies, as well as laying down a specific authorization procedure for corresponding missions.

Luxembourg continues to strengthen its public research institutions and has developed a space master programme that will feature, amongst others, courses on space resources utilization. Through its engagement with the European Space Agency, Luxembourg has provided dedicated R&D support to companies.

In the area of investment, Luxembourg signed an agreement with the European Investment Bank to enhance access to finance for innovative projects supported under the SpaceResources.lu initiative.

In closing, Luxembourg is keen to establish partnerships with companies, research centres, investors and organizations from around the world, for regulatory, research, innovation or finance related areas.

CONTACTS FOR FURTHER INFORMATION

Whether you are a company, a governmental organization or an investor, if you require any further information about the study or the SpaceResources.lu initiative, please contact the following persons of the Luxembourg Space Agency team:

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The view expressed herein does not necessarily reflect the official opinion of either the European Space Agency or the Government of Luxembourg.