INVESTIGA R&D&I 2018/2019

SPECIFIC WORK GUIDE ON "SEARCH FOR EXTRATERRESTRIAL RESOURCES"
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Introduction

Next year the 50th anniversary is going to be celebrated of the end of the so-called**space race**with the culmination of the first manned mission that reached the Moon and it has been nearly 60 years since robot missions sent to our satellite began starting with the success of*Luna 2*as the first human probe which impacted on its surface in 1959 and following the rest of the Soviet*Luna*missions, the American*Ranger*and*Surveyor*. Back then, use of the selenitic resources was not a priority, but several samples were collected of lunar rocks witha scientific nature and even nowadays their geological composition is still being analyzed.

We are currently living in a whirlwind of a **"second" space race** with the goal of taking man to Mars. Both new private agents such as Space X, Blue Origin, Virgin, etc.; together with rising public organizations (the Chinese and Indian agencies as well as the Japanese agency, JAXA) have jumped on the bandwagon– or spacecraft –of this new space race.

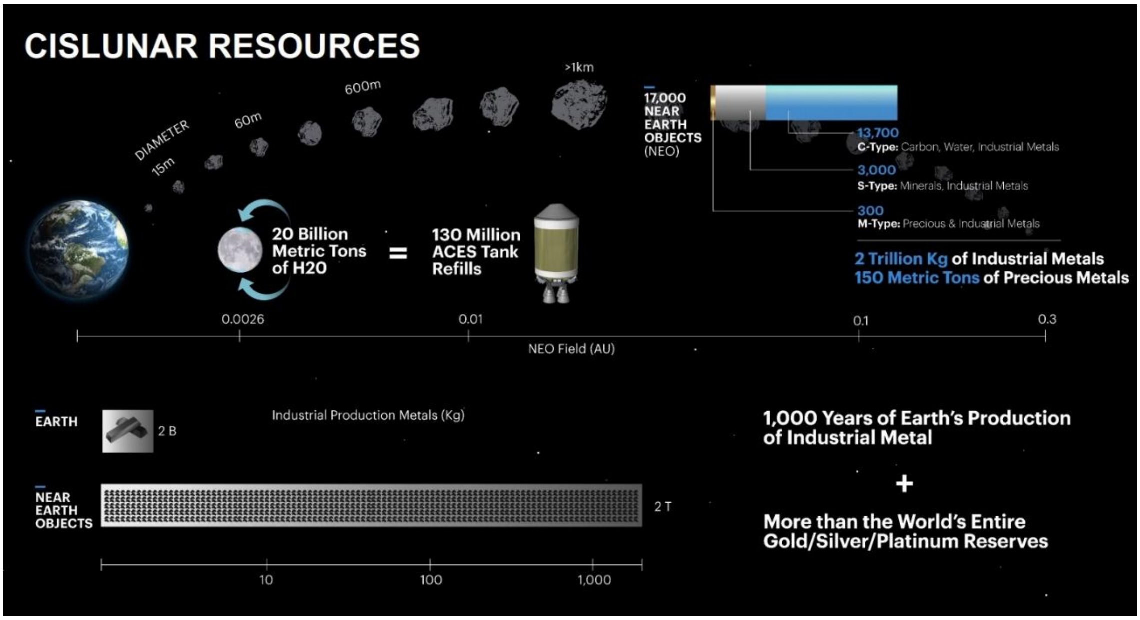
We find ourselves before a key moment in the field of lunar exploration in particular and space exploration in general. Not just from the scientific viewpoint of astrobiology or the search for extraterrestrial life, but also from the viewpoint of exploration and commercial exploitation. New business cases are arising such as space tourism and the management of**space resources** necessary for the search for an emergency exit in case we run out of the ones on Earth, something very likely if we continue to grow and use up resources at the same pace that we have been on our finite planet.

Image of Excalibur Exploration

Unlike the unmanned missions of the ’60s and ’70s, the future missions to Selene aim at establishing **permanent colonies**, as a testing groundto take a leap towards manned exploration of other planets in our solar system; specifically, Mars. For the first time, humankind could have another place to go to and, perhaps, live at. A scientific and technological challenge also with implications from an ethical, social and cultural perspective (space tourism, regulation of human settlement, heritage of humanity, mining business).

What is a space resource?

The key to a sustainable future in space is the development and use of the resources of space itself. These resources will have to be based on an economy beyond Earth, in the so-called**cislunar**[i]space. The closest and most accessible economy with resources is the Moon.

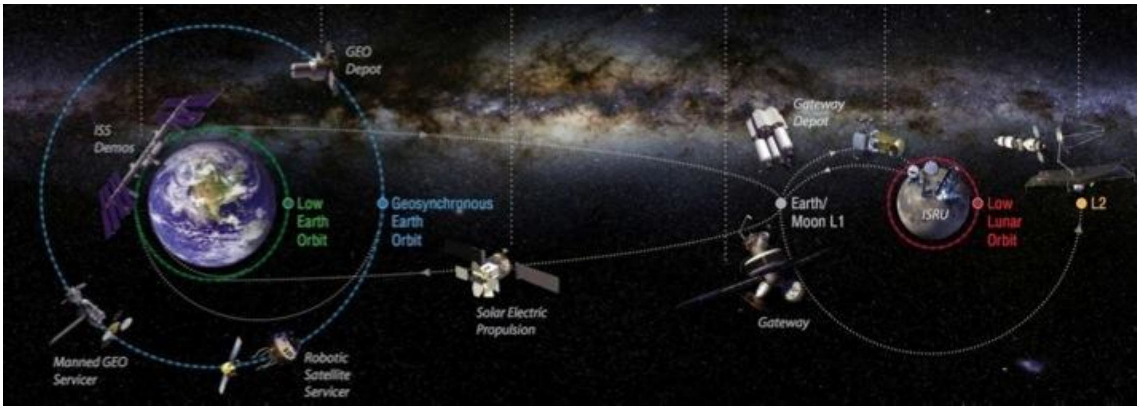


A space resource would be a certain element of value in space or some other heavenly body. There are several characteristics which define it:

- It must require some process or specialized equipment to mine it from its native environment.
- It has to be able to complete some function, process or have some useful intrinsic value.
- It can participate on the market, generating revenues either through the process, function or through direct sales.

The most necessary ones are**Energy and Water**,which are essential resources for human exploration of the so-called*Space Mineral Resources*, *SMR*.

An energy system needs to generate energy regardless of its location. The constituents of water, oxygen and hydrogen, when they are separated and liquefied, are the most efficient known chemical propellants for rockets. Propellants coming from space could dramatically reduce the cost of all the other activities in cislunar space, as well as the Mars missions.



Why the Moon?

After an interval of nearly fifty years, human exploration of the Moon and permanent human presence on the lunar surface are on the space exploration agenda of the most developed countries.

The final success of a permanent self-sufficient lunar base or so-called*moon village*will depend both on the use of available resources and on optimum enabling technology for space exploration.

One of the reasons why scientists wish to study the Moon is because it can offer a unique vision of the processes which the Moon and the Earth might have experienced in the primitive Solar System. This is due to the fact that the surface of the Moon bears physical marks and the chemical history of its voyage together with the Earth unshielded as it hardly has any atmosphere. But the reason why engineers want to return to the Moon is for the challenge of the logistics of space exploration. The Moon could be the testing ground for:

- Building a base on another planet. We can use the experience from remote bases like the research stations in the Arctic and Antarctica, but there is a lot to be learned about how to build a habitat outside of our planet. In order to explore this more in-depth, the Moon is a necessary step.

- Developing and implementing procedures to use natural resources on the lunar surface to reduce what must be brought from Earth, known as *In Situ Resource Utilization*, or ISRU). Local resources could supply material necessary to build habitats, protect astronauts from radiation, supply raw materials for life support systems and even for fuel for planetary exploration beyond cislunar space. Their use is being actively tested by space agencies and this work will provide knowledge for the Moon and planetary missions.
- Treating risks for health and equipment, such as radiation and lunar dust. The experience of industries like nuclear power plants and mining will help us, but it will be necessary to adapt itbefore implementing it on the lunar surface. Water is believed to be a good shield from radiation, but how to we get water on the Moon? It's too heavy to take it there in large quantities, so it would have to be melted from theice that there is at the Moon's poles.
- Planning operational missions with limited food and water: underwater, polar and International Space Station (ISS) missions can help us to gain information, and efforts must be made to grow food on the Moon.
- Equipping a habitat with the right tools: underwater, polar and ISS missions can help us to create lists of equipment, and a workshop might be necessary on the Moon in order to build and repair small equipment parts. Moreover, three levels of redundancy must be incorporated for the life support equipment to guarantee astronauts' safety.
- Dealing with medical emergencies far away from medical personnel: the underwater, polar and ISS missions have taught us a lot, but there are still doubts about the treatment of infections, the treatment of minor surgery and even toothache. A partial solution could be to have a doctor as part of the crew. The psychology study on living in an extreme atmosphere far from the family is also something worrying.
- Oxygen is vital for the propellant (or, in the long run, as a possible fuel recharge station for interplanetary voyages) and for life support, so it has been a priority in most of the ISRU research. However, it has been argued that energy production on the Moon is as important as oxygen, for a sustainable presence.
- The in-situ resource utilization of the lunar regolith to produce silicon and oxygen on the Moon will be key since with the Si, the in-situ

production of lunar solar panelswill make it possible to increase the power available for lunar facilities with the minimum material required from Earth. A potential benefit more in the long term might be to use the solar panels for other space applications.

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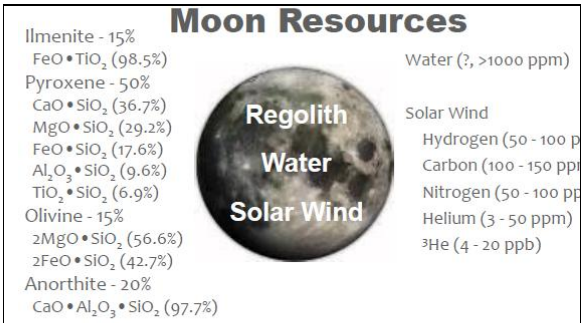

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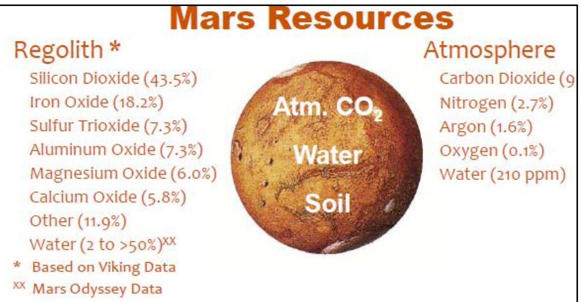

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Lunar Resources

Oxygen is the most abundant element on the Moon: 42% of the regolith mass.

The volatile elements deposited by the solar wind are available at low concentrations.

Different metals such as iron, rare soils and semi-conductors like silicon are abundant in the lunar regolith. Ideal for construction and solar cells.

Water could be available at the poles if the ice is melted.

Lunar mineral resources are understood at a global level with Apollo samples for calibration.
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Resources on Mars

Atmospheric gases, and in particular carbon dioxide (95.5%), are available everywhere at 6 to 10 torr (remember that on Earth, the atmosphere has a much greater pressure; 760 torr).

O_2can be extracted by electrolysis.

The data fromVikingandMars Odysseyshow that water was very widespread, but the spatial distribution and form of water / iceare not well understood (hydrated clays and salts, permafrost, liquid aquifers and / or dirty ice).
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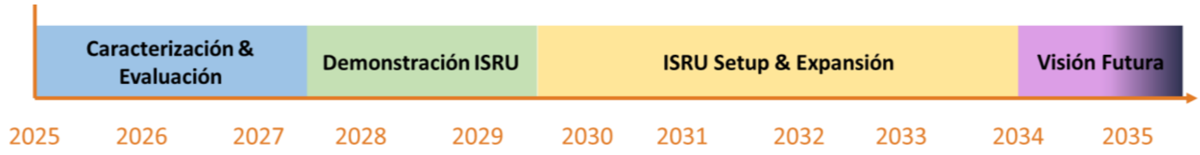
The Moon and Mars Resource Comparison

What is In Situ Resource Utilization (ISRU)?

On producing resources outside of Earth’s gravity, ISRU can provide ameans of reducing the mass of launches, and therefore, the cost from the Earth.

ISRU involves any hardware or operation which takes advantage of and uses resources "in situ" to create products and services for human exploration and robotics. "ISRU" is a capacity which involves multiple elements (mobility, storage and product delivery, power, crew maintenance and / or robotics, etc.) to achieve final products. "ISRU" doesn't exist by itself. By definition, it must be connected and linked to the users / customers of the ISRU products and services. To this effect, several phases first have to be followed with a more or less defined timeline:



Evaluation and characterization of resources (prospecting)

It's easy to list the resources which are needed: imported, physical, mineral, chemical, water, ground, geology and environment... But there are huge challenges in the prospecting, mining and processing of their use. There are engineering challenges in the infrastructure required and in the development of detailed maps of the resources on the Moon. Beginning with a detailed evaluation of resources in order to end up identifying them, we need:

- Affordable, detailed mapping images.
- Prospecting–testing of celestial bodies in zero gravity or microgravity.
- Digging and drilling–in zero gravity or microgravity.
- Gathering of the atmosphere.
- Benefit before processing.
- Transportation.
- A favorable legal and ecological system.

Acquisition of resources and processing of resources / Consumable Production

The mining and processing of resources into products of immediate use or as a raw material for construction and manufacturing can be generated in different ways:

Manufacturing in situ

Production of spare parts, complex products, machines and integrated systems from raw materials derived from one or more processed resources. 3D printing technology will be key at this point.

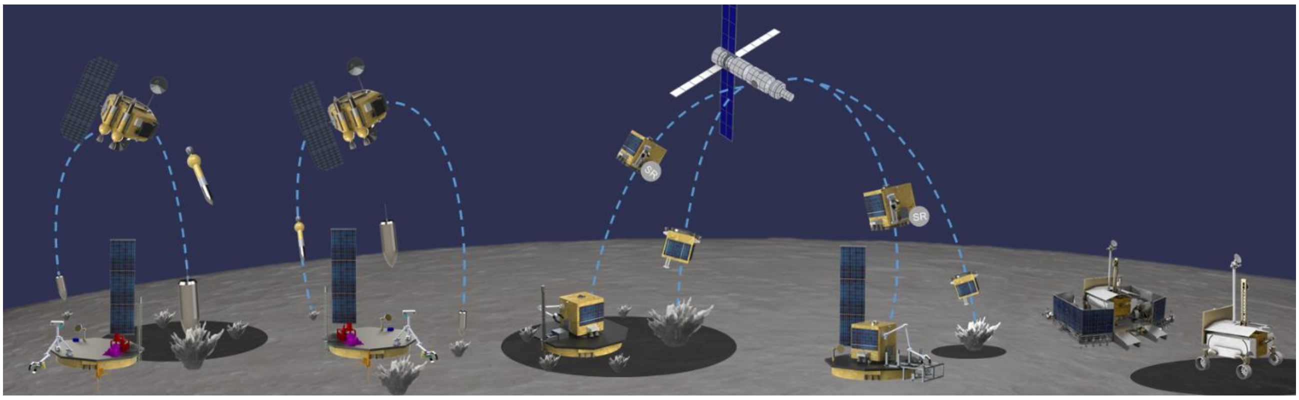
Construction in situ

Civil engineering, infrastructure location and construction of structures using materials produced from ISRU. Radiationshields, landing pads, roads, berms, habitats, etc.

Energy in situ

Generation and storage of electric, thermal and chemical energy with materials derived in situ. Solar panels, thermal storage and energy, chemical batteries, etc.

Different set-ups oroutlinesand plannings are arising through the different projects already launched by the main space agencies. Ex.:



Source: MSc SpacE Exploration & Development Systems (SEEDS)

Space Mineral Resources, SMR, as a business

Over the last few years, greater interest has been observed in the subsurface explorations of planets, asteroids and comets. The previous missions like HAYABUSA by JAXA, ROSETTA with PHILAE by ESA and the Mars ROVERS by NASA have led to better understanding of the surface properties of other planets, asteroids and other small space objects which might be a source of minerals. For this reason, new initiatives have arisen in search of new business cases. In these business terms the question which springs up is not "how" to take care of space mineral resources for a scientific benefit, but rather, "how best" to take advantage of them in order to draw an enticing economic return. The preliminary economic conclusions include:

(1)The architectures based on the return of precious metals to earth markets in themselves don't seem to make sense.

(2)The existence of customers in space for propellants, consumables, structural materials and shielding could make asteroid mining economically feasible.

(3)The long-term hybrid architectures with customers both from Earth and from outer spacemight be feasible as costs decrease and the size of the market increases.

With these technological demands, great needs will arise. That's to say, from all of this, new and more efficient technologies will appear like that oftransmitting data directly to the Earth throughoptical communications links (the new paradigm of space communications very much in fashion on the international scene; seeFacebook, Google). These large multinationals are already working separately on projects to offer generalize Internet access from anywhere in the worldby means of a network which includes a space optical segmentto support the huge bandwidth which is predicted to be necessary. This could be extended to the level of outer space and, according to analysts, it will be part of the "new space race".

Legislation

Large-scale human activities in space, and in particular space mining, are about topose an unprecedented threat to the conservation of the environment in outer space, the Moon and other heavenly bodies. The only "effective" regulation is the ***Outer Space Treaty - OST***of the United Nations (by its*UNOOSA*office) which deals directly with protection of the extraterrestrial environmentin the second paragraph of Article IX.

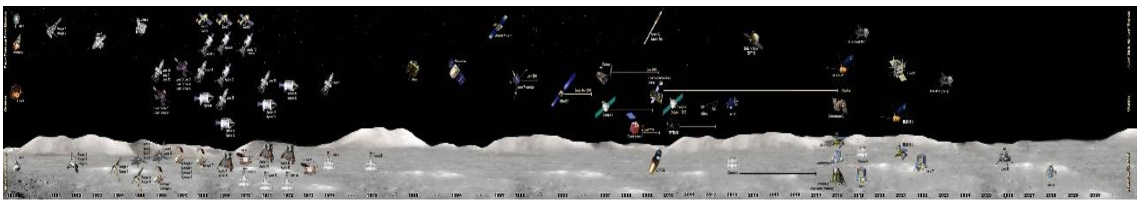
Such a provision, despite its imprecise terminology and its restricted field of application, still constitutes the main framework for any international legal regulation. Before engaging in complex negotiations in the sector's legal framework, it is necessary to clarify a common focus for the interpretation of Article IX in light of a fundamental ethical question: Is the extraterrestrial environment worthy of protection per se or is it exclusively instrumental for human interests? Anthropocentrism vs. Ecocentrism are the opposing stances.

Currently the United States and Luxembourg do not agree to respect the cultural heritage found out there. They are enacting enabling legislation which establishes private property under the OST, which establishes the capacity of nations to develop their own legal regimes for*SMR*.

Planetary protection

The biological use of resources in situ for lunar exploration is now a reality. The bacteria can help us as**biomining**for the mining of materials such as Si or Fe from the lunar regolith through bacterial proteins. And at the same time as **gas producers**, since the bacterial reduction of the lunar regolith releases a variety of useful gases like $H_2$and methane for fuel or $CO_2$for vegetable photosynthesis. Also as**Bioprinters**, 3D bacterial printing enables the production of bioactive materials and the direct use of the materials mined.

But the use of bacteria has its limitations so as not to pollute the different ecosystems. Biological protection is very important; thus, the bacteria must be handled in a closed, safe setting, since it is specific to each planet and the organisms modified synthetically would have to be exterminated automatically as soon as they changed environments.



Lunar samples exist in an environment of minimal air and water and away from contamination sources such as humans, spacecraft and the Earth's atmosphere. Studying samples on the Moon therefore reduces the risk of sample change and contamination during transport. However, the cost and technological challenge of developingand launching scientific instruments that are small enough and that function in lunar gravity and don’t contaminate with biological remains from the Earth limits what analysis can be performed on the lunar surface.

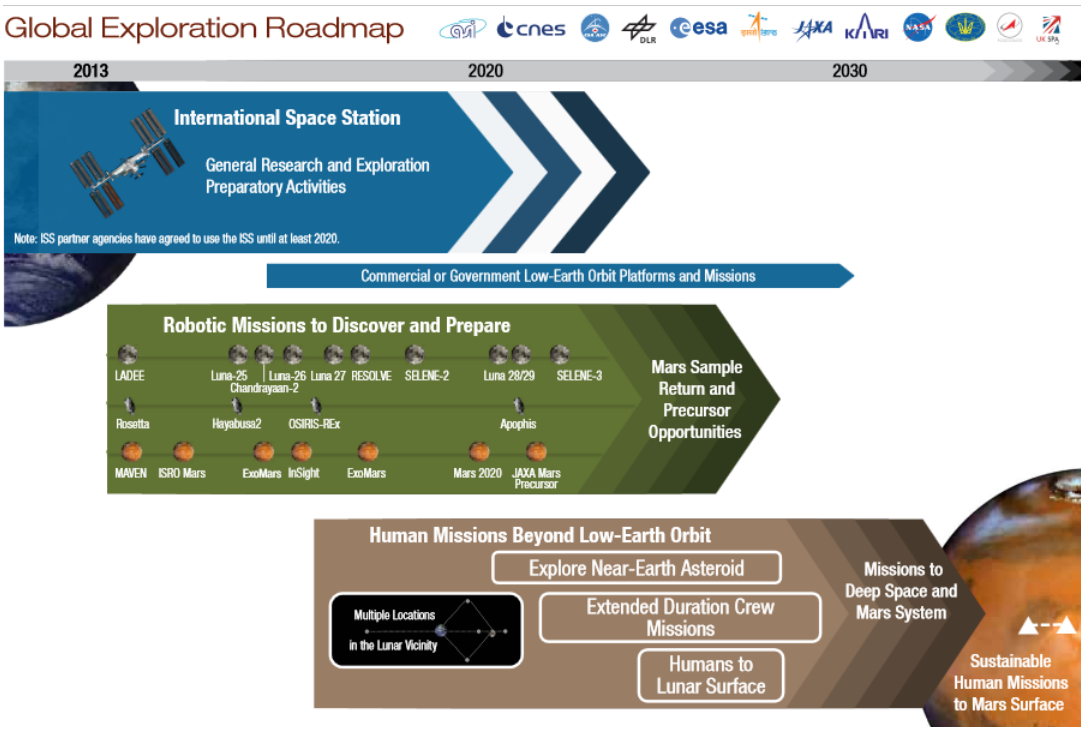
The rock boxes designed for the Apollo missions are a good example of how challenging this task can be. They were designed to keep oxygen and water away from the samples during the journey back to Earth; however, in some cases the abrasive nature of the lunar dust degraded the seals and the samples were exposed to air and humidity. Another consideration will be ice core sampling. Ice cores collected by drilling may be damaged by heat generated during the collection process, and collected ice cores will presumably need to be transported back to Earth in specially designed containers to protect the samples fromheat, light, radiation, oxygen and biological contamination.

All of these planetary protection policies managed by the*Committee on Space Research* (COSPAR) began to be implemented back with *Surveyor 3* (April 17th to 20th, 1967), which dug up lunar soil, finding pebbles at a depth of 15.2 cm. Its remains were analyzed by the Apollo XII mission in November 1969, to study lunar contamination in experiments on quarantine.

The most restrictive and updated one is the Hayabusa 2 mission which is currently underway and it will return to us, as its first successful version, to bring samples of outer asteroids back to Earth: (https://www.microsiervos.com/archivo/espacio/hayabusa-2-segundo-simulacro-toma-muestras.html)

Future vision

You can catch a glimpse of the future by following the roadmap elaborated by the*International Space Exploration Coordination Group*, **ISECG.**



With regards to the large agencies, NASA has announced that it is planning to orbit and land on the Moon around 2023, but to do so a "great effort" is needed like the one that was made with Apollo 11. But the great aim is to reach Mars in thedecade of the '30s, although the most realistic programs situate it a decade later. All of that, if some initiative from a private agency doesn't advance first.

The availability of resources on the Moon is fundamental for humans to survive there and it will be a focus of the robot missions led by the Russians. *Luna-27*, the main mission of the cooperation between the ESA and Russia, will land near the South Pole of the Moon and will search for frozen water and other potential resources. If there is enough water, it could become a source of oxygen and hydrogen to sustain life andsupply rockets with fuel to take us further in the Solar System.

The ESA will provide a precise landing system for the Russian lander*Luna-27*and a system to drill the lunar soil, take samples and analyze them in order to establish their potential as future resources. The ESA will also provide communications and navigation support for every mission using its network of Earth stations, supporting the landing and operations of both European and Russian scientific instruments.

References

Due to scant information on the subject in Spanish because of it being relatively new, nearly all of it comes in the form of links to resources on the Internet with the latest news:

NASA's Lunar and Planetary Science website with a map of the locations of the Apollo missions: https://nssdc.gsfc.nasa.gov/planetary/

The Lunar and Planetary Institute website, which provides support services to NASA and the scientific community, includes information and resources for students and teachers: https://www.lpi.usra.edu/

https://www.scienceinschool.org/content/challenging-logistics-lunar-exploration

Lunar Museum of Fresnedillas (Madrid Apollo Station) to continue with updates on lunar exploration: http://museo.fresnedillasdelaoliva.es/

ESA'S Package for Resource Observation and In-Situ Prospecting for Exploration, Commercial Exploitation and Transportation (PROSPECT) http://exploration.esa.int/moon/59102-about-prospect/

About the Moon Village: https://www.esa.int/About_Us/Ministerial_Council_2016/Moon_Village

http://exploration.esa.int/moon/59878-workshop-towards-the-use-of-lunar-resources/

For planetary protection topics:https://planetaryprotection.nasa.gov/intpolicy

Benefits of returning to the Moon:http://youbenefit.spaceflight.esa.int/back-to-the-moon/

Lunar heritage of humanity?https://www.forallmoonkind.org/

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[i]*Glossary and acronyms*

"Cislunar" is a term commonly used in space jargon todenominate the region near the Moon, or the region of space closer to Earth than the Moon's orbit. However, more recentlyit has been used to denominate the region of space within the Earth's gravitational influence, which includes the Moon. When I talk about cislunar economy, I'm referring to economic activities taking place in space either on the Moon or in orbit around the Earth or the Moon.

This is an important distinction, mainly because a "space economy" already exists, at least up to the geostationary belt (GEO). There are some 450 satellites currently operating in GEO, about 75% of them commercial, most of them relaying video, data or voice connections to Earth. Below those, we have the navigation constellations (GPS, GLONASS, Galileo, BeiDou) in medium Earth orbit, and below them in low Earth orbit most of the Earth observation satellites, an ever-increasing swarm of cubesats, telecommunications constellations and space debris, and the International Space Station. All this activity makes for a sizeable movement of money worldwide, with a total industry size of about320 billion U.S. dollars in 2015.

ESA: European Space Agency
ISRU: In Situ Resource Utilization
ISS: International Space Station
SMR: *Space* Mineral *Resources*
OST: *Outer SpaceTreaty*