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General exchange of views on potential legal models for activities in the exploration, exploitation and utilization of space resources

Luxembourg – Input to the Working Group on Legal Aspects of Space Resource Activities

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Current Status and Priorities of Space Resources Utilization

Views provided by the European Space Resources Innovation Centre

Introduction

Launched in 2020, European Space Resources Innovation Centre (ESRIC) is an initiative of the Luxembourg Space Agency (LSA) and the Luxembourg Institute of Science and Technology (LIST) in strategic partnership with the European Space Agency (ESA). ESRIC is a national centre dedicated to space resources with the objective and mission to become an internationally recognised centre of expertise for scientific, technical, business, and economic aspects related to the use of space resources for human and robotic exploration, as well as an in-space economy for peaceful purposes.

ESRIC aims to promote open innovation by providing access to unique research facilities and experts, support technology transfer between space and non-space applications, nurture the emergence of a lunar economy by supporting related business-driven initiatives and incubating start-ups, facilitate dialogue and information exchange between community members world-wide, and promote public and private investments in Space Resources related activities.

In the following overview, ESRIC provides its views about the current status and priorities for selected key areas related to space resources utilisation.

I. Current Status Overview of Space Resources Technology

The use of resources found in space, such as water, oxygen and metals, has the potential to transform space exploration, providing the means to support longer missions to the Moon, Mars and beyond and to increase significantly our activity in space. This can only be achieved through international collaboration, innovation, and promises not just to scientific advancement but also to the unlocking of new economic and technological opportunities.

In recent years, the Moon has become the focus of interest for space-faring nations, with a significant increase in planned missions. This renewed lunar focus, driven by initiatives of the states with advanced space capabilities, signals a shift towards not only returning to the Moon but establishing a sustainable human presence there. Much of the focus of recent and planned missions is on finding water ice on the Moon, which would support refuelling and human life support in addition to generating significant scientific value to the planetary science community.

The topic of space resources is broad, encompassing many disciplines and many parallel developments in technology.

1. Technology Research and Development

- **Resource characterization**

Knowledge of resources, for example the size and location of resources of interest, is the first step in what is often referred to as the 'value chain' for production of usable resources in space. Scientific interest in the composition of planetary bodies in our Solar System, particularly the Moon and Mars, has resulted in many missions to gather data from satellites by remote sensing, and in situ at the surface.

Data collected by satellites orbiting the Moon provides information on surface temperature, elemental composition and inferred water content, in addition to images from cameras. Surface measurements included composition and inferred water content. Current satellite data to detect water is limited by spatial resolution (e.g. a low number of measurements per unit area), which "ground truth" data demonstrating the presence of water have been limited, namely the LCROSS impactor in 2009 which showed the presence of water in a permanently shadowed region near the Moon's

South Pole. Missions planned in the coming years will seek to find, characterize and quantify this potential resource and to prospect for lunar resources, especially for water ice, in the south pole region.

- **Harnessing resources**

The extraction of water, oxygen and metals from planetary materials has been the key focus for R&D efforts related to in situ resource utilization (ISRU) for several decades. The lunar regolith contains 40% oxygen, and several technologies have been proposed to chemically separate the oxygen from the other elements comprising the minerals that make up the lunar regolith (e.g. iron, titanium, aluminium). Currently electrolysis is the favoured approach, either molten regolith or molten salt – neither of these technologies have been tested in the space environment to date. The research is based on technology and process development, and on understanding the operation of these technologies on Earth using lunar regolith simulants. Various approaches have been proposed to extract water ice from regolith, such as heating, however technologies are based on current knowledge of water ice, which is limited.

In addition to the extraction process, technologies to excavate the regolith, transfer the material into the reactor, transfer material and products out of the reactor, purify and store the product are all required. Each of these processes requires expertise from a different discipline, with the knowledge of the space environment. There exist numerous challenges in adapting these processes efficiently for viable long duration lunar operations, which highlight the need for further development to ensure reliable operation and to understand the economic viability in extraterrestrial environments.

- **Infrastructure**

To support the future space resources vision, there is a need to build essential basic infrastructure, such as landing pads, shelter and transport routes on the Moon, in addition to providing for the power needs. Research effort to date in construction has focused on the use of the lunar regolith to build structures using additive manufacturing (both with and without polymer binders), thermal treatment (e.g. sintering) and making bricks and tiles. Due to the relative simplicity compared to the extraction of usable material (see above), there have been many studies and approaches proposed. Technological development for viable long duration missions and adaptation to the space environment are key considerations.

With respect to power, most of the focus has been on the use of solar power – in particular the production of solar panels made from lunar regolith is the focus of two industrial actors in the sector. Novel technologies for energy storage are also under development. Nuclear power is not under consideration at present by every country active in this field.

- **Challenges**

There are numerous challenges in developing technology that will support future space resources activities from individual units to the entire system. A lack of in situ data on resource characterization and physical properties of the lunar regolith present challenges in developing effective extraction and processing technologies. There is a scarcity of in-situ acquired samples with which to compare simulants. A lack of clear target locations and/or vision results in a lack of clear design guidelines (e.g. scale) for the systems that are being developed. There is a need for common standards and interoperability.

2. *Research on Earth and Development*

To support the R&D effort to develop ISRU systems that will operate in the space environment, ground-based facilities are being built. These will support the community to derisk technology, raise technology development level for complex units and systems, and to compare and optimize systems prior to spaceflight. Below are described specific technology blocks to support future lunar missions.

- **Systems testing**

While much of the R&D effort is focused on individual units or processes, there is a need to test components and units as part of a larger "end-to-end" system. ESA is supporting the design and eventual construction of a ground-based pilot plant, based around the process for production of oxygen from lunar regolith, which will be hosted at the ESRIC. Some states are developing facilities will enable testing of integration of advanced technologies to ensure scalability, operational feasibility, and comprehensive system understanding.

- **Relevant environment**

Global infrastructure for space resources research includes ESA's LUNA Moon surface analogue test bed in Cologne with regolith simulant and similar facilities worldwide plus a wide range of test beds filled with various simulants, multiple Dusty Thermal Vacuum Chambers (DTVCs) for testing in space-like vacuum and dust conditions, and low gravity simulation through parabolic flights and drop towers, and space flight certification centres.

- **Challenges**

The development and integration of space resource utilization technologies face significant challenges, particularly due to the diversity of technologies involved and their up- and downstream dependencies. Integrating systems ranging from resource extraction to processing and utilization requires seamless interoperability across a broad spectrum of technological platforms, each with its unique specifications and operational parameters. Addressing these challenges necessitates a multidisciplinary approach, combining expertise in materials science, robotics, thermal dynamics, and other fields, to ensure the reliability and efficiency of space resource utilization missions.

II. Priorities

1. Knowledge of resources

Understanding the composition, distribution, and accessibility of space resources is critical. Data obtained for resource characterization, both remote and in situ is of significant importance to the planetary science community in addition to the space resources community. Knowledge expansion in these areas will guide mission planning, technology development, and the identification of potential resource-based opportunities.

2. Lunar environment

Detailed studies of the lunar environment, including its regolith varieties, topography, and potential resources, are essential for designing effective resource utilization strategies and supporting infrastructure.

3. End-to-end system development

Integration of scientific and technical priorities is vital for the development of technologies that are efficient and scalable to the needs of future missions. This includes considerations for system architecture, operational methodologies, and environmental impact.

4. Scaling

The economic viability of space resources activities depends on developing a clear value proposition for space resources in existing and future markets. This encompasses market analysis, investment in accelerators and business incubators, and the formulation of financial models that account for the high upfront costs and long-term returns of space resource initiatives.

5. Economic Impact

The focus on the Moon not only signals a shift towards sustainable extraterrestrial exploration but also the increasing role non-governmental actors. Some national governments are engaging with the private sector to support their efforts and strengthen their capabilities and economic impact. In the future, scientific developments and discoveries might lead to new economic opportunities and creation of jobs over the next 15-20 years. This development is incentivised by governmental support, marking the Moon as a primary objective for current and future space activities.

6. Diverse Sectors

The technological development associated with space resources and space exploration is characterized by its diversity, spanning energy, healthcare, and construction sectors, with commercial entities playing a crucial role.

7. Technology Transfer

Moreover, space exploration's role as a technological incubator promises substantial spillover effects across multiple industries, including materials science, manufacturing, robotics, and data analytics. Historical innovations exemplify the terrestrial benefits derived from space technologies. This trend is expected to continue as current and future lunar missions foster new technologies with potential Earth-based applications and facilitating the transition of space-originated innovations into everyday products.