STRATEGY NOTE

SPACE/NON-SPACE CROSS-FERTILIZATION:

A MAJOR STRATEGIC AXIS FOR A SHARED EARTH-SPACE FUTURE

The case of upcoming lunar exploration

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Established in 2019, the ANRT Destination Moon Group gathers space and non-space actors to bring together vision, innovation and communication on the project of a sustainably expanding human base camp on the Moon. The transformation of the space industry through new technologies opens up possibilities and gives new meaning to inhabited exploration of the Moon. The group is chaired by Claudie Haigneré and supported by CNES.

EXECUTIVE SUMMARY

Since 2019, the ANRT Destination Moon Group has made intersectorality the pillar of a European lunar strategy. The next step involves Space/Non-Space Interdependence, known as the SNSI approach. As lunar exploration kicks off again, this approach initially stems from observing the diverse range of new skills and knowhow required to explore space today and tomorrow. It is then based on the existence of mutual dependence between space and non-space sectors to develop the future technologies of space exploration. In exchange, space exploration also brings the potential for innovation in breakthrough technologies for the future of our planet.

The key is to act on this paradigm shift to reaffirm the important role played by public powers and take a new look at existing synergies between space and non-space actors in order to, at the very least, facilitate mutual technology transfers between sectors and, at most, encourage close collaboration in defining, implementing, and carrying out space operations. Along with mutual economic benefits, at the same time this cooperation means establishing an Earth-Space connection for the applications developed.

SNSI ensures close collaboration between earthly actors that have developed or are developing earthly knowledge and expertise, *on Earth*, with space actors who possess detailed knowledge of the specific requirements of the space environment.

Ultimately, SNSI affirms the possibility of a *space/non-space* cross-fertilization fostering the synchronization of complex, complementary technological developments, aimed at setting up new integrated value chains and European service capacities. In our note, we apply this to the case of the Moon, but our satellite could also act as a testbed to later envisage the deployment of an SNSI strategy to explore the rest of space.

INTRODUCTION

Since the start of its work in 2019, the ANRT Destination Moon Group has made intersectorality the pillar of a European lunar strategy. We have highlighted how important it is for non-space companies to include the Moon in their agendas and engage in space, as a continuation of their earthly activities, and thus contribute to and benefit from the expected progress in innovation. This idea has been put forward to various French and European government bodies working on space and industrial policies. Already today, a space/non-space transmission can be observed in Europe in different exploration projects. This strategic reflection is also taking place at a key moment in Europe's commitment to space exploration, may it be in cooperation or autonomously. All paradigm shifts are an opportunity to rethink the dynamics between actors and stakeholders.

In this note and as an evolution of our work, we have moved on a step: we no longer only speak of space/non-space intersectorality, but of space/non space *interdependence* (hereafter, the SNSI approach). Not wishful thinking, not hand-waving, simply an observation. The SNSI approach affirms that, over and above intersectoral cooperation, there is a mutual dependence between space and non-space sectors for the development of future technologies to explore space. In return, the exploration of space is also a potential area for innovation in breakthrough technologies for the future of the Earth. The SNSI approach[1] is both the observation of a need and a strategic necessity. With SNSI, European exploration of space in general and of the Moon in particular takes on a quadruple duality: ***space-non-space, Earth-Space, public-private, civil-military***. Beyond the technological aspects, SNSI is also rooted in geo-economic domains, and in attracting and mobilizing young talents from space and non-space companies, making space exploration an opportunity to develop major projects that bring new solutions for humanity.

Although NewSpace has diversified sources of funding for space activities, states and their agencies still play a key role in implementing large space projects – in particular through investment policies and calls for tender. The implementation of a strategy based on the SNSI approache therefore requires support from public powers. Support that is all the more vital since it means giving a positive signal and encouraging non-space actors by inviting them to get involved in a field they are not initially familiar with. In studying the manifestation of this support, our note looks through a French lens. Yet it fits in with a space collaboration movement at European level. France can be the strategic leader and the laboratory of an autonomous SNSI approach strategy.

1/ Space-non-space interdependence: definition of an approach

Defining SNSI

The mutual technological benefits of Earth-Space are already a reality. On the one side, numerous technologies developed for earthly purposes have seen their scope of action extended to include space, with a few adaptations. Examples of these so-called "spin-ins" include the development of photovoltaic solar panels, batteries, fuel cells, and electronics for space. Conversely, technological progress aimed at space has had useful and direct applications for Earth, known as "spin-offs". The development of services resulting from navigation and satellite telecommunication has led to the improvement of services for emergency assistance, monitoring of people and inhabitants, and local

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[1] Space - non-space interdependence

agronomic developments. Two precise examples are worth mentioning. First, the development of a turbomachine to refrigerate biological samples on the international space station in 2006 led Air Liquide to industrialize its compact, reliable Turbo-Brayton range to reliquefy natural gas boil-off in LNG containers, thus avoiding greenhouse gas emissions. Another example is research on osteoporosis and its treatment, initially to limit bone loss in astronauts. This reciprocity has taken place within different frameworks: responses from space and non-space manufacturers to calls for tender from agencies, international cooperation on space, etc.

The arrival of sustainably expanding base camps on the Moon will give new impetus to the development of space technologies. We can easily imagine that by making these camps a new technological and social laboratory – to which humans with their multiple needs will also be sent – the Moon will act as a key catalyser of spin-ins and spin-offs.

This mutual benefit is the inspiration behind the SNSI approach. More than a collaboration between space and non-space actors, the approach centres on their interdependence. In the context of a new kick-off for space and moon exploration, the SNSI approach stems from observing the diverse new skills and knowhow needed to explore space today and tomorrow. They key is to take stock of this paradigm shift to take a fresh look at existing synergies between space and non-space actors in order to, at the very least, facilitate mutual technology transfers between sectors and, at most, encourage close collaboration in defining, implementing, and carrying out space operations. Along with mutual economic benefits, at the same time this cooperation means establishing an Earth-Space connection for the applications developed.

This SNSI approach, based on interdependence between space and non-space actors, is a strategic necessity. New space exploration missions aim to take humans and robots into space for extended periods with new programmes (search for and use of water, extraction and exploitation of resources, etc.). Needs in terms of energy autonomy, habitat, life and robot support take on a new configuration. The SNSI constitutes a condition for the feasibility and efficiency of missions: it ensures close collaboration between earthly actors who have developed or are developing earthly knowledge and expertise, *on Earth*, with space actors who possess detailed knowledge of the specific requirements of the space environment. In a more forward-looking way, the space context to a certain extent offers a test-run for some future earthly conditions that will require adapting to a hostile environment (pollution, climate change, etc.) in a constrained space (e.g. space agriculture could inspire tomorrow's controlled-environment agriculture).

The aggregation of an extended economic fabric around a major space exploration project can ensure the creation of greater value around that project and transform its cost into an investment. By taking on board actors that already deploy skills on Earth that are useful for space missions, these same actors are invited to build the laboratory of their future space applications. In a more forward-looking way, in-orbit manufacturing will mean direct manufacturing in space of electronic components and molecules easier to produce in microgravity. In 2020, NASA selected several companies to carry out in-orbit manufacturing experiments on cables and optical components (such as ZBLAN optical fibres). This mutual Earth-Space exploration movement establishes synergy between actors, capable of guaranteeing the costs of a space exploration project while durably maintaining the interest of economic actors.

Examples of SNSI approaches for the Moon

The lunar organization of the SNSI approach is based on the observation made above: in other words, the installation of a sustainably expanding base camp on the Moon involves radically different needs compared to the short Moon stays of the Apollo programme. The question is no longer how astronauts can survive on the Moon but rather how they can live on the Moon, partly using local resources for on-site production.

The moon SNSI requires close collaboration between space and non-space parties in a wide variety of domains:

- Energy: with on the one side earthly technologies already adapted or to be adapted to lunar needs (photovoltaic solar, radioisotope generators, small modular reactors (SMR: small nuclear reactors in the range of 10 to 1,000 kWe), electrolysis or catalysis technology for In Situ Resource Utilization (ISRU), etc.), and on the other side, technologies developed for lunar usage but that, due to their earthly potential, could be interesting for non-space actors (energy-storage batteries, compact energy sources, etc.). A very strong synergy could exist between investments made for the energy transition on Earth (low-carbon hydrogen industry), and technological requirements for storing available intermittent energy in space.
- Space habitat: by necessity, space-habitat in the most closed circuit possible, where as much as feasible everything must be reused or rapidly recycled for new usages. The cost of space transportation calls for optimum recycling of the resources brought in (such as water) – the space habitat could here constitute a laboratory of the future earthly habitat, involving Earth-based actors right from the design of the lunar habitat.
- **Health: the long-term presence of astronauts on the lunar surface will for example involve equipping bases with healthcare equipment (x-rays, scanners, etc.) adapted to space conditions and optimized/miniaturized for space transportation. Companies in the medical imaging sector could take this opportunity to develop lightweight, miniature medical units, useful for rapid transportation on Earth in emergency situations or remote areas.**
- Life in space: in connection with the previous section, astronauts will also need to be sustained, requiring air to breathe, water and food. All technologies involved in life support can be interesting for the earth and space sectors.
- **Mobility: long-term presence on the lunar surface will require greater mobility for astronauts away from the base camp. The features of space and the lunar surface invite the development of transportation solutions such as airless tyres/wheels suitable for an uneven, dusty, abrasive terrain – here Michelin's work is important. This equipment could have immediate earthly uses on the ground or in arid areas that have similarities with the lunar environment. Moon vehicles will also need to be equipped with suitable motorization. Associating automobile manufacturers with the space industry to develop this kind of vehicle can be part of an SNSI approach with mutual benefits.**
- **In situ resource utilization: the water stored as ice at the poles of the Moon is a resource for which a beneficiary business plan can be imagined in the mid-term. Initially, the challenge will be to prospect for this resource and identify the richest sites. This will involve adapting the prospection techniques used on Earth for use in lunar environments, and will open up partnership possibilities between industry and geophysical exploration, equipment manufacturers, and academic laboratories. In a second stage, the massive exploitation of**

other lunar resources will ultimately require extraction and refining facilities. The expertise of mining and chemical industries could be employed to develop these infrastructures.

- Digital: a long-term presence on the Moon raises the issue of connectivity. It is essential to be able to transmit data and continuously communicate with on-site infrastructures (including on the far side of the Moon). In parallel, the improvement of predictive models and numerical modelling could serve both Earth and base camps on the Moon. Also relevant here is AI, which can be used as a companion for astronauts and to support the technical management of the base.
- **Refuelling in orbit: lunar resources will be used to manufacture fuel in space, for space, and take advantage of six times less gravity on the Moon than on Earth to make journeys into any orbit (i.e., even travelling into low orbit requires less energy from the Moon than from Earth). Therefore, setting up standard, interoperable refuelling facilities in different orbits would extend the lifespan of spacecraft, reduce debris, bring down the total cost of missions, and consequently lead to more sustainable space operations. Numerous synergies with gas-filling stations (e.g. low-carbon H2, biogas) are being developed for earthly mobility and low-carbon aviation.**

In addition to generating mutual industrial/technological advantages for Earth and space, these developments given as examples could position Europe on transversal services, which all of the nations present will need and which are therefore likely to foster international collaboration – the cornerstone of sustainability since it involves common, global scientific and technical action. Provided, however, that standardization and interoperability polices are implemented between the nations involved.

2/ Space/non-space interdependence: fostering the approach

The importance of a strategic vision to foster the call for tenders-SNSI tandem

Calls for tender are central to the SNSI approach because they are a manifestation of the strategic volition of states and public space actors, as well as major companies in the sector that would launch calls for tender aimed at their partners and sub-contractors. Nevertheless, ensuring that calls for tender are as beneficial as possible to SNSI requires being able to rely on a long-term, negotiated, shared European vision and strategy to solicit lasting public support and obtain adequate resources to meet the targets. Too many space projects have not seen the day due to a lack of long-term support. It is also fundamental to define objectives of common sovereignty in terms of commercial activities, services, technologies, transport, etc. All of these strategic choices should in addition take into account the overall landscape of Europe's international space partnerships to decide what the continent can commit to in a sovereign manner and define its priorities as a frontline partner. For example, Europe could want to develop a sovereign technology for radioisotope generators (which the US, China and Russia already possess), but a European activity on nuclear thermal propulsion is only currently feasible as a contribution to a more widely international programme. Europe could, for example, develop regenerative fuel cell systems (based on hydrogen technology), used to store intermittent energy and produce electricity with higher yields, bringing direct benefits for users on Earth.

Concerning strategic considerations, it is interesting to compare European strategy documents with those adopted by NASA.

On the other side of the Atlantic, these documents (e.g. NASA Technology Roadmaps, 2020 NASA Technology Taxonomy, NASA Strategic Technology Integration Framework), generally comprising hundreds of pages, precisely describe which technology bricks to develop and can directly serve as guides for calls for tender aimed at complex, multi-actor technological developments (e.g. the KRUSTY 1-10 electric KiloWatt reactor). In contrast, European strategic documents (e.g. ESA Terra Novae 2030, ESA strategy for science on the moon) are much shorter, centre on programme objectives, and rarely mention the necessary technological developments. Yet it is these strategic documents that precisely identify the domains in which space and non-space actors could work together. Even more importantly, these same documents are the guarantee of coherent, strategic elaboration of an ambitious policy on calls for tender.

While waiting for a more precise definition of European objectives regarding the exploration of space, and of the Moon in particular, national programmes and certain European initiatives can appear to be insufficiently coordinated, inadequately taken into account in strategic research programmes for earthly applications, or too occasional and disjointed. This raises concerns regarding:

- The few connections with space actors involved in Priority Research Programmes and Equipment (PRPE) concerning batteries, hydrogen, and Advanced Energy Systems Technologies (AEST) (solar PV, etc.).
- The absence of a space field among the themes that feature in the annual calls for proposals made by the French National Research Agency (ANR) (which does not exclude proposing research themes useful to the space field in general fields like numerical simulation, materials, and scientific exploitation of space data).

The elaboration of a long-term vision and common strategy that are sufficiently precisely defined to be broken down into key technology road maps (like the NASA documents) is clearly an important step in Europe to ensure that calls for tender from space agencies and other actors (national programmes, etc.) are more effectively targeted. This concerns key technologies and intersectoralities that need to be developed to attain the degree of autonomy/sovereignty sought after for new missions like the exploration of the Moon (instead of simply pursuing partnerships and cooperation stemming from former space missions that Europe participated in). To do so, Europe must ensure its autonomous access to space and the Moon using its own heavy-lift launcher with, for example, the launch of the EL3 Argonaut by 2030. This independent access will enable the sovereign, autonomous development of European scientific and commercial activities in space and on the Moon in particular, including projects that have opted to take an SNSI approach. Providing these space projects with a sufficient budget remains a fundamental condition.

Once the long-term vision is in place, the following actions would accelerate its implementation:

- In calls for tender, focus should be put on the maturation of “value chains”, rather than brick-by-brick technological maturation: this would encourage setting up consortiums of complementary actors ready to coordinate their development efforts towards a service. To follow through with the SNSI rationale, calls for tender could make having mixed space / non-space / start-up industrial teams one of the response criteria. Ultimately, and more globally still, the calls for tender-SNSI tandem could be employed for concrete large missions – as defined by Mariana Mazuccato in her recent essay, *Mission économie* (Fayard, 2022) – to accompany the technological and societal transitions needed for a sustainable future.
- Small-scale, low-maturity demonstrations should be carried out, in orbit or on the lunar surface, when possible **for all future commercial missions, to demonstrate the commercial usages and stimulate the market through the rapid emergence of a new service supply (the supply**

generated by institutional orders will stimulate the cislunar market, and not the other way round). To this end, ensuring availability to different installations or lunar analogues in France and/or Europe would be a real plus point. These installations would in particular give non-space actors access to a test and qualification centre, which is vital for getting to know about space environments.

Facilitating SNSI

Without dismissing the importance of calls for tender, three essential factors will boost SNSI:

- Firstly, the question of the cost of the *spatialization* of non-space technologies. Adapting earthly technologies to the specific conditions and needs of space can represent an excessively high cost compared to the potential turnover that earthly manufacturers could initially generate from these technologies. In this spirit, private-public partnerships could be developed between space institutions and earthly champions of industry, to bring the marginal effort required to spatialize robust technologies that exist on the Earth and are needed on the Moon. While spatialization is a risk in its own right, it does require support.
- In the same vein, secondly, developing standards is vital to truly facilitate collaboration between space and non-space sectors. Even more importantly, the same standards would enable non-space industrialists to develop upstream solutions and technologies compatible with space.
- Dual innovation programmes need to be encouraged, through research and development policies. It would be interesting to take inspiration from the strategies developed in civilian-military research policies. In non-space engineering schools, another possibility is to establish modules to raise awareness of space technologies and initiate and support challenges that trigger space/non-space disruption.
- Lastly, European access to the lunar surface needs to be encouraged taking a similar approach to the CLPS missions (see below) initiated by NASA. Ultimately, an objective in this direction would be a European call for tender for one or more Moon landers in order to deploy both useful institutional loads (ESA or Member States) and useful commercial loads.

Learn from the Commercial Lunar Payload Services (CLPS) programme

In the United States, NASA’s CLPS programme finances the transportation and deployment of private lunar landers subject to a call for tender. The objective is to use the expertise of private actors to design and send equipment to the Moon.

European technological expertise is a key asset for developing lunar activities. The implementation of a CLPS-type programme at European level makes particular sense. While initially space actors are the first to get involved in this type of programme, an incentive policy to collaborate on SNSI could encourage non-space companies to find opportunities. The ISpace HAKUTO-R mission was also made possible by ArianeGroupe, which assembled, integrated and tested the lunar lander at Lampoldshausen in Germany. The combined skills mobilized led to the design of a propulsive system to land on the Moon. It is essential to capitalize on this type of knowhow to develop other lunar activities.

3/ Examples of fields and examples of space / non-space cross-fertilization concerning the Moon

The table below presents a *non-exhaustive* list of the fields and examples of space/non-space *cross-fertilization* concerning the exploration of the Moon. The left-hand column features space technologies, and the right-hand column non-space technologies. The combination of these two columns illustrates a community of technological features shared by the Earth and the Moon.

Space technologies	Non-space technologies
MOBILITE	
▪ Lunar rovers ▪ Moon modules ▪ Surface drones (prospection, reconnaissance)	▪ Electric motorization ▪ Earth drones ▪ Gas-fuelling and automatic cyrogenic stations on Earth
CONSTRUCTION/HABITAT	
▪ Manufacture of lunar building materials (e.g. regolith base) ▪ Construction and equipping of lunar habitats and shelters (hangars, stockages) ▪ Logistics and advanced robotics.	▪ Construction and buildings (esp. extreme environments: deserts, polar regions, underwater environments): cement manufacturers; insulation, waterproofing, electrical networks and fluids industries ▪ Architects ▪ Logistics and robotics. ▪ Interior designers
HEALTH	
▪ Telemedecine ▪ Ancillary medical equipment ▪ Healthcare metaverse	▪ Telemedecine ▪ Conditions for studying the malleability of the living world to apply to the problem of ageing populations and the resulting emergence of chronic diseases ▪ Medical equipment (ultrasound scanners, defibrillators, respirators, monitoring systems, analysis apparatus, etc.) ▪ Earthly extension of medication developed for astronauts
CONNECTIVITY	
▪ Connected objects for astronauts/infra lunar: communication, environment sensors, medical/mental diagnosis, technical surveillance ▪ Lunar communication networks ▪ Ground stations	▪ Connected objects ▪ Local networks ▪ Earthly networks
ALIMENTATIONs	
▪ Synthetic food ▪ Space agriculture	▪ Biotechnologies, GMOs ▪ Cellular agriculture (stem cells ->meat, fish) ▪ Controlled-environment agriculture, hydroponics, aeroponics, low-input cropping systems ▪ New protein sources to feed the planet and respond to demographic challenges (insects, unicellular organism production, etc.) ▪ Crop optimization using AI
AI	
▪ Assistants/astronaut companions ▪ Optimized use of resources ▪ System autonomy ▪ Mission planning	▪ Development of vocal assistants ▪ Task automation ▪ Autonomous vehicles and drones
ISRU	

▪ Lunar geological prospection ▪ Synthetic fuels for spacecraft	▪ Geological prospection ▪ Mining of minerals, metals ▪ Chemical industry
PHOTOVOLTAIC SOLAR	
▪ Lightweight solar panels *(Thales Alenia)* 2.2 kg/m², 90 W/m² ▪ Flexible, foldable solar panels ▪ InGaP/AlGaAs/Si heterojonction cells ▪ Concentration cells using lenses	▪ High-yield PV solar *(Perovskite, Tandem perovskites/SiC, etc.)* ▪ InGaP/GeAs/Ge heterojonction cells ▪ Dye-sensitized cells ▪ Power electronics *(undulators, etc.)*
BATTERIES	
▪ High-energy density batteries ▪ Li-CFX 500 Wh/kg batteries ▪ High-capacity batteries	▪ High-performance solid electrolyte batteries (450 Wh/kg) ▪ Increased capacity batteries (Ah/kg) *(lithium-sulphur, sodium-ion, magnesium-ion)* ▪ Organic batteries ▪ Power electronics *(GaN, SiC, Diamant, etc.)*
FUEL CELLS AND OTHER HYDROGEN TECHNOLOGIES	
▪ PEM fuel cells 2.5 kW – 4.5 kWh 10 kg H_2/O_2 (for Mars) ▪ *(Prototech, Airbus DS, Air liquide)* Low temperature control ▪ SOFC-SOEC reversible fuel cells ▪ Regenerative fuel cells ▪ Electrolysers	▪ Use of fuel cells developed for space for earthly purposes ▪ Yield of low-carbon hydrogen production facilities ▪ Regenerative fuel cells ▪ Electrolysers
NUCLEAR TECHNOLOGIES	
▪ Radioisotope generators *(Pu238, Am241, etc.)* ▪ 1-10 kWe nuclear reactors (KRUSTY, etc.) ▪ 20 kWe-1 MWe nuclear reactors ▪ 100s nuclear thermal propulsion reactors	▪ Radioisotope generators *(CIGEO, etc.)* ▪ Nuclear reactors
MATERIALS	
▪ Composite materials (carbon fibre, ceramic, etc.) ▪ Composite polymers composites with carbon nanotubes ▪ Protection against space debris ▪ Lightweight, pressurized H_2, O_2 tanks ▪ Inflatable cryogenic tanks	▪ Composite materials (carbon fibre, ceramic, etc.) ▪ Pressurized H_2, O_2, etc. tanks ▪ Inflatable cryogenic tanks
NUCLEAR SCIENCE & INSTRUMENTATION	
▪ Radioprotection ▪ LIBS ▪ Long focal length telescopes (50-100 m) for high-energy astronomy (hard X-rays, gammas, etc.) ▪ Seismometry to survey the seismic risk of the Moon and its deep structure ▪ Detectors of lunar gravitational waves	▪ Radioprotection ▪ LIBS spectrometer ▪ Geophysical instrumentation for resource prospection ▪ Magnetometers ▪ Imaging (IR, visible, UV, X, etc.) ▪ Isotopic analyses ▪ Activation analyses
OTHER ENERGY TECHNOLOGIES	
	▪ Numerical simulation of components and electric networks or multi vectors ▪ Control and driving of components and networks ▪ Recovery of heat loss and residual energy ▪ Heat storage ▪ Usage convergence for optimized management (habitat-mobility, etc.)