GLOBAL SPACE EXPLORATION IS AT A TURNING POINT

SUPPORT THE DEFINITION OF ESA EXPLORATION STRATEGY 2030+ TO SECURE THE RIGHT LEVEL OF EUROPEAN PRESENCE IN INTERNATIONAL EXPLORATION ENDEAVOURS

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Background

In the context of the preparation of ESA future exploration strategy, and of the ensuing programme proposal in view of the C-Min 2022, the ESA Human and Robotic Exploration directorate initiated a unique dialogue with industry players involving **a coordinated three-dimensional approach**, built around a **survey**, a direct dialogue opportunity through a dedicated **workshop**, and the initiation of an industry-led process for the production of a **position paper**.

This position paper is prepared in view of supporting the further definition of ESA's exploration strategy. It was elaborated by a dedicated Eurospace Task Force assembled in February 2020.

The exploration strategy cannot be envisioned without the expanse and contribution from the whole of the European sector programmes and capabilities, as it exhibits strong synergetic dimensions and will take advantage of existing and budding capacities. Terrae Novae will support and build upon synergies with other programmatic areas implemented by, or together with, other directorates. Key synergetic domains have been identified in this paper and further detailed as appropriate in a cross-sectoral synergies annex. These synergies support and complement Terrae Novae.

In addition, ***new programmatic proposals*** *relevant to Exploration are supported by industry in the context of the new flagship programmes promoted by ESA Director General, they are recalled in annex and are also included in a dedicated Eurospace position paper.*

1. Introduction

Global space exploration is at a turning point, reaching to a new dimension beyond human presence in low Earth orbit, with a clear vision and roadmap to the Moon and Mars. This vision is spearheaded by the USA and NASA, while China, Russia and India are announcing their own plans for expanding Human presence in the solar system. Europe shall now embrace this dimension with a renewed exploration programme writing its own path to planetary exploration.

The ESA exploration strategy for 2030 and beyond shall aim at securing the right level of European presence in international exploration endeavours, shall be able to add value to European expertise, and create the conditions to expand on new capabilities and technologies, and shall ensure that European companies, large and small, established and emerging, are given a chance to contribute.

The current ESA proposal of the Terrae Novae programme, with its three components (LEO, Moon and Mars) considered in synergy and with a stepped approach, has the potential to meet the growing European expectations for a strengthened human and robotic presence beyond the boundaries of Earth. The European space industry, represented by Eurospace, welcomes the proposal, and looks forward to further contributing to its definition, substantiation and to enhancing its ambitions.

European governments shall lay the foundations to allow European industries to play a major role in outer space. This can be achieved by:

- Creating a long-term exploration policy that will represent a solid ground to **attract political interest and generate additional financial support**;
- **Exploiting synergies at European institutional level to combine public funding into wider, more impactful projects and missions** - particular attention shall be given to ensure the programme attractiveness for smaller member states to build a solid European-wide momentum;

- Implementing ambitious missions that **accelerate knowledge and technology advancemen**t with particular attention to **securing technological non-dependence** in areas for which Europe has been traditionally reliant on foreign contributors or suppliers;
- A **sustainable programmatic context** where logistic, resources and communication are accessible on a regular basis;
- Creating a **balanced regulatory environment where business rules are fair and transparent**, and where customers (including agencies) adopt a more delivery/goal-oriented and less controlling or prescriptive approach[1].

The Space Exploration Terrae Novae roadmap should therefore aim at supporting the European industry to provide competitive systems and products that can be further valued within international cooperation encompassing partnership in a service-oriented approach. Industry competitiveness shall not only be driven performance considerations, but also by time-to-market and price effectiveness, by considering the following requirements:

- **Europe and ESA shall aim high and secure significant sustainable and autonomous contributions to the global exploration strategy to anchor strongly Europe in the international geopolitical framework of exploration programmes**. The time is critical: when the USA, China and others are accelerating their plans, Europe has a unique position to propose transversal contributions (e.g., space resources value chains and other space services to support a multi-mission approach), that could benefit all partners and competitors and eventually truly foster worldwide cooperation;
- **Permanent presence in LEO, Moon and Mars is the long-term objective.** The exploitation of synergies between LEO, Moon, and Mars destinations is thus paramount. There is a technological and capability continuity to build upon, taking advantage of the solid European heritage, of technology spin-in and spin-offs, and leveraging on the variety of national, EU and ESA programmes and directorates;
- **Technology and innovation will provide the bedrock of European involvement in Exploration programmes**, creating the capabilities and building blocks to secure the participation of Europe with the right levels of autonomy that Europeans deserve. European contributions to the exploration strategy shall ensure value added on technology capabilities and current heritage, and focus development efforts on key building blocks and enablers for Europe to keep an edge. Bridging Earth and Space innovation (i.e., leverage existing Earth R&D, promote spin-in / spin-off, promote cross sectoral collaboration), should become a new common way of working, to accelerate development loops (i.e., stop re-inventing the wheels), and because the future cis-lunar economy is certainly a continuum between Earth and Space Industry;
- To **shorten development loops and reduce time-to-flight**, Institutions could encourage sub-scaled demonstrations at low maturity level, in piggy back on existing missions (European or international opportunity missions within bilateral co-operations), to demonstrate key functions as soon as possible (including with revised/renewed qualification processes), and build programmes on iterative successes;
- **A critical challenge: European autonomous human access to LEO** (see the Synergies annex for more information);
- **Fostering the emergence of the LEO/Moon/Mars ecosystems is an essential paradigm shift**, supported by emerging players and established players alike, with new and disruptive propositions that will be enabled by the institutions promoting the exploration programmes. Institutions shall promote procurement paradigm changes and the emergence of a service-based demand, somewhere

[1] There are growing expectations for the European industry to enable a more pro-active contribution to the ESA exploration programme, with many areas expected to develop as a new ecosystem enabling more risk taking in an environment where the ESA procurement scheme would evolve towards commercial service provision rather than prescriptive hardware procurement. This may require profound adaptations of ESA procurement regulations.

paving the way from exploration to long-term sustainable presence. Industry could then consider to invest, take risks and accept different and disruptive financing schemes, based on sustainable programmes and clear economic perspectives;

- **The science and societal added value of Exploration for all humankind will be demonstrated as the exploration challenges unfold and with Europe stepping up its ambitions to support the programmes**. Planetary exploration challenges, from an environmental and sustainability perspective provide an extremely valuable test bed for humans to address critical Earth bound environmental and resources related issues. Furthermore, human exploration sets the highest marks for international cooperation, economic diplomacy, soft power and is an instrument for global peace, for outreach towards the younger generations, and for scientific production.

2. The long-term ESA exploration strategy in the European and international geopolitical framework: positioning Europe on key contributions ensuring long term added-value and presence in international programmes

Europe needs to create a solid long term space exploration policy that will allow the implementation of European autonomous exploration capabilities that can be made available to international collaboration initiatives.

Europe and ESA shall aim high and secure significant sustainable and autonomous contributions to the global exploration strategy **to anchor strongly Europe in the international geopolitical framework of exploration programmes**. The time is critical: when the USA, China and others are accelerating their plans, Europe has a unique position to propose transversal contributions (e.g., space resources value chains and other space services to support a multi-mission approach), that could benefit all partners and competitors and eventually truly foster worldwide cooperation.

We need to start first with the capabilities in Europe –mobility in space from Earth to space, landing and return, high-quality space systems and payloads and human spaceflight. A **second step** – well recognised in Terrae Novae - **is to agree on the targets and objectives, focusing on international targets with workshare opportunities**. Finally, the most critical and challenging part is to agree on the suitable level of European contributions (and related budget commitments), either in full complementarity to the international partners contribution or with additional European capacity to be offered to the partners for ride sharing, instrument sharing or infrastructure sharing opportunities. Europe should also take the initiative to propose missions of outstanding scientific quality to attract international partners under European leadership.

Industry recognises that Exploration technologies and building blocks have strong synergies across all destination targets, it has identified the key priorities capabilities to favourably position the European contribution (and European industry shares) in the future missions in an international cooperation frame (starting with LEO and Moon, and scaling up for Mars).

Beyond Terrae Novae: a wholesome science and exploration vision for Europe (see the Synergies annex for more information).

A. The LEO infrastructure - key priorities

- **ESA shall support and contribute to the international initiatives in order to maintain an adequate level of LEO exploitation** (astronaut flights and micro-gravity research), to engage in a smooth transition from institutional-led to commercial-led LEO panorama, and to consolidate technologies transferrable to deep space applications, once more clustered around habitation, autonomy and human factor;

- **The future LEO infrastructure will likely involve a mix of legacy utilization** (e.g., science, technology demonstration) **and emerging fields** (e.g., resupply, manufacturing and assembly), combining both crewed and automated and robotics elements. The resulting architecture should support the core requirements, including a resource module and a pressurised environment, with suitable docks for future expansion (e.g., CLTV-Like, SciHAB...) in support of emerging applications (e.g., a detachable co-orbiting free-flyer for science). The future infrastructure should also be able to operate autonomously during periods when crew is not present. All European mission opportunities shall be optimised for launch with European launchers (Ariane and Vega);
- **While preparing for the future infrastructures, Columbus refurbishment and rejuvenation is necessary** and shall focus on a reduced subset of capabilities, improvements and add-ons, namely: autonomy/tele-operations, robotics, computation, data management and communication and crew technologies:
  - The ISS (and other LEO platforms) should continue to provide flight opportunities for European astronauts. The strengthening of tele-operation capabilities would enable the development of new forms of usage, spurred by scientific and commercial demand, that may ultimately favour the transfer of operations to the private sector. Industry sees potential with space manufacturing, high-quality research facilities for third party operations, in-orbit maintenance, refuelling, servicing.
- **ESA should contribute possibly through partnerships with European commercial operators** for the implementation of either a "multi-purpose" pressurised facility or an ad-hoc one, e.g., manufacturing, robotics or science labs, Mars Transit Simulation facility. This in-kind contribution shall of course be further analysed by considering also the ESA scientific and technology plan, and the preference or need of the Station Operator(s) to drive a sustainable business case. It is of paramount importance that this new infrastructure(s) will take into account exploitation, complementarity and compatibility with other past and current habitation modules, high Delta-V atmospheric re-entry and landing (e.g., SpaceRider evolution and CLTV);
- **Core infrastructure should be based on institutional investment**: opportunities for private services may then develop (e.g., communication system based on constellations or laser communications) based on business cases. For the LEO destination, an incremental approach on required systems and products developments-has to be carefully implemented. This will enable a relevant level of adaptability/versatility with regard to potential future (institutional and commercial) partners. This careful implementation is essential in an ecosystem still to be upcoming, inherent uncertainties on when it will materialise and the scope to be embraced (in terms of type of services, applications etc.).

B. The Moon - key priorities

- **Continued support to the Lunar Gateway** is an essential step to anchor European contributions to an international infrastructure with durable and recurring contributions. The proposal of new Gateway or cislunar elements, such as a refuelling hub, to support re-usable systems like landers and deep space transportation vehicles, would enhance the value-added proposal for the European sector;
- **Moon transportation and Logistics are an essential building block, and a prerequisite for any sustainable international co-operation**, since it makes Europe's exploration programme resilient to any change of policy by international partners. Furthermore, it makes Europe a more valuable and desirable partner, and it increases our leverage and standing in the international context. The service module capability with the ESM was developed through a NASA barter, and a similar frame should be pursued to develop robotic transportation towards Moon surface, with the EL3, that could lead to bring the first European astronaut on the Moon surface before the end of the decade with an outlook to a sustained and sustainable human and robotic presence:
  - **Investing in a "all-EU" multi-purpose element that lends itself to recurrent business (up to series-production) and several missions,** such as EL3, will generate strong long-term benefits;

  - Cooperating internationally for the **provision of a lunar surface mobility element**, able to be a universal transportation system (including pressurised-habitable sections) will durably position Europe as an essential partner.
- **The transportation framework shall position and leverage European heritage assets, Ariane, Vega and the launch site at Kourou.** Commercial initiatives shall be considered and supported to guarantee competition and continuity of services, as well as the development of agility solutions for rideshare missions;
- **Going to the Moon also means the mastering of a number of technology-driven pillars**:
  - **Precise navigation and landing technologies** (including hazard avoidance) to rely on a solid logistic service;
  - Develop **in situ H2O/O2/H2 value chains** for the benefit of space transportation, life support, and energy production and storage facilities;
  - **Advanced habitation features, such as autonomy, robotics, crew technologies, advanced ECLS**…, (which could also conveniently build upon enhancement areas identified for ISS rejuvenation);
  - **Energy production and management**, which in turn impact availability of all other commodities and capabilities (consumables, mobility, habitation etc.). A viable technology mix should include nuclear energy and radioprotection (with the associated mandatory supporting legal framework), fuel cells and innovative space solar power:
    - To enable continued and sustainable surface operations and to keep high-value lunar surface assets operational for several years, it is of paramount importance to ensure energy production and storage in permanently shadowed regions or during the long Moon night.
  - **Refuelling capabilities** (in-orbit and on lunar surface) developed in the frame of the European contributions to the Gateway will lead to further exploitation in other missions;
  - **Lunar communication and navigation systems**, planned to complement Gateway capability and ensure European autonomy to access the Lunar polar areas or the far side. The telecommunication infrastructure is essential to reap the (foreseeable and unforeseeable) benefits of technological and societal transformations that the lunar experience can bring:
    - Communication systems would be coupled with space edge-computing and space data-centres in view of a long-term continued human and robotic presence on the Moon;
    - This is also seen as an opportunity for a commercial service deployment in support;
    - They should also enable generalised participation by scientists, business and the general public.
  - Supporting the implementation of **high-performance technological standards**, such as advanced communication protocols, modular avionics, radiation protection solutions etc., which can double as building blocks for other exploration elements.

C. Mars - key priorities

The final goal is to secure European competences and capabilities, in order to make ESA a central, proactive and reliable contributor for the global exploration roadmap (with the final goal to acquire a key, forefront positioning among the strongest players in deep space exploration). To this end, ESA/Europe shall develop a portfolio of missions, including flagship missions, medium class as well as affordable, fast-track, and highly non-dependent scientific exploration missions with a clear and coherent global approach that can:

- **Improve European knowledge of the Martian environment in preparation for human exploration**, with missions such as weather and space weather network, geological and in-situ resources investigation through surface mobility and drilling capability, but also high-quality remote sensing missions;

- **Promote the re-use of platforms/solutions already designed, of assets already deployed, and of technology already developed for other destinations** and programmes (e.g., LEO & Moon, planetary missions, science missions, other space applications, telecommunications or space safety);
- **Enhance the capabilities portfolio of European industry for future leadership.** Key technologies should be tested and developed when not yet available in Europe to prepare furthers steps, such as nuclear propulsion, aerial mobility, atmospheric entry, operational ISRU, the Mars communication and navigation network mission needs to be studied to support the lander missions and data transmission.

Europe shall **identify elements for barter** via carefully selected missions including flagship missions as well as contributions to the international pioneering effort, in line with what has been done on the Moon (e.g., investigating deep space transit habitat, ISRU to implement CO2 and H2O to O2/H2/CH4 value chains, weather network).

3. Synergies of three destinations LEO, Moon, Mars: considering application potential for all destinations from the onset will add value to the European technical proposal in the medium to long term

The evolution, maturation and reuse of technologies for different destinations is an excellent opportunity to reduce cost, risk and schedule. Considering reuse and synergy potential from the onset will leverage the long-term value of European investments in technologies and capabilities.

Technological synergies between LEO, Moon and Mars allow to use one destination as stepping stone for other, more distant and complex, destinations. They allow to gradually increase European capabilities in exploration. Industry recommends to consider, right from the beginning of each technology roadmaps, if and how a system or technology could be used for different destinations:

- For the definition of technology and system requirements for a stepwise utilisation;
- Provide the programmatic requisites to follow this development approach.

Beyond straightforward synergies among Exploration destinations, such as e.g., GNC and vision-based navigation for rendezvous or landing, or autonomous robotics means, synergies will mostly develop around:

- **Habitats and advanced life and crew support systems;**
- **Technologies needed to gain life support and crew on board autonomy** (e.g., food production, closed loop ECLSS/life support technologies etc.) can be tested in LEO. Fast and continuous access will accelerate the maturation of these technologies before final testing in the actual operational environment (being Moon or Mars surface);
- Gradual **on-board crew independence**, possibly with the assistance of “intelligent” on board tools, can be implemented in order to simulate and gain experience on the operational environment of a Moon (but mainly Mars) mission;
- Development of **resources extraction, processing and storage** on the Moon will enable the establishment of fuel depots in Moon orbit (and LEO) able to support refuelling of reusable landers, tugs and fuelling of manned Mars vehicles. Capabilities developed for Moon missions (dust protection, ISRU, waste recycling) will in turn be useful for Mars missions, but also on Earth to have a more sustainable planet.

4. Innovation, game changers, showstoppers: European strengths and singularities to bridge critical gaps and ensure the highest added value of European contributions and capabilities to global exploration programmes

A. Context

Today, exploration of LEO/Moon/Mars in Europe is largely focused on gaining scientific knowledge: we are continuously learning what it means to live and operate in a hostile space environment. More than twenty years of experience of human presence in LEO demonstrates how complex and articulated this process is.

It is important to build a common European roadmap in the exploration domain and to identify the relevant building blocks considering the right balance between large and highly ambitious missions, and more frequent missions that can allow to build resilience and safety and accumulate experience faster for European companies, avoiding dispersion of efforts.

- Industry recommends **focusing on some fields where to reach, or to maintain, level of excellence** like habitation modules, power stations, propellant refuelling stations for satellites and rocket upper stages space tugs LEO as a hub and a work place, surface mobility, landing capability and safe return from space, multi domain cargo;
- Industry recommends to invest on a few **reusable and multi-role capabilities, with long term prospective**, rather than to optimise lot of capabilities on each precisely dedicated mission. A core development with very high future potential for sample return missions, from LEO to Mars, would be high velocity (>10 m/s) re-entry capability (including aerobraking technologies), enabling sample return missions and upper-stage reusability;
- Industry recommends to **consider the unique opportunities to be leveraged from establishing a capacity to manufacture and operate space systems** (satellites and launchers) from the surface of the Moon. The Moon provides a very efficient environment (from the Delta-V point of view) to reach GEO and LEO with large infrastructures. This may justify the development of specific business cases in the long run, but this needs to be traded against more conventional approaches regarding cost, risks and schedule.

Overall, Europe shall build on industry heritage for critical enabling technologies and added value, emphasising green technologies and reusability as they are the key for a space exploration ecosystem protecting both our planet and our destination:

- Core technologies for **fully autonomous European capability of precision landing** on Moon and Mars;
- Core technologies for **power generation, storage and distribution**: In terms of power management and delivery in Moon-night regions the European capabilities with RPS or nuclear power systems are well developed. The choices to serve these demands in space are limited. Europe should exceptionally agree politically enabling the space transportation and provision of radioactive and nuclear power for dedicated exploration missions. The Regenerative Fuel Cells Systems (RFCS) using Hydrogen are also an alternative to be studied, offering high energy density, high powers and a high potential of spin-ins and spin-offs (that could also benefit energy transition priorities on Earth);
- Core technologies for **in-orbit refuelling** capacities;
- Core technologies for **ISRU value chains** implementation.

B. Key areas targeted for European industry capability enhancement

Very high priority:

The ability to enable and sustain human presence, in particular beyond LEO and for extended periods of stay is the guiding principle.

This is a long-standing flagship characteristics of European space industry: the underlying industrial competences and capabilities shall be safeguarded and enhanced. This includes the availability of crew rated cabins for transportation vehicles, habitats for long term orbital and surface outposts, and deep space transit habitats, with all the associated technological building blocks.

The landing capability (on Moon as well as on Mars) is a key technology building block that should be mastered in Europe for robotic missions. This enables meeting important European autonomy and sovereignty objectives, but represents also a good vector of cooperation with international partners.

Human transportation and human flight operations are a European competence which needs to be fostered and maintained to keep Europe on a par with the main space powers (see Synergies annex for more information).

High priority:

Moon (and Mars) **mobility** with rovers or other systems like aerial vehicles and related autonomy are key short-term enablers with high scalability for Mars missions. Here Europe has a lot of heritage and assets to be leveraged. Increased autonomy of operations will be a critical goal.

ISRU capabilities are also essential, as they contribute to the sustainability of the global mission profile. For example, using regolith to produce oxygen and fuel for ascent vehicle and crew support, hydrogen for energy storage as well as producing the material to support infrastructure and habitat construction brings definitive advantages.

Energy is a critical requirement. Radioisotope technology as a heating unit or as a thermal generator would allow to thermally condition the payloads even during the long lunar nights (up to 14 Earth days). An important prerequisite for European independence in this field is not only the technology and product itself, but also that Europe has qualified and certified its launch vehicle in accordance with international regulations for the transport of such sensitive payloads. Regenerative fuel cells systems (RFCS) using hydrogen are also to be studied for lunar night survival, offering high energy density, high powers and a high potential of spin-ins and spin-offs (that could also benefit energy transition priorities on Earth).

The ability to handle the massive amount of **data** that will be transmitted from the LEO, Moon and Mars environments will call for dedicated data relay capabilities around the Moon. Here, one can leverage from the technologies and experiences developed for Earth-based communication constellations.

Medium priority:

New missions in LEO, Moon and Mars will benefit from higher bandwidths in space to ground data links and from the establishment of outer space networks. The volume of telemetry data will increase significantly. Thus, the **ground management and exploitation of the data** – at mission operations and thereafter - request new digital technologies at the ground and user segments. The European exploration strategy also needs to address further developments in on-ground infrastructure and technologies.

Propellant **refuelling** capacities (in-orbit and on Moon/Mars surface): leveraging on the ESPRIT developments for the LOP-G, Europe could develop quickly LEO propellant depots, to extend the lifetime of satellites (and consequently reduce debris / reduce TCO of the missions).

Developments in propulsion technologies, including chemical, electric and advanced systems are instrumental to the exploration roadmap (see Synergies annex for more information).

To support future prospects for sample (and human) return missions, **atmospheric re-entry with high velocity** (>10 km/s) and landing capability are still a capability gap that Europe shall address to achieve operational status.

5. Fostering the emergence of the LEO/Moon/Mars ecosystems: an essential enabler for future exploration missions.

It is envisaged that "Space" travel will follow a similar course to the one seen in airspace and aviation. From the early age of pioneers, exploration and conquest of airspace encountered a continuous growth, boosting scientific and technological advances, connecting people and cultures, bringing goods closer, enhancing security by worldwide united regulation, allowing Earth survey from above and offering new services and employment benefiting to the greatest. Aviation is nowadays a pillar of global economy and a guarantee of stability and cooperation.

The conquest of Earth vicinity for the benefit of deeper space exploration can be seen as a natural expand and a logical continuation of the atmospheric history; bridging Earth/Space innovation drivers and trends in cross sectoral collaboration, will leverage more budgets (such as the significant effort allocated to Energy Transition on Earth - incl. hydrogen technologies development) with the objective to reach common goals and technologies.

The creation of a LEO/Moon/Mars ecosystem requires **stability of resources, procurement agility** and continuity, considering that versatile and incremental systems, driven by the long-term wide range of missions, can provide cheaper and valuable solutions than the traditional accumulation of individual solutions precisely optimised for each dedicated mission.

For Europe, it is essential to take responsibility on a critical path in international co-operation, on a level playing field with other partners. For industry, it is important that programmes are sustainable, based on long-term agreements in international co-operation to provide a solid and credible long-term exploration plan with solid funding, **specific business cases, a regulatory environment**. **This will enable and protect investments with proper assessment of investment risk and ROI perspective in a meaningful timeframe** (5-10 years). This applies to the transportation of goods and people, the development of infrastructure, and the operational management of the station, mission for LEO, Moon, and Mars.

This is essential to promote the emergence of a viable ecosystem where private initiative can flourish, agnostically **allowing established and emerging players, large and small, to contribute to the exploration initiatives**. It is recommended to procure in parallel several solutions encouraging a variety of providers to enable future flexibility in services. It is also important to work at promoting common interfaces and interoperability of systems and subsystems (e.g., for fuelling, maintenance, building, assemblies, waste etc.).

ESA shall elicit, steer and fund the deep-tech preparatory work, not just as an enabler to space exploration, but also as a powerful leverage to bring industry cross-contamination, beneficial technological and economic fallout, and much-needed involvement of small and medium players. As first stepping stone, **ESA shall act as a facilitator hub** for industrial application-driven research that addresses techno-developments, demonstrators and components required by the key technological capabilities already identified for the exploration roadmap. ESA should provide pathfinder- type of opportunities to lead the way towards commercial initiatives.

The attraction potential for external funding sources and potential private investment of the exploration ecosystem is hinged on the creation of a continuous demand for solutions (products and services) and the modernisation of the ESA procurement policy, where risk is rewarded with the likelihood of larger revenues. Some pilot initiatives could be launched where ESA, besides being a development agency, can also be a procurement agency. The dimensioning of the demand, starting with early phases of the programmes will enable to position industry investments, e.g., if logistic demands are available such as level of tonnage to transport up and down to Earth, type of goods and reliability and safety demands.

In the short term, industry would mainly invest in supporting the development of government ambitions: both in terms of specific technologies to quickly mature exploration-driven solutions or, as a new entrant, to become an attractive player in international collaborations to establish future European capabilities.

6. Science and societal added value of Exploration for all mankind

The human exploration programmes carry a significant political and cultural dimension with the fullest of expressions in the international dimension. Such endeavours as the Apollo-Soyuz orbital docking, the Spacelab, the International Space Station have demonstrated how space exploration could be a driver for humanity to join forces. The future planetary programmes must push the envelope even further.

Industry believes that space exploration is a tool for positioning Europe relatively to the USA, China, Russia, India and Japan, offering lot of opportunities and limited losses and casualties' risks. The positive impact on the geostrategic presence and international prestige of exploration programmes with respect to the budget effort is absolutely unique and would be worth a detailed assessment, just as the ratio to visibility and proudness with respect to the implied human resources and financial effort.

And - in the sense of Article 1 of the UN Outer Space Treaty from 1967, "*the exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries and shall be the province of all mankind*" - a strong European participation in exploration activities seems more than appropriate. **A peaceful collaboration in space exploration among nations and international institutions will help to balance the (geo-)political interests of participating countries**.

Earth is a data point in the origin and evolution of the Universe, and of life in it. Moon and Mars constitute additional essential data points. Understanding the origins of life, the impacts of cosmic radiation and events as well as planetary evolution will also help us in developing processes to preserve Earth.

Space Exploration is a formidable societal momentum wheel:

- It contributes to **progress basic knowledge and science**, and it helps to understand our solar system and highlights the unique special position of our Earth;
- Exploration programmes are **fuel for inspiration and imagination of younger and future generations, they contribute to accruing interest in STEM** and increase the global visibility and public interest of all space programmes;
- It is a powerful **soft diplomacy** tool;
- It is an enabler of **new technologies development for both space and Earth applications;**
- Its self-sustainable dimension can generate **solutions for a greener society on Earth;**

- Space exploration data-demanding missions may represent **pathfinders for advanced solution developments in the field of digitalization, robotics and AI applications**. The software expertise in the European Space industry is key for success;
- Human exploration sets the highest marks for **international cooperation, economic diplomacy, soft power and is an instrument for global peace**, for outreach towards the younger generations, and for scientific production.

Annexes

Annex: Cross sectoral and multi mission synergy highlights

Synergies exist and will be enhanced and further developed across ESA directorates and programmes, with the "multi-domain" projects, such as the Moonlight initiative led by TIA, or the in-space transportation initiatives within STS.

Inter-directorate synergies will provide an additional dimension and value added to the ESA exploration programmes, and may provide combined budget opportunities.

A critical challenge: European autonomous access to Space

Europe shall avoid creating an additional dependence situation in the context of future space exploration endeavours, and shall advance its own proposals and stepping stones towards human rated solutions to access LEO and beyond.

Transportation efficiency, sustainability and high frequency of operations will only be enabled by reusable systems for launch, and for cargo and crew delivery. The launch vehicle, cargo and crew capability to LEO, Moon and Mars must be further developed. Current capabilities of the European heritage launcher systems would be progressively increased to match the capabilities of international partners (in particular increased capacity for trans lunar injection and trans-Mars orbits).

Access to LEO, Moon and Mars implies the capacity to access to space repetitively, quickly, safely and at low cost. As a common building block and enabler for reaching these destinations, we recommend to support the development of disruptive vehicles, capable of crossing the atmospheric/space boundary many times seamlessly and designed for versatility.

Reusable systems (including in-orbit refuellable) for the access to LEO are mandatory for Europe, we recommend injecting, from the starting point, ambitious human rated requirement in a single versatile family of vehicles rather than to develop apart some non-human rated and human rated transportation systems.

Human transportation and human flight operations are a European competence which needs to be fostered and maintained to keep Europe on a par with the main space countries.

The launch vehicle cargo (and crew) capability to LEO, Moon and Mars must be further developed. Current capabilities of the European heritage launcher systems would be progressively increased to match the capabilities of international partners (in particular increased capacity for trans lunar and trans-Mars injection orbits).

Beyond Terrae Novae: a wholesome science and exploration vision for Europe

While Terrae Novae provides a vision for LEO, Moon and Mars, the future also holds plans for scientific expansion towards other targets not suitable for human presence. Venus-missions will provide a better understanding of the evolution of a planet subject to dramatic climate change, but also to find eventually traces of early life. Asteroids are not only exciting scientific study objects (also to better understand the potential threat they constitute), they also represent a vast and diversified potential for resources exploitation. The Terrae Novae vision, roadmaps and achievements will have positive spill-over effects on the whole science and exploration ambition of Europe, it will feed and enhance a wholesome vision for space science and exploration.

Developments in propulsion technologies, including chemical, electric and advanced systems are instrumental to the exploration roadmap

In chemical propulsion technology, Europe has an excellent starting position, in particular due to the investments in the test infrastructure. This infrastructure allows completely different technologies to be brought to product maturity at the same time. For chemical propulsion, the trend for green and highly efficient propellants must be pursued further, especially in order to replace today's solid and toxic propellants with environmentally compatible propellants by species, which might also be produced on Moon and Mars.

For electrical propulsion, engine and power systems are required that can operate with electrical input of up to 200kW with as little losses as possible in order to generate only a small amount of dissipated heat. For very high-power propulsion systems, Europe can rely on existing nuclear terrestrial technology that needs to be adapted for space applications and can then be used as a source for the propulsion heat generation.

The propulsion roadmap shall also consider the support of in-orbit space transportation assets with a view of enabling a wider variety of satellite rideshare missions and preliminary activities in Lunar orbit (such as data-relay, navigation, observation, landing sites spotting, etc.).

Annex: New flagship programmes supported by Eurospace in the Exploration domain

As expressed in ESA Agenda 2025, ESA DG Josef Aschbacher is proposing to have a European “Space Summit” and to start a reflection about new flagship programmes of Europe in space. To support these reflections, the European Space manufacturing industry, brought together within Eurospace, has proposed its most innovative ideas covering the fields of “Sustainable Space”, “Space Data for Citizens”, “Active contribution of Space against Climate Change” and “Exploration.

Human spaceflight

Rationale for action:

All major spacefaring nations (i.e., USA, China, Russia, India) target long term human presence in space, with established plans for the Earth orbit and beyond (Moon and Mars). The USA and China have well established exploration roadmaps now, with Moon settlements before the end of the decade. For them Mars is more than just a long-term ambition: both China and the US have active rovers on the Mars surface and are planning to further collect scientific data in preparation of future human landings.

Europe is currently bartering with the USA its astronaut flights against the provision of space hardware. The role of Europe in Exploration might become marginalised in the future when numerous human spaceflights to LEO and the Moon will be launched.

This is why developing a human space flight independent capability should be a goal for Europe, in a world where space capacity will be a key asset for playing a role in the booming space economy altogether with reinforcement of global influence. Securing independent access to space for human missions for European astronauts will serve many objectives i.e., exploration, science, Lunar activities, space mining and resources, in-orbit manufacturing and operations, but it will also enable capabilities for other future applications like point-to-point space transport or space defence.

Europe cannot afford not being part of this evolution, or to simply take a back seat.

What is to be expected?

This endeavour can be prepared incrementally, based on strong existing assets. The European industry is already involved in human spaceflight, via ISS Programmes. It develops the Orion European Service Module (ESM) and highly reliable launchers.

Europe should aim for the development of a full-fledged human-rated and cargo space transportation capability that will allow Europe to catch up with the USA & other major spacefaring nations. It would own a civil (and potentially dual use) strategic asset for the development of critical technologies, and renew the European pioneering spirit through a flagship project.

The vehicle, fully developed in Europe, will notably leverage on:

- European crewed capsule and cargo capabilities derived from past programs/studies (e.g., Hermes, X-38 CRV, Columbus, ARD, IXV, Orion ESM, Space Rider);
- Re-entry capabilities (e.g., IXV, Space Rider...);
- All the investments made for European launchers, e.g., in propulsion that would require minor adjustments to serve human rated flights;
- All skills developed in aeronautics;
- The European spaceport(s).

An ambitious flagship programme targeting human spaceflight shall put all the necessary means to:

- Adapt European heavy launcher (Ariane 6 or evolutions) for crewed and cargo flights within a stepped approach;
- Need to develop a rigorous end-to-end safety process to protect our European astronauts;
- Develop a human rated vehicle based on strong European heritage, with a versatile design to enable an array of missions, including: cargo to the Moon, habitat and transfer modules;
- Develop space infrastructures to create Space Highways in the Solar System starting from the infrastructures serving routes between Earth and Mars;
- Develop innovative and critical technologies to raise the standard of European access to space and embrace growing in-space and from-space applications;
- Adapt European Space Ports towards new access to space services, and in particular human launch;
- Develop life support techniques (air and water revitalisation). These technologies would also benefit on Earth in response to the increased need for more circular economy.

Users, timeframe and budget:

Such a programme will serve both institutional and commercial human-rated and cargo transport demand for:

- LEO orbits (e.g. to ISS, commercial stations and free-flying missions) with versatility to address cargo as well;
- GEO orbit (e.g. In-Orbit Data Centres, Solar Power Stations);
- Lunar destinations and beyond.

European private sector would gain access to a rapidly growing market of significant strategic interest, and spin-offs would be created (e.g., point-to-point transport, reusable Upper Stage, full reusability).

Institutions would master all required space capabilities to secure European participation in relevant fields of growth and future sovereign questions (e.g., industrial policy, access to resources, future growth).

A first flight in LEO could be demonstrated before 2030.

Oxygen/Hydrogen in-situ production and distribution for a sustainable presence in Space

Rationale for action

In-space production of O_2 and H_2 would be the cornerstone of multiple on-orbit operations and exploration-related applications such as long-term space transportation (O_2/H_2), life support (O_2), energy production and storage (H_2). It is a critical enabler solution for long term planetary exploration goals.

It would enable, e.g., the life extension of launch vehicle upper stages to support orbital operations, debris reduction, reduced mission Total Cost of Ownership as well as allowing a sustainable presence in space.

If Europe positions itself quickly on the implementation of gas and cryo refuelling stations in orbit, this could give Europe an agnostic federating and transversal role and promote collaboration between other space powers such as the US, China, and Russia.

Finally, the development of these technologies for space would benefit energy transition on Earth via spinoffs. Would be of particular interest to all aspects related to the emerging hydrogen and fuel cell economy.

What is to be expected?

The demonstration and the set-up of O2/H2 in-space production and distribution infrastructures would require three steps:

1. Step 1: Orbital demonstration basic technology building blocks
    - Sending water as "passenger" in unused volumes of the launchers;
    - Demonstrate
        i. Water storage in orbit;
        ii. Electrolysis in orbit into O_2/H_2;
        iii. Liquefaction;
        iv. Transfer/refuelling to spacecraft in orbit;
    - ➢ Premise of a deposit of rocket propellants in orbit.
2. Step 2: O_2 in situ resources for processing, e.g.
    - Demonstrate:
        i. O_2 extraction from Lunar regolith;
        ii. O_2 Storage;
        iii. Refuelling of lunar vehicles;
        iv. O_2 transfer to on-orbit propellant depot;
3. Step 3: H_2O in situ resources for processing
    - Demonstrate:
        i. H_2O extraction from the Moon;
        ii. H_2O Electrolysis
        iii. Transfer O_2/H_2 from the Moon to the different propellant depots in orbit
        iv. H_2 for on orbit energy production

Users and timeframe:

The implementation of H2O, O2, H2 value chains in space from space resources could completely reinvent the way space missions are designed, by being able to go deeper, stay longer, extend the lifetime of spacecrafts, and consequently reduce again the cost of access to space.

The users will be rocket upper stages for long duration transportation (O_2/H_2 refills), manned spacecrafts (H_2O and O_2 refills for life support), lunar surface mobility (H_2 energy), and every process requiring energy in orbit or on the Moon surface (H_2 Energy).

The processing of in-situ lunar resources could be demonstrated before 2030.

This would address the sustainability of space activities, reducing carbon footprint on Earth and debris production in Space, for the benefit of international cooperation associated with Europe leading the path forward on sustainability. Being at the forefront of these technology and solution developments would strongly benefit Europe's space economy and industry, and foster a needed cross-sectoral collaboration (space and non-space industries will be needed to build end-to-end value chains).

Europe should be an actor in the exploration and governance of the space resources on the Moon. It should reaffirm the values that should structure the current and future lunar momentum, in particular the multilateral approach and sustainable development.

Moon economy - Science and exploitation

Rationale for action:

The Moon race is currently dominated by the USA and China, with Europe (via ESA) being a partner to the American programme (Orion, Gateway) and studying future important elements (lander, cargo) and considering taking parts in the Chinese and Russian International Lunar Research Station (ILRS) programmes. However, a permanent presence on the Moon in the long run will only happen with some key drivers, such as science, research, pride, political and societal ambitions, geo-political considerations (the new 'space race') and with unlocking the critical enablers, in particular the harnessing and exploitation of local in situ resources. An important contribution to these goals should be envisaged if Europe’s role is to be more than a supplier to American or Chinese programmes.

For an effective exploitation of the Moon from both a commercial and scientific viewpoint, the availability of suitable infrastructures for telecommunication, navigation, resource generation and delivery is mandatory. Europe could therefore reinforce its role by investing on them.

What is to be expected?

The European industry has world-class unique capabilities which are fully relevant to develop the “Moon economy”: lander technologies (from exploration), surface mobility with rovers, space astronomical payloads (optical or radio) that could be installed on the far side, unique in-situ resource technique to extract water, radioisotope power sources or Regenerative Fuel Cell Systems to survive the lunar night, communications and navigation satellites, etc.

A commercial market for the Moon exploitation will take some time to establish and European institutions could foster this development by funding the first steps of exploitation (communications, surface mobility, science, resources) and support the European industry to propose services to the future Moon base in the next decade.

Among the above-mentioned needed technologies, the electric power distribution to the users across the lunar surface is one of the fundamental services to be provided. The development of a network of wireless transmitters/receivers (e.g., via laser or RF beams) that transfer the power from the solar power plants operative on the daylight hemisphere of the Moon surface to the users in the night zone (e.g., human outposts, scientific observatories) can provide the solution to this issue.

Two possible solutions exist:

1. Produce electric power on the Moon surface;
2. Produce the electric power in Moon orbit and deliver it wireless on surface.

Some studies and first prototypes have been carried out in the past, the demonstration and set-up of these solutions would require two steps:

1. Step 1: prototype and demonstrate the solutions on Earth with an on-orbit test to evaluate the possibility and performances;
2. Step 2: deploy the solution(s) on the Moon surface and/or orbit on time with regard to the commercial and scientific missions. The deployment should be done step by step growing with the demand of power and energy.

Users, timeframe and budget:

Such a programme will serve both institutional and commercial Moon mission demand for power and energy on surface.

The European private sector would gain access to a rapidly growing market of significant strategic interest, and Europe could play a significant role in the Moon race (and beyond) as provider on a vital infrastructure for Moon colonisation.

A first on Earth demonstration should be targeted before 2023 with a first small infrastructure deployed on the Moon before 2026.

Annex: ESA-Industry exploration June 2021 workshop conclusions

The early feedback gathered from industry participants to the June 21-22 2021 workshop is extremely positive. The open dialogue opportunity, the possibility to present company views and the structured approach (survey, workshop and position paper) have been very much welcome by Eurospace and SME4space members. **This innovative approach has proved extremely valuable as it allowed bidirectional exchange of information, the improvement of mutual understanding and the identification of common issues, objectives and ambitions for the future European exploration programme**. Industry has welcomed this opportunity and looks forward to the possibility to elaborate other such structured exchanges with ESA on other programmatic areas.

Executive summary

Europe and ESA shall aim high and secure significant and autonomous contributions to the global exploration strategy to anchor strongly Europe in the international geopolitical framework of exploration programmes. The time is critical, when the USA and China are accelerating their plans.

Permanent presence in LEO, Moon and Mars is long-term objective. The synergies between LEO, Moon, and Mars destinations are important. There is a technological and capability continuity to build upon, taking advantage of the solid European heritage, of technology spin-in and spin-offs, and leveraging on the variety of ESA programmes and directorates.

Technology and innovation will provide the bedrock of European involvement in Exploration programmes, creating the capabilities and building blocks to secure the participation of Europe with the right levels of autonomy that Europeans deserve. European contributions to the exploration strategy shall ensure value added on technology capabilities and current heritage, and focus development efforts on key building blocks and enablers for Europe to keep an edge.

Fostering the emergence of the LEO/Moon/Mars ecosystems is an essential paradigm shift, supported by emerging players and established players alike, with new and disruptive propositions that will be enabled by the institutions promoting the exploration programmes. Institutions shall promote procurement paradigm changes and the emergence of a service-based demand. Industry must now be ready to invest, take risks and accept different and disruptive financing schemes.

The science and societal added value of Exploration for all humankind will be demonstrated as the exploration challenges unfold and with Europe stepping up its ambitions to support the programmes. Planetary exploration challenges, from an environmental and sustainability perspective provide an extreme test bed for humans to address critical Earth bound environmental and resources related issues. Furthermore, human exploration sets the highest marks for international cooperation, economic diplomacy, soft power and is an instrument for global peace, for outreach towards the younger generations, and for scientific production.

Detailed conclusions

The long-term ESA exploration strategy in the European and international geopolitical framework

Session conclusions

Europe and ESA shall aim high and secure significant and autonomous contributions to the global exploration strategy to anchor strongly Europe in the international geopolitical framework of exploration programmes. The time is critical, when the USA and China are accelerating their plans.

- There are strong expectations for Europe to develop and contribute to autonomous capabilities and to secure prominent roles for Europe in the global exploration scenarios.
- Budget constraints, leverage and opportunities: the European budget for exploration is growing but the NASA budget is still way much higher and may be providing consistent business opportunities for companies, European companies have high expectations from international cooperation at both institutional and private sector levels. Industry has high hopes regarding the growing commitment of European states towards exploration in the future.
- More frequent missions to build more resilience and safety and accumulate experience faster for European companies, big missions are not the only way to go. Small missions have a lot of added value, they are vital to the European exploration strategy, they enable to plan ahead, to generate standardisation, they allow more risk taking, they lower the entry barrier for smaller players and new entrants.

Synergies of three destinations LEO, Moon, Mars

Session conclusions

Permanent presence in LEO, Moon and Mars is long term objective. The synergies between LEO, Moon, and Mars destinations are important. There is a technological and capability continuity to build upon, taking advantage of the solid European heritage, of technology spin-in and spin-offs, and leveraging on the variety of ESA programmes and directorates.

- LEO, Moon and Mars represent 'one' exploration programme with a stepped approach and built-in synergies at all levels, providing a comprehensive narrative;
- There are significant synergies and commonalities at technology and programmatic levels between the three destinations. There is high added value in ensuring continuity for technologies and capabilities shared by all destinations, and in particular:
  - In-space transportation and propulsion aspects;
  - Rendezvous technologies (e.g., GNC and vision-based navigation) and proximity operations;
  - Autonomy, robotics, and artificial intelligence (for in-orbit and planetary surface operations)
  - Human machine collaboration and co-bots;
  - Advanced structures and manufacturing (in-orbit and on planetary surface), ISRU;
  - Habitats;
  - Advanced life support, health management systems;
  - Power systems;
  - Secure systems and connectivity.
- Synergies also exist and will be enhanced and further developed across ESA directorates and programmes, with the "multi-domain" projects, such as the Moonlight initiative led by TIA, or the in-space transportation initiatives within STS. Inter-directorate synergies will provide an additional dimension and added value to the ESA exploration programmes.

Innovation, game changers, showstoppers: technology, the ultimate enabler?

Session conclusions

Technology and innovation will provide the bedrock of European involvement in Exploration programmes, creating the capabilities and building blocks to secure the participation of Europe with the right levels of autonomy that Europeans deserve. European contributions to the exploration strategy shall ensure value added on technology capabilities and current heritage, and focus development efforts on key building blocks and enablers for Europe to keep an edge.

- Europe shall build on its strong heritage, particularly in robotics and autonomous operations. The technology is maturing fast so we can consider quick roll out. There will be challenges for the training of artificial intelligence but growing information gathered and the creation of digital models will accelerate the pace. The precursor and validation objectives will include a priority on ground analogues for Moon and Mars, this is an area of potential leadership for Europe;
- Transportation is a key step. Without a European autonomous access to LEO, then Moon and Mars, Europe will not be able to establish consistent roles in future exploration schemes. Europe shall first aim at delivering cargo missions, but should consider stepping up with human rated systems very soon. The challenge is more on safety implementation rather than on technology. Human rated launch systems can be readily available for Europe in the medium term. In this context, reusability for launcher elements and human and cargo modules, is not an option anymore, it is a mandatory requirement for efficiency and sustainability;
- Europe should gain increased autonomy for the preparation of human arrival on the Moon, and later on Mars. The first priority is to acquire autonomous landing capabilities (EL3);
- Propulsion represents another important challenge, embracing three key technology solutions, chemical systems, high power electric propulsion and nuclear propulsion. The development roadmap must be defined according to specific advantages of each solution. Europe shall be able to engage in all technologies, because each will play a part in the global logistics approach. Close consideration shall be given to in-orbit refuelling options and technologies, and for on-planet solutions for propellant production and management. These are necessary steps in the global architecture and

logistics scenario. In the context of the end-to-end logistics approach, the agency shall be able to create the possibilities for commercial services, providing a new template for commercial opportunities to flourish around the exploration ecosystems;
- Power generation, storage and distribution be it for in-space long distance travel as for on-planet infrastructures and operations is a major challenge. The power budgets associated to human long duration mission requirements are at least one order of magnitude higher than current systems available in orbit. The variety of mission profiles considered require the development of specific capabilities with innovative solutions, including, and not limited to, radioisotopes for on-planet power stations and the recourse to local resources (e.g., hydrogen mining and fuel cells) for energy generation;
- Habitats are of course a must, and the Gateway programme will be a great learning opportunity, but the challenge really lies in long duration travel. Here the challenges for long duration health support (radiation shielding, atmosphere and water regeneration, food processing and waste management) are particularly acute, and may provide the possibility for Europe to position itself as a leading provider. This is an area with great opportunities for spin-in from Earth-bound applications (submarine, hospitals and patient care, water treatment, etc.) and potential spin-offs from advances achieved to support, in particular, mass reduction and lower energy consumption that will benefit the circular economy requirements of Earth environmental policies. Europe also needs to gain expertise in space weather and radiation monitoring and protection;
- The European industry demonstrates the mastering of a broad portfolio of technologies and opportunities. The European ecosystem is considered quite complete and competitive.

Fostering the emergence of the LEO/Moon/Mars ecosystems

Session conclusions

Fostering the emergence of the LEO/Moon/Mars ecosystems is an essential paradigm shift, supported by emerging players and established players alike, with new and disruptive propositions that will be enabled by the institutions promoting the exploration programmes. Institutions shall promote procurement paradigm changes and the emergence of a service-based demand. Industry must now be ready to invest, take risks and accept different and disruptive financing schemes.

- The European exploration strategy shall enable the balanced participation of the whole supply chain, enabling to leverage the capabilities of new players in complementarity with the heritage provided by historic players. The right balance between disruption, and heritage, and between service approach and assets development will be achieved by the conjunction of new and established players towards the provision of a new set of services and products supported by new business cases;
- With this in mind, Europe shall create the opportunities to commoditise space services and space resources for a global exploration initiative to grow and develop. A move towards services provision rather than assets procurement, will create the conditions for business models to emerge and be validated, and will create the possibility for emerging demand to develop. Europe shall ensure that the role of institutions evolves accordingly, by giving more authority to the private sector, and more room for private initiatives, innovative solutions and disruptive architectures;
- The services environment, supporting the Moon and Mars missions, such as communications services, will become the first area for implementing the new service-based approach, with such precursor initiatives as ESA Moonlight or NASA CLPS. These will provide a test bed for more business-driven approaches and the development of the new ecosystem;
- The access to space resources will be a major enabling factor for human exploration. A logistics infrastructure for the collection, transformation and exploitation of valuables (water, hydrocarbons,

regolith, metals) is a necessary step, to allow an effective link between celestial bodies, the earth, and to enable the safe and cost-effective expansion of humans in space. Resource efficient missions will have to consider in situ resource utilisation;

- There is an ISRU value chain to be promoted, but the programmatic environment is a challenge (how can the demand emerge without infrastructure? and how can infrastructure be developed lacking a demand?), notwithstanding there are strong value propositions from industry to make this a business case;
- Recommendation to foster the emergence of an eco-system:
    - De-risk technology;
    - Anchor tenancy from ESA for services;
    - Provide visibility on long term institutional commitment to enable co-investment;
    - Promote interoperability between international partners (this is also an objective of the Artemis accords);
    - Enable industry models to lower the cost of resources.

Science and societal added value of Exploration for all mankind

Session conclusions

The science and societal added value of Exploration for all humankind will be demonstrated as the exploration challenges unfold and with Europe stepping up its ambitions to support the programmes. Planetary exploration challenges, from an environmental and sustainability perspective provide an extreme test bed for humans to address critical Earth bound environmental and resources related issues. Furthermore, human exploration sets the highest marks for international cooperation, economic diplomacy, soft power and is an instrument for global peace, for outreach towards the younger generations, and for scientific production.

- Exploration programmes are part of humanity's storytelling for the past, present and future;
- Exploration programmes are fuel for inspiration and imagination of younger and future generations, they contribute to accruing interest in STEM and increase the global visibility and public interest of all space programmes;
- Human exploration, in its international dimension, and both its collaborative and competition aspects, provides a basis for geopolitical stability and contributes to global peace;
- Exploration programmes, and related technologies, will provide lessons-learned, technology spin-offs, and value added for the long-term sustainability of human activity on Earth. Mars is not a planet B, but a long-term sustainability template for our planet Earth;
- Exploration programmes support in depth knowledge of planetary physics, supporting scientific gains in astronomy and astrophysics. They contribute to the global knowledge and understanding of the Earth dynamics as a planetary system and its situation in the universe;
- The exploration programme shall define and identify clear targets (outreach, science, political etc.) with achievable performance indicators to ensure that benefits will be delivered in time and to the greatest numbers.