

Most promising technologies

Perspective on sustainable growth and effective innovation policy in Finland

beyond the obvious

In order to become a leading country in sustainable growth, Finland must invest in areas of expertise where we have special top-level expertise and competitive advantage. By investing in these areas, we can promote sustainable growth globally.

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Preface: Finland's road to a leading country in sustainable growth

In the recent years, there has been a lot of discussion about the technology and innovation policy of Finland and the ways Finland can become a leading country in sustainable growth. At the moment, the objective approved jointly by all parties in the Parliament is to increase RDI funding to four per cent of GDP by 2030. The burning question is: how should this funding be targeted so that it creates sustainable growth and new international business in Finland as efficiently as possible.

In order to become a leading country in sustainable growth, Finland must invest in those areas where Finland has special top-level expertise and competitive advantage. By investing in these areas, we can promote sustainable growth globally.

New technologies are needed to solve global challenges. Investing in research and expertise in technology is essential to enable sustainable growth.

We must be able to allocate RDI funding wisely so that our research-based technology expertise can really create commercially significant innovations and thus new business and value for society. In addition, the generation of new solutions and scientific breakthroughs should always be supported.

The allocation of funding is hampered by the fact that scientific leaps and new technologies are often complex to understand and that there are many different areas of research that compete for funding. How to make choices between different sectors so that funding is as effective as possible in terms of the competitiveness and economy of Finland as well as in terms of the environment, climate and social sustainability?

This vision paper proposes which areas of technology - emerging from the advances in science - Finland should invest particularly in order to achieve its economic and sustainability goals.

Our paper gathers the views of Finland's leading technology researchers on the most promising areas of technology expertise based on science and research, as well as the factors that play a key role in the creation of innovations.

This paper does not refer to technologies already in the market, but to research-based competence platforms. They are based on recent scientific breakthroughs that are progressing at researchers' desks and laboratories in higher education institutions, research institutes and the research and development units of companies. As they enter the market, they revolutionise the world. Each of them also contributes to solving global sustainability problems.

Our vision paper provides a view on two questions:

1. How should the public RDI funding be targeted to effectively support the development of research-based expertise into innovations and sustainable growth?
2. Which research-based areas of technology expertise should Finland invest in?

As a result of the green and digital transitions and crises facing the world, the global market is undergoing a major transformation. The current technology base and following the existing development paths is not enough to respond to the burning environmental and social challenges we face. It is time to discuss which are those areas of technology expertise, where we have unique, internationally competitive expertise in Finland, and in which areas we should invest in based on that.

Choices are needed to form expertise hubs that produce global innovations. The closer one is to the market, the less public steering there should be. In this vision paper, we are discussing research expertise related to new technologies, which creates enormous new application opportunities. These opportunities arise when the competence base is strong enough. Strengthening competences requires choices and long-term investments.

Methods for strengthening the impact of research

1. Choices must be made between research areas, and long-term public funding has to be directed to generate cutting-edge expertise hubs.

It is important that Finland makes choices on the allocation of research funding. The resources of a small country are limited. Funding should be directed especially to the research areas whose scientific level is proven to be globally state-of-the-art and which have the potential to produce sustainable, scalable and commercially viable solutions.

In this paper, we present a view of the most promising new technology related research areas that are most promising for Finland. All these areas have a huge variety of application possibilities. Extensive economic and societal benefits will only arise if the research areas grow into world-class expertise hubs, are linked to close cooperation with companies, and can provide solutions to global challenges.

In order to achieve the national RDI target of 4%, two thirds of the increase in RDI investments must come from companies. This means additional investments of billions of euros from companies. In Finland, approximately 70 per cent of individual RDI investments come from companies in the technology industry.

In other words, investments in research related to the development of new technologies and the strengthening of technology expertise are essential for leveraging private investments. A company's investment decisions are significantly influenced by whether strong world-class expertise needed by the company is available in Finland and whether there is a prospect that the development of such exper-

tise area will be supported in the long run.

In order to create impact, RDI funding must be directed in a long-term manner, guided by clear principles.

The sustainability of solutions is a significant trend and an advantage for Finnish companies to stand out from their international competitors and how Finland can achieve its climate goals and be larger than its size in solving the world's sustainability challenges. The ability of the technology expertise area to produce solutions in line with sustainable development should, therefore, play a key role alongside the scientific level in assessing where RDI investments should be directed. In addition, the potential of various growth opportunities and their significance for Finnish business life must be taken into account in the choices.

International cooperation must also be taken into account in the allocation of funding together with the competitiveness of Finland's expertise on an international scale. The most celebrated research ideas, concepts and inventions are born in an international research and development environment. Finland should strive for significant 'niches' in which expertise is internationally unique and which attract both foreign partners and new experts to Finland. This provides Finnish companies linked to expertise hubs with an excellent channel for strengthening their competences.

The creation of significant innovations is best promoted by systematic and long-term support for the structures and operating models that enable cooperation. National and international funding instruments are often siloed and short-term, focusing on one part of the innovation process.

In this case, the generation of innovations can become a game of chance: will the

author of an applied study find the result of a basic research that is perhaps years old and will the commercialising actor find this applied research. Such a system does not support innovations systematically or in the most efficient way.

Instead, in a well-functioning expertise hub, basic research that creates a new competence base is carried out at the same time as the research results achieved earlier are developed towards applications. In other words, work is carried out over various time spans. This requires effective collaboration between many parties.

2. Funding and operating models need to be reformed to enable cooperation between research and companies as well as the dynamic development of ecosystems.

Operating and funding models must be reformed as soon as possible. In terms of innovation creation and societal benefits, the most important thing is to enable close cooperation between research and companies.

Research cooperation with companies has been one of Finland's strengths, but it has weakened significantly in the 2010s¹⁾. At the same time, however, companies in other parts of the world have increased their cooperation with research communities.

Finland needs funding instruments and innovation programmes that enable long-term cooperation and genuine co-creation between researchers and companies. In most cases, this also requires a high-quality development and piloting environment.

With the help of risk-sharing funding and joint development and piloting environ-

ments, companies can join research at an earlier stage, which will increase the understanding of the potential of new technologies among all parties.

At the moment, there are not enough funding instruments in Finland that would enable an efficient path through which research can progress through companies towards societal benefits.

For example, the Academy of Finland's Flagship Programme has developed the academic aspect of expertise hubs, but Finland lacks a match for the programme, which intensifies cooperation with companies and creates systematic paths towards innovations.

The funding of Business Finland is focusing too much on improving companies' existing products and services, rather than enabling radical innovations that renew industry. Business Finland should therefore clearly have better opportunities to fund ecosystem-based cooperation between companies and research as well as innovation programmes aimed at solving significant societal challenges.

Funding instruments must also take into account that the development of revolutionary innovations always involves major risks. Companies estimate the risks in many potential growth sectors to be too high for themselves unless they receive support for development activities. In order to lower the threshold, funding instruments and piloting projects are needed that enable more future-oriented innovation with less risk - without high pressure to immediately produce value for the invested money.

¹⁾Hajikhani & Suominen, Elsevier 2021

How innovations arise – from pipeline-thinking to supporting a dynamic innovation process

The creation of innovations has traditionally been described as a pipeline: basic research, applied research, commercialisation. This model does not correspond to reality. Instead, innovations that solve significant challenges arise dynamically, in close cooperation between many operators.

In the innovation ecosystem, people from research organisations, companies and other functions of society work together to develop something new. The aim is to solve a multi-dimensional challenge that cannot be solved through a joint innovation process involving one or only a few actors. The key engine of the innovation is the need for change – at its strongest, a crisis threatening society or the environment.

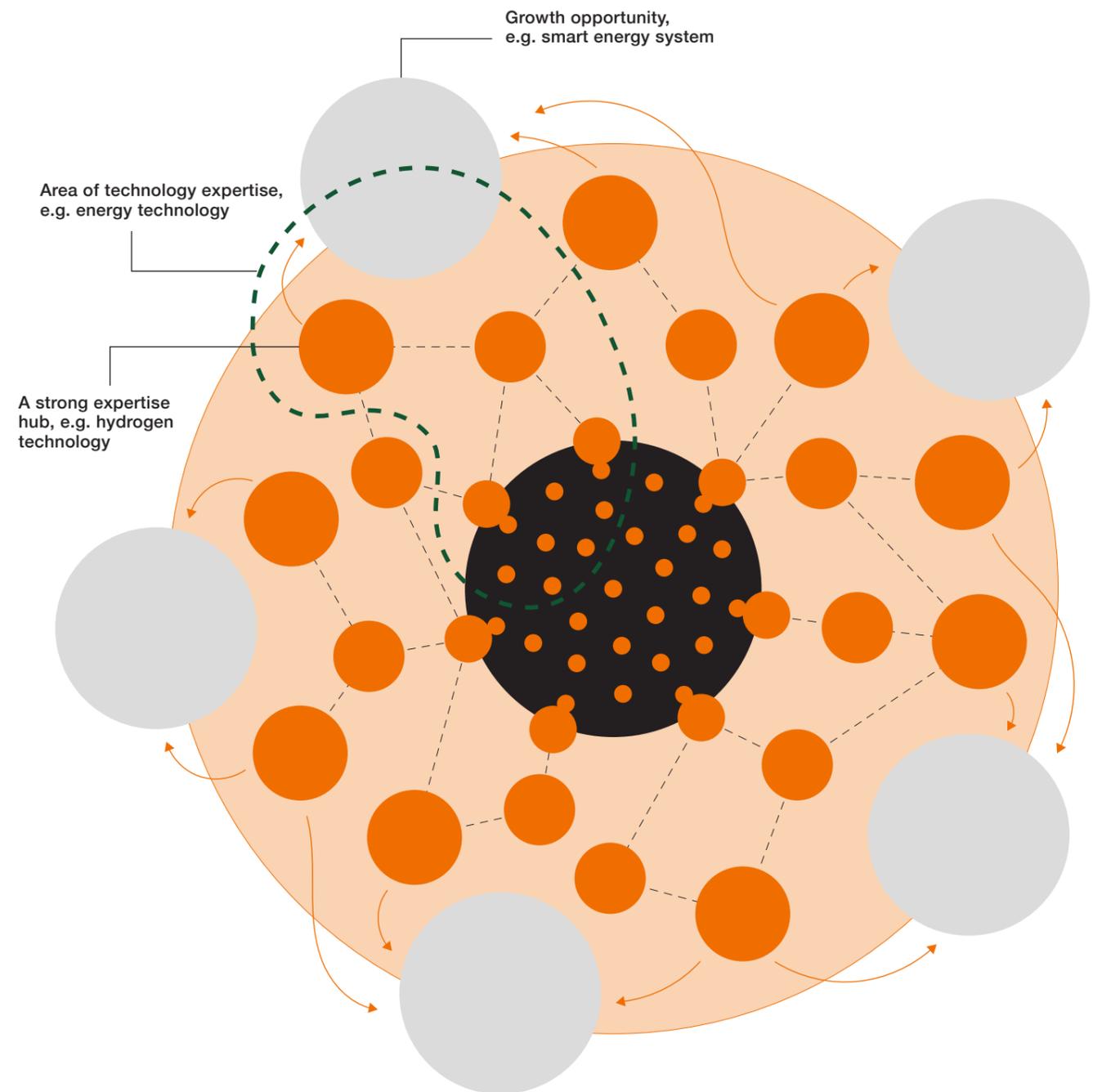
In a well-functioning innovation ecosystem, people have complementary multidisciplinary expertise and networking is international. Shared understanding of the objectives is a key tool for guiding the development of the ecosystem. The aim is to put research results and expertise into practice. The end result should be new solutions that are beneficial for end users and create value for society.

At the core of the ecosystem is high-level basic research that generates unique expertise. The construction of globally significant expertise hubs requires choices, long-term and predictable funding and multidisciplinary international cooperation. An innovation ecosystem is created as companies in several different roles join this network and the network's partners start doing research and development genuinely together. This "cross-pollination" produces innovations that create plenty of growth opportunities for various application fields.

The creation of innovations requires, above all, plenty of interaction and genuine cooperation between researchers, companies and other actors in society at every stage of the development. In addition, the ability to combine unique expertise with solving problems is essential. Innovations that solve significant challenges arise most effectively in ecosystems.

At the moment, this cooperation is not working well enough in Finland. In order to correct this, we must enable long-term collaboration between people in research, development and innovation activities. It is important that Finland's innovation system improves its ability to promote and maintain ecosystems.

-  Strong basic research
-  Area of technology expertise
-  Strong expertise hubs (niches)
-  Cooperation between research, companies and the society
-  Growth opportunity



How are sustainable growth generating innovation ecosystems born? The expertise hubs created through strong basic research involve extensive cooperation between companies in different roles and various fields of research. Working together generates innovations that enable sustainable growth in many sectors. The figure outlines this principle as a whole, i.e. several innovation ecosystems at different stages of development are described.

Our most promising areas of technology expertise

This vision paper presents 11 areas of technology expertise based on science and research in which Finland should invest. The areas have been selected with the help of top experts in the Finnish research field and views based on several recent reports²⁾.

The areas of technology expertise have been assessed on the basis of two criteria.

1) Impact

The area must have a strong potential for creating growth and sustainable well-being in Finland and globally.

2) Expertise

Finland has long-standing research and development expertise in the area, which gives us the ability to become the world's leading provider of solutions.

Finland's promising areas of technology expertise are grouped into two categories:

Areas 1 to 6 are **enabling technologies**, i.e. areas of technology expertise that enable various solutions in a wide range of industries.

Areas 7 to 11 are **converging technologies** that group together different areas of technological expertise used to develop a specific application area (e.g. energy, health, safety). For example, several different areas of technology expertise are used to develop the energy system – for example, those described in sections 1–6.

²⁾ Finland's technology policy in the 2020s: *Teknologialla ja tiedolla maailman kärkeen*, Ministry of Finance publications 2021:30; *OECD recommendations on Finnish innovation policy*; *Kestävä talouskasvu ja hyvinvointimme tulevaisuus*, Ministry of Economic Affairs and Employment publications 2021:12; *Evaluation of the Academy of Finland*, Publications of the Ministry of Education and Culture 2022:7.

The most promising areas of technology expertise for Finland:

Enabling technologies:

1. Wireless networks
2. Artificial intelligence
3. Microelectronics and photonics
4. Quantum technology
5. New materials
6. Biotechnology

Converging technologies:

7. Energy technology
8. Manufacturing technology
9. Health technology
10. Security technology
11. Space technology

1. Development of wireless networks enables radical automation

5G and 6G technologies enable radical automation of various industries. This is a business revolution in which Finland can act as a leader based on its strong expertise - as long as we invest in 6G technology and strengthen international cooperation.

Why is the area significant?

Industrial production has hardly become more efficient in recent decades, but now the world is going through a new transformation that will make processes more effective in all sectors and thus enable energy saving, more efficient use of materials and, overall, sustainable development.

In a nutshell: things are done more efficiently and with smaller resources.

This transformation is based on the development of wireless information networks. The 5G ecosystem is constantly being refined. The next breakthrough will take place in private 5G networks that replace WiFi networks in restricted environments: factories, airports and ports. Private 5G networks are more reliable and secure network environments and create business opportunities for technology companies such as Nokia, as well as for many other technology adapters, such as Finnish mechanical industry companies.

6G technology will be in use around 2028. For its part, it will enable a transformation in various sectors: industrial processes, factories, machinery and services can be produced entirely automatically without human workers. The automation of society will be taken to a completely new level: unnecessary movement of resources, people and information will come to an end. Many solutions

are related to the enhancement of logistics, which in turn is of vital importance for the reduction of emissions.

Distributed cloud services integrated into wireless networks improve the efficiency of data network usage and reduce energy consumption. New technologies such as edge computing enable the processing of data locally close to the data collection location, which means that the amount of energy required for data transfer will probably be low and the information security can be improved.

Why is Finnish expertise among the best in the world?

For 30 years, Finland has been one of the world's most important technology experts in mobile technologies. Thanks to in particular Nokia's research and business operations, Finland has an extensive ecosystem and expertise in both higher education institutions and companies in developing and selling wireless information networks and applications globally.

Finland has the opportunity to be one of the most central influencers in the 6G transition, but this will not happen automatically. Competence accumulates where investments are made and where experts accumulate.

Finland can become a pioneer in de-

veloping sustainable ICT solutions. Mobile networks and data centres are increasingly consuming electricity.

Finland's National Climate and Environmental Strategy for the ICT Sector (2021) is exceptional. It describes the sector's potential to reduce emissions from other sectors and also sets a target for reducing ICT's own climate outputs. This is a good starting point for Finland for developing solutions that require less cloud and computing capacity, transfer less data and are more sustainable as a whole.

Transport and logistics, industrial environments, care and health care, education, agriculture and forestry, and so on, are all creating ecosystems and value chains of their own. This is not so much a technological revolution (which is also needed), but an ecosystem and business revolution in which Finland can act as a pioneer due to its size.

How to turn expertise into sustainable growth?

Finland needs to make choices that enable us to target R&D investments effectively. Choices must be made on the basis of international comparisons: in which areas is Finnish expertise truly at the top of the world. This is the case for the area of wireless networks.

Choices must be considered from the perspective of international export and needs, not just from the Finnish perspective. In information networks, we have the ability to scale locally operating solutions to global markets.

Finland is part of the European Union, and European political decisions and research funding support the development of wireless networks. However, Finland may lose Euro-

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pean competition if it does not invest in 6G technology. Countries such as Germany, Italy and Spain have steered hundreds of millions of Europe's RRF funding into the research and development of wireless networks. For 6G, we also need to build cooperation with Japan and Korea outside the EU.

Within the EU, Nordic cooperation should perhaps be accelerated even more: Nokia and Ericsson are currently key drivers in 5G and 6G development. Why not to strive for an operating model that would create a unique Nordic centre of expertise in order to strengthen the competitiveness of the future?

It is important that multidisciplinary technology experts are trained in Finland, as wireless networks, artificial intelligence, software technology, microelectronics and component technology all work and develop together and influence each other. Wireless technology is a neural network that connects all of this.

2. Accelerating artificial intelligence is Finland's asset

Artificial intelligence drives digitalisation and affects everything from medicine to climate research. Finland can offer new solutions for making AI technologies more reliable and understandable so that they use less data, energy and computing power.

Why is the area significant?

It is difficult to precisely limit the impact or significance of artificial intelligence, as artificial intelligence is everywhere and it is related to digitalisation as a whole. No global challenge will be solved without data and efficient computing, which artificial intelligence basically is. In other words, artificial intelligence affects everything from medicine to climate research.

The precise economic impacts of artificial intelligence are difficult to assess, as digitalisation is driven by data and artificial intelligence, and it cannot be distinguished which economic impacts are generated by artificial intelligence and which are the result of the digitalisation process. In any case, the impact is considerable.

Why is Finnish expertise among the best in the world?

As a well-educated and technology-oriented society, Finland is a place where digital technologies should be developed and tested. In addition, Finland already has top expertise and the world's best data archives, for example in medicine.

A key factor in Finland's top expertise is the technological knowledge base and its growth. There have been passionate AI researchers in Finland who have created the next generation of researchers. Now this expertise should be capitalised.

Artificial intelligence applications that are currently being commercialised are based on basic research done 30 years ago and have done their breakthroughs now that enough data is available.

Modern technology uses a lot of data and machine learning and requires the computing power that modern computers can do. Companies that use old technology and have a lot of data at their disposal, such as large technology companies, have gained quick profits. The development of data infrastructures should thus also be utilised in the creation of services using artificial intelligence.

However, scaling of the current form of artificial intelligence will become up against a brick wall. The deep neural networks currently used in image recognition may not always be reliable, and it may be difficult to put into words the principles guiding their operation.

The question for the future is how to create more reliable and understandable techni-

cal conditions that use less data, energy and computing.

Efforts have been made in Finland to solve these problems. We have for a long-time developed technology that does not require a large amount of data.

How to turn expertise into sustainable growth?

Finns often think that Finland does not have the resources to develop artificial intelligence; instead, Finland should focus on applications and their development.

However, this way of thinking is problematic – if something is easy, others will do exactly the same. Our task is to do the difficult. In the technology sector, this mindset does not work either because the introduction of new and emerging technologies requires integration and expertise in technology.

For example, the European Commission's Lighthouse network is an exemplary project in the sense that it has been understood that not everyone needs to be a top researcher. Top expertise is a lighthouse, and the activities must be built around these lighthouses.

Finland has a 'lighthouse' in the field of artificial intelligence, and the sector is striving

As a well-educated and technology-oriented society, Finland is a place where digital technologies should be developed and tested.

to build an interactive ecosystem. It is difficult, however, because it does not have its own funding.

For example, the Finnish Center for Artificial Intelligence (FCAI) receives flagship funding intended for carrying out basic research, and it is not enough to run the ecosystem itself. Alternatively, Business Finland funds individual projects.

3. Microelectronics and photonics are the foundation of the digital transformation

Innovations in microelectronics and photonics play a key role in the development of e.g. robotics, quantum computers and communication technologies. Finland has unique expertise in the area, but its commercialisation requires a long-term approach to funding and education as well as clarity on intellectual property rights and the use of research equipment.

Why is the area significant?

Microelectronics, nanoelectronics and photonics are enabling technologies. This means that other digital technologies are built on these applications. For example, robotics, artificial intelligence, quantum computers or communications technology could not be developed without innovations in microelectronics and photonics.

Microelectronics and photonics are the science and technology for handling light, electric current and electric field. The applications include e.g. cameras, sensors, and light sources such as LEDs and lasers. Another important area is the manufacturing of components and materials, which includes, among other things, various nanofabrication technologies. Many new innovations, which are currently revolutionising the world, use microelectronics and photonics in some way: for example, in the sensors of production facilities, in the data sources of sensors needed by robots, or in the camera technology of satellites and mobile telephones.

Why is Finnish expertise among the best in the world?

Finland has many top-level expert groups working with microelectronics and photonics applications. In addition, Finland has a unique, world-class infrastructure for the development of microelectronics and photonics.

For example, Finland carries out research that creates new mechanisms for manufacturing microelectronics and related applications, as well as creates prototypes for applications. For example, the dramatically growing solar energy sector utilises photonics and microelectronics manufacturing techniques. There is demand for Finnish technology expertise around the world, even though the production of solar energy itself is ultimately cheaper in China than in Finland.

Research in microelectronics and photonics has been invested in Finland since the 1950s, and our tradition in the area is globally state-of-the-art. In Nokia years, large amounts of money were invested in Finland especially in photonics research to support the manufacture of mobile phones and due to camera technology in mobile phones. Therefore, Finland has built high-quality expertise that can also be commercialised.

How to turn expertise into sustainable growth?

Innovations in microelectronics and photonics have been refined into business activities for a long time, and further business

potential is constantly being found. In order for the potential to become reality, boundaries between companies, higher education institutions and research institutes must be dismantled.

Finland has plenty of opportunities to develop various specialised solutions based on microelectronics and photonics as well as production technologies that enable manufacturing other digital technologies. It is important that Finnish companies carry out their own research and development in Finland, even though mass production will most likely continue to take place in other parts of the world.

Start-ups should be able to easily use the existing research and development infrastructure in Finland, which is usually located in the premises of universities or research institutes. Currently, both the price of facilities and long processing times are obstacles. In Finland, permission procedures take up too much time. This leads to the drying up of enthusiasm for new entrepreneurs who are starting business ideas that often require fairly large investments. Who wants to wait for a year to be able to promote their own idea? It would therefore be natural to try to streamline the time spent on these procedures so that ideas could be developed faster into business.

The investment costs in the area are rising for many reasons. First, the high technology laboratory facilities needed to develop microelectronics and photonics and build prototypes are expensive in terms of operating costs. The prices required for research and business activities easily rise to sums that most start-ups cannot afford to pay.

Second, companies in the area utilise the intellectual property rights of innovations

created in higher education institutions. The sector needs clear processes to make the most effective use of intellectual property rights so that conflicts of interest are not created.

Many new innovations that are currently revolutionising the world make some use of microelectronics and photonics, for example in the sensors used in quality control of production facilities, in the data sources of sensors needed by robots or in the camera technology of satellites and mobile phones.

The funding of research as well as the pricing of the use of immaterial rights and research infrastructure should be long-term and support both the development of existing expertise and attracting new researchers and companies to Finland.

At the same time, young people should be encouraged to study photonics and microelectronics. The number of students has been declining for a long time, even though the importance of these sectors for society and businesses has grown.

4. Quantum technology is revolutionising computing power

A well-functioning ecosystem of basic research, applied research and industry has developed for the Finnish quantum industry, and successful start-ups have also emerged from the centres of excellence. The challenge now is to find sufficiently skilled workforce for the sector.

Why is the area significant?

Quantum technology enables revolutionary technological advances in computing power and computer simulation. In the future, quantum technology can be utilised in many different sectors, such as in the development of new vaccines in pharmaceutical technology, the transfer of data that is encrypted in security technology or the design of extremely sensitive sensors in the technology industry.

In addition to the high-tech industry, quantum technology has plenty of potential uses e.g. in the banking and insurance sector.

Why is Finnish expertise among the best in the world?

Finland has a long tradition in quantum technology research and development. We have done quantum research more than half a century, which has laid the foundation for the current competence base. Competence has been strengthened by several centres of excellence, in which new technological innovations have been developed together with the basic research.

A well-functioning ecosystem of basic research, applied research and industry has developed in the quantum sector. A strong

competence base and interaction with industry have made it possible for the centres of excellence to also generate successful start-ups.

Finland has developed excellent conditions for quantum research. Research infrastructure favourable to quantum technology has been built on higher education institutions, and the manufacturing and measurement opportunities needed for experimental research have strengthened Finland's competitiveness in the sector.

In addition to developing the actual quantum technology, we also have good conditions for developing enabling technologies, such as cooling technology. Enabling technology is utilised in current quantum technology implementations. For example, a global market leader in manufacturing ultra-low temperature refrigeration equipment for laboratory conditions is established and operating in Finland.

As the competition will become more intense in the future, expertise in the quantum sector must be continuously developed. In the future, in addition to developing physical products, Finland will have the greatest potential in software and algorithm development. Interesting opportunities will emerge if we combine this development of new computing with industries in which Finland has strong existing expertise.

How to turn expertise into sustainable growth?

At the moment, education and a lack of skilled workforce are the biggest bottlenecks for the development of quantum technology. Domestic demand for skilled labour is considerable. Technology is still at a stage where basic research plays a key role in the development of technology.

The area has received plenty of attention and expectations due to its enormous potential. In the midst of expectations, we should take the time to invest in the sector in a long-term manner, without forgetting education and basic research.

A well-functioning ecosystem of basic research, applied research and industry has developed in the quantum sector. A strong competence base and interaction with industry have made it possible for the centres of excellence to also generate successful start-ups.

5. New materials enable carbon-neutral material cycles

Finnish expertise in materials focuses on renewable bio-based materials, the circular economy and advanced material design – and the integration of these areas. If Finnish companies can offer sustainable, scalable material solutions, the global growth opportunities will be huge.

Why is the area significant?

Materials are the platform that defines the technological development. Innovations in material science have a broad impact on almost all industrial sectors, from construction to the mechanical industry and food to health technology.

The development and circulation of materials are at the core of sustainable growth. In this decade, each industry should rapidly detach itself from fossil raw materials and replace them with carbon-neutral alternatives. At the same time, materials should also be better circulated to overcome global resource shortages and to decouple economic growth from overconsumption of natural resources.

Rapidly developing new and advanced materials science offers new and revolutionary solutions to these challenges. They enable a sustainable circular economy in which material consumption can be limited to planet's carrying capacity. If Finnish companies can offer sustainable, scalable material solutions and develop low-carbon manufacturing processes, the global growth opportunities will be significant.

Why is Finnish expertise among the best in the world?

The Finnish materials expertise and innova-

tions have been among the best in the world for a long time.

Finnish expertise in materials focuses on three areas: renewable bio-based materials, the circular economy and advanced material design – and the integration of these areas.

Renewable bio-based materials can be used to replace fossil-based materials in a sustainable manner. They are often reusable, recyclable and biodegradable and do not generate waste. Finland's long history in the forest, chemical and processing industry has created unique expertise in cellulose-based biomaterials and alternative materials. Bio-material technologies are also flexible, as they can also be used for non-wood-based waste fibres: for example, food and textile waste can be recycled into materials that are as good as virgin materials.

Circular economy solutions reproduce functional materials from useless side streams or waste and steer the flow of materials more efficiently into circulation.

Material innovations based on the circular economy have been carried out in Finland for over 20 years. They are used, for example, to recycle biowaste to plastic that is as good as virgin plastic, waste textiles to new textiles, side streams of construction sites to eco-concrete, or to take valuable metals from scrap waste and re-direct them into circulation. With the help of recycled materials,

companies can strengthen their own production of materials, for example scrap iron can be reprocessed into high-value refined steel when mixed with chromium. The recycling of textiles also opens new opportunities for sales of pulp in the forest industry.

Advanced material design utilises machine learning and artificial intelligence to accelerate material development. While traditional material development has often taken 20–30 years, virtual material development and artificial intelligence can be used to design and model materials atom by atom to meet the final need. Finland has strong expertise in computational virtual materials science.

How to turn expertise into sustainable growth?

Finland has a long-term and extensive expertise in material innovations. Numerous successful examples include bio-plastics, eco-concrete and recycled textiles.

Our pitfalls are mainly related to scaling up new material solutions to an industrial scale and growing them into commercial success. The jump from a laboratory to a factory often requires large investments of up to tens of millions of euros.

For material expertise to turn more often into industrially and commercially significant solutions, Finland needs:

- a) Long-term research and development collaboration between research institutes and start-ups developing material innovations as well as Finnish and international business partners. Public RDI funding should support the creation of long-term cooperation between research and companies.

If Finnish companies are able to offer sustainable, scalable material solutions and develop low-carbon manufacturing processes, the global growth potential is huge.

- b) Support for piloting new materials. This may mean common piloting platforms where research institutions and companies can pilot and scale material innovations without having to invest in their own infrastructure. In addition, financial support is needed for new test sites and pilot projects where new sustainable materials can be tested with limited risk.
- c) Rationalising the regulation of materials. In traditional sectors, it may be difficult to introduce new materials due to the associated risks and regulations by the authorities. Regulatory obstacles and restrictions should be eliminated. This means, for example, licensing new factories, but also rationalising provisions such as the EU Single Use Plastics Directive (which currently also bundles many fibrous and cellulosic biomaterials into single-use plastics). Regulations and restrictions must be based on research and enable the development of new alternatives. Finland with its strong material expertise could assume the role of a pioneer of material innovations in both national and EU regulation. This requires our decision-makers and officials to be in close dialogue with research and innovation actors.

6. Biotechnology enables radical sustainable innovations

Biotechnology utilises nature's own processes to make industries sustainable. Finland could be among the top experts in this radical technology area if we invest in biotechnology research that utilises breakthrough science and advanced methods on a long-term basis.

Why is the area significant?

Biotechnology is currently one of the most radical technology areas. It enables the development of sustainable solutions in a broad range of sectors, such as the energy, chemical, pharmaceutical, forest, food or mining industries.

Biotechnology utilises nature's own processes for industrial use. With the help of synthetic biology, researchers shape the DNA of living organisms and create new types of biological organisms that function as so-called cell factories in the production process.

Genetically modified microbes can produce, for example, biofuels, chemicals, plastic or leather-like materials, medicines or food – or act as metal solvent in mines.

The ability to shape nature's processes and achieve the desired end result is so fundamental that the application areas of biotechnology are virtually infinite. As biotechnological processes mimic the principles of nature, they are also inherently sustainable. They enable the use of renewable raw materials and waste streams and the circulation of materials. Many countries, including the EU, consider biotechnology, particularly driven by synthetic biology, to be one of the most important future technologies.

Why is Finnish expertise among the best in the world?

In Finland, strong biotechnology expertise has been developed for over 30 years. We have been pioneers in industrial and medical biotechnology. For example, companies such as Alko, Cultor and Valio carried out long-term bold research and development work for decades. In addition, VTT and universities have played an important role. This was based on Sitra's significant funding, which was used to introduce gene technology methods in Finland very early. In the 1980s and 1990s, Finland was a pioneer of biotechnology.

Decades of investments in biotechnology are visible today as significant companies and industry's interest. For example, industrial enzymes are produced in Finland, and our traditional industries, such as the forest industry, strive to utilise biotechnology more and more in production processes. Smaller biotechnology start-ups have also emerged alongside traditional industrial companies, focusing on health technology, such as diagnostics and pharmaceutical development, or new food and material innovations.

In the future, our special strength could be in combining artificial intelligence and biotechnology expertise, which can be used,

for example, to create completely new bio-synthetic materials.

How to turn expertise into sustainable growth?

Biotechnology is a sector that is developing extremely fast, and keeping pace with it now requires a highly strategic and long-term investment from Finland. It would be essential to obtain sufficiently long-term and significant funding for biotechnology research that utilises the latest breakthrough science and the latest methods.

The entire biotechnology ecosystem needs to be strengthened. It is important that Finland has high-quality biotechnology education and that young researchers are encouraged to the field. We must also support the creation and development of start-ups in the sector, invest in the infrastructure required for research, such as robotics and automation, and support cooperation between companies and research institutes.

Our special strength could be found in combining artificial intelligence and biotechnological expertise, which can be utilised, for example, to create biosynthetic materials.

7. Energy technology is at the core of the fight against climate change

Finland has a well-organised energy sector and expertise in new energy solutions in many different industries. Developing new energy system solutions is an enormous opportunity for Finland, but it still requires more patient and long-term funding.

Why is the area significant?

In order to combat climate change, the energy system needs to be changed. Geopolitics brings a new dimension to this. Changing the entire energy system is a major project, but it offers countless opportunities for developers of new solutions.

Energy technology affects almost all industries.

In the energy industry, electricity and heat production must be changed from the current ones.

For example, in the process industry, we want to turn emissions into raw materials. Industry will still need hydrocarbons as raw material. Chemical industry uses methanol as its raw material. While hydrocarbons are currently produced fossilily, they could be compiled from emissions from process industry in the future.

In the electrical sector, the production of green hydrogen by electricity requires massive infrastructure and equipment optimised in a new way.

The use of hydrogen and other gases requires new types of energy transmission networks.

Fertilisers made from green hydrogen are already on the horizon in the chemical industry.

In addition, electrical mobility will require the development of charging infrastructure

and battery recycling solutions. The entire transport sector will be transformed.

Significant revolutions in the manufacturing industry include new process equipment, electrolysers, synthesis reactors and the construction of energy storage facilities.

Why is Finnish expertise among the best in the world?

In Finland, the energy sector is well organised and progressive, the electricity network and infrastructure are in good condition and it is possible to build a new one on top of the current one. The production of renewable energy requires land surface, which is available in Finland. The production of wind power, for example, could be massively increased in Finland.

In addition, Finland has expertise in new energy solutions in many different industrial sectors. Developing new energy system solutions is an opportunity for Finland.

As regards the chemical industry and, for example, fertilisers, industrial projects are already underway in Finland, and pilot plants are currently being developed.

There is plenty of manufacturing industry in Finland, and the industry is used to manufacturing process equipment. A change from pulp production to synthetic fuel manufacturing facility would be possible.

Finnish expertise could also be utilised in smart grids and charging infrastructure, where the information technology and telecommunications play an important role. Finnish telecommunications and software expertise also supports the integration of the best expertise in information technology and energy technologies, thus creating something new.

Finland has also a tradition within heavy industry and export on that sector. For example, in the case of process equipment, Finnish technology and manufacturing industry could produce synthesis reactors, electrolysers, their electricity supply devices, energy storage and battery technology, as long as the product concepts were competitive.

Finland's strong process industry offers opportunities for producing and supporting synthetic fuels. The key question is how to bring new production to Finland.

In addition, the forest industry, which is important for Finland, is undergoing a transformation and requires new solutions as the demand for paper decreases but cardboard and pulp rises. The forest industry is a sector where there is a lot of capital and it has the prerequisites for renewal. New solutions that utilise biomass, and other use of fibres, for example in the manufacture of clothing, are an opportunity for Finland. In the future, however, the production of biomaterials will become more difficult in the EU if emissions from manufacturing processes are not reduced. For this reason, it is important to invest in the development of low-water and low-carbon processes in Finland and to examine whether carbon dioxide could be utilised in synthetic fuels in the future.

In addition, Finland is developing high-speed technology, i.e. the development of gas turbines and microturbines as well as

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hydrogen combustion in microturbines and new types of heat pumps. The question at the moment is: which industry or company is capable of seizing these new solutions.

How to turn expertise into sustainable growth?

While for example gaming companies can quickly create a commercialised business model, innovations in the energy sector require longer-term work, which also requires patient and longer-term funding. Basic funding should be increased and project funding directed towards longer periods.

Nokia's success was based on long-term development work. The right commercialising partners should be found alongside researchers, which means that research and people experienced in business should be made to communicate with each other.

8. Manufacturing technology plays a major role in solving sustainability challenges

Finland has strong expertise in manufacturing technology, but RDI investments are mostly limited to the financing of product and production technology innovations. Additional investments would be needed in long-term cooperation between research and companies, which aims at, for example, developing the digitalisation of industrial processes or manufacturing.

Why is the area significant?

Manufacturing technology is an area in which technology is developed for manufacturing physical products.

The sector covers a very wide range of various technologies. The combining factor is that they produce physical products that are further developed for various needs. Digitalisation is almost always present in the manufacture of products.

A digital model is initially created for the product, after which the physical appearance of the product is created through a highly automated production process. Digitalisation usually follows the manufactured product also after its completion in the form of various digital services, such as remote maintenance.

Manufacturing technology both generates and solves global challenges.

As products, developed from new innovations, are produced for the market and their demand increases, it should also be possible to increase the number of products in a way that the development is also sustainable. Therefore, manufacturing technologies play a major role in ensuring that the increase in the number of products does not excessively consume resources or contribute to increasing the single-use culture.

Why is Finnish expertise among the best in the world?

Finland focuses especially on the manufacture of high added value products. These high-tech products have taken major steps towards autonomous operations. Domestic products of high added value include lifts, rock drills or forest harvesters.

Manufacturing products with a high degree of processing requires strong expertise. Ideally, employees engage and develop with the company. This means that continuous learning plays a major role in achieving the production and quality objectives.

Finland has good capabilities, especially in the development and production of technologies that utilise robotics and flexible automation. Many smaller companies have begun to develop technological solutions in which the production of products is strongly based on robotics.

The domestic development of manufacturing technology is currently limited by an acute shortage of expertise. Compared to the needs of the field, too few Master of Science (Technology) or engineers who major in production technology, packaging technology or similar area of manufacturing technology are graduating in Finland. Due to a shortage of workforce, significant invest-

ments will be needed especially in robotics and developing automation in the future.

How to turn expertise into sustainable growth?

The most efficient way to support the development of manufacturing technology in Finland is to invest in education and training in the field, as well as in the cooperation between research organisations and companies in the manufacturing industry.

The domestic funding is currently rather focused in product and production technology innovations. For this reason, many areas of manufacturing technologies are barely invested in Finland, and therefore e.g. the development of the digitalisation of industrial processes or manufacturing is lagging. This means that production and, consequently, tax money will drain out of Finland.

When talking about breakthrough technologies, the time span of development may be blurred. This is particularly true for manufacturing technology, where the development of physical equipment takes decades, and new technological innovations developed several decades ago, such as friction welding in aluminium processing, are still considered to be new technology. For this reason, investments in the sector require a

Manufacturing technologies should ensure that the increase in the number of products does not unduly consume resources or contribute to a culture of disposable use.

particularly long-term approach.

New, sustainable ways to reduce the risks posed by large start-up investments in development projects and the long-term span of development work should be found for the development of manufacturing technology.

9. Health technology enables proactive and effective treatment

Health technology innovations shift the focus of care from reacting to anticipation and individual care. Finland has unique opportunities for utilising health data and high-level expertise in health technology. The bottlenecks are public sector resources and the siloing of expertise.

Why is the area significant?

The current health system is reactive in nature. When the patient has a problem, they seek treatment and are treated based on the best available information. Unfortunately, the potential for better often remains unexploited.

Health technology opens new opportunities for shifting the focus from reactive towards preventive medical care: identifying and minimising risks together with individual care. Health technology solutions can be used to monitor patients' coping at home, the development of their health status and the effectiveness of treatment.

The benefits of this transition for individuals are obvious - early diagnostics and closer monitoring of treatment support the patient's health, well-being and ability to work.

The benefits are also reflected in our economy. Social welfare and health care services are the largest expenditure items in Western societies. The ageing population and the resulting growing need for services challenge the Finnish social welfare and health care system, as is the case in many countries. Without technology, it is impossible to guarantee high-quality services for everyone.

Health technology can make resource use and management more efficient. The transi-

tion to more proactive treatment also curbs cost growth: dealing with a problem that has already arisen is typically much more expensive than preventing it.

Why is Finnish expertise among the best in the world?

Finland has strong expertise in health technology, and scientific advances have been seen in this area.

Everything is based on a well-functioning health infrastructure and an understanding of how we can utilise accumulated and accumulating health data. Finland has unique health registers and a legislative support for the secondary use of health data.

Based on this, world-class expertise has been built in Finland, for example in measurement technology. The purpose of the technology may be, for example, to identify and diagnose health risks or to monitor the treatment and state of health of patients who have become ill.

There is potential in data-based innovations to identify risk patients, monitor the effectiveness of treatment or improve the efficiency of health care service units.

Finnish health technology companies have significant international growth and business opportunities.

How to turn expertise into sustainable growth?

Despite the potential of health technology, there are still many obstacles to innovation and growth. Some of the challenges are systemic, as technological development is carried out at the mercy of the health care service system.

Even though a strong competence base creates revolutionary technology, health care units often have limited capacity to apply the new solution as part of the service system.

The bottlenecks are human resources and investment capacity of the public sector. If there is no improvement in these, there will also be no push for new technology-based innovations in the everyday life of health care.

Creating growth also requires the development and connecting of Finnish expertise.

Finnish technology expertise is strong, but cutting-edge technology is often created in narrow areas, in own silos. A company can obtain preliminary evidence that the new technology measures medically important issues and has good usability, but this is not enough. We must invest in the further processing of these promising ideas and the packaging of the technologies, produced in silos, into commercial products.

Increasing interaction between research actors and companies is important. At the moment, cooperation is randomly focused. In the best-case scenario, commercially successful products are generated through a process that involves brainstorming, testing, studying and discarding weak applications. Large leading companies and ecosystems based on concrete co-creation projects are needed in the health technology sector.

Everything is based on functional health care infrastructure and understanding of how we can utilise accumulated and accumulating health data. Finland has unique health registers and a legislative support for the secondary use of health data.

It is also clear that the growth potential of the health sector also requires funding. Obtaining early funding for small health sector growth companies is a challenge and a prerequisite for innovation. Without investors, it is difficult for a company to develop technology far enough to be able to further develop it into a commercial product.

The so-called Secondary Use Act opens up the possibility of conducting research and combining health data from different sources, but on the other hand, it does not allow companies to access public health data. Data should also be made better available for health technology development.

10. Security technologies provide critical protection for society and businesses

Finland has advanced security technology research and globally competitive companies. Winning the international competition requires closer cooperation between companies and research institutes. Joint studies combining theory and practice and national funding for the sector would support a pioneering position.

Why is the area significant?

Security technologies play a critical role in the functioning of society as a whole, as our industrial and social infrastructure and services, from energy production to the banking sector, currently rely very much on digital systems.

In addition to the information security sector, the sector includes cyber-physical sectors in which the physical and software components are integrated into a unified functional entity. Security technologies aim to improve people's safety and quality of life around the world.

In addition to the well-being of individuals, security technologies also play a crucial role in safeguarding the basic functions and data protection of companies and organisations.

The sector aims to create solutions, preparedness and recovery methods for situations where attacks are targeted at various digital services or cyber physical systems. The security technology services include maintaining the security of physical devices, networks, cloud services and certificates.

As the sector is truly global, it has plenty of commercial potential.

Why is Finnish expertise among the best in the world?

Finland carries out a great deal of research related to security technologies in various research institutes and universities. In addition, there are a lot of ongoing joint research projects between companies and research organisations. Finland has both small and growing global companies specialising in the development of security technologies.

The research focuses currently on access and privacy technologies, quantum cryptography and critical communication solutions. In recent years, security technologies have become increasingly important, especially in cyber-physical sectors.

We have both horizontal expertise and the ability to combine and apply sector-specific expertise in different fields as part of the cyber-physical process.

How to turn expertise into sustainable growth?

The development of security technologies is a continuous international race in which domestic actors should remain involved. Keeping up with the development would require broader cooperation between com-

panies, universities and research institutes. In addition, national funding should be used more strongly to support cooperation within the sector.

For example, joint studies conducted by organisations specialising in security technologies with cyber physical companies would support the development of the entire sector. Cooperation projects are already under way, of course, but this type of cooperation that combines theory and practice should be promoted.

Joint research projects would require companies aiming to create new kinds of value-added business relationships between each other. In this way, multi-chain entities could be formed around the projects, which, if successful, would generate new turnover for companies.

There is a particular need for funding academic research, as it lays the foundation for commercial breakthroughs in the coming years. The time span of technological development should be taken into account in the allocation of funding, i.e. basic and applied research should be funded in a balanced manner with funding for commercial projects.

In particular, the sector should focus on observing situational awareness and devel-

The development of security technologies is a continuous international race in which domestic actors should remain involved. Keeping up with the development would require more extensive cooperation between businesses and research institutes. In addition, national funding should be used more strongly to support cooperation within the sector.

oping risk understanding as well as preparing for exceptional situations and events. When cyber attacks occur, organisations must have well-planned action and recovery plans so that, if risks are realised, society's functions can be maintained.

11. Space technology revolutionises mobility, communication and observation

The decline in the production costs of space technology gives small operators, such as Finland, the opportunity to succeed. Finnish expertise can be found, for example, in small satellites and the services built on them. Companies should be attracted through national investments and pilot projects.

Why is the area significant?

Space technology works through satellites from space, but its impacts are visible on the planet both as a better functioning society and in national security. It is used to create radically better conditions for mobility, communication and observation.

Technology gives us reliable and accurate information for navigation, we can observe events in nature and cities in a completely new way, and we can communicate in areas where there are no preconditions for terrestrial information networks for economic or geographical reasons.

Remote sensing and imaging services provide up-to-date information on the state of the planet and the climate, such as climate change or situational awareness, for the use of the security and defence sector.

Positioning and timing services lay the foundation for accurate timing and synchronization of the stock exchange and energy networks as well as positioning-based consumer services such as Uber or Wolt.

Telecommunications services provide a connection for example to Arctic regions or places where terrestrial infrastructure is not possible for economic reasons – or if it has been destroyed.

Why is Finnish expertise among the best in the world?

In the recent years, space technology has been a rapidly growing and developing sector.

Traditionally, satellite development has been slow, and all technological choices have been locked years in advance. A device that has been launched into the space has also worked there for a very long time exactly as it was originally designed.

There has been a great leap forward: we are currently living in the so-called New Space era. As production costs decrease, small operators like Finland now have better opportunities to participate in the development of satellite technology. Finnish expertise can be found especially in the development of small satellites and the services built on them as well as in telecommunications services.

Miniature technology can be utilised in very small satellites. In this way, equipment that is reasonably affordable can produce very valuable data. We have a strong expertise background in this area.

In recent years, Finnish space technology operators have improved in the implementation of small satellite constellation and the miniaturisation of SAR radar technology for

remote sensing and imaging. In addition, Finland has a long history and expertise background, thanks to the heritage of Nokia, in the development of telecommunications systems.

In the future, large investments will be made in satellite telecommunications systems globally, and Finland is well placed to participate in this development work. Good examples of large telecommunications systems include over 2000 satellites in SpaceX's Starlink and Secure Connectivity system planned in Europe.

How to turn expertise into sustainable growth?

The most direct way to promote the development of space technology in Finland is to increase cooperation projects between companies and research institutes.

National funding is a key part of the development of space technology. Currently companies perceive entering the space sector as a major economic risk. National investments and pilot projects would be needed to lower the threshold in order to obtain successes and references at national level and thus better conditions for participation in international projects. This could also attract international risk financiers.

National funding is a key element of the space technology development. At the moment, companies perceive entering the space sector as a major economic risk. National investments and pilot projects would be needed to lower the threshold in order to obtain successes and references at national level and thus better conditions for participation in international projects.

International projects and cooperation with large space sector actors such as ESA, NASA and JAXA require good references. Local projects implemented with national funding and their references could serve as an effective channel for organisations to access international markets.

Thank you for the experts!

VTT has compiled the views of this vision paper based on interviews with top experts in the Finnish field of research, development and innovation. Thank you very much for your background discussions, expertise and time.

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The creation of innovations requires genuine cooperation between researchers, companies and other actors in society at every stage of the development. Funding should enable the creation of significant ecosystems and long-term cooperation.

VTT is a visionary research, development and innovation partner. We tackle global challenges and turn them into opportunities for sustainable growth. We help society develop and companies grow with technological innovations – we think beyond the obvious. We have 80 years of experience in ground-breaking research and science-based results. Welcome to the sweet spot where innovation and business come together.