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Summary Report

Space **Exploration** and **Innovation**

Space Policy and Coordination Unit



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1. Introduction

Space exploration, the human and robotic investigation and discovery of extra-terrestrial environments¹, has been driven since its outset by the USA and the Soviet Union/ Russia. However even in these traditional space-faring nations space exploration is at a turning point: the International Space Station will be extended at least until 2020 and most probably to 2028, the US Space Shuttle programme is coming to an end, and a key decision on human spaceflight in the USA has been to cancel the Constellation (Moon) programme; meanwhile developing countries such as China have shown that they are able to master human access to space and India has increasing ambitions in this area. Europe is currently in the process of developing its future plans for space exploration within this global context.

While there are a number of rationales for investing in space exploration activities (political, technical, scientific, educational etc.), this report focuses on the *impact of space exploration on wider European innovation activities* and the resulting impact of these innovations in the economic, social and environmental domains.

This report considers the role of space exploration on innovation from two angles:

- Firstly, the historic impact of space exploration generated via spin-offs from past investments
- Secondly, a forward look at the potential impacts that might arise from a more proactive approach to innovation via closer collaboration between space and non-space sectors in the development of technology and solutions to meet both space exploration and non-space challenges – so-called ‘Common, Joint or Synergistic Research and Development (R&D)’.

2. The Context of Space Exploration in Europe

Space is an area of European strength that has the ability to influence and facilitate innovation² through its inherent requirements for complex technologies and a highly skilled workforce as well as its capacity to support innovative downstream applications enabled by space infrastructure, such as communications and satellite navigation.

Space exploration is just one aspect of Europe’s wide ranging space activities which encompass fields such as Earth observation, telecommunications, global positioning and space science. European nations pursue space exploration predominantly through ESA as a coordinated effort and it currently accounts for around 15% of the ESA budget³.

At present, exploration activities are focused on European contributions to the International Space Station (including the European Astronaut Corps, the Automated Transfer Vehicle (ATV) etc.), robotic missions to Mars and other planetary bodies and technology programmes such as developing advanced life support systems for future human planetary missions.

3. Innovation from Space Exploration

In general, innovation from space activities can arise in a number of ways: the creation of novel downstream services based on the data provided by space infrastructure; the transfer, adaptation and use of space tech-

¹ Space Exploration was defined for this study, by ESA and DG ENTR as: *the discovery of extra-terrestrial environments via synergistic robotic and human activities, which will open up new frontiers for the acquisition of knowledge and peaceful expansion of humankind*

² Innovation activities refer to the *creation, adaptation and adoption of new or improved products, processes or services* (DG ENTR definition).

³ ESA Budget by Programme (2009) http://www.esa.int/esaMI/About_ESA/SEMNO4FVL2F_0.html

nologies in non-space applications (spin-offs); and more general knowledge spillovers to non-space actors and sectors via the space community's contribution to the stock of scientific and technical knowledge.

Space exploration is unique among space activities in that its primary objective is extending human understanding of space. Therefore its main output is new scientific and technological knowledge generated by extra-terrestrial exploration activities *and also* new knowledge generated as a result of over-coming the significant technological challenges inherent in accessing and exploring the extra-terrestrial environment. Unlike other space activities, such as satellite communications, Earth observation and global positioning which support economic activity directly via enabling downstream services, space exploration impacts on the economy and society indirectly - through subsequent terrestrial innovation activities based upon the new knowledge and technologies generated for, and by, space exploration.

Furthermore space exploration presents much more demanding technological challenges than other European space activities. Taking robots and humans beyond Earth's orbit requires significant technological developments in a range of areas: transportation and communication across extremely long distances; human life support outside of the Earth's ecosystem; protection against the hazards of space (radiation, extreme temperatures, low gravity etc.); and scientific instrumentation for exploring harsh and unfamiliar environments. Solving these challenging technological requirements offers the potential of substantial, possibly disruptive, innovations on Earth, stimulating economic growth and improving the quality of life of European citizens. A number of the technical challenges of space exploration have parallels to significant challenges on Earth in, for example, the fields of energy, environment, security and health, and therefore the potential for innovation triggered by space exploration is considerable. These parallels also present an opportunity for the co-development of technologies across the space and non-space communities.

4. Historic Benefits from Space Exploration: Spin-offs

4.1 Volume of Space Exploration Spin-offs

The most recent report on space spin-offs (1997 to 2008) collated by the ESA Technology Brokers reported 183 spin-offs of which 37 (20%) were identified as originating in space exploration. This number represents a *lower bound estimate* as, in a number of cases, the origin of space spin-offs is not readily identifiable. These 37 spin-offs equate to three spin-offs a year from a (current) space exploration annual budget of €0.6 billion per year.⁴

By comparison, NASA - which has had, and continues to have, a significantly larger space exploration budget and activity level - recorded a higher level of space exploration spin-offs. An assessment of the NASA spin-off database⁵ revealed an average of 16 spin-offs a year (also lower bound estimate) from a (current) annual budget of approximately €7 billion.⁶ This literature on spin-off numbers refers only to the number created and takes no account of their subsequent level of commercial success of the spin-offs (see cost-benefit section below).

The consultation conducted as part of this study, suggested that in addition to this formal route there are substantial informal flows of know-how (tacit knowledge) and technologies within companies and across company boundaries, often mediated by individuals. These types of knowledge flows are notoriously difficult to track and account for, but are nevertheless an important route for the diffusion of knowledge from space exploration to other sectors.

⁴ ESA Budget by Programme (2009) http://www.esa.int/esaMI/About_ESA/SEMNO4FVL2F_0.html

⁵ <http://www.sti.nasa.gov/spinoff/database>

⁶ NASA FY 2009 Budget Request Summary

4.2 Space Origins and Terrestrial Markets for Space Exploration Spin-Offs

Taken together, the space origins and destination markets for the NASA and ESA exploration spin-offs are fairly broad encompassing: on the space side, technologies that underpin the physical process of transporting humans and equipment into space, ensure crew health and safety and enable scientific investigations; and destination markets for these technologies in healthcare, automotive, aerospace and materials. However there are differences in the pattern of origins and markets between NASA and ESA that appear to be based in the different scale and scope of historic NASA and ESA investments.

NASA, which makes investments across the full spectrum of space exploration technologies, has stimulated spin-off activity based upon a wide range of its technologies and deployed in a wide range of sectors – with a strong focus on applications in healthcare (27%), automotive, transport and logistics (14%), security and defence (13%), and ICT (10%).

In Europe, by contrast, both the space exploration origins and application areas are more restricted. Nearly half of all European spin-offs originated in technologies supporting access to Earth orbit and re-entry - reflecting ESA's past investment in programmes such as Hermes, and a further 30% originated from ESA investments in technologies for robotic exploration activities and their on-board scientific instrumentation. This more restricted technology resource has led to a narrower range of applications, with the largest market for spin-offs being in the automotive transport and logistics area (30%), followed by other manufacturing areas and the aerospace sector (both at 14%) and materials (11%).

In comparison to NASA, ESA funded technology appears to have had limited impact in the healthcare market. However more informal evidence, from the consultation, suggests that there have been spin-offs in this area and their absence appears to be a feature of the process of recording spin-offs rather than an accurate reflection of technology application.

4.3 Cost-Benefit of Space Exploration Spin-Offs

The literature on the economic cost-benefit of spin-offs from space exploration is extremely limited, as very few studies focus solely on space exploration. A study of NASA life science spin-offs based on 43 companies (which, due to the life science focus, can be taken as originating in space exploration activities) found a ratio of benefits to costs of 6:1, with a total benefit of \$1.5 billion over a 37 year period from 1960 to 1997.⁷

The current study, based on detailed case studies of the 37 ESA spin-offs in space exploration, yielded a ratio of benefits to costs of 1.4:1. With a total benefit of €3.5 million over a 13 year time period from 1997 to 2010.⁸

As is typical of investments in innovation activities, the benefits in both the NASA and ESA studies, are highly skewed, with most of the benefits come from a small number of spin-offs. In both studies approximately 90% of the benefits came from 10-15% of the spin-offs. That the benefit ratios in both

⁷ Henry R. Hertzfeld, Measuring the Returns to NASA Life Sciences Research and Development. Space Policy Institute, George Washington University, 1998.

⁸ This figure is lower than a previous estimate of 3:1 of the indirect economic impacts of European space investment (BETA study, 1992). However, it should be noted that the BETA study had a much wider scope. Not only did it cover all space activities (not just space exploration) but it took a much broader view of the term 'spin-off effects', including benefits within the the space sector. (Bureau d'Economie Theoretique et Appliquee, based at the University of Strasbourg - Bach, L., Cohendet, P., Lambert, G, Ledoux, M.J.: Measuring and Managing Spin-offs: The Case of the Spin-offs Generated by ESA Programs, The American Institute of Aeronautics and Astronautics, Inc, 1992).

studies are positive is indicative that total economic benefits (if not for each individual spin-off) are greater than the costs.

This difference in cost-benefit of NASA and ESA spin-offs is considerable and is likely to be a result of the sheer scale of the NASA space exploration activity. With a skewed distribution of success, a larger scale of investment and the subsequent higher number of spin-offs will increase the opportunities for creating a few highly successful spin-offs. Furthermore, it should be noted that NASA's high profile, not just in the US but worldwide, enhances its ability to reach potential non-space users of its technologies.

It should be noted that tracking and accounting for spin-offs is not a simple process and therefore data on their numbers and their success are generally incomplete. The transfer of technology from the space to non-space sectors may occur at any stage of technology development with different stages having different levels of codification of the technology - from informal transfers of knowledge between technical experts (knowledge diffusion) which are extremely difficult to track, through re-use of knowledge within technology firms, to licensing of intellectual property and the more traditional 'spin-off'. The latter will only represent a fraction of the technology transfer that takes place.

5. Prospective Benefits from Space Exploration: Innovation Via Common R&D

The most significant challenges of space exploration lie ahead of us. Robotic and human missions beyond low Earth orbit require radical innovations in a number of fields, such as efficient and long-term energy generation and management and comprehensive human life support systems that encompass efficient food production, water management and remote healthcare. Innovation is also required in more generic areas such as technology miniaturisation, reliability, robustness and autonomous systems. These innovations, driven by the high level specifications of space exploration have the potential to act as major innovation triggers in non-space fields that also face similar technical challenges.

While investment in space exploration on a larger scale will increase the potential for creating successful spin-offs, a different route to non-space innovation has also been proposed. Many of the technological challenges of space exploration have parallels with significant challenges on Earth and therefore non-space innovation could be stimulated and/or accelerated through co-development of key technology and systems across space and non-space sectors. This form of collaborative development has been termed 'common R&D'.

This form of collaborative R&D partnership across the space and non-space sectors is a fairly new idea and is not, as yet, widely in use. However, the concept has been piloted, for example ESA is in a partnership with a laboratory equipment company to develop a miniaturised automated system for sampling and monitoring the microbiological quality of air and surfaces for space and healthcare applications. This partnership, developed over several years, has enabled ESA to access specialist technical expertise in a field not available within the traditional space community and to secure the development of equipment essential for human spaceflight. At the same time the company has received funding to conduct additional R&D to improve their technology against a highly challenging space specification. These improvements also have application in non-space sectors such as pharmaceuticals and healthcare services.

The concept of common R&D describes a model of joint space/non-space R&D, where knowledge and technology is co-produced, in pursuit of highly innovative dual-use technologies. Its key features are:

- A technology-based challenge common to space exploration and at least one non-space sector
- Pooled space and non-space technological expertise and skills
- Space and non-space funding for R&D

5.1 Innovation Themes: Opportunities for Common R&D

Widespread consultation with technology and commercial experts across non-space sectors (public and private) revealed a number of areas where there are synergies in the technology challenges faced by space exploration and non-space sectors. Four areas were identified where space exploration requirements align with significant global challenges – that is challenges of great economic, social or environmental importance which require concerted public and private efforts at the European level to develop solutions, and where the solution is dependent, to a large extent, on technological innovation:

- Renewable Energy (Global Challenge: Climate Change)

There is a pressing need, on Earth, for low carbon (i.e. renewable) energy sources to meet international agreements and to limit climate change in the longer term.

Space exploration requires capabilities for efficient, reliable and compact energy generation and storage on-board spacecraft and on the planetary surface. These energy sources are, by the very nature of space exploration, not based on fossil fuels and therefore fall into the 'renewable' energy category. While not all terrestrial opportunities for renewable energy generation have parallels in space (e.g. wind, wave, tidal), there are a number of synergies in areas such as fuel cells, batteries, photovoltaics, and nuclear power.

- Healthcare for an Ageing Population (Global Challenge: Healthcare)

The costs of healthcare provision in Europe are increasing year on year due, to a large extent, to meeting the needs of an ageing population. Improved understanding of the conditions of ageing (osteoporosis, cardiovascular problems etc.) along with the miniaturisation of medical technologies and their integration with communications technologies will enable better and 'smarter' diagnosis and treatment that can be delivered at the point-of-care i.e. at home or a local clinic. These developments have the potential to reduce the cost of healthcare provision, improve the quality of healthcare services and ensure ongoing quality of life for citizens.

The provision of equipment and services to manage and maintain crew health on long distance space-flights has similar requirements. Point-of-care delivery of healthcare by small (or even embedded) intelligent and autonomous systems is essential as inter-planetary travel timescales will be of the order of years rather than months, and unplanned and premature return to Earth is not an option. Furthermore, spaceflight (even short duration) creates physiological effects that are akin to accelerated ageing (reduced bone density, cardiovascular de-conditioning etc.). Therefore improved understanding of cardiovascular and musculoskeletal systems and development of countermeasures (e.g. nutrition and exercise regimens) is essential to ensure crew remain healthy throughout long duration missions.

- Secure Access to High Quality Water Resources (Global Challenge: Water Supply)

Water supplies on Earth are likely to come under increasing pressure in the future as a result of population growth and climate change. The availability of high quality water resources to meet human needs requires more efficient use of existing water resources. This can only be achieved through increased re-cycling and re-use of waste water. Furthermore, widespread provision of high-quality water will help to avoid consequences of lack of access water, such as displaced populations and conflict.

Similarly, space missions have access to limited water supplies to support all human needs (drinking, cleaning, food production). Launch costs and weight restrictions limit the amount of water and other 'consumables' that can be supplied at the start of a long duration mission and therefore all supplies must be efficiently managed with a re-cycling/ re-use factor approaching 100%.

- Secure Access to Oil and Gas Resources (Global Challenge: Energy Supply)

Despite the moves towards a low carbon economy, humans will continue to rely on oil and gas as a significant energy source for many years to come. Existing reserves are rapidly being depleted and the remaining unexploited oil and gas fields are in difficult to access locations and/or harsh environments such as under the polar ice cap and in deep and ultra-deep water. Therefore the oil and gas sector requires technologies to increase the automation and autonomy of oil and gas exploration to access and explore these reserves, reduce the costs of production and ensure safe and secure operations.

Space exploration also has significant requirements for robotics, automation and safe operations – not only for robotic precursor missions to the Moon and/or Mars but also in support of human missions. More specifically, projected space exploration activities include autonomous robotic sub-surface exploration of planetary surfaces (i.e. drilling, sample collection, preparation and analysis) for scientific purposes and for the discovery and deployment of materials to support human activities (*'in situ'* resource utilisation).

At the current time these four opportunities for common R&D are tentative in the sense that both space and non-space stakeholders acknowledge the apparent synergies in the technological innovation required in these areas. However, as emphasised by all consulted, the exact nature of the commonality in R&D needs would require considerable further dialogue between space and non-space specialists at a much more detailed technical level. Furthermore, these four areas are unlikely to represent all potential opportunities for common R&D but, despite the substantial barriers to common R&D (see below), these areas have been identified by both space and non-space experts as areas of mutual interest and therefore they currently present the most fruitful opportunities for common R&D in near-term.

5.2 Benefits of Common R&D

Co-production of knowledge and technologies between the space and non-space sectors can lead to benefits in terms of the scale and quality of both innovation inputs and innovation outcomes.

More and Better Innovation Inputs

In the short to medium term (5–10 years) common R&D can improve and the scale and quality of innovation inputs by pooling financial and intellectual resources across space and non-space sectors. The financial leverage effectively increases the R&D budgets available to the two communities and the pooled skills and experience improves the range and quality of technical inputs while also retaining the different objectives of the two communities. It also provides the two communities access to different sets of complementary infrastructures such as testing and prototyping facilities.

More and Better Innovation Outcomes

The pooled inputs to innovation can be expected to lead to more and better innovative solutions to both space and non-space challenges and to achieve these results faster than if the two communities worked in isolation.

Common R&D will:

- Expand the pool of competences and solutions with which to address major global challenges
- Expand the pool of competences and solutions to solve mission-critical space exploration challenges
- Increase number of space-exploration derived technology spin-offs with wider relevance
- Improve space/ non-space linkages and thereby improve the valorisation of space-derived knowledge spillovers

Potential Impact of Space Exploration on Innovation - via Common R&D

European technological innovation in the four global challenge areas identified above will yield economic benefits through enhanced competitive position of European businesses in the markets for new technological solutions and through more efficient use of resources. Furthermore the resolution of the global challenges will lead to significant social and environmental benefits - reducing the effects of climate change, improving citizens' health and well-being, reducing the cost of healthcare provision, and securing access to energy and water resources. Space exploration has a role to play in contributing to the development of technologies underpinning this terrestrial innovation.

Estimating the space exploration contribution to the economic (and the social and environmental) impact of solving such complex global challenges is not straightforward. The technology developments required are large in both scale and scope and will result from R&D activities undertaken by a range of actors and, furthermore, the developments are also dependent on social and political factors. In addition, the barriers to common R&D are such that the synergies in space and non-space needs are not as yet, in many cases, recognised by the key stakeholders in both communities and therefore the sector experts consulted were very often unable to offer sector-based estimates of the impact of space exploration investments. Therefore, the assessment of the potential economic impact of space exploration has been made based upon a methodology that attributes to space exploration a proportion of published estimates of the projected benefits of solving the four identified global challenges. This approach has produced a tentative and higher bound estimate of the contribution of space exploration to non-space innovation.

In this approach space exploration is taken as both a contributor to the wider stock of knowledge as well as a specific challenge that may act as an important focal point for innovation activities and so accelerate the development of solutions.

Figure 1 below provides a summary of the estimated higher bound economic benefits plus descriptions of the social and environmental benefits that may result from common R&D between the space and non-space sectors. It should be noted that timescales for each of the benefits differ based on the economic projections available in the literature. In addition, benefits in the short to medium term are fairly small in scale, while the more significant economic impacts will take time to accrue, with significant benefits arising in longer term, typically on timescales greater than 10 years.

Figure 1 Summary of Impacts in Europe

Technology challenge (non-space)	Estimated annual contribution of space exploration to non-space economic impact (higher bound estimates)	Social impact (Long-term)	Environmental impact (Long-term)
Renewable energy sources to limit climate change	Short-term (<5 years): €25M (new markets) Longer-term (>20 years): €6B (savings due to limiting climate change)	HIGH IMPACT Limiting displacement of populations through avoidance of/ reduction in the effects of climate change	HIGH IMPACT Protection of the physical environment through avoidance of/ reduction in the effects of climate change
Healthcare for an ageing population	Medium to long-term (10-20 years): €1.5B (savings in healthcare provision)	HIGH IMPACT Improved health with age & improved quality of life through improved care & reduced hospital visits Reduced (public) costs of healthcare provision Improved healthcare provision (eHealth) to remote locations & in developing countries	No or limited impact

Technology challenge (non-space)	Estimated annual contribution of space exploration to non-space economic impact (higher bound estimates)	Social impact (Long-term)	Environmental impact (Long-term)
Secure access to high quality water resources	Medium-term (6-7 years): €60M (savings due to efficient water use)	HIGH IMPACT Social impacts in third countries: improved systems for the management of water resources & delivery of high quality water in developing countries	HIGH IMPACT Improved management & maintenance of water resources throughout the water cycle and resulting protection of dependent flora and fauna
Secure access to energy resources (oil and gas)	Short-term (<5 years): €100M (savings due to automation) Medium-long term (5 – 20 years): €2B (access to new reserves)	No or limited impact	No or limited impact

Barriers to Common R&D

Notwithstanding the benefits of common R&D, the study revealed *substantial barriers to this new approach to technology development*:

- **Information failures:** There is a general and widespread low level of awareness of the activities, plans and needs of space exploration among non-space sectors. Most individuals are unaware that Europe is planning space exploration missions. Even in those sectors with some awareness of space activities, the specific needs of space exploration are often unknown and therefore any potential alignment with their own needs, to them, is indiscernible.
- **Preconceptions:** Both the space and non-space sectors hold strong preconceptions of each other. These encompass a wide range of complex issues based in different industrial cultures such as different approaches to design and engineering and the management of risk, different approaches to the balance of product price and performance, and even different languages and terminology. While some of these sector differences are undoubtedly real, the extent of the misconceptions is a significant barrier to interaction and collaboration.

The combination of a lack of awareness and preconceptions requires that communication levels are increased to ensure that the very close relationships that are required to undertake common R&D can be developed.

Even where the informational and preconception barriers are overcome, further hurdles exist – the identification of common technical challenges is necessary but not sufficient to the implementation of common R&D projects. Sector experts (space and non-space) take the view that common R&D is much more likely to occur and be successful if there are also commonalities in the fundamental R&D objectives, innovation timescales, and a roughly equal balance in space/non-space R&D funding contributions to ensure equity in the collaborative relationships. Finally common R&D requires contractual arrangements that are suitable and acceptable to all parties.

Comparison of Spin-offs and Common R&D

Spin-offs and common R&D have been conceptualised as separate and distinct routes to innovation from space exploration; they have different characteristics and support and promote innovation in non-space sectors in very different ways.

Many spin-offs will occur in any case (even if they go unrecorded and unaccounted for) so it is not a matter of the public institutions selecting this mechanism, rather a choice of the degree to which spin-off activity is proactively encouraged, managed and accounted for. While spin-offs are an expected benefit of space exploration investments, they are, in the main, an unplanned and serendipitous consequence of its activities, and space R&D is conducted with no preconceptions as to the non-space application areas of future spin-off activity. Therefore the potential application areas are wide in scope and require no upfront input from non-space application sectors. For spin-offs the space and non-space R&D and innovation activities are distinct and sequential and involve, in the main, separate funding and expertise.

Common R&D on the other hand pre-determines the non-space applications areas from the outset and while it may focus on areas with high potential impact, this pre-selection also limits the scope of future non-space applications. Pre-selection of common R&D themes requires significant upfront commitment from public institutions (the Commission, ESA, Member States) and non-space stakeholders - to identify detailed themes for common R&D, build relationships with potential partners, develop project specifications and support and conduct the R&D.

These differences indicate that spin-offs and common R&D provide different paths to innovation and do not need to be, nor should be, considered as alternatives. Both have a part to play in non-space innovation.

6. Conclusions: Space Exploration as a Driver of Terrestrial Innovation

The considerable technical challenges of space exploration would appear to offer substantial opportunities to stimulate innovation in the wider economy. The commonality of the technological challenges of space exploration and key global challenges faced on Earth create the potential for a series of 'focal points' for the flow of knowledge and skills across sector boundaries. These may act to accelerate innovation in both space exploration and non-space sectors.

Spin-offs will occur as a matter of course, the issue is the degree to which spin-offs are proactively facilitated, managed and accounted for. Historically the impact of space exploration spin-offs in Europe has been at a fairly low level compared to the USA, although this is largely a result of a relatively low level of European activity in space exploration. Spin-offs have occurred where Europe has historically invested - in areas such as launch vehicles and scientific and robotic instrumentation. The NASA evidence suggests that there is the potential for much more spin-off activity and successes; higher levels of investment in technology appear to lead to higher numbers of spin-offs and the sheer scale of spin-off activity increases the opportunity for successful spin-offs to emerge. Therefore European spin-off activity would be expected to increase with increased investment in space exploration and from the resulting higher profile of significant European activity in the worldwide exploration endeavour.

Common R&D has the potential to stimulate and accelerate innovation in technological areas that are vital to solving important global challenges faced on Earth, through direct collaboration and sharing of expertise and funding across the space and non-space communities. While the exact extent of the impact is, like all R&D and innovation investments, highly uncertain, pooling a proportion of European resources and skills in these key areas can be expected to generate new ideas and innovative solutions and, as a result, yield substantial economic, social and environmental benefits.

Four themes have been identified where space exploration has the greatest potential to impact areas of global significance. Innovation in these areas will yield economic benefits through enhanced European competitiveness in markets for new technological solutions as well as social and environmental benefits resulting from addressing global challenges - reducing the effects of climate change, improving citizens' health and securing access to energy and water resources. Step changes in technological innovation in areas such as renewable energy and smart miniaturised medical devices have the potential for significant impact, assuming all other economic and social factors facilitate the wider diffusion and uptake of these

developments. As it is most likely that Europe will contribute to an international space exploration endeavour, these four themes should be considered, along with other factors, when selecting the focus of the European contribution.

However common R&D in this context is at present a largely untried and untested approach to innovation triggered by space exploration and there are significant barriers to overcome. Therefore, it is unlikely to occur without public support. Public support is required not only in terms of providing finance to stimulate collaborative R&D, but also in terms of providing appropriate instruments to facilitate networking, relationship building and collaboration.

Public support for common R&D needs to be approached on an experimental basis, starting with support for further activities to identify potential projects in detail in one or two of the four themes, alongside activities to develop and build relationships with key non-space stakeholders. This would lead on to a pilot programme of common R&D focused on a small number of projects, closely monitored and evaluated before extending the programme (if appropriate).

As mechanisms to stimulate innovation, the spin-off and common R&D routes are entirely different. The spin-off route to innovation is wide in scope in terms of the originating space technologies and non-space application areas but is typically unplanned and often unaccounted for. Common R&D offers a much more planned and structured route that is narrower in scope but highly directed. Spin-offs and common R&D do not need to be, nor should be, considered as alternatives and both have a part to play in stimulating innovation.

7. Recommendations

The recommendations that follow are focused on where public support can best be utilised to foster innovation in non-space sectors triggered by space exploration. The recommendations focus on public support for common R&D (rather than spin-offs), as common R&D is likely to be an effective route to non-space innovation and one that is amenable to a pro-active approach to innovation support. By contrast, spin-offs are to a large extent serendipitous, and while public support can increase opportunities to make connections between the space and non-space communities (as is the case of the ESA Broker activities), any networking and collaboration activities under a programme of common R&D will also, as a matter of course, enhance opportunities for spin-offs.

7.1 Innovation Themes

The most fruitful opportunities non-space innovation lie in the areas where members of both space and non-space communities already acknowledge that synergies exist in the technical challenges they face. These are:

- Renewable energy generation and storage – covering technologies such as fuel cells, batteries, photovoltaics, and nuclear power.
- Healthcare – covering two areas (i) increased understanding of the (similar) effects of ageing and space-flight and (ii) the development of autonomous, minimally invasive devices for healthcare monitoring, diagnosis and treatment.
- Efficient systems for water use and re-use – covering water and waste treatment systems, water recycling technologies, quality control and modelling and simulation tools.
- Autonomous and flexible robotic systems for harsh environments – including, in particular, systems for drilling, sample collection and analysis.

In addition to providing technological solutions to global challenges, these four areas are areas of particular European strengths in space exploration. If Europe is to play an important role in the international space exploration endeavour it needs to focus on and extend its expertise in these areas. Co-production of technologies not only stimulates innovation in non-space sectors but also ensures that space technologies exploit state-of-the-art knowledge and skills wherever they may lie.

7.2 Innovation / Common R&D Budgets

Support for collaborative R&D in pursuit of innovation in important European sectors (including space) falls within the remit of the Commission and therefore the budgets presented for innovation support via common R&D are deemed to be the responsibility of Commission.

The barriers to common R&D are fairly substantial and therefore the extent of success in establishing and implementing such projects is uncertain. Any new approach to technology development is not without risks and these risks must be managed and mitigated as much as is possible as any delays or failures in technology development might contribute to delayed space exploration missions. Therefore it is recommended that:

- Common R&D is not implemented as the sole method for developing technologies in the four space exploration technology challenge areas identified in this study.
- It is recommended that budgets for common R&D start at modest levels, increasing further as the mechanism is proven to be successful (or otherwise)
- An initial budget for a pilot common R&D programme that is equivalent to 10% of that portion of the European budget for space exploration that is allocated to the *four themes identified*. This would rise to 25% if the pilots prove successful.
- The European budget for space exploration has yet to be formally defined, nevertheless one estimate puts it at €5 Billion per year⁹. Based on this figure the recommendation above is estimated to amount to €125M a year (at the 10% level) in 2014 and rising, if activity is shown to be successful, to €300M a year from 2018 (see Figure 2 below).¹⁰
- Around 5% of the common R&D initial budget of €125M p.a. (i.e. an estimated €6M), possibly more, would need to be allocated to the preparatory stages of common R&D (raising awareness, confirming and developing R&D themes, establishing relationships with non-space sectors etc.). Without this vital first step common R&D cannot be implemented.

Figure 2 provides a summary of the investments and anticipated benefits of a European Commission *programme of common R&D supporting and stimulating innovation in non-space sectors triggered by space exploration investments*. It should be noted that:

- The total investment figure for the period 2014 - 2020 is based on a 7 year programme, with a ramping up of investment from €125m p.a. up to €300m p.a. (with an average of €200m p.a.).

⁹ Exploration: Challenges and Opportunities for Technical Innovation, M. Courtois, ESA, EC-ESA Workshop On Innovation And Technology Within Space Exploration, April 2010.

¹⁰ The four theses (energy, health, water re-cycling, robotic exploration) have been estimated to make up 25% of the space exploration budget. This is a rather speculative figure and any budgets for common R&D would need to be adjusted in accordingly once the future European space budget has been fully specified.

- The investment figure for the period 2021-2030 has been based on a continuation of the investment for common R&D of €300m a year and makes the assumption that common R&D has proved to be a successful model.
- The benefits will take time to accrue and therefore there will be a time lag between investments and benefits. As stated in section 5, the estimated economic benefits from Common R&D are tentative and represent an upper bound figure.

Figure 2 Investments and Anticipated Benefits of Common R&D

Time period	Investment (total)	Benefits
2014-2020	€1.4 billion	€1 billion a year from 2019 onwards
2021-2030	€3 billion	From €1 billion a year in 2021 rising to €10 billion a year in 2030

A Common R&D Programme

It is recommended that common R&D policy should encompass a phased approach:

- **Phase 1** Confirm and develop common R&D themes and establish relationships with relevant non-space sectors. Conduct a series of outreach/awareness activities to reach a wide audience in the sectors being targeted to raise awareness of potential common technology challenges
- **Phase 2** Develop detailed specifications and design appropriate R&D funding instruments
- **Phase 3** Pilot common R&D projects
- **Phase 4** Wider implementation
- **General wider communication of the plans and needs of space exploration**

The proposed mechanisms above will enhance the awareness of space exploration technology challenges outside the space sector and therefore will also serve to widen the supply base and increase opportunities for technology spin-in to space exploration.

The nature of common R&D, with its space/non-space R&D collaboration and shared funding, would suggest that the Framework Programme collaborative projects funding instrument would be appropriate in many cases. However it should be noted that the ESA experience with common R&D projects has demonstrated that projects take considerable upfront resources and time to identify partners and negotiate project objectives, confidentiality etc. before they can commence, and therefore these issues need to be taken into consideration when developing common R&D project calls.



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