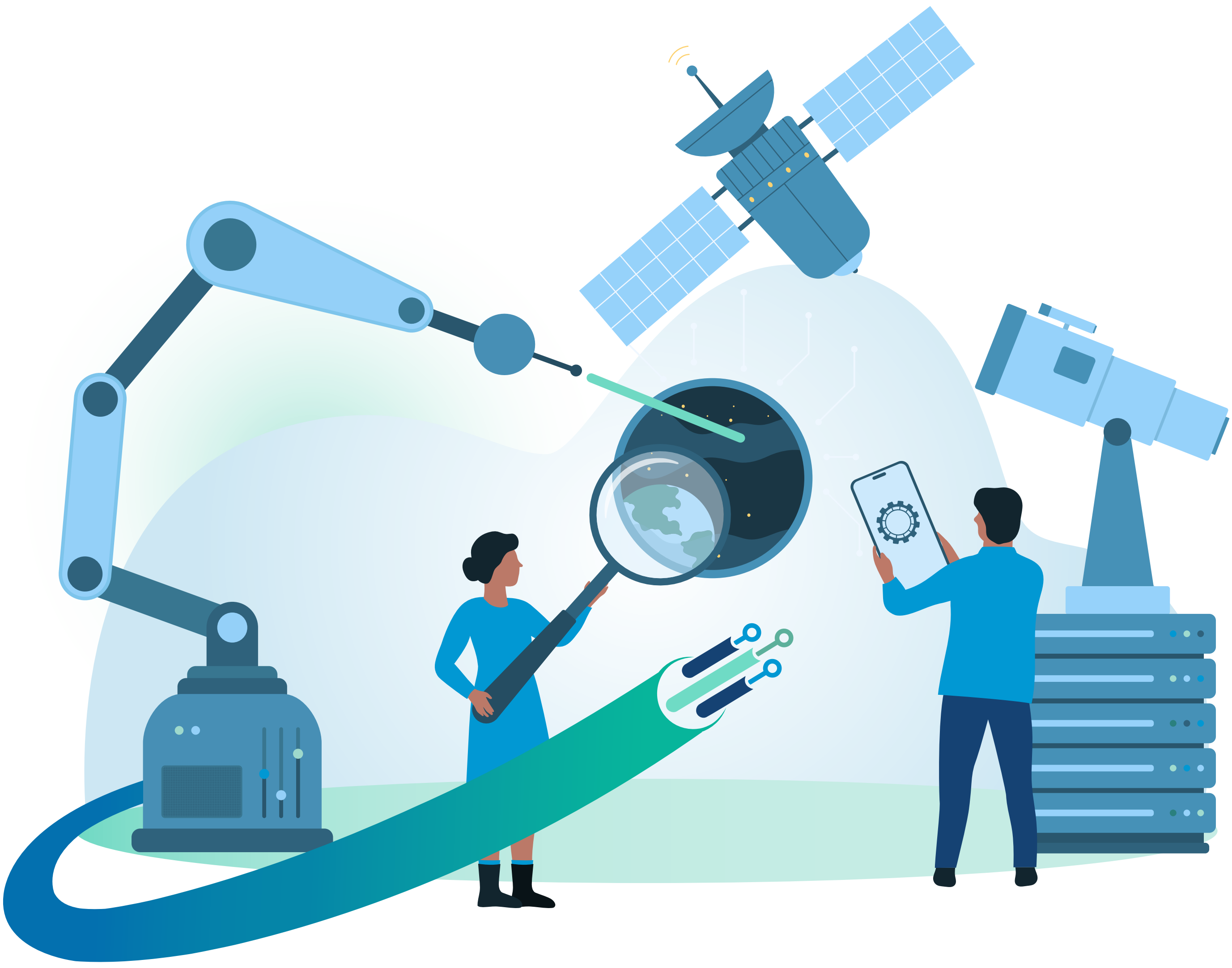
Ministry of Economic Affairs
and Climate Policy

National Technology Strategy

Building blocks for strategic technology policy



National Technology Strategy

Building blocks for strategic technology policy

Executive summary

Why now?
- International technological competition has greatly increased
- Other countries are focusing more specifically (and more smartly) on strategic key enabling technologies
- Technology can resolve challenges in healthcare, security, etc.

What is the NTS?
The NTS prioritises ten key enabling technologies that:
1. make a major contribution to our earning potential
2. are crucial to resolve the challenges our society faces
3. are important to protect our national security
4. allow the Netherlands to be a technological leader

Strengths of the Netherlands
- High-quality scientific research
- Well-educated population
- Strong international relationships
- Many public-private partnerships

Zwaktes NL
- R&D investments have fallen behind
- Technological applications (valorisation)
- Limited focus on key enabling technologies

What else are we doing?
- Focusing on all 44 key enabling technologies through the mission-driven innovation policy
- Broad base: focusing on the development, application and upscaling of technology with innovation policy, enterprise policy and industrial policy

The ten priorities
- Optical systems and integrated photonics
- Quantum technologies
- Process technology, including process intensification
- Biomolecular and cell technologies
- Imaging technologies
- Mechatronics and optomechatronics
- Artificial intelligence and data science
- Energy materials
- Semiconductor technologies
- Cybersecurity technologies

Agendas and ambitions
We have formulated a single agenda with ambitions for each priority. These are our long-term objectives. Which position do we want the Netherlands to reach by 2035? What do we need to do to achieve that objective?

What is needed?

Talent - Recruiting, retaining and developing (top) talent at all levels.

Facilities - Sufficient upscaling facilities for the development and application of technologies.

Financing and market creation - Providing sufficient financing for upscaling and good market access. Studying how the government can act as a launching customer.

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Introduction

Technological developments are proceeding very rapidly and new technological applications are becoming increasingly important and numerous. After all, as humans, we never stop striving to make our lives easier, more sustainable, better, more enjoyable and smarter. There are many examples, from faster smartphones and better weather forecasts to video assisted refereeing in football. The Netherlands is good at developing new technology: our researchers and industry are at the forefront of developments in machine building, computer chips and medicines. To ensure that we retain our leading position, the Ministry of Economic Affairs and Climate Policy has developed the National Technology Strategy in partnership with industry, civic organisations and knowledge institutions.

We believe it is important for the Netherlands to keep up with the rapid pace of global technological developments. Various countries, including the United States, Japan, China, the United Kingdom and Germany, are prepared to invest heavily to maintain or strengthen their own technological position. This particularly applies to technologies of great strategic importance, such as computer chips and artificial intelligence[1]. We in government are also concerned about the potential accompanying geopolitical tensions. Not all players play the game fairly. In addition, if a single country acquires a leading position in a particular technology, we may become disproportionally dependent on a single party for that technology. That may make us vulnerable, for example if we lose access to that technology.

If we wish the Netherlands and Europe to remain relevant, we must invest in strategic technologies and support the companies that develop them. Innovative companies must be given the space to grow, prosper and remain internationally competitive. This will help the Netherlands stay prosperous and resilient.

Ultimately, technology affects us all. We must ensure that technology is used in a way that benefits us as a society. For example, new technological breakthroughs can lead to new medicines for cancer, and the development of new seeds can lead to better harvests and new crops. However, technological progress can also give rise to ethical questions: how should we approach generative artificial intelligence and the role it will play in the classroom and on the work floor? Warfare is also becoming increasingly hybrid and technological, which means technological developments also affect our national security.

If we wish to protect our leading global position and make a positive impact on society, we must make choices. The Netherlands cannot lead the way in all areas; we are too small for that. We must continue to collaborate with our partners in Europe and beyond, preferably with countries that share our standards and values.

We can do so more smartly: our industry and knowledge institutions can work together to develop unique knowledge, products and services that are indispensable globally. For example, Dutch knowledge institutions and companies develop equipment for manufacturing computer chips that gives us a unique position in the global market.[2] We can – and must – think more strategically about how we can continue to acquire similar leading positions. This demands not just government investments, including new investments. We also need to think smartly about how the government can create the right conditions to encourage other public and private parties to invest.

This National Technology Strategy provides the building blocks for a strategic technology policy by identifying key enabling technologies where Dutch knowledge and industry can make a positive impact and where the Netherlands can develop a unique position.
These technologies are:

- Optical systems and integrated photonics
- Quantum technologies
- Process technology, including process intensification
- Biomolecular and cell technologies
- Imaging technologies
- Mechatronics and optomechatronics
- Artificial intelligence and data science
- Energy materials
- Semiconductor technologies
- Cybersecurity technologies

Reading guide
In this strategy, we start by outlining the current position of the Netherlands and the European Union in the development and upscaling of technologies, as well as the impact of those technologies. We subsequently consider the policy context into which the NTS can be integrated, namely a strategic technology policy with an effective combination of broad incentives and focus. The largest part of this strategy consists of the agendas for the technologies, as each technology demands a tailor-made solution. These agendas briefly describe each technology and the ambitions that the parties we approached propose for that technology.

The ambitions we have formulated are specific long-term objectives: which position do we wish the Netherlands to have acquired by 2035 for each key enabling technology, and what is needed to achieve that objective? The latter is explained based on the lines in the government's Strategy to Strengthen Research and Innovation Ecosystems, which was presented to the House of Representatives in 2020. This results in a holistic picture, which includes: 1) devoting attention to recruiting, retaining and developing (top) talent, 2) facilitating sufficient upscaling facilities for the development and application of technologies and 3) ensuring that there is sufficient financing for upscaling and good market access, with a role for the government as a launching customer where possible.

This document is an updated version of the document launched in January 2024, which means that this version also contains the agenda for *Cybersecurity technologies*, which was published at a later date. With the exception of a few minor corrections, the remaining text is the same and has not been updated for the latest developments.

Analysis
the current position of the EU and the Netherlands and the impact of technology

Our future broad prosperity, welfare and national security will largely be determined by how we harness the opportunities presented by new technologies, how we mitigate the associated risks and how we give those technologies a place in our society. Due to the increased international competition in strategic technological development, we can no longer take our leading position for granted. This affects the broad prosperity of the Netherlands[3] in three areas, namely 1) our national security, 2) our earning potential and competitiveness and 3) the challenges faced by, and aspirations of, our society. As well as serving our own national interests, the Netherlands' leading technological position helps to bolster the international position of the EU as a whole. This serves the interests of both the Netherlands and Europe: European and international collaboration is essential to acquire or retain a strong position in the technologies of the future, for example by developing a good knowledge position, achieving sufficient economic scale, developing international standards or guaranteeing the supply of critical raw materials. This will ultimately improve our international competitiveness and national security and allow us to make better use of technology to tackle the challenges we face as a society. This part of the strategy first focuses on the current position of the Netherlands in the development and application of technologies. We subsequently describe the impact of technology on the aforementioned three areas: 1) national security, 2) our earning potential and competitiveness and 3) the challenges faced by, and aspirations of, our society. Each section also considers the European and international dimension.

The current position of the Netherlands: leading position under threat

The Netherlands is a knowledge economy with strong international relationships, high-quality research and science, and good digital and physical infrastructure.[4] We have scored well in international rankings for years, including the European Innovation Scoreboard and the Global Innovation Index (see Table 1). We are amongst the top group of European innovation leaders, although a downward trend can be seen in the Global Innovation Index.

	2018	2019	2020	2021	2022	2023
European Innovation Scoreboard	4	4	4	5	4	4
Global Innovation Index	2	4	5	6	5	7

Position of the Netherlands on the European Innovation Scoreboard and Global Innovation Index.[5]
Source: WIPO (2023) - Global Innovation Index 2023 & Europese Commissie (2023) – European Innovation Scoreboard 2023

The Netherlands also has a well-developed research and innovation ecosystem with an attractive research environment[6], a well-educated population[7] and many partnerships between industry and knowledge institutions.[8] In addition, the Netherlands is home to a crucial link ('control point') in some international value chains, for example semiconductors.[9] With our broad scientific base and our strong position in the European and global knowledge landscape, the Netherlands is a leading global player in scientific research and innovation.[10] Dutch researchers are also very successful in European research programmes and Dutch universities score well internationally.[11]

The Netherlands scores very highly within the EU for top publications in the field of key enabling technologies, for example biotechnology and *quantum technologies*. However, the percentage of publications in the Netherlands on key enabling technologies (28%) is low in international terms.[12] An average of 34% of the research published by the EU-15 concerns key enabling technologies, while more than 50% of research in China, for example, concerns key enabling technologies. This reflects the relatively low percentage of scientific publications on nature and technology from the Netherlands, which encompass many key enabling technologies.[13] We also see that the Netherlands invests too little in R&D to meet the EU R&D target of 3%. This is partly due to a lack of R&D intensive economic activity. In particular, experimental developments where R&D is closer to the market receive too little attention in the Netherlands compared to other relatively knowledge intensive economies[14]. The Netherlands has also fallen behind in the valorisation of knowledge: [15] Dutch universities are less successful at transforming knowledge into (deep tech) economic activity than our European neighbours.[16] While there is great potential for collaboration between industry and knowledge institutions, they often fail to connect. They also regularly encounter practical obstacles, including in the commercialisation of intellectual property and the associated ownership structures. The development of startups and scaleups in the Netherlands and Europe is also a fundamental problem due to a lack of venture capital, particularly for knowledge-intensive and capital-intensive startups and scaleups[17]. There is a major shortage of (highly educated) technically trained staff [18]. This is partly because the Netherlands trains relatively few employees in technical fields.[19] Another important factor is that, as a consequence of natural demographic developments, the number of students from the Netherlands itself is falling.[20] More than half of the academic employees in the engineering faculties of our universities are foreign. This is the largest percentage in any field.[21] This means that measures that make Dutch education less attractive for international students may exacerbate this shortage if they fail to take account of the need for technical staff. This same applies to measures aimed at expats who wish to come here to work.[22]

Aside from the above points, which primarily relate to the extent to which the Netherlands is capable of developing and deploying high-value technology, there are also increasing problems with the basic preconditions for economic activities in the Netherlands.

Although this list is not exhaustive, four important preconditions are explained below:

- Access to critical raw materials: economic activity in healthcare, renewable energy and digitalisation requires critical raw materials, including magnesium, titanium, lithium and gallium. Access to these materials cannot be taken for granted, which is why the government is working to improve access to raw materials and reduce our dependence with the national raw materials strategy and related initiatives at European level.[23]
- Access to physical space: there is increasing pressure from various other spatial needs, including agriculture, housing and migration. In technological hotspots in particular, including the Zuidvleugel Randstad and Brainport regions, it is already difficult to find physical space for economic activity, or it may be in the near future. The Nationaal Programma Ruimte voor Economie (National Room for the Economy Programme) focuses on strategic spatial planning to retain sufficient space for the growth of innovative technology in the Netherlands.[24]
- Access to labour: the difficulty of finding technical talent described above is part of a wider trend. There is a historical labour shortage, which is also largely structural.[25]
- Access to energy: the war in Ukraine and other developments have led to major increases in energy prices in Europe. Although the market currently appears to be stabilising, it seems that higher gas prices[26] are here to stay. This particularly affects the energy intensive sectors of the economy. Due to the rapid electrification of the economy, grid access is also a major problem; new major consumers are unable to establish in many parts of the Netherlands.[27]

National security and the EU in strategic technological competition

Technological developments directly affect our national security. This includes the development of domestic capacities and also the emergence of new risks. Technology can give rise to new threats, or combine and exacerbate existing threats.[28] Specific threats include espionage, sabotage, cyber attacks, undesired influence and undesired knowledge and technology transfer. These threats can affect the continuity, integrity and security of systems, including digital systems, and our vital infrastructure. International technological competition has greatly increased. Economic instruments are also being used to project power.[29] For example, major subsidies are being awarded across the globe, and governments are investing to acquire leading positions in the value chains for semiconductors, artificial intelligence and other fields.[30] We also see that the supply of critical raw materials – which are essential for battery technology, amongst other things – is increasingly acquiring a geopolitical dimension.[31]

In the context of this increased strategic technological competition, the relative technological position of the Netherlands – and Europe – has worsened compared to that of China and the US.[32] We see that the performance of European companies, particularly in the digital domain, is increasingly falling behind that of American and Chinese companies.[33] A worsened economic and technological position can adversely affect our national security, for example if high-risk dependencies arise in the value chain, undesired influence is exerted on strategic technologies, or if commercially developed technologies also have military applications.

China has taken gigantic strides in technology in recent decades. In 20 years, the percentage of scientific publications from China has increased fivefold and has thus caught up with the EU. China also focuses much more on strategic key enabling technologies than the EU, particularly the Netherlands.[34] For example, Figure 1 shows that in China, the percentage of publications related to these technologies compared to all scientific publications is almost twice that of the Netherlands. These developments create opportunities for innovative partnerships, but also risks. China's technological developments focus on self-sufficiency and technological and scientific independence from foreign countries in strategic sectors. By ensuring that the country has access to essential technologies, China can minimise the risks associated with dependency.[35] This focus has geopolitical implications, and is paying off for China in the form of an increasingly strong economic and military position in the most complex technologies, including digital technologies.[36] China remains a partner, competitor and systemic rival.[37]

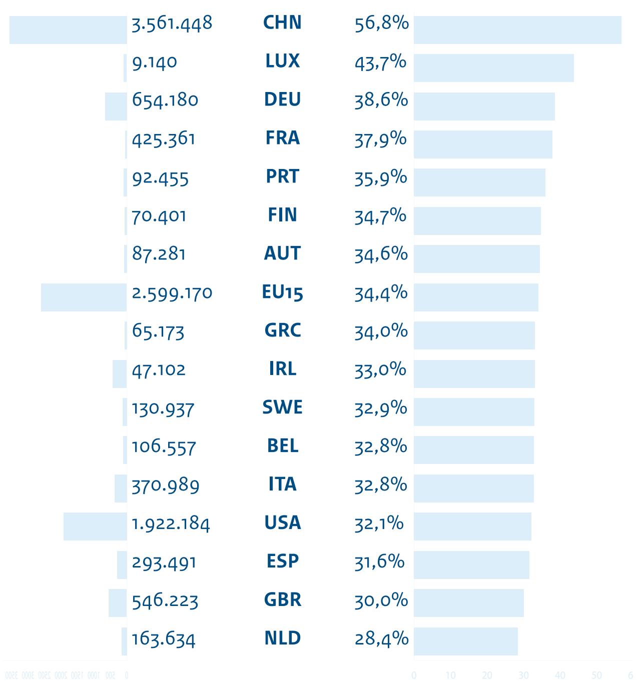


Figure 1. Research output for key enabling technology research (left panel) and as a percentage of total output (right panel) of NL and comparable countries in the period 2013-2022. Source: Elsevier (2023) – Quantitative analysis of Dutch research and innovation on key technologies / Scopus

To protect our national security, it is important that the Netherlands continues to increase its domestic capacity for technological development and that we retain free access to technology developed elsewhere. This will allow us – based on a system of mutual dependencies – to retain access to the technologies we need to defend ourselves, to influence the international rules and to influence the course of technological development. This demands a technologically resilient Netherlands and Europe. To achieve this, the Netherlands must focus more on technological leadership in key enabling technologies, and on retaining and strengthening our control points in value chains.[38] We see that various countries, including the US and UK, are setting priorities for the development of strategic technologies.[39] If the Netherlands focuses more on developing key enabling technologies and key positions, as China, the US and the UK have done, we can reduce the risk that international strategic technological competition will negatively affect our national security.

Innovation is the foundation for a strong, resilient revenue model

The development and application of new technology make a major contribution to our economy and can also protect and enhance the earning potential of the Netherlands[40]. Together with knowledge development, entrepreneurship, human capital (including training and digital skills) and properly functioning domestic and international markets, technological developments and innovation are the driving force behind a more productive population. Innovation drives economic growth by allowing the factors of production, including labour, to be used more smartly and efficiently. This in turn increases productivity, creates new opportunities and improves our international competitiveness.

Land, raw materials and labour are becoming increasingly scarce. By promoting technological innovations and entrepreneurship, we can reduce land usage, develop alternatives to crucial raw materials and make employees more productive. It is also important to do more with fewer people, due to our ageing population and the associated healthcare costs and pensions. As well as knowledge development, investing in technology requires an industrial base, as this sector invests more in R&D than others and because it is strongly linked to productivity growth and our international competitiveness.[41] Targeted investments in high-value technologies and knowledge and innovation ecosystems can also help Dutch companies produce more complex, high-quality products and services. We must devote specific attention to the challenges faced by, and opportunities for, (deep tech) startups, scaleups and innovative SMEs, as these companies are particularly capital intensive and high-risk, and also generally very R&D intensive, and because they can be the foundation for the Netherlands' future earning potential.[42]

As a small country, we must also identify the technological niches, or combinations thereof, where we can lead the world. ASML's lithography machines are a prime example. These niches stem from our knowledge position, our infrastructure, including digital infrastructure, and public-private partnerships. We also depend on our services sector, legislation and regulations and international relations to help us acquire high-value positions in value chains.

Importance of technology to society

New technologies and their applications are essential to improve our broad prosperity and to realise the transitions that our society faces. We owe our life expectancy, our quality of life and the opportunities we are offered to the research and development carried out through the centuries.[43] Looking to the future, new innovations also have a huge potential to influence our lives and to contribute to solving the challenges our society faces.[44] New technological developments are also essential if we wish to realise the energy transition and the transition to a circular economy while maintaining our current broad prosperity.[45] These are global challenges, and as such they demand solutions from scientists, researchers and innovative companies from across the world. However, the aforementioned geopolitical developments are negatively affecting multilateral efforts and international collaboration, and thus also the protection of knowledge.[46]

New technological developments, including the rise of artificial intelligence, have consequences and create new ethical and social problems [47]. Technological leadership and public scrutiny are required to steer them in the right direction.[48] In partnership with knowledge institutions, advisory councils, civic organisations and industry, the government has the responsibility to ensure that new innovations, including technological innovations, proceed in the right direction and make a positive contribution to our society. New technologies are developed across the globe and at breakneck speed. By investing strategically with our European partners, we can ensure that the development and application of these technologies are not monopolised by other countries.[49] We must ensure that the development and application of the prioritised key enabling technologies, as well as having a positive effect, do not significantly harm our earning potential, our society or our national security. This principle aligns with the Safe and Sustainable by Design approach currently under development by the EU.[50] Safe and Sustainable by Design is an approach to developing sustainable chemicals and materials that ensures that they do not harm people or the environment.[51]

New key enabling technologies will only be successful if they are also used in practice and have a positive impact on our society. Technologies must be designed for a real, complex context and must take account of the behaviour of people and/or must fit into industrial ecosystems. People-oriented design methodologies and designs for social transformations are required. The rollout of these technologies in society must go hand in hand with a dialogue with civic organisations and research into their acceptance by society. Social sciences and humanities can play a very important role in this respect. It is important that research is carried out not just in, and by, knowledge institutions and industry, but also in partnership with a broad range of parties from across society, from patient associations to schools, consumer associations, water authorities, etc. When combined with the link between technical sciences and other fields, this is known as interdisciplinary research. It is an important part of the solution to the complex challenges faced by our society.[52] Applied research organisations and practice-oriented research also have an essential role.

Conclusions in response to analysis

The international race between different power blocs to lead the development of strategic technologies, which is motivated by both economic and geopolitical interests, threatens the Netherlands' strong international position in technology and innovation. Despite the high quality of our scientific research, the Netherlands scores lower for the percentage of publications on key enabling technologies, R&D investments, valorisation and technically trained staff. We are also failing to provide the essential preconditions for economic activity. To protect our national security and future earning potential and to ensure that technologies continue to make a positive impact on society, the Netherlands must respond appropriately and invest strategically in the development of new technologies. We must reduce high-risk strategic dependencies by protecting and strengthening our role in Europe and by acquiring control points in value chains. This is essential to protect our national security within Europe. To guarantee our future earning potential and competitive edge, we must promote technological innovations and entrepreneurship to create opportunities and increase our productivity and international competitiveness. It is essential to realise transitions through domestic and international partnerships with scientists, researchers and innovative businesses to ensure that technologies and innovations continue to serve the public interest. However, it is just as important to pay attention to and manage the ethical and social issues that arise from new technological developments. By doing so, we can protect and increase our broad prosperity and maximise the positive impact of technologies on our society.

Policy context

The Netherlands cannot lead the way in all technologies. Nevertheless, defending the position of the Netherlands and Europe in the increasingly intensive strategic technological race is essential to protect our future earning potential, to resolve the major problems faced by our society and to protect our national security. This implies that the government must make targeted investments in several prioritised key enabling technologies based on a strategic technology policy.

A strategic technology policy consists of a mix of generic measures to promote technology-driven economic activity, a proactive focus on specific technologies and strategic investments in priority technologies where the Netherlands aims for technological leadership. At present, public and private direct investments in key technologies are limited compared to other countries.[53]

The National Technology Strategy will help to flesh out the strategic technology policy by building on the strong generic base with investments in the development, application and upscaling of technology with innovation policy, enterprise policy, industrial policy and digitalisation policy.[54] This strategy identifies several priority key enabling technologies with a strong base in the Netherlands: technologies that create the greatest economic and social value and contribute to our national security. The purpose of a strategic focus on investments in technology is to increase our economic and social resilience, to reduce dependencies in the field of strategic products, research and development (R&D), energy and raw materials and to protect our national security. In addition to this strategic focus, it is also essential to continue investing in the broad base to avoid blind spots, and because combinations of new and existing technologies and scientific discoveries often lead to new innovations, products and services. These combinations of technologies often play a crucial role in resolving the challenges faced by our society. In this respect, focusing on knowledge security is essential to prevent undesired knowledge and technology transfer.

A broad base for innovation: generic policy

The government promotes scientific and technological research and development with science policy[55] and innovation policy[56]. This includes devoting specific attention to impact[57] and valorisation[58]. Enterprise policy[59] and industrial policy[60] focus on creating the right conditions for the successful upscaling of technology-driven businesses to achieve technological leadership. This includes a specific focus on startups, scaleups and innovative SMEs that can challenge established businesses and create totally new markets to achieve a healthy economic dynamic.[61] The government has also informed the House of Representatives about the general structure of the digitalisation policy.[62] This policy focuses on promoting and embracing opportunities to accelerate the digital transition in a way that protects our values as a society. The letter sets out the government's ambitions and objectives for the digital transition of Dutch society and the economy around four themes: the digital base, digital government, digital society and digital economy.[63] The next stage of development of the NTS agendas must take account of existing digitalisation policy to the extent that this is relevant.

Steering innovation in the right direction: specific focus

As well as creating the right preconditions, we will focus on technologies where the Netherlands can and wishes to excel, by promoting research and development for 44 key enabling technologies[64] with Knowledge and Innovation agendas as part of the mission-driven innovation policy.[65] Our society faces various major challenges that can only be overcome by realising a transition. These include tackling climate change, the energy transition, the transition to a circular economy, improving our health and care, the transition in our food system and increasing our national security. Key technologies, and particularly

Strategic Technology Policy

3	**National Technology Strategy** **Strategic priorities** Strategic focus on priority key enabling technologies and specifically the niches in markets and control points in value chains with the greatest opportunities for the Netherlands.
2	**Specific focus** Focus on the 44 key enabling technologies through the mission-driven innovation policy.
1	**Broad base** Focus on the development, application and upscaling of technology with innovation policy, enterprise policy, industrial policy and digitalisation policy.

Figure 2. Strategic technology policy. A graphical representation of the various components of a potential strategic technology policy

combinations of these technologies, are essential to tackle the challenges we face as a society. They also have the potential to make a major contribution to the economy. The expectation is that, by specialising and focusing on key enabling technologies, new economic activity and markets will emerge more rapidly and the competitiveness of the Netherlands will improve. We also aim to increase the scope of influence, and thus also the economic and social impact, of domestic and international R&D investments through European partnerships, including Horizon Europe.
By working securely, globally and in a mutually beneficial way, we can also absorb the latest innovations and make them available to our industry and society. The *Innovatie Attaché Netwerk* (Netherlands Innovation Network), which is active in sixteen important knowledge economies in and outside Europe, can also play an important role as a mediator and intervenor.

Targeted focus on innovation: strategic priorities

In this National Technology Strategy, we have selected ten priority technologies from the 44 key enabling technologies. The priority key enabling technologies have a strong base in the Netherlands and make a major contribution to our current and future earning potential, to resolving the challenges faced by our society and to increasing our national security. We have worked with knowledge institutions and industry to develop agendas to strengthen or attain a position of technological leadership in these priority technologies. We have opted for a broad approach, in which we first identify an ambition for the development of each technology. This is followed by an explanation of how we intend to achieve that ambition through sub-ambitions (see the following chapter for a more extensive explanation). These sub-ambitions are formulated in relation to the ten challenges in the government's Strategy to Strengthen Research and Innovation Ecosystems, which was presented to the House of Representatives in 2020.[66] We have thus chosen a holistic approach that takes account of talent, legislation and regulations, financing and organisational capacity. The challenge is to select the technologies that have the greatest potential for the Netherlands. The priority technologies were chosen based on a combination of qualitative and quantitative data on the existing position of the Netherlands in each key enabling technology, and also on the expected impact of each technology on our national security, our current or future earning potential and the challenges faced by our society. In specific terms, the following assessment framework for technological leadership (see Figure 3) was used to make the selection[67]:

- Which key enabling technologies make an important contribution to the current and/or future economic earning potential of the Netherlands?
- Which key enabling technologies play an essential role in tackling the challenges faced by our society?
- Which key enabling technologies contribute to our national security?
- Which key enabling technologies build on the Netherlands' existing strengths in science and technology, R&D and ecosystems?

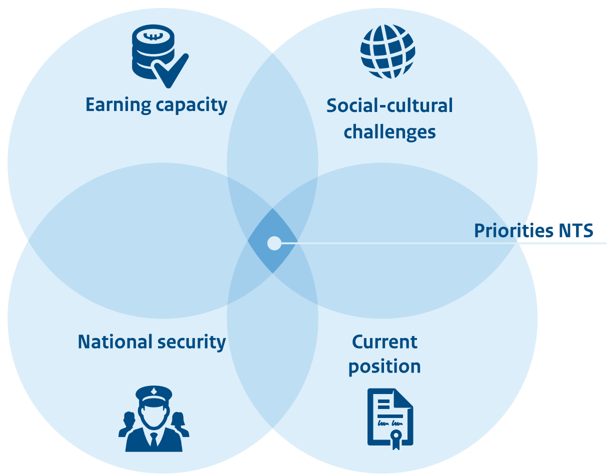


Figure 3. Technological leadership assessment framework. Technologies that score highly for these four facets of the assessment framework were selected as priorities in the National Technology Strategy.

What are key enabling technologies?

Key technologies are technological domains where the Netherlands has a strong scientific position and that are expected to have a major social and economic impact in the coming years. These technologies have broad applications or reach in innovations and sectors and facilitate the development of innovations in the medium term. They play an essential role in tackling the challenges we face as a society and in increasing our national security. They also make a major contribution to the economy, in part due to the new economic activity and markets they create.
The 44 key enabling technologies are part of the mission-driven innovation policy and play an important role in the Knowledge and Innovation Agenda (KIA) for Key Enabling Technologies, the development of key enabling technologies within the various Topsectoren (Top Sectors), the National Growth Fund and calls from the NWO (Dutch Research Council). The list also serves as the framework for investments from regional funds and EU co-financing.
The list of 44 key enabling technologies that the Netherlands will focus on is divided into eight technology domains: Advanced Materials, Photonics and Optical Technologies, Quantum Technologies, Digital and Information Technologies, Chemical Technologies, Nanotechnologies, Life Science and Biotechnologies and Engineering and Fabrication technologies.

EU developments – What is the relationship between the National Technology Strategy and European policy?

In the autumn of 2023, contemporaneous with the development of the National Technology Strategy in the Netherlands, the European Commission identified ten critical technologies that are important for the security of the EU. The National Technology Strategy employs a broader assessment framework than the Commission, as it considers not only national security but also the impact on our earning potential, the challenges faced by our society and the areas where the Netherlands already has a strong knowledge position. However, the Netherlands greatly values the Commission's approach, which aligns with the priorities in the National Technology Strategy and the agenda for Digital Open Strategic Autonomy. The Commission argues that, in the context of the growing geopolitical tensions in today's world, economic integration and rapid technological progress, certain economic dependencies and technological developments can lead to risks. In response, the Commission intends to carry out risk assessments for the first four technology domains in early 2024. The objective is to identify potential vulnerabilities in partnership with the member states and with input from business. The four domains are: 1) advanced semiconductor technology, 2) artificial intelligence technology, 3) quantum technology and 4) biotechnology. All these technology domains have a high risk profile in the context of technology security and transfer and are thus priorities. The risk assessments for the remaining six technology domains will be carried out in 2024. The European Commission also announced the Strategic Technologies for Europe Platform (STEP) last June. The platform aims to promote targeted investments from existing and new EU funds in critical technologies, namely: 1) deep and digital technologies, 2) clean technologies and 3) biotechnologies. The programme aims to increase the independence, resilience and security of the European economy.

Priority key technologies

In the following section, we present detailed agendas for the priority key enabling technologies. These agendas consist of two parts. They present an initial impression of the opportunities for targeted investments in these technologies. They present an overview of the technologies and potential ambitions for the Netherlands in each case. A short explanation of the structure of the agendas and the partnerships for the development and specific details of each agenda is given below, followed by the agendas themselves.

Part 1 – Definition

In part 1, 'Definition', we start by explaining the importance of each key enabling technology. We use the NTS assessment framework and explain why the technology is important in relation to the four lines in the framework. The following formulation is used, with amendments where necessary, with a reference to the relevant report[68]. This is based on the definition agreed by TNO (Netherlands Organisation for Applied Scientific Research) and NWO (Dutch Research Council) in a previous phase. We explain how the key enabling technology is related to other key enabling technologies and show graphically how they are hierarchically related.

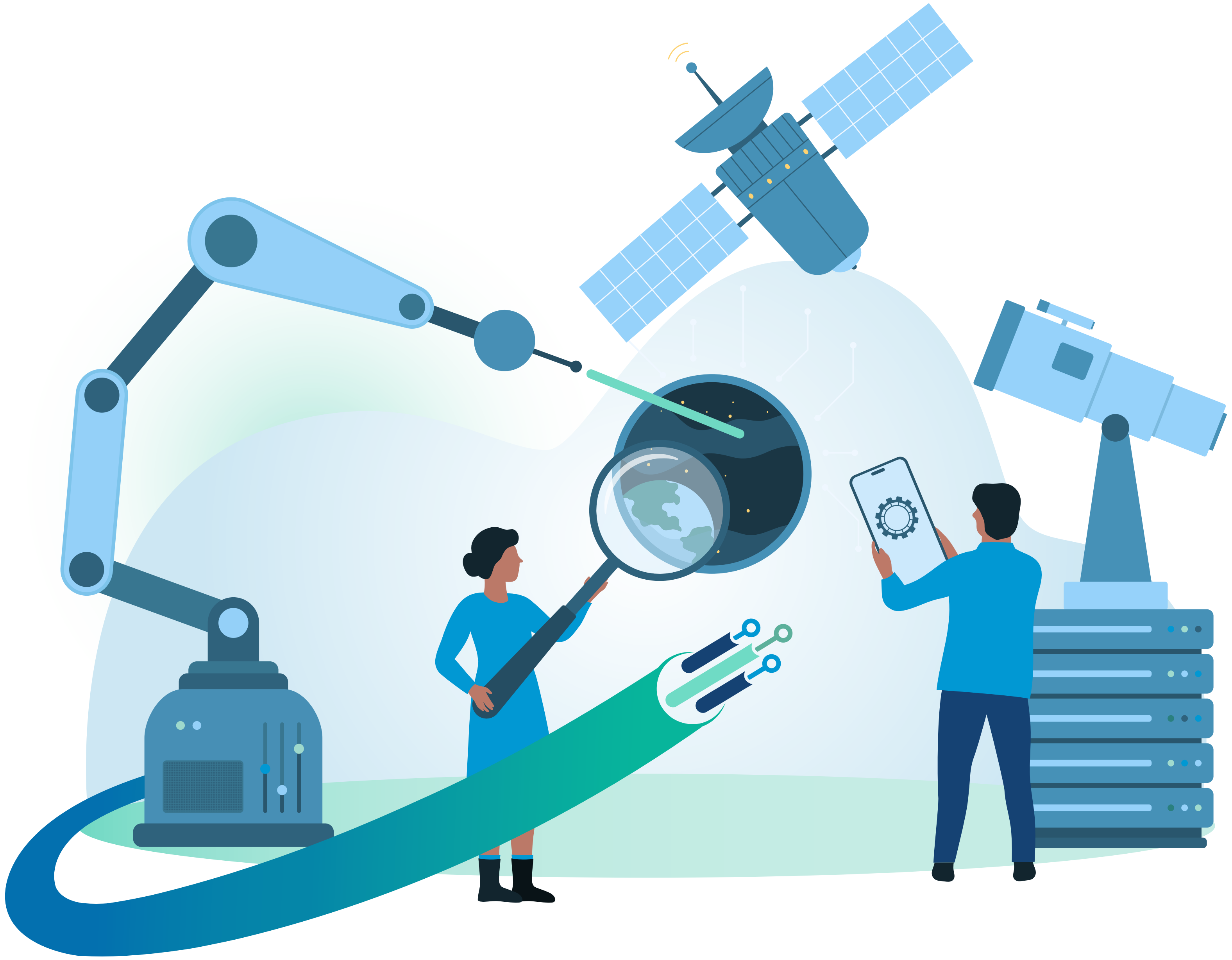
Part 2 – Ambition

In part 2, we look to the future. We start by formulating an ambition that is as specific as possible: where do we aim to be with this technology in 2035? How can we actively position our industry and knowledge institutions to develop this technology? How will this contribute to realising social objectives and protecting our national security? We subsequently analyse this long-term objective based on the ten long-term challenges identified in the government's Strategy to Strengthen Research and Innovation Ecosystems[69]. For each of these challenges, which are formulated in generic terms, we consider: is it relevant to the key enabling technology in question, what is the challenge and what do we aim to do or achieve to tackle that challenge?

Contributions to the agenda

The agendas were developed by the Ministry of Economic Affairs and Climate Policy and published by the outgoing caretaker government. As well as the knowledge and expertise of TNO and NWO, both of which played an important role as project coordinators for the agendas, we also – and perhaps more importantly – made use of the knowledge and expertise of our partners in research and innovation. More than 100 experts from knowledge institutions, industry and other relevant organisations actively contributed to the final agendas. TNO and NWO played an active role in the process of nominating and selecting experts. We are very grateful to these experts and appreciate their valuable input.

1 Optical systems and integrated photonics



1.1 Definition

1.1.1 Importance of the key enabling technology

Optical systems and integrated photonics encompass the technology behind optical systems. This key enabling technology consists of two parts, each with its own characteristics and ecosystem(s). In combination, they make it possible to build advanced, versatile optical systems (see section 1.2 for a more detailed explanation of the differences). There are numerous potential applications for this key enabling technology, including in lithography systems, freeform mirrors and lenses, wireless optical communications (including Li-Fi and laser satellite communications) and lighting.

Optical systems and integrated photonics are crucially important for our future earning potential and national security. The Netherlands excels in optical and lithographic systems for the semiconductor industry, a stable growth market with a CAGR of approx. 8%. The Netherlands is also a hub for *integrated photonics* in Europe. Due to the use of advanced chips in military and other security applications, as well as the close relationship with the semiconductor industry, these technologies are also important for our national security. This means that high-risk strategic dependencies should be avoided as much as possible.

Optical systems and integrated photonics can play a role in tackling the challenges faced by our society, particularly as we strive to develop energy efficient applications. Although Dutch research in this field leads the way in Europe, it must be recognised that we are not yet at the same level as the US and Japan. However, the Netherlands has invested and built up a leading position in the industrialisation of this technology, with an end-to-end value chain within Europe. It is essential to continue investing in improving the existing infrastructure to reach world-class level. Initiatives such as the EU Chips Act offer opportunities in this regard. For example, an application is currently being prepared for an integrated European photonics pilot line, in which the Netherlands can function as a European photonics hub.

The developments in wireless optical technology for laser communications have produced promising results in test environments and are now being demonstrated in various environments, particularly those where security is a priority, such as military bases. The step towards industrialising this technology should be possible in the coming years.

1.1.2 Definition

Optical systems are constructed systems that refract, reflect or manipulate light to fulfil various optical functions. For example, photons can be used as information carriers for communications.

Integrated photonics is the technology that integrates various photonic functions (generating, modulating, detecting, etc.) into a single functional photonic chip known as a Photonic Integrated Circuit. Systems integration is an important element of the application of *integrated photonics*.[70]

Although *integrated photonics* and *optical systems* are comparable, as they both involve processing light, there are clear differences in the maturity, applications and scalability of these key enabling technologies. The ecosystems within optical systems also have different technology readiness levels. In the following sections, we therefore discuss this key enabling technology as two key sub-technologies, each with its own ecosystems. A short description of the characteristics of each key sub-technology is given below.

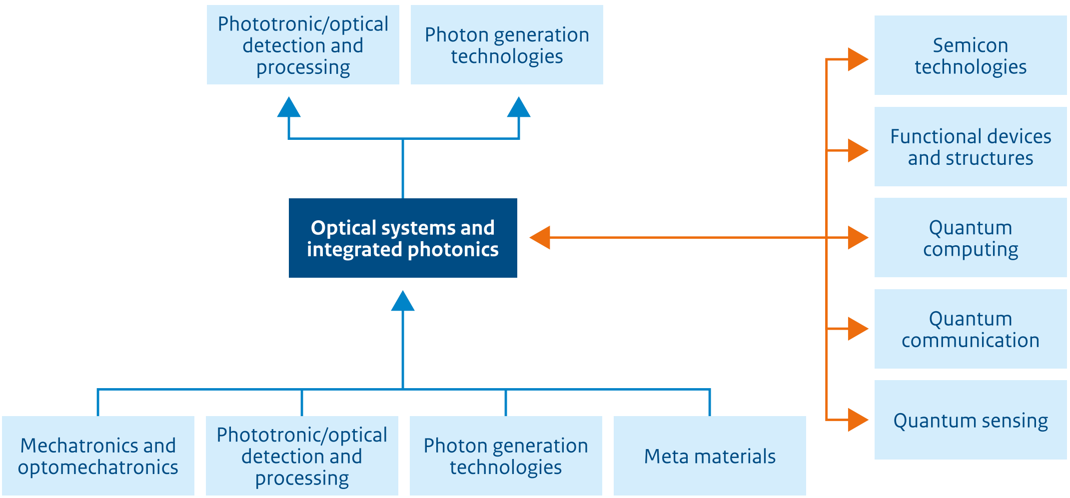
Optical systems
- consists of various sub-technologies and applications, each with its own ecosystem or potential ecosystem.
- technology readiness level: optical systems are already produced and used on a large scale, although there are also new developments with a low TRL level.
- applications: wide range of applications.
- scalability: there are also wide variations in the scalability of this key enabling technology. *Optical systems* are very large and complex, which makes adapting or adjusting for large-scale production challenging. However, some applications, such as optical fibres, are easy to upscale.

Integrated photonics
- maturity of the technology: small-scale niche applications, with the exception of telecommunications and data communications, where there is steady growth.
- applications: generic and specific applications in communications and sensing, including transceivers for telecommunications and data communications (generic) and biosensors for the agrifood sector (specific).
- scalability: the technology integrates optical functions onto a single chip in a comparable way to electronic circuits. This means that the scalability of optical functions on a chip is very high, and the costs relatively low, thanks to the use of 'wafer scale' production. Technology from optical systems is necessary for the further upscaling of *integrated photonics*.

1.1.3 Related key enabling technologies

Within the domain of *physical optics, photonic/optical detection and processing* and *photon generation technologies* share a common knowledge base. Both key enabling technologies are part of the same discipline and have an overlapping network of scientists and expertise, as well as a shared focus on *metamaterials*, particularly *optical metamaterials*. Building complex optical systems also requires expertise in *mechatronics and optomechatronics*, which require the same knowledge at the system level, although the specific components may vary. Alongside these related technologies, which are part of the same discipline, there are also complementary key enabling technologies, including *semiconductor technologies, functional devices and structures (at nanoscale), quantum communications, quantum sensing* and *quantum computing*. Although they are part of separate disciplines, these technologies can be deployed in the same system, for example by using discrete resistors, coatings, including nanoscale coatings, and quantum applications such as internet, sensing and computing applications. It is important to note that this list is not exhaustive, given the ongoing developments in these technological domains.

Related key technologies



Source: TNO/NWO (2023) Recalibration of key technologies

1.2 Ambition

1.2.1 Main ambition

In 2035, the Netherlands will be a global leader in the development and manufacture of next generation systems based on *optical systems and integrated photonics*. By continuously innovating, we will grow faster than the competition. This will contribute to our security and economic independence.

1.2.2 Sub-ambitions

The main ambition is divided into several sub-ambitions. In 2021, the government identified ten challenges to be addressed to strengthen our research and innovation ecosystems. The sub-ambitions are described in relation to these lines where relevant.

Long-term vision and relationship to investments in research and innovation

The various roadmaps, detailed agendas and programmes can be coordinated better: activities do not take account of one another and complement one another insufficiently. There is also no long-term vision for how existing initiatives can be structurally supported.

Sub-ambition: A unified long-term agenda will be developed soon. It will have a clear mission, vision, approach, structural financing and support from the government. This agenda will allow organisations including Optics Nederland, PhotonDelta and PhotonicsNL to continue developing the ecosystems in the future. Organisations like these must be capable of supporting the ecosystems and maintaining contact with all stakeholders.

Investments in research and test facilities

The Netherlands has an excellent research infrastructure, with facilities at the UT (University of Twente), TU/e (Eindhoven University of Technology) and elsewhere. However, the infrastructure for Pilot, Test and Production Facilities (PTPF) requires further development. Although some facilities already exist, there is too much focus on short-term business cases in the Netherlands, which hinders the financing of these facilities. This also means that financing for maintenance is not taken into account. In addition, the existing infrastructure and facilities do not fully meet the needs of the roadmaps and agendas.

Sub-ambition: In 2035, the Netherlands will have a state-of-the-art PTPF. Its continuity will be guaranteed through structural financing, which will also take account of the long-term maintenance of the PTPF. This PTPF will meet the needs of the existing roadmaps and will be combined into a single partnership structure (following the example of Imec).

Financing for startups and scaleups: early phase financing and growth

Attracting private capital for larger projects is difficult. Insufficient use is currently made of the opportunities to promote these technologies through public procurements. Venture capital for deep tech in the Netherlands is also still in its infancy. This means there is a shortage of venture capital. Investors often lack the background and knowledge needed to assess whether an investment will be profitable.

Sub-ambition: In 2035, the government will have successfully realised major public procurement processes. This will have considerably increased our innovative capacity. This in turn will have resulted in a flourishing partnership between a wide range of industrial partners, including startups and scaleups. The investment climate will also have improved substantially, thanks in part to the increased intention paid to the sector and targeted support for startups and scaleups (for example tax incentives for employees of startups).

Involving users in research, innovation and market creation: The partnership with end users can be improved, particularly in *integrated photonics*. The PITC/Holst Centre and participating companies are taking important steps. Partnerships with research institutions, such as those established by ASML, can also make an important contribution. These partnerships can shorten the learning curve from research to manufacture and accelerate the upscaling of production. They can also contribute to bridging the gap between development and application. However, the opportunities for co-financing these partnerships are limited in practice.

Sub-ambition: We will involve users more through targeted partnerships between the government, industry and research institutions. The government can play a greater role as a launching customer to bridge the gap between development and application. The government can thus be seen as a partner in mission-driven innovation. The government can finance front-end innovation, while also improving the financing climate for launching customers.

Skills and absorption capacity of SMEs

It is difficult for SMEs to include innovations in their product strategies, because bridging the gap between mid-TRL and mid-MRL[71] is capital intensive. In the past, there were schemes such as the IOP (Innovation-oriented Research Programme), which helped SMEs to bridge the gap between mid-TRL and mid-MRL. However, there are no such schemes at present.

Sub-ambition: We will adapt the innovation instruments to make them more suitable for innovation in production processes. The instruments will be expanded to create more opportunity to cover the commercial risks that SMEs face, for example by allowing production lines, including pilot lines, to be developed with capital from the government and other parties. Inspiration can be drawn from the instruments available in other countries, including Germany.

Developing, attracting and retaining (top) talent

Universities and industry have great difficulty attracting trained staff with expertise in specific technical areas. There is also a lack of support from the government to coordinate these efforts. There are also no specific programmes (at vocational or academic level) for this technology in the Netherlands. Aside from education, it is difficult to attract staff from abroad and it is also difficult to retain staff.

Sub-ambition: In 2035, specific education programmes (at vocational and academic level) for *optical systems and integrated photonics* will have been created in partnership with knowledge institutions and industry. The government will provide incentives. These programmes will also be attractive for foreign students, as they will be entirely taught in English. The Netherlands will also continue to be an attractive destination for talent by offering benefits to knowledge workers from abroad.

Strengthening knowledge transfer and the valorisation process for greater impact

At present, knowledge often remains on the shelves of knowledge institutions. There is a lack of standards and guidelines (from the government) for the transfer of IP from universities to spinoffs, for licences and for the requested compensation (e.g. shares). The process of knowledge transfer from universities to major companies is often also fraught with difficulties. There are often intensive discussions about the ownership of IP and the value assigned to IP when it is transferred to a company.

Sub-ambition: In 2035, clear standards and guidelines will be available for transferring IP to spinoffs and for the valuation of IP transferred to companies.

Links between ecosystems

It is essential to look further than the existing ecosystem to strengthen the market position of innovative products abroad and to protect our own position. The links with related value chains in the Netherlands can also be improved. These links are still being intensively developed for chip design and system design for *integrated photonics*, for example. As a result, the available knowledge is fragmented.

Sub-ambition: In 2035, the *integrated photonics* and optical systems ecosystems will be well connected thanks to the adoption of a cross-disciplinary approach. This will include bringing together various National Growth Fund projects (including Quantum Delta NL and NXTGEN HIGHTECH), analysing strategic partnerships with foreign partners, such as that between ASML (NL) and Zeiss (DE), and preventing foreign trade restrictions to maintain robust value chains.

2 Quantum technologies

2.1 Definition

2.1.1 Importance of the key enabling technology

In the long term, *quantum technologies* (computing, communications and sensing) will be crucial for our earning potential and security. They will facilitate solutions in sectors such as energy, health and security, including cybersecurity. Quantum computing makes calculations possible that would be impossible with conventional computers, for example to help us understand molecular behaviour and develop new materials. Quantum communications can make secure long-distance communications possible. Quantum sensing allows us to make measurements with unprecedented accuracy.

To be able to play an important role in the market for *quantum technologies*, the Netherlands must retain and expand its leading position.[72] The potential market in 2035 exceeds a trillion dollars. There are also major synergies between *quantum technologies* and other technologies, including upcoming technologies. The development of *quantum technologies* will therefore lead to spillovers into other industries. The development of *quantum technologies* depends on progress in other fields, including electronics, photonics, metrology and high performance computing.

The Netherlands has a leading global position in quantum science. Investments primarily come from the National Growth Fund (Quantum Delta NL) and knowledge institutions. There are no tech giants with a focus on quantum (as is the case in the US), and there is also insufficient venture capital. It is crucial that we consolidate a position in the global value chain. This will also contribute to avoiding undesired, high-risk strategic dependencies. If the Netherlands works with partner countries including France and Germany to develop a European quantum hub, it is highly probable that Europe will be able to set the standard for elements of *quantum technologies* and build up a quantum industry that can make a serious impact in the global and European quantum value chain.

2.1.2 Definition

Quantum technologies make use of the dual character of the smallest particles known to science, including photons, atoms and electrons, as well as comparable systems that display quantum characteristics. These systems can adopt pure quantum states. The smallest particles display non-local behaviour, and quantum states can be entangled. This paves the way for quantum computing (with associated quantum software), *quantum communications* and *quantum sensing*. A quantum bit (a unit of digital information) can be 0 and 1 at the same time. This allows calculations to be carried out in a different way, which allows solutions to complex problems to be found. In most applications, quantum computers will work together with conventional (high performance) computers in a hybrid manner.

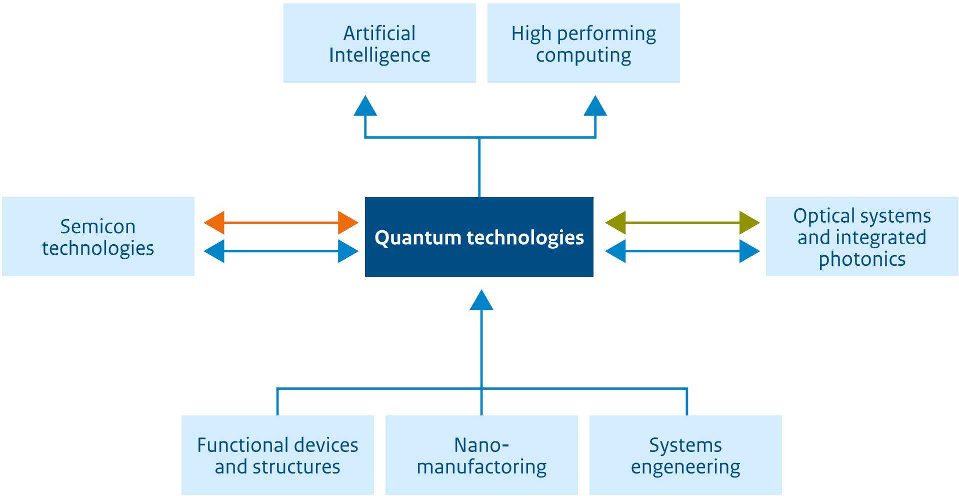
2.1.3 Related key enabling technologies

Quantum technologies build on several complementary technologies (the blue arrows). Knowledge and infrastructure from the nanotechnology sector (*functional devices and structures* and *nanomanufacturing*) are essential for the development of quantum chips (quantum computing) and *quantum sensors*. Quantum systems are exceptionally complex. *Systems engineering* is essential to handle this complexity.

Quantum applications will increasingly use knowledge from *semiconductor technologies* to develop chips and systems. Supporting and interconnected conventional chips are required for quantum applications. Hybrid integration of the various platforms and cryo-CMOS, including on-chip integration, will support (early) quantum applications. Quantum technology may compete (orange arrow) with specific *semiconductor technologies* applications.

Optical systems and integrated photonics are complementary and sometimes related (green arrow) technologies for *quantum communications* and many quantum computing and *quantum sensing* applications.

Related key technologies



Source: TNO/NWO (2023) Recalibration of key technologies

2.2 Ambition

2.2.1 Main ambition

In 2035, the Netherlands will have a world-class quantum ecosystem, in both academic and industrial terms. It will be an international magnet for economic activity and talent. The Netherlands will lead the way with control points in international value chains for all three of the described technology areas, with players that compete at international level. Within the EU, the Netherlands will be part of a leading group and will have a strong position in manufacturing and commercialisation.

2.2.2 Sub-ambitions

The main ambition is divided into several sub-ambitions. In 2021, the government identified ten challenges to be addressed to strengthen our research and innovation ecosystems. The sub-ambitions are described in relation to these lines where relevant.

Long-term vision and relationship to investments in research and innovation
In the current ecosystem, Quantum Delta NL is responsible for long-term coordination. Once this organisation is disbanded 2028, there will be no organisation to ensure the long-term coherence of the national quantum agenda and budgets, including ensuring a strong international position and coordination.

Sub-ambition: Industry, science and the authorities will prioritise research and innovation through related research and investment agendas and joint prototype and pilot line development. The authorities will provide knowledge institutions with stability and a safe and secure environment for commercial investments by providing continuity through long-term planning, support and investments in programmes such as Quantum Delta NL.

Investments in research and test facilities
There is a need for accessible research and test facilities, as described in the EU Chips Act, to facilitate cutting edge research and promote innovation. The high costs of test facilities and clean rooms mean that startups have difficulty testing and developing their equipment.

Sub-ambition: In 2035, the Netherlands will have world-class research institutions, test facilities and production lines for *quantum technologies*, and a workforce and industry to match. To achieve this, it is crucial that existing institutions (e.g. QuTech, NanoLabNL, QuSoft) continue to exist and grow. Accessible test facilities are essential. Consultations with startups and scaleups will ensure that their specific needs are taken into account so that they can realise the first, small-scale production processes.

Financing for startups and scaleups: early phase financing and growth
The available financing to allow quantum startups to grow into scaleups is too limited, particularly compared to other parts of the world. Private investors in particular see major risks, profitability that is too far in the future, an uncertain market potential and potential legal barriers to sales.

Sub-ambition: In 2035, the Netherlands will have multiple scaleups and at least one unicorn. We will help startups and scaleups to grow by encouraging private investments, including venture capital, with attractive tax incentives for private investments in key enabling technologies and by linking with government strategy and budgets.

Involving users in research, innovation and market creation
Potential end users are currently rarely involved with the development of *quantum technologies*, primarily because the existing applications are not yet profitable.

Sub-ambition: In 2035, end-user applications in other sectors will drive the R&D of various *quantum technologies*. End users will be involved with the development of *quantum technologies* at an early stage, for example through co-creation in the precompetitive phase and by having the government act as a launching customer.

Developing, attracting and retaining (top) talent
There is competition from abroad in the market for talent. It is also difficult to retain our own domestic talent. There is a particular shortage of practically trained technical workers.

Sub-ambition: In 2035, the Netherlands will have world-class facilities, study programmes (vocational and academic) and research (a position in the global top ten). In combination with our pleasant living environment and competitive work/life balance, this will attract foreign talent. We must focus more on broad, technical teaching from kindergarten onwards and on ensuring that we have sufficient practical technicians.

Strengthening knowledge transfer and the valorisation process for greater impact
There is a risk that the knowledge of research institutions, the expertise of industry and experience with regulations will continue to exist in isolation, rather than being effectively combined.

Sub-ambition: Knowledge and expertise transfer will be encouraged, for example by promoting job switching between the sciences, industry and government. Industry and the government will also have early access to quantum computers, networks and sensors. Knowledge institutions (applied research organisations, science) will also focus more intensively on valorisation, with an emphasis on maximising the positive impact on society.

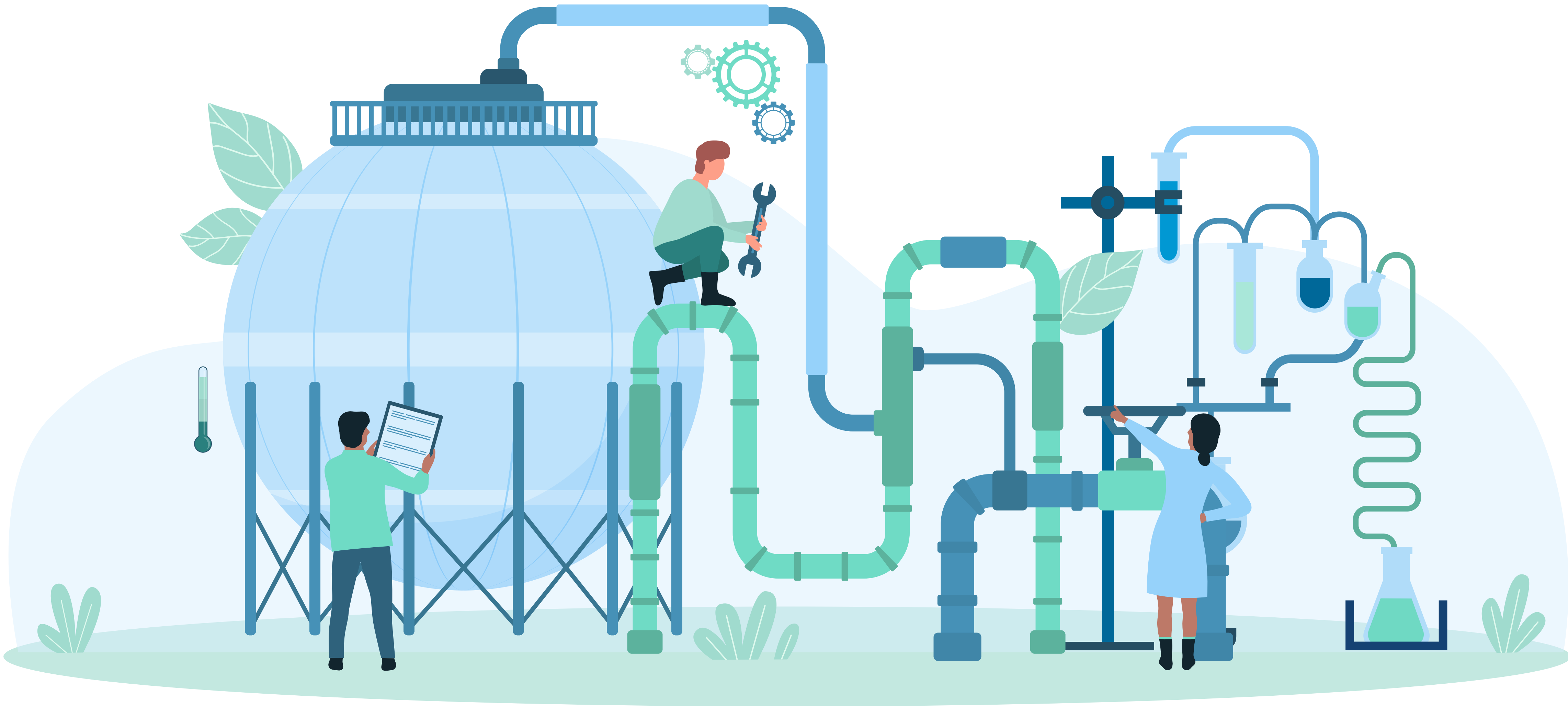
Links between ecosystems
While access to knowledge and markets in other countries is crucial for the development of *quantum technologies*, many countries are in fact committed to protecting their own ecosystems to safeguard their national security. The commercialisation of these technologies also depends on knowledge from fields such as semiconductors and *integrated photonics*. However, there is little interaction between these fields at present.

Sub-ambition: The Netherlands will use its organisational capacity and leadership to adopt a coordinating and strategic role in international partnerships with central hubs in Europe and like-minded countries elsewhere in the world. Within the Netherlands, collaboration in research, innovation and production with related key enabling technologies (including photonics through the PhotonDelta programme and semiconductors) will be sought, and the first end users will be involved with developing the technology.

Devoting attention to legislation and regulations earlier in the process
Technological developments are proceeding rapidly, but policy and investments are failing to keep up. For example, quantum computing creates new standardisation and security problems, which are often only addressed once these problems become acute. The challenge is to develop policy that keeps up with these developments, that strikes a balance between national and economic security and that acts as an incentive in the short term while ensuring effective implementation. There is also a need for policy to deal with future risks.

Sub-ambition: The Netherlands will have a range of instruments to promote continuity and to provide an impulse for development. At European level, the Netherlands will work to ensure 'quantum preparedness', including for the Netherlands itself, and regulations for business that promote innovation (e.g. for encryption standards), and to protect national security through export controls for *quantum technologies*, the Knowledge Security Screening Act (Wet Screening Kennisveiligheid) and the Investments, Mergers and Acquisitions Security Screening Act (Wet VIFO). It is crucial that policy is developed on time, before these new technologies are further developed by the industry.

3 Process technology, including process intensification



3.1 Definition

3.1.1 Importance of the key enabling technology

Process technology, including process intensification makes it possible to transition from fossil feedstocks to sustainable feedstocks, such as plastic waste streams, including mixed streams, first-generation and second-generation sustainable biofuels and CO_2 in the chemical industry. With *process technology*, these sustainable feedstocks can be transformed into fuels, intermediaries and food. These raw materials can subsequently be used in a wide variety of sectors, including the manufacturing industry, plastics industry and pharmaceuticals. This key enabling technology is therefore crucial for the raw materials and climate transition. Its impact on national security is limited, as there are no direct defence applications.

At present, the Netherlands has a strong industry with connections to *process technology*. However, our current scientific position is less impressive than is the case for some other key enabling technologies[73]. It is important to continue developing these technologies in the interests of many companies that export their products to the rest of the EU. For example, Dutch cracking plants meet at least 25% of the European demand for plastics. Although the global market for sustainable feedstocks is still relatively small, explosive growth is expected: while the global market for bioplastics is a few billion dollars at present, it is expected to grow with a CAGR of 20%.[74,75]

This means this technology is of considerable importance for the future earning potential of the Netherlands. There are opportunities for the Netherlands to adopt a leading position in several platform technologies, provided that we are able to launch several trailblazing projects at precommercial scale to demonstrate the commercial viability of processes.

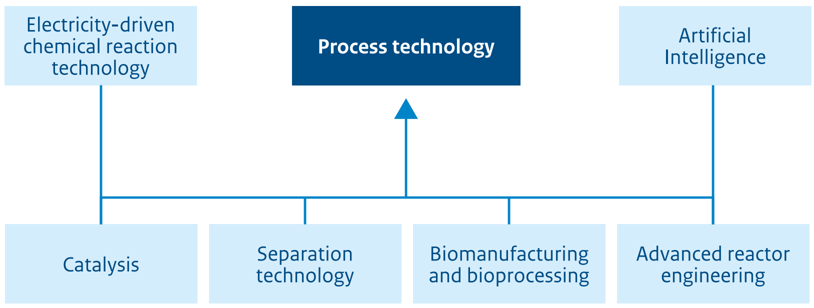
3.1.2 Definition

Process technology, including process intensification focuses on the optimal, stable and safe design of chemical production processes, including green processes. It encompasses aspects such as scalability, heat integration, safety, optimal downstream processing, use of space and cost efficiency. Separation technology and conversion technology are essential parts of chemical production processes. An important trend is the increasing use of sustainable raw materials in production processes, while limiting byproducts and residual waste streams and reusing or recycling them as much as possible. This agenda assumes the use of carbon-based raw materials. Metals and minerals will not be considered, at least for the time being.

3.1.3 Related key enabling technologies

There are various closely related key enabling technologies that are essential building blocks for the central process in *process technology, including process intensification*. The synergy between these related key enabling technologies is crucial to efficiently convert

Related key technologies



Source: TNO/NWO (2023) Recalibration of key technologies

sustainable raw materials into valuable products in the *process technology* domain.

Complementary key enabling technologies
Catalysis plays a crucial role in facilitating chemical reactions and the conversion of raw materials into useful molecules. Optimising catalytic processes is an important part of efficient *process technologies*.

Separation technology is essential to separate desired products from undesired byproducts and impurities, but also in the use of heterogenous raw materials, such as plastic waste (including mixed plastics).

Biomanufacturing and bioprocessing involve the production and processing of biological raw materials into biomolecules. This includes fermentation processes, strain development, biotechnology, biorefining, synthetic biology and bioreactor development.

Advanced reactor engineering makes it possible to develop new reactor technology that delivers a specific improvement in energy and raw material efficiency when converting sustainable raw materials into valuable end products.

Electricity-driven chemical reaction technologies include technologies such as electrochemistry, biochemical and bioelectrochemical processes, electrochemical fermentation and plasma technologies. These technologies have the capacity to turn sustainable raw materials or CO_2 directly into useful molecules, which means they complement *process technologies*.

Artificial Intelligence can be used in many process steps, including the design of new processes with microbiological strains, in operational processes and in the analysis of incoming waste streams of indeterminate composition.

3.2 Ambition

3.2.1 Main ambition

By 2035, the Netherlands will have lowered its emissions by realising a select group of commercial platform technologies for bio-based raw materials, waste conversion and CO_2. By exporting and implementing technology, including essential hardware, we will also contribute to reducing emissions internationally. To achieve this, we will realise pre-commercial flagship plants (e.g. pyrolysis oil refining, biorefining, syngas and methanol and ethanol fermentation), import green intermediates and transportable bio-based raw materials and transform the existing Dutch chemical industry to make it future proof and sustainable.

3.2.2 Sub-ambitions

The main ambition is divided into several sub-ambitions. In 2021, the government identified ten challenges to be addressed to strengthen our research and innovation ecosystems. The sub-ambitions are described in relation to these lines.

Financing for startups and scaleups (early phase financing and growth)
The first link in the chain is the conversion of sustainable raw materials into basic chemical products. This has the potential to make a major impact, but requires large, scalable factories to become profitable. In addition, the viability of the business case is strongly dependent on existing and future legislation and regulations, as CO_2 emissions are not yet fully priced in, which means fossil alternatives continue to be cheaper. This dependency and the necessary scale make it difficult to attract financing for startups and scaleups. In addition, validating technologies requires investments in unprofitable small-scale test plants. Considerable costs can result if a technology fails. This risk creates an additional barrier to financing new companies.

Sub-ambition: The Netherlands will study the possibilities for initiating more risk financing. This may involve a risk fund that brings together public and private financing. This will help to cover some of the costs with public money in situations where new technologies do not yet function optimally in small-scale test plants. Invest NL may be able to play an important role here.

Links between ecosystems
When transitioning to a new raw material, companies need to forge new partnerships. Given the scale required for profitable chemical plants and the decentralised nature of sustainable raw materials, this can be challenging.

Sub-ambition: The Netherlands will work to establish specific partnerships in *process technology* ecosystems. We will also study the extent to which various partnership frameworks set up by the government for the energy transition can also be used for the materials transition. We will explicitly consider partnerships at cluster level, given the major importance of infrastructure for the operation of commercial chemical plants.

Devoting attention to legislation and regulations earlier in the process
Regulations can be a barrier to the development of *process technology*. Firstly, the use of fossil carbon as a raw material is not sufficiently priced in. The use of renewable sources to generate energy is also encouraged by the Renewable Energy Directive, while this is in fact less sustainable. This increases the costs of sustainable raw materials, without an increase in the willingness to pay for sustainable products. The waste status, and uncertainty about the status, of bio-based raw materials, pyrolysis oil and mixed waste streams is also a barrier to the transport and use of waste and certain biofuels as raw materials. The certification process for new technologies is also expensive and time consuming, which delays implementation. The answer is long-term, consistent policy.

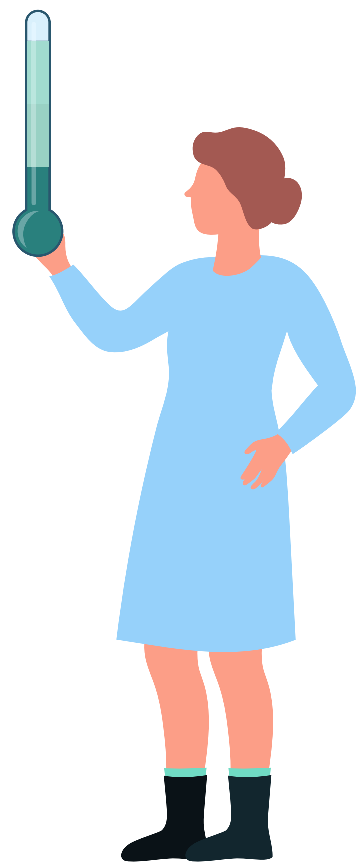
Sub-ambition: We will work to obtain a final waste status for plastic waste streams, including mixed streams. We will also promote a level playing field through either standardisation (e.g. with a blending mandate) or pricing (e.g. through the ETS)[76]. Ultimately, given the number of multinationals in the chemical industry, it is important to create a level global playing field for fossil and renewable sources. A comparable mechanism to the Carbon Border Adjustment Mechanism (CBAM) for the chemical sector would help in this regard.

Investments in research and test facilities
There are currently few pilot and demo facilities for *process technologies*. They are also unprofitable by definition, given the large scale of commercial parties.

Sub-ambition: In 2035, a combination of public and private dilutive and non-dilutive funding will be available to allow startups without major capital resources to establish facilities. In 2035, pilot facilities for platform molecules will also be available, both in a multipurpose form and as specific flagship pilots for specific process innovations.

Involving users in research, innovation and market creation
Realising sufficient scale (in the demo phase) is only possible with support from major chemical companies. The existing instruments already facilitate this. However, there is a difference between 'drop in' solutions and completely new platform chemicals: end users are less willing to be involved with the latter, while it is in fact just as important that they are included at an early stage.

Sub-ambition: Research will be carried out into the use of product development knowledge by technical innovators and whether this could help to ease the step between business and knowledge.



4 Biomolecular and cell technologies

4.1 Definition

4.1.1 Importance of the key enabling technology

Biomolecular and cell technologies are part of the broader biotechnology field. This key enabling technology focuses on molecules and cells. The Netherlands has a strong knowledge base in *biomolecular and cell technologies* and a strong position in the international field. This position can be retained and expanded.

Biomolecular and cell technologies play an important role in realising future earning potential for the Netherlands and can also play a major role in tackling the challenges faced by our society. These technologies can be used in a wide variety of applications[77], including life science and health, plant breeding and seed technology, the food industry and the chemical and biochemical industries. The Netherlands already has a strong knowledge position in many of these areas of applicability, with potential for expansion.

While the Netherlands scores highly for scientific and technological development, there are also barriers and obstacles to the further development of economic activity in this domain. Valorisation lags behind the development of academic knowledge. Although financing is available, from both public sources (including the National Growth Fund and programmes from ZonMw) and from venture capitalists, these instruments do not align well. There is a lack of long-term (5-10 years) financing. There are also opportunities to improve the integration of the regulatory and legislative framework in the Netherlands and the EU with areas of application and development phases. See, for example, the difference in the rules for gene editing for fundamental and applied research.[78]

4.1.2 Definition

Biomolecular and cell technologies involve analysing, measuring and using molecules such as DNA, RNA and proteins/metabolites. This includes sub-technologies such as *omics, gene editing, stem cell technology* and *synthetic cell technology*.[79]

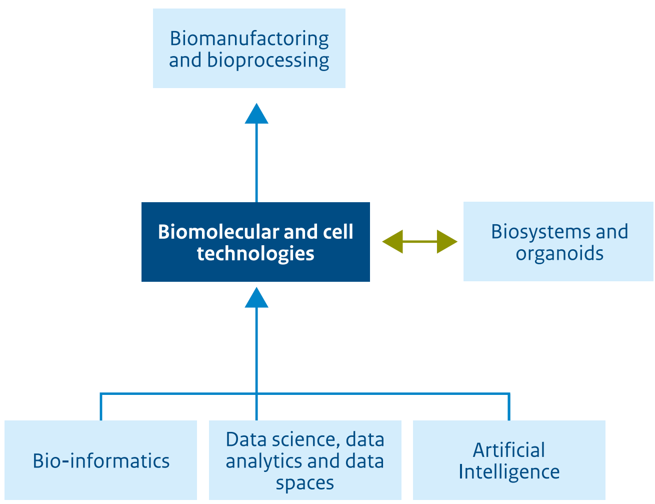
4.1.3 Related key enabling technologies

The most important related key enabling technologies are:

- Related: biosystems and organoids
- Competitors: none
- Complementary: bioinformatics, data science, data analytics and data spaces, Artificial Intelligence (AI), biomanufacturing and bioprocessing

Biosystems and organoids are related to *biomolecular and cell technologies* (and can even be seen as a sub-technology). *Bioinformatics, data science* and *AI* all support this key enabling technology by allowing relationships and patterns to be identified in the large datasets used in *biomolecular and cell technologies*. This in turn facilitates the identification and development of applications for biomolecules. *Biomanufacturing and bioprocessing* use technology from *biomolecular and cell technologies* for other applications.

Related key technologies



Source: TNO/NWO (2023) Recalibration of key technologies

4.2 Ambition

The Netherlands is in a good position to host a *biomolecular and cell technologies* ecosystem that can be amongst the best in the world (together with European partner regions).

4.2.1 Main ambition

In 2035, the Netherlands will be a global leader in research and applications for *biomolecular and cell technologies* for a healthy and sustainable society. We will have expanded our existing strong position in research to create a complete ecosystem, in which valorisation and market applications are fully embedded. The Netherlands will lead the way in this key enabling technology in two areas:

- Precision health, early detection, personalised prevention and treating illnesses
- Sustainable production in agriculture and horticulture, food production and non-food bioproduction

4.2.2 Sub-ambitions

The main ambition is divided into several sub-ambitions. In 2021, the government identified ten challenges to be addressed to strengthen our research and innovation ecosystems. The sub-ambitions are described in relation to these lines where relevant.

Long-term vision and relationship to investments in research and innovation

There is no comprehensive, long-term vision with a clear framework for the Netherlands' future ambitions and for how these relate to various challenges[80]. The absence of this vision has limited collaboration between regions and universities, has led to policy objectives that fail to align and fragmented knowledge.

Sub-ambition: A national vision for biotechnology will be published in 2024. This will include *biomolecular and cell technologies*. This vision will help to define the contribution that biotechnology can make to resolving the major challenges faced by our society and to developing our long-term earning potential. As part of the process of developing the vision, a public dialogue will be initiated to gather various opinions about *biomolecular and cell technologies*.[81]

Investments in research and test facilities
It is essential that a state-of-the-art public-private research infrastructure is available for both fundamental and applied research. Startups and SMEs often have limited access to existing facilities for translational research due to the high costs.

Sub-ambition: We will study the opportunities to open research and test facilities, for example for the three areas of application: health, agrifood and the biochemical industry. Multiple research disciplines and stakeholders will work together in these accessible, shared research and test facilities.[82]

Financing for startups and scaleups: early phase financing and growth
Financing applied translational research and upscaling is difficult. The equipment and locations required for this key enabling technology are complex to use and expensive, particularly for startups and SMEs. The development time for biotechnology applications is also long (generally more than a decade). This demands patience from investors, continuity in financing, more effective instruments and optimisation of the entire financing chain[83]. There is a need for structural support for startups, scaleups and SMEs to realise the opportunities.

Sub-ambition: We will ensure that the available financing for startups and scaleups from the government and private parties matches their needs in terms of form, scale and conditions.

Developing, attracting and retaining (top) talent
There are several major challenges that affect the development, recruitment and retention of talent. Firstly, there is a shortage of technical professionals at vocational level to implement technical processes. Attracting and retaining international top talent is another major challenge.

Another problem is that education in the Netherlands pays little attention to valorisation and entrepreneurship. The result is that while the Netherlands is strong in research, this does not always lead to commercial applications.

Sub-ambition: Working in the Dutch *biomolecular and cell technologies* ecosystem will be attractive, thanks to the wide range of opportunities for personal development. The specific requirements of the market will be studied and analysed in a human capital agenda.

Strengthening knowledge transfer and the valorisation process for greater impact
The Netherlands must devote greater attention to transforming research into practical applications. One reason for this is that technology transfer in the Netherlands is fragmented and is not clearly organised. A nationally organised TTO organisation for all affiliated universities and other knowledge partners can establish streamlined, uniform working methods.[84]

Sub-ambition: We will study the possibilities for setting up a nationally organised TTO programme, possibly by continuing and expanding the Biotech Booster. This programme helps researchers at all affiliated Dutch knowledge institutions with the business and organisational aspects of setting up a company.[85]

Organisational capacity of research and innovation ecosystems
Activities are often carried out in isolation at present: there is a lack of communication between different areas of application and between various ecosystems within this key enabling technology. By establishing a well-organised ecosystem organisation, the various 'islands' can learn from one another, for example about how to handle valorisation, IP, financing and regulations.[86]

Sub-ambition: The ecosystem that includes *biomolecular and cell technologies* requires a better organisation. This organisation will be a partnership between universities, vocational education institutions, training centres, applied research organisations, industry, civic organisations and other relevant parts of the research and innovation ecosystem.[87]

Devoting attention to legislation and regulations earlier in the process
The legislation and regulations covering *biomolecular and cell technologies* in the Netherlands and Europe are strict compared to other regions.[88] This has resulted in a growing gap between knowledge and technology development and applications, as well as an economic disadvantage for European and Dutch companies. This affects the three areas of application described in this agenda.[89]

Sub-ambition: The legislation and regulations governing *biomolecular and cell technologies* are often agreed at European level. The Netherlands cannot unilaterally change these rules. We will study the possibilities that do exist. This means that, as part of the government-wide vision (sub-ambition 1), it is important that the Netherlands presents a consistent and logical position at European level.

5 Imaging technologies

5.1 Definition

5.1.1 Importance of the key enabling technology

Imaging technologies are technologies that make it possible to analyse, generate and duplicate images. Imaging technologies have broad applications in the medical sector, the semiconductor industry, the security domain, agriculture, industry, traffic and spaceflight.

There is already a major market for some applications of *imaging technologies*, while the market for others is expected to grow in the coming years. The global market for medical imaging is $36.5 billion, with a CAGR of 4.2%[90]. *Imaging technologies* are used in the medical sector to build better imaging equipment and scanners. Innovation can contribute to early detection, diagnostics, fundamental research, medical treatments and prevention.[91] The market for semiconductor metrology and inspection, for example, is much smaller – an estimated $5 billion – although it is also growing with a stable CAGR of around 5%. It also aligns well with the strengths and competences of Dutch industry.[92,93]

Applications involving the targeted mapping of soil and dyke quality and locations where harmful substances are emitted may also have a smaller or limited direct economic impact. However, they are essential for the success of numerous economic activities and make a positive impact on society. Given the broad scope of the technology, that impact is in any case considerable. This technology is also important from the perspective of national security in the light of its increasing importance for the security sector.

The Netherlands is in a good starting position in *imaging technologies*: in addition to existing economic activity, our research makes an above-average impact. While the degree of specialism is below the global average, it is relatively high compared to several other key enabling technologies. There are opportunities not just to improve *imaging technologies* themselves, but also the analysis, storage, exchange and security of data, for example by using AI. The economic capacity of the Netherlands can be further increased by making targeted investments in the extensive knowledge that is already present in the Netherlands and by valorising innovations.

5.1.2 Definition

Imaging technologies (part of Engineering and Fabrication Technologies) encompass generating, collecting, duplicating, analysing, processing and visualising images (optical and non-optical). This includes the overall imaging chain, which requires both hardware and software.

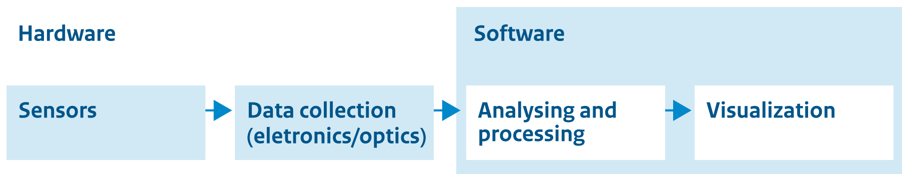


Figure 6. The overall imaging technology chain.

5.1.3 Related key enabling technologies

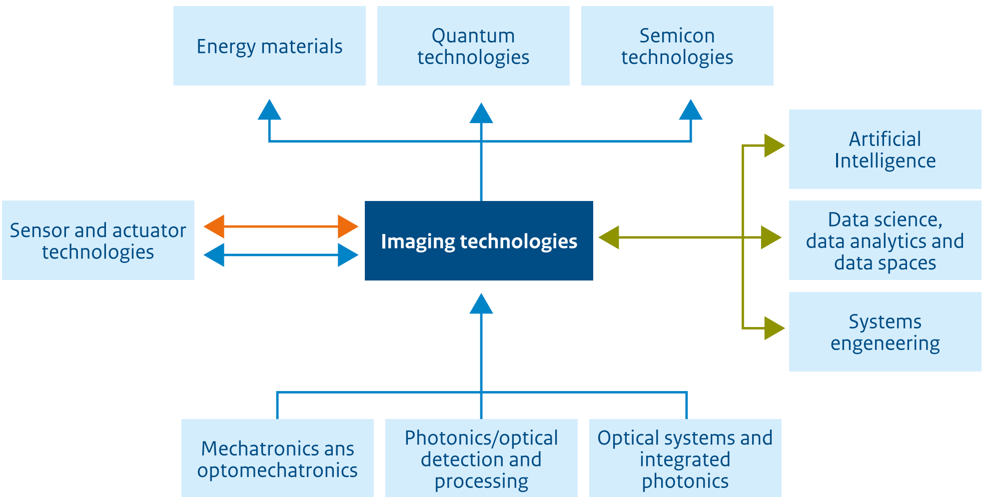
Imaging technologies are closely related to several other key enabling technologies. Processing, analysing and visualising data also require expertise in data sciences, data analytics and data spaces (including the Digital Twin concept). *Artificial Intelligence (AI)* will play an increasingly important role in expanding the potential applications of *imaging technologies*. The increasingly multidisciplinary nature of *imaging technologies* and the resulting complexity make *systems engineering* increasingly important. The green lines in the figure below show this relationship.

As regards *sensor and actuator technologies*, better/more accurate sensors make it unnecessary to use *imaging technologies* in some cases (orange line). However, improved sensors can also be a reason for additional research using *imaging technologies* (blue line leading to the key enabling technology). *Mechatronics and optomechatronics*, *photonic/optical detection and processing* and *optical systems and integrated photonics* are also complementary technologies (blue lines leading to the key enabling technology), as progress in these technology areas contributes to the further development/application of *imaging technologies*. Breakthroughs in *imaging technologies* will also make an important contribution to key enabling technologies such as *energy materials*, *quantum technologies* and *semiconductor technologies* (blue lines from *imaging technologies*).

5.2 Ambition

The Netherlands is in a good position to become a leading global player in *imaging technologies*. The main ambition and sub-ambitions are explained below.

Related key technologies



Source: TNO/NWO (2023) Recalibration of key technologies

5.2.1 Main ambition

In 2035, the Netherlands will be a global leader, in both knowledge and economic activity, in applied scientific research and the chain integration of *imaging technologies*, including new technologies, which will be enhanced using AI. We will achieve this with an open and innovative ecosystem that facilitates new applications and contributes to our earning potential and to resolving the problems faced by our society (including healthcare needs and labour shortages). We will influence the entire chain and we will create it ourselves where necessary.

5.2.2 Sub-ambitions

The main ambition is divided into several sub-ambitions. In 2021, the government identified ten challenges to be addressed to strengthen our research and innovation ecosystems. The sub-ambitions are described in relation to these lines where relevant.

Long-term vision and relationship to investments in research and innovation

Developing *imaging technologies* and tackling the problems faced by our society will require innovation and unconventional technologies. Predicting future technological breakthroughs is challenging. It is essential to develop a flexible strategy to respond to changing circumstances and new opportunities.

Sub-ambition: We will incorporate flexibility into financing strategies and be open minded about supporting new and sometimes unconventional methods of developing innovations.

Investments in research and test facilities

There is a need for more widely accessible research and test facilities, particularly for SMEs, to facilitate cutting edge research and promote innovation.

Sub-ambition: By investing in research and test facilities, the Netherlands will provide high-quality, advanced laboratories, test environments and equipment that can be used by scientists, researchers, startups and companies, including SMEs. This will promote collaboration and knowledge sharing between various players in the *imaging technologies* ecosystem.

Financing for startups and scaleups: early phase financing and growth

The fact that the major opportunities for knowledge valorisation and growth of startups in the *imaging technologies* sector have not yet been utilised is partly due to a lack of financial resources.

Sub-ambition: In 2035, there will be additional, specialised financing opportunities for both startups and scaleups in the *imaging technologies* domain, with a specific focus on upcoming areas of application. There will also be facilities for supporting startups and scaleups, including incentives for knowledge startups and forging strategic partnerships with major companies.

Involving users in research, innovation and market creation

It is important to take the entire value chain of each innovation into account. This includes end users such as medical professionals in the case of medical imaging applications, as well as production staff. Studying the needs and wishes of end users (often 'the customer's customer') can help to ensure that the development of new technologies takes full account of market demands and the challenges that our society must overcome.

Sub-ambition: We will focus on user-oriented research and actively involving end users in developing innovations and validating new technologies.

Skills and absorption capacity of SMEs

Involving SMEs often requires specific, high-value knowledge and skills, for example about *AI* implementation. SMEs in particular have limited time available for education and training programmes.

Sub-ambition: We will actively encourage SMEs in the *imaging technologies* value chain to innovate with targeted subsidies to promote coordination and cooperation in the value chain. Knowledge sharing and network forming will be promoted by involving new companies. The broader SME sector will be inspired with *AI* applications that are implemented in a way that aligns with existing working processes.

Developing, attracting and retaining (top) talent

There is a shortage of sufficiently qualified imaging talent. Technology is undervalued in the Netherlands and the entire technological base needs to be strengthened. By devoting specific attention to *imaging technologies* and *AI* in vocational study programmes, we can ensure that SMEs have access to this knowledge in the long term.

Sub-ambition: To ensure that we have sufficient talented people with an interest in *imaging technologies* in the future, we must make our education programmes (at university and vocational level) more attractive and show that there are good career opportunities in the Netherlands. To achieve this, we must offer a broad technological base that can be easily combined with specific *imaging technologies* applications. As foreign talent is essential, we must create a favourable environment for talent.

Strengthening knowledge transfer and the valorisation process for greater impact

Dutch companies have an innovative collaborative culture, with many successful spinoffs. However, our technical universities, research centres, industry and government do not always work together optimally. There are opportunities to strengthen the knowledge base and optimise the chain from development to application of the technology.

Sub-ambition: It is crucial that we strengthen collaboration between research institutions, universities, universities of applied sciences and industry. This can be achieved by creating programmes that promote knowledge and expertise sharing between researchers, education and sectors.

Organisational capacity of research and innovation ecosystems

Imaging technologies have many areas of application, each with its own ecosystem in many cases. There is currently no leading organisation to monitor and manage the overall imaging ecosystems and adopt a facilitative role. There are opportunities for improvements in the chain integration, thematic networks and interregional collaboration.

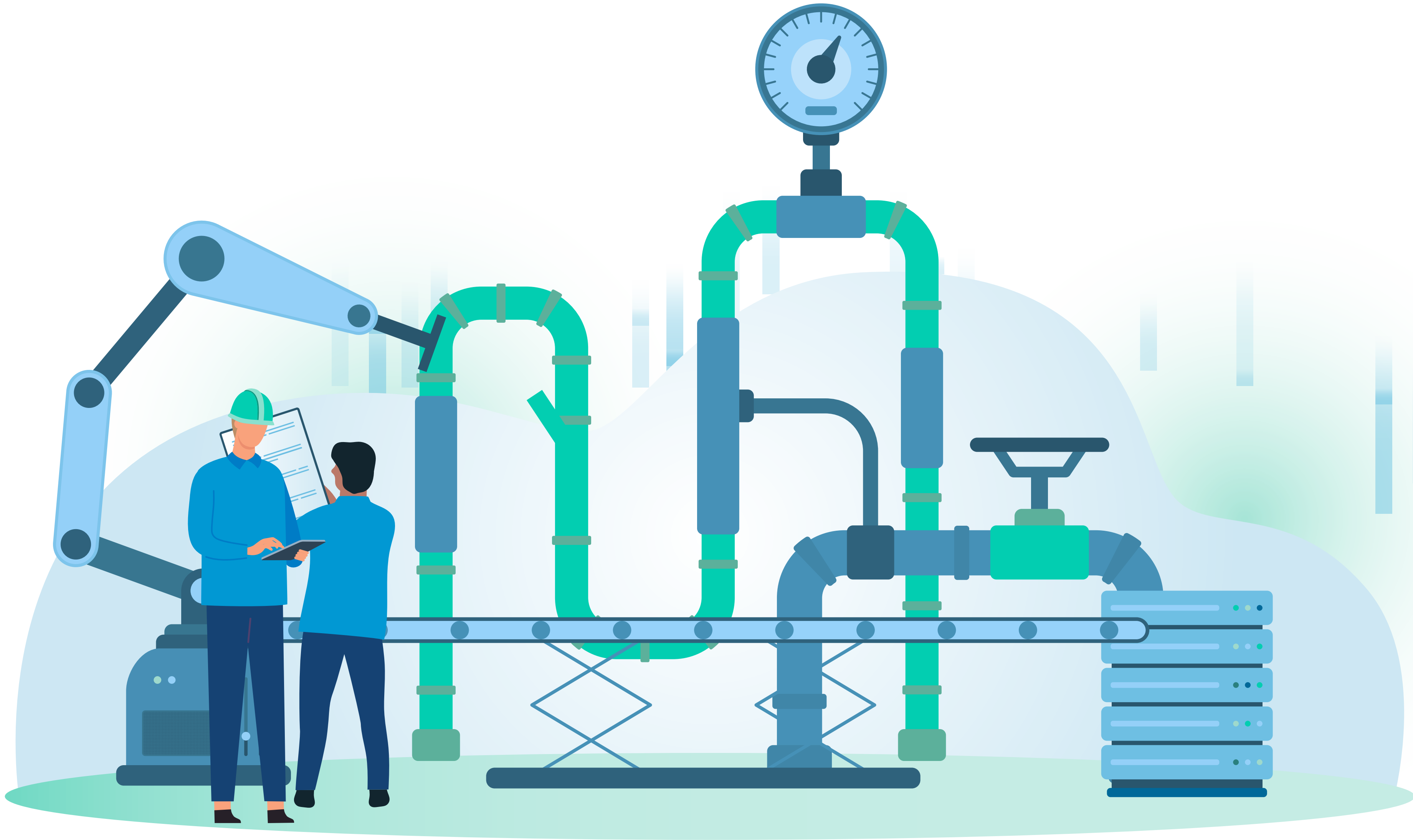
Sub-ambition: We will promote networks and partnerships between the government, industry, research institutions, universities and nonprofit organisations. These networks help to create synergies and mobilise resources to promote innovation. The goal is to create a self-sufficient and viable ecosystem for the future.

Devoting attention to legislation and regulations earlier in the process

The Dutch and European regulations for *imaging technologies* are stricter than in other regions. New regulations have also recently been added, including the GDPR, EHDS, EU Data Act, EU *AI* Act, MDR and RoHS/REACH. This ever-increasing regulation can be restrictive for companies and researchers. The regulations in the United States and Asia are less restrictive, which gives companies greater operational freedom.

Sub-ambition: We will involve stakeholders at an early stage in the development of legislation and regulations, so that their interests are taken into account more effectively. We will promote regulations that support and encourage innovation in the Netherlands and Europe.

6 Mechatronics and optomechatronics



6.1 Definition

6.1.1 Importance of the key enabling technology

Knowledge of complex electromechanical systems and control and automation technology, often in combination with optical technology, is a vital part of essential applications in various sectors. These include semiconductor machinery building, medical equipment, components for the automotive and aviation industries, spaceflight applications such as laser satellite communications, equipment for manufacturing semiconductors, food processing, agriculture and logistical processes. Manufacturing these complex machines and systems also plays an important role in the increasing automation of processes to increase labour productivity and tackle structural labour shortages. This requires a high level of *systems engineering*, which in turn relates to other technologies. This makes this technology very important for our future earning potential. The Netherlands has a very good market position: we build high complexity, low volume machinery for the entire world. The Netherlands is also a global leader in research in this field. This is demonstrated by the fact that Dutch *mechatronics and optomechatronics* consortia are overrepresented in Horizon applications.

Mechatronics and optomechatronics play an important role in solving the challenges faced by our society. This key enabling technology is used to design and build systems and machines, which in turn produce products that contribute to solving these problems. It is also important for our national security, as technological leadership can help us to acquire unique positions in essential supply chains, including semiconductors. This is essential to protect the geopolitical position of the Netherlands and Europe.

6.1.2 Definition

Mechatronics consists of the integrated development of mechanical systems and associated control and automation systems. It combines mechanical engineering, physics, electrical engineering and ICT. Optomechatronics involves the integration of optical technology into mechatronic systems. *Optomechatronic* systems play an important role in the production of semiconductors, scientific instruments, 3D printing, medical equipment, spaceflight (including laser satellite communications) and robotics. *Mechatronics and optomechatronics* are part of the Engineering and Fabrication Technologies cluster, as described in the Herijking sleuteltechnologieën (Re-evaluation of key enabling technologies) report.[94]

6.1.3 Related key enabling technologies

Optical systems and integrated photonics complement (green arrow) *mechatronics and optomechatronics*. *Optomechatronics* integrates optical systems, and the latest generation of optomechatronic systems increasingly use *integrated photonics*.

Imaging technologies and sensor and actuator technologies are also complementary key enabling technologies. They are important for the operation of mechatronic systems and for innovation in *mechatronics and optomechatronics*. Combining these technologies makes automation possible in numerous sectors. This closely relates to digital manufacturing technologies (and also *AI and data spaces*). *Mechatronics and optomechatronics* also provide the innovation required for *robotics*.

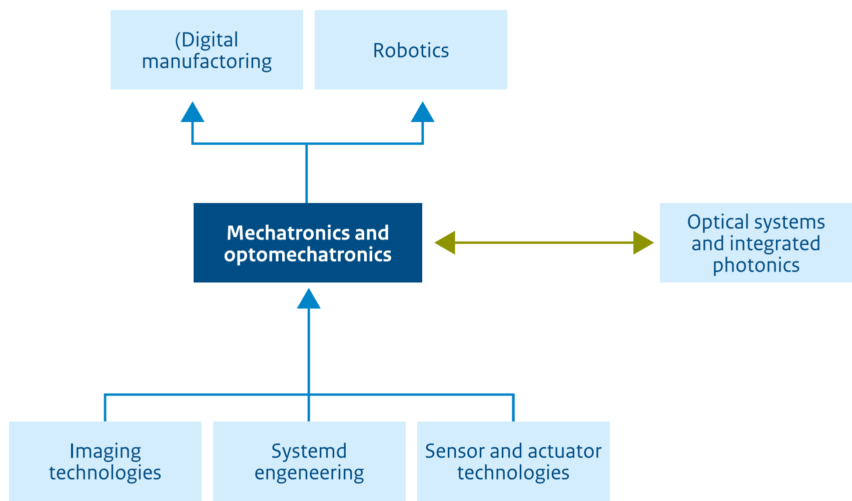
Systems engineering is a complementary methodology that facilitates the realisation of these mechatronic systems and assemblies. This makes *systems engineering* an integrated part of *mechatronics*. Designing and assembling mechatronic systems is a specialism.

6.2 Ambition

6.2.1 Main ambition

In 2035, the Netherlands will have strengthened its leading international scientific and industrial position in mechatronics and optomechatronics, including in the design, integration and production of complex systems. This key enabling technology will contribute to the earning potential of solutions to the challenges faced by society and to open strategic autonomy. We will maintain a strong competitive edge in the international value chains where we already have a strong position. We will also expand into new applications in a select range of new value chains, including agrifood, medical and spaceflight.

Related key technologies



Source: TNO/NWO (2023) *Recalibration of key technologies*

6.2.2 Sub-ambitions

The main ambition is divided into several sub-ambitions. In 2021, the government identified ten challenges to be addressed to strengthen our research and innovation ecosystems. The sub-ambitions are described in relation to these lines where relevant.

Long-term vision and relationship to investments in research and innovation

Relatively few technology roadmaps are available for *mechatronics and optomechatronics* in the Netherlands and Europe. However, various roadmaps are available that relate to the existing and potential areas of application of mechatronics and optomechatronics. It is important to identify the relationships between technologies and areas of application to promote spillovers.

Sub-ambition: In the short term, a matrix will be developed for *mechatronics and optomechatronics* showing the relevant technologies, sub-technologies and areas of application, with references to existing organisations and facilities. A central point of contact will be set up/appointed to develop and manage this matrix. This can help to bring together companies across the boundaries between areas of application.

Investments in research and test facilities

These facilities are not always easy to find at present. There is also no central lab with a cooperation agreement signed by the various parties. By creating this, the Netherlands can acquire a leading position by strengthening collaboration between universities/TNO (Netherlands Organisation for Applied Scientific Research)/WR (Wageningen Research).

Sub-ambition: In 2035, a platform will have been created to show all relevant facilities in the Netherlands. This platform can contribute to coordination and provide leverage.
A coordinating body will also be created to maintain oversight and monitor investments. The possibility of establishing a shared lab with a cooperation agreement will also be studied, following the example of Imec. The focus of this lab will be different to that of Imec.

Financing for startups and scaleups: early phase financing and growth

There are limited financing options for the startup phase in the Netherlands. Perseverance from the government as an investor is very important. Private capital in Europe is relatively risk averse.

Sub-ambition: In 2035, the government of the Netherlands will play a role as a launching customer, particularly in mechatronics and optomechatronics, in which development processes often have long lead times. These will often be applications of mechatronics and optomechatronics. Launching customership for machinery that is primarily used in B2B environments will be arranged in another way. Specific attention will also be paid to validation research (test before invest) in second-phase and third-phase financing.

Involving users in research, innovation and market creation

An existing network and various working groups are available as a base. To ensure that they function effectively, the 'not invented here' principle and the timidity of industrial parties must be tackled.

Sub-ambition: In the short term, a public-private platform will be set up to strengthen and expand this network. This platform can be developed as an extension of the NTS programme, which also involves the various departments. The fixation on semiconductors must be addressed by focusing more on other domains, such as MedTech. Diversification should also be promoted. There are also growth opportunities for the Netherlands in this area.

Developing, attracting and retaining (top) talent

There are challenges at all levels, from vocational to higher education. Certain basic competences are missing, including design engineering, materials science and manufacturing engineering. This may be because funding from universities takes insufficient account of these competences, or because there is an excessive focus on disruptive or new innovations and directions.

Sub-ambition: An MBA for engineering will be set up in the Netherlands. This MBA will be based on academic knowledge with the help of existing hands-on experience. The MBA will also be available to graduates of vocational programmes, which will promote synergies between educational levels. There are also opportunities to improve the onboarding of foreign mechatronic and optomechatronic engineers. There is a particular lack of hands-on experience in this area. Encouraging sufficient numbers of women to choose engineering continues to be challenging.

Strengthening knowledge transfer and the valorisation process for greater impact

Most research focuses on the semiconductor industry. The internal knowledge transfer from universities and knowledge institutions to the industry is good. However, little knowledge is fed back from the industry to knowledge institutions. Much research is carried out by the industry, which results in targeted research. However, the knowledge generated is not always used in other areas of application.

Sub-ambition: In 2035, there will be more opportunities for mobility between areas of application, industry and public research in the form of sabbaticals. IP will also be made available for other areas of application through IP safe houses.

Organisational capacity of research and innovation ecosystems

There are several coordinating organisations/platforms for mechatronics and optomechatronics, namely the Werkgroep Mechatronica (Mechatronics Working Group) and the Dutch Society for Precision Engineering. While organisations in the field communicate effectively with one another, the financing and clout required to develop specific agendas are lacking. As regards areas of application, MedTech and agrifood are highly fragmented. There is no central register of where particular knowledge is or what particular field labs do. This results in duplication of effort and a lack of focus.

Sub-ambition: In the short term, an agenda will be developed, the existing situation will be analysed and collaborations will be initiated at the crossover between specific areas of application of mechatronics and optomechatronics.

Links between ecosystems

There is limited collaboration between the Netherlands and other countries. The lack of a strong national organisation inhibits participation in major European partnerships across different areas of application. The collaboration at regional level is more effective than at national level, although there is room for improvement in the collaboration between the Delft and Eindhoven regions. There is also limited collaboration between areas of application. Due to the mature nature of the technology, knowledge spillovers between different areas are sometimes difficult.

Sub-ambition: European collaboration is the top priority.
For agrifood and MedTech, the first step is to identify potentially valuable partners for this technology. Germany is an important partner for mechatronics and optomechatronics. We also aim to increase the level of knowledge within the national government, or to establish a knowledge forum made up of experts to advise the government. A joint agenda will also be developed for the areas of application to improve management and coordination.

7 Artificial Intelligence and data

7.1 Definition

7.1.1 Importance of the key enabling technology

The WRR (Netherlands Scientific Council for Government Policy) has designated *Artificial Intelligence (AI)* as a systemic technology.[95] It will change how we work, learn and create, it will make other innovations possible that are easily scalable and it can help to increase labour productivity.[96] This means it will have a major impact on our society and earning potential. The past decade has seen very rapid changes. The recent emergence of generative *AI* is a good example.[97] The power of *AI* lies in its capacity to process huge volumes of data, learn models and use them to make decisions and predictions and carry out generative tasks.

Data is important due to its potential uses, for example in *AI* applications, as well as in other areas. For the Netherlands, data processing technologies and their adoption are particularly important to resolve the challenges faced by our society.
Dutch industry and consumers also benefit from the economic and social opportunities unlocked by sharing data. The capacity for data sharing between businesses is also important. This is crucial to make the most of the opportunities of data in the Netherlands.

The Netherlands has a leading scientific position on parts of the *AI and data* knowledge spectrum. We play a more modest role in the development of large *AI* models and data processing technology, as do other European countries. This is due to the lack of a shared data infrastructure and the required *AI* computing power to train powerful models. The major tech companies benefit from their dominant position in both areas.

A paradigm change is therefore necessary. We need to focus on the decentralised sharing of data and *AI* models, rather than being dependent on major international players that use a central model. This can help Europe to stand out, with the Netherlands as a potential leader. By agreeing the FAIR principles[98], the scientific world has already taken major steps. It is now up to industry and government to do the same. The decentralised paradigm begins with data sovereignty: companies, institutions, the government and individuals have control over the data to which they hold rights. The most important opportunity involves networks, including business networks, to allow decentralised activities.

7.1.2 Definition

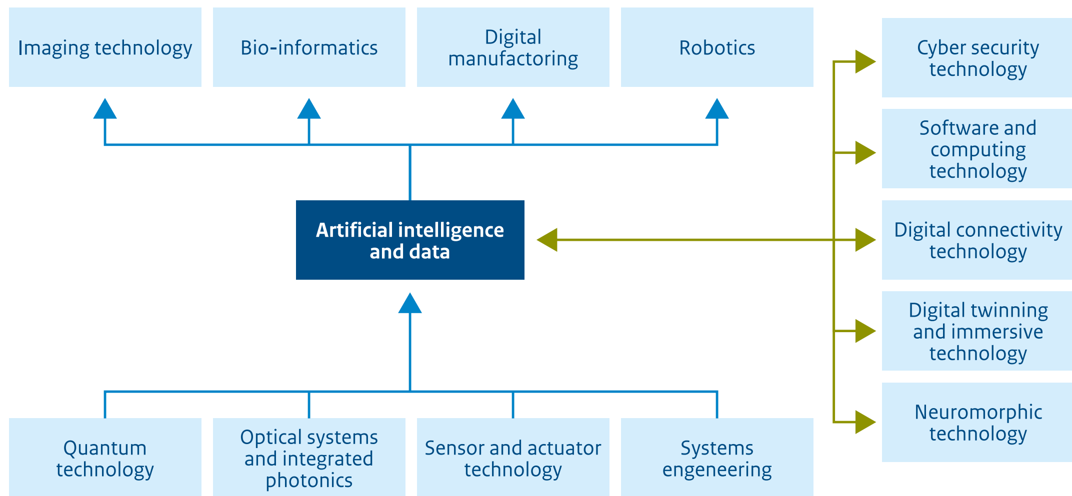
Artificial Intelligence (AI) is a systemic technology that involves using machines to realise behaviour that resembles natural intelligence. There are various *AI* learning strategies: supervised machine learning, unsupervised learning, reinforcement learning and deep learning. Hybrid *AI* forms are increasingly being developed, in which humans and *AI* work together, along with knowledge-driven models with data-driven machine learning. Generative *AI* has received a great deal of attention in recent years. This technology allows text, images, audio and other content to be generated automatically based on input from users.

Data science, data analytics and data spaces encompass all aspects of using data processing technology to collect, manage, connect, share, process and analyse data to create value. Data science uses scientific methods, processes and systems to derive knowledge and insights from data. Data analytics focuses on interpreting data to obtain valuable insights. A data space is a decentralised structure based on standards that allows the voluntary sharing and reuse of federated data. Many different forms of data are used to train today's *AI* models.

7.1.3 Related key enabling technologies

AI and data are very closely related to many key enabling technologies. Most importantly, they are related to other key enabling technologies that are part of the Digital and Information Technologies cluster: cyber security technologies, software technologies and computing, *digital connectivity technologies*, *digital twinning* and *immersive technologies* and *neuromorphic technologies*. These technologies are connected with green lines in the figure below. Complementary key enabling technologies (the blue lines) can support one another, and one key enabling technology can use the other. Because *AI* is a systemic technology that depends on data, *AI and data* complement many other key enabling technologies. Only a limited number of key enabling technologies are shown in the figure in the interests of readability.

Related key technologies



Source: TNO/NWO (2023) Recalibration of key technologies

7.2 Ambition

7.2.1 Main ambition

In 2035, the Netherlands will have the capacity to work with a combination of *AI and data* technology that contributes to open strategic autonomy, that leads to innovations for all sectors and that accelerates transitions in society.

7.2.2 Sub-ambitions

The main ambition is divided into several sub-ambitions. In 2021, the government identified ten challenges to be addressed to strengthen our research and innovation ecosystems. The sub-ambitions are described in relation to these lines where relevant.

Long-term vision and relationship to investments in research and innovation

To protect our competitive edge, the Netherlands must prepare for the further development and use of foundation models. This will require computing power on a scale that was previously unimaginable. It is also important to consider the future needs of society and industry and to choose a design that can adapt to changing technological landscapes.

Sub-ambition: We will develop projects to increase computing power. This will involve a major investment in technological progress through a multidisciplinary approach to computing, as well as strengthening existing initiatives.

Investments in research and test facilities

Investments in research and test facilities are the backbone of forward-looking innovations. They promote public-private partnerships by combining the expertise and resources of the government and industry.

Sub-ambition: We will set up test environments to test and validate new technologies and innovative solutions in a realistic way. SMEs will be involved and links will be established with existing EU projects. This will not only promote technological progress, but also the practical applicability of new ideas.

Financing for startups and scaleups: early phase financing and growth

In the Netherlands, investment decisions are not taken as rapidly as in the US, for example. This is due to factors including the availability of venture capital, the fact that investors have limited knowledge and a lack of willingness to take a forward-thinking approach to investments. The government can use financing instruments and InvestNL to reduce the risks associated with investing and can facilitate blended finance. Support for the demand side and the adoption of new technology can also help to improve investment policy.

Sub-ambition: We will improve access to financing and the preconditions for financing in the Netherlands by reducing the risks associated with investing in innovative companies and improving the knowledge of investors.

Involving users in research, innovation and market creation

Involving users in research, innovation and market creation is important for the successful development of AI. A strategic focus on SMEs is essential to ensure that, as well as benefitting from the generated data, they also actively participate in the process of data sharing, modelling and applications.

Sub-ambition: Users can be involved more by working together in research and innovation labs. By increasing the number of labs and their visibility, we can increase the synergy between academic knowledge, industrial needs and SMEs. This will promote the development of *AI and data* technology on a broad scale.

Skills and absorption capacity of SMEs

Due to a lack of knowledge, skills and contacts, it is difficult for SMEs to explore and harness the new opportunities of *AI and data*. The current labour shortage makes this even more difficult.

Sub-ambition: We will focus on strengthening the links between SMEs, knowledge institutions and major companies in the field of AI, for example with a temporary injection of employees with extensive knowledge of *AI and data*. This can help to strengthen regional partnerships, as is already the case in seven *AI* hubs.

Developing, attracting and retaining (top) talent

There is a shortage of *AI and data* talent at all levels.

Sub-ambition: We will make the Dutch labour market more attractive for domestic and international talent with *AI and data* skills by creating more opportunities for training and retraining, by offering good terms of employment and career perspectives and by building up strong clusters, in which industry and knowledge institutions work together to create a fertile environment for talent.

Strengthening knowledge transfer and the valorisation process for greater impact

The *AI and data* domain faces unique knowledge creation, knowledge sharing and valorisation challenges. Knowledge-driven data models are the intellectual property in this domain. When startups become independent of a university or parent organisation, they often lose access to these data models and data, which means they also lose some of their value. This demands valorisation strategies that are appropriate for *AI and data*.

Sub-ambition: In 2035, new companies will be helped to gain or retain access to knowledge-driven data models and data itself, and successful companies will be helped to upscale.

Organisational capacity of research and innovation ecosystems

There are many different ecosystems for *AI and data* in the Netherlands. Most of these ecosystems have links to ecosystems for technologies that *AI and data* can complement, as they are partly dependent on data from other sectors.

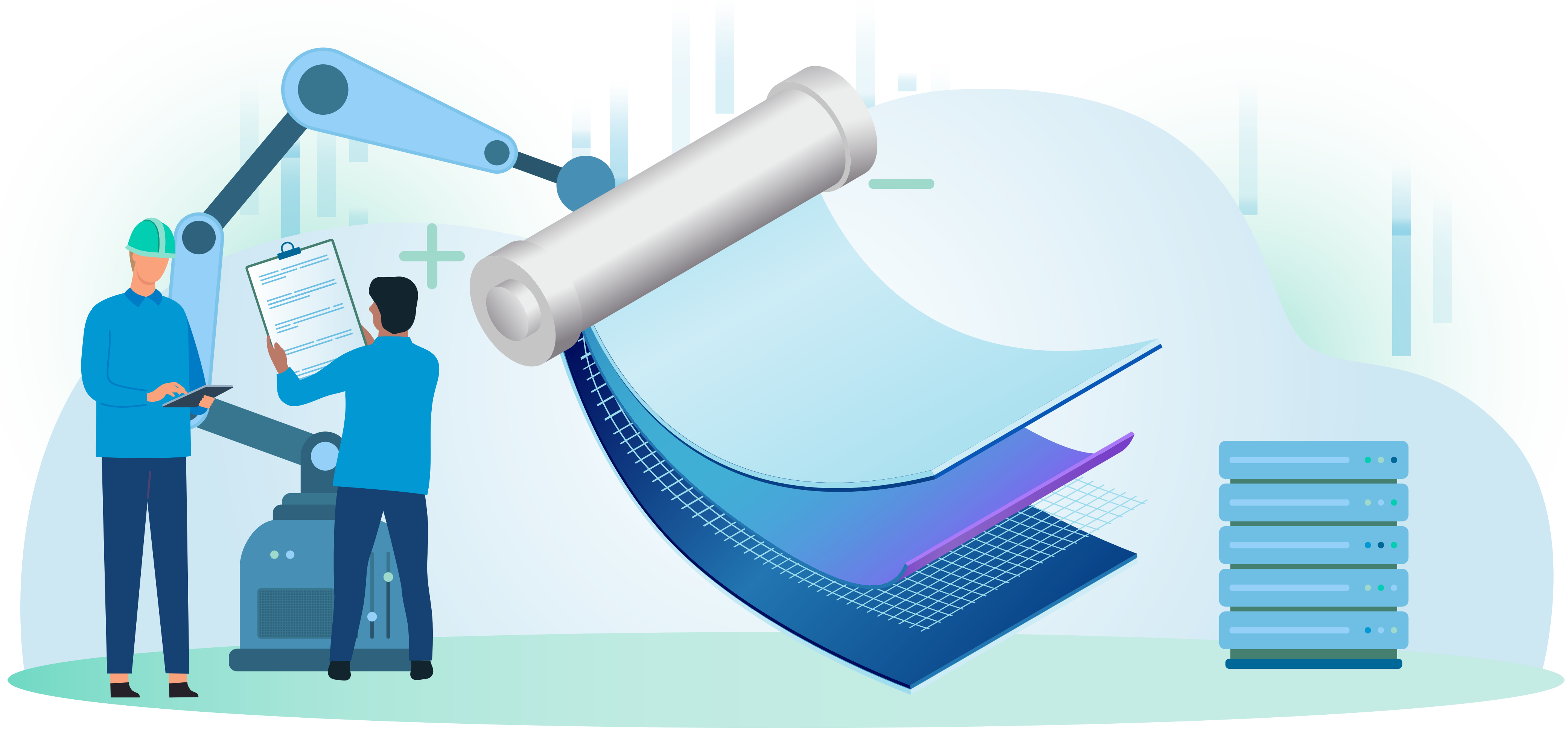
Sub-ambition: In 2035, the collaboration between *AI and data* ecosystems will be stronger. The individual strengths of these ecosystems will also be combined effectively. This will create synergies and allow investments and resources for innovation to be deployed in a more targeted way. A common approach will also make an important contribution to standards and policy in the European Union.

Devoting attention to legislation and regulations earlier in the process

The new European digital legislation offers sufficient opportunities for innovation. However, many of the organisations that share data or work with *AI* are unaware of the possibilities. The enforcement of existing and new legislation is hampered by the fact that developments in *AI and data* are very rapid.

Sub-ambition: The further development of *AI and data* requires adequate legislation and regulations. It is very important that existing and new legislation is designed dynamically. Innovation in sandboxes may simplify this process. It is also important that knowledge about legislation and regulations is shared and is made available to stakeholders in the field in an understandable form.

8 Energy materials



8.1 Definition

8.1.1 Importance of the key enabling technology

Energy materials are materials that make it possible to capture, store and transport energy, including renewable energy, and to convert it into another form or energy carrier. *Energy materials* are used in storage and conversion systems, where they make a crucial contribution to the energy transition and climate transition, for example in wind turbines, batteries and electrolysers. In contrast to the key enabling technologies in the other NTS agendas, this key enabling technology is essentially about materials rather than technologies. Various technologies are being developed and used to allow these materials to be used in the energy transition. In this agenda, we use the chains in the National Energy System Plan (NPE) to show the various areas of application of these materials. These chains were chosen as they are in common use in the field.

Energy materials are characterised by their high conductivity, catalytic activity, chemical inertness, storage capacity and long-term resilience under changing conditions.

The energy transition will result in a high dependence on several critical raw materials (including lithium, cobalt and iridium) for certain technologies. While these raw materials are essential for the current commercialised *energy materials*, their extraction causes problems for local communities and threatens biodiversity and natural environments. There are also strategic risks, given that some of these materials are processed in a limited number of countries, with which the Netherlands has unstable diplomatic relationships. All this confirms the necessity of developing alternatives that are more sustainable and less dependent on critical raw materials.

The Netherlands has a major chemical industry, which can contribute to the development of *energy materials*. Research in the Netherlands into *energy materials* has a high impact but a low degree of specialisation. China in particular is a rapidly growing player in research into this technology. In any case, users of these materials (the systems manufacturers) are often not based in the Netherlands or even in Europe. For example, up to 70% of batteries are made in China[99]. This raises the question: how can we retain knowledge and expertise in our country, how can we transform them into impact and what do we need to do to make that happen?

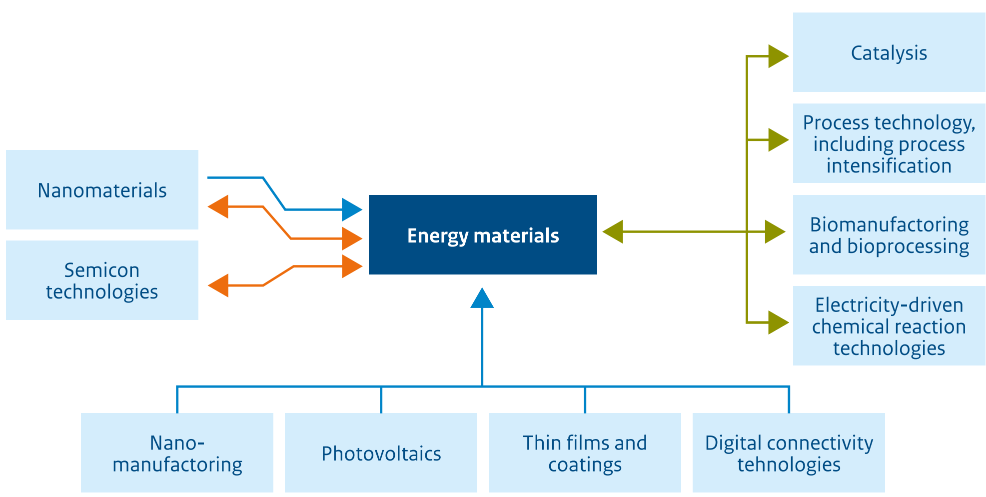
8.1.2 Definition

Energy materials are all materials that make it possible to store and transport energy, including renewably generated energy, to capture it efficiently and efficiently convert it into another form or energy carrier.

8.1.3 Related key enabling technologies

Energy materials have several complementary and competing key enabling technologies. *Nanomanufacturing, process technology*, *including process intensification* and *thin films and coatings* are complementary, as these technologies are used to produce *energy materials*. *Electricity-driven chemical reaction technologies* include many technologies used in *energy materials*, such as electrolysis. *Photovoltaics* are used to generate renewable energy. Finally, *digital connectivity technologies* allow the efficient connection and control of equipment related to *energy materials*. There are also several related technologies. *Biomanufacturing* and *bioprocessing* and *catalysis* are related to *energy materials* because they rely on the same knowledge base, although they are not directly used for the production or improvement of materials for energy storage or conversion. Finally, *nanomaterials* and *semiconductor technologies* are competing technologies, as they compete for the same factors of production. However, *nanomaterials* are also complementary, as many *nanomaterials* are also *energy materials*.

Related key technologies



Source: TNO/NWO (2023) Recalibration of key technologies

8.2 Ambition

8.2.1 Main ambition

In 2035, the Netherlands will be a leading player in the development of the next generation of *energy materials*. The design process will take account of circularity, sustainability and reducing our dependence on critical raw materials. These *energy materials* will be used on a large scale to produce battery systems, electrolysers and heat storage systems. We will focus on the large-scale domestic upscaling of this manufacturing. We will also help international partners to integrate these *energy materials* into their production systems.

8.2.2 Sub-ambitions

The main ambition is divided into several sub-ambitions. In 2021, the government identified ten challenges to be addressed to strengthen our research and innovation ecosystems. The sub-ambitions are described in relation to these lines where relevant.

Long-term vision and relationship to investments in research and innovation

Despite the many partnerships in the *energy materials* domain, there is no clear long-term vision. The wide range of partnerships sometimes results in a lack of coordination.

Sub-ambition: In 2035, the Netherlands will have an organisation to coordinate the sectors in the *energy materials* domain. This organisation will coordinate the long-term strategy and will have access to sufficient financial resources.

Investments in research and test facilities

There is a need for more accessible research and test facilities, particularly for SMEs, to facilitate cutting edge research and promote innovation. There is a specific need for pilot lines for various energy carriers, including hydrogen, as well as multiscale and multipurpose test facilities. It is important that these facilities are accessible to create a level playing field. These may be facilities in the Netherlands, as well as facilities in other EU countries.

Sub-ambition: In 2035, Dutch companies will have access to pilot lines for various energy carriers and also multiscale and multipurpose test facilities.

Developing, attracting and retaining (top) talent

Many technically trained employees at both vocational and academic level are needed to develop and produce *energy materials*. There is currently a major shortage of technical staff. This problem is not unique to the Netherlands; it also affects other countries. This means we must develop technical (top) talent at all levels in the Netherlands, as well as recruiting and retaining international talent. The research field is currently fragmented, as research into materials science is part of several different fields (including physics, chemistry and mechanical engineering). In contrast, materials science has been taught as a discipline in its own right in countries including the US and Switzerland for decades.

Sub-ambition: In 2035, the Netherlands will be a leading destination for international technical (top) talent. This will be achieved by creating an attractive environment for talent that goes beyond financial incentives. The research field will also be less fragmented.

Financing for startups and scaleups: early phase financing and growth

Policy measures and programmes focused on the energy transition, including innovation schemes and National Growth Fund programmes, can contribute to the development of *energy materials* by focusing not just on direct CO_2 reduction, but also indirect CO_2 reduction. There is also a 'first plant risk' associated with upscaling to TRL 8. This requires the realisation of the first large-scale production facility, which is relatively high risk. This puts off investors and can complicate and delay efforts to attract financing for the development of the technology.

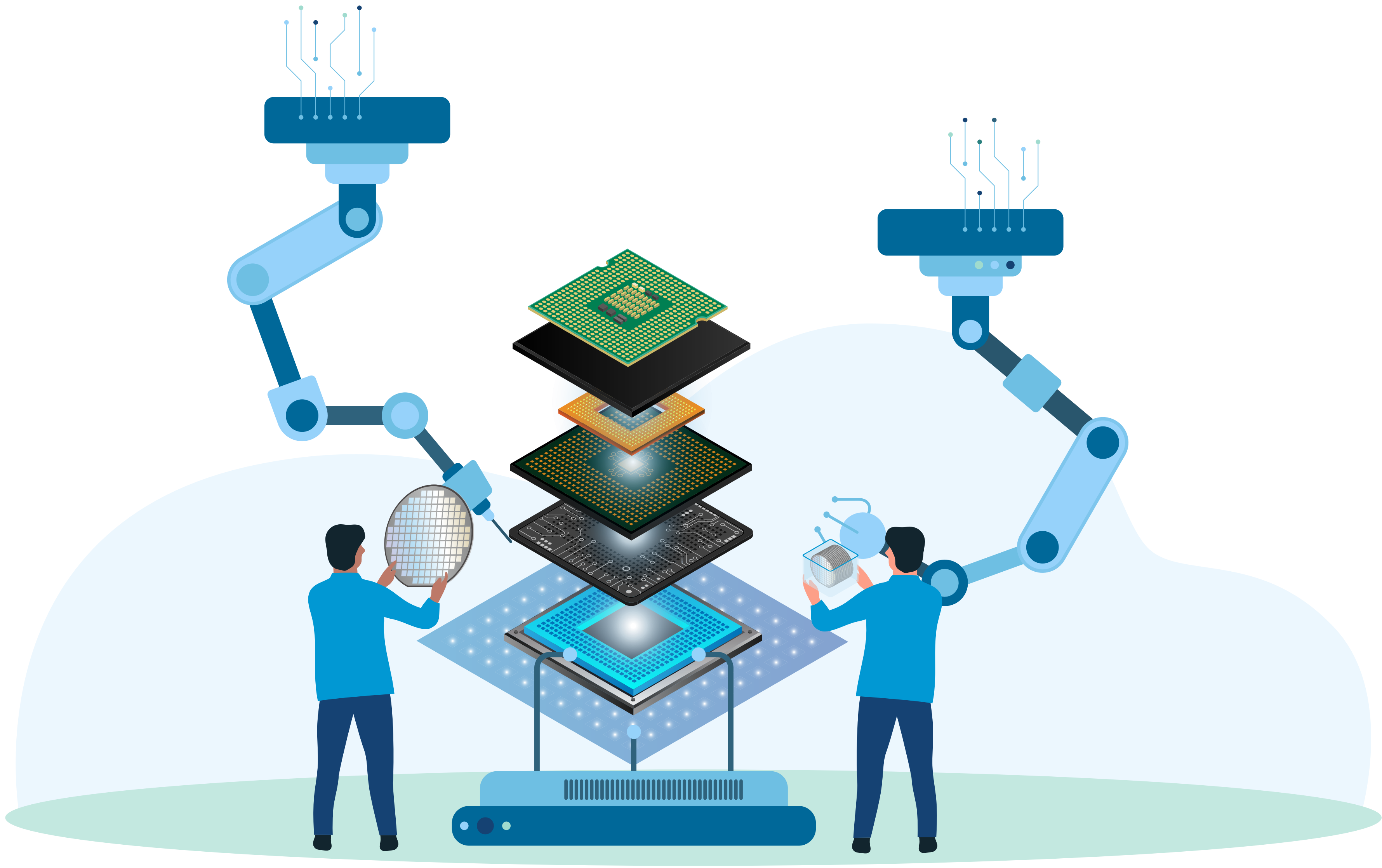
Sub-ambition: We will ensure that there is sufficient financing for technology that makes indirect CO_2 reduction possible, particularly in the upscaling phase. We will also study how Dutch industry, including the manufacturing industry, can become more resilient by promoting collaboration and the forming of ecosystems. Tender conditions that reward the use of particular innovative technologies developed by local industry are an example of how this can be approached.

Strengthening knowledge transfer and the valorisation process for greater impact

The hydrogen market is currently in an early stage of development. This means that valorising knowledge and technology in this field is particularly important for the future of *energy materials*. A few major multinationals currently lead the way in domestic upscaling projects for hydrogen production. There are major opportunities for improving collaboration, knowledge sharing and sharing lessons learned between these multinationals, knowledge institutions and Dutch SMEs.

Sub-ambition: In 2035, there will be more knowledge sharing between multinationals and Dutch industry, including SMEs. This will allow knowledge and lessons learned from the upscaling of domestic hydrogen production, for example, to be used in the Dutch knowledge ecosystem.

9 Semiconductor technologies



9.1 Definition

9.1.1 Importance of the key enabling technology

Semiconductor technologies are of crucial importance to our society. This technology can be seen as the beating heart of all electronically driven equipment and machines. Important areas of application include the automotive industry, the computer industry and the communications sector, as well as important medical equipment such as pacemakers and advanced scanners, which could not exist without *semiconductor technologies*[100]. *Semiconductor technologies* also play a major role in the energy transition and digitalisation. *Semiconductor technologies* are also crucial for defence applications, which means this technology is important for our national security. With the ongoing development of data-driven technologies and other technologies, it is expected that the demand for *semiconductor technologies* will only increase.

Semiconductor technologies encompasses the entire semiconductor value chain. With several major machine builders, a strong ecosystem and chip developers in specialised value chains, the Netherlands has a strong position in the semiconductor value chain. Our economy is heavily dependent on this sector, which provides many high-value jobs.

Recent chip shortages have shown how dependent we have become on this technology. Given its major importance for our economy and security, we have a geopolitical and strategic interest in retaining and strengthening our leading position in this industry. It is also important that we are not fully dependent on other major powers for access to this technology. This means that *semiconductor technologies* also play a major role in discussions about open strategic autonomy. The European Chips Act was introduced to strengthen the position of Europe and reduce dependencies. This legislation will mobilise investments of €43 billion in the semiconductor industry.

9.1.2 Definition

Semiconductor technologies encompass semiconductor components and/or highly miniaturised electronic subsystems and their integration into larger products and systems. This includes manufacturing (including metrology and characterisation), the design, packaging and testing of semiconductor components, microscale systems that integrate multiple functions on a chip (semiconductor devices) and the development and construction of machines to carry out these activities. This technology also includes high-frequency and mixed signal technologies, which combine digital and analogue signals from various sources into an integrated system.

Semiconductor technologies are part of the Engineering and Fabrication Technologies cluster.

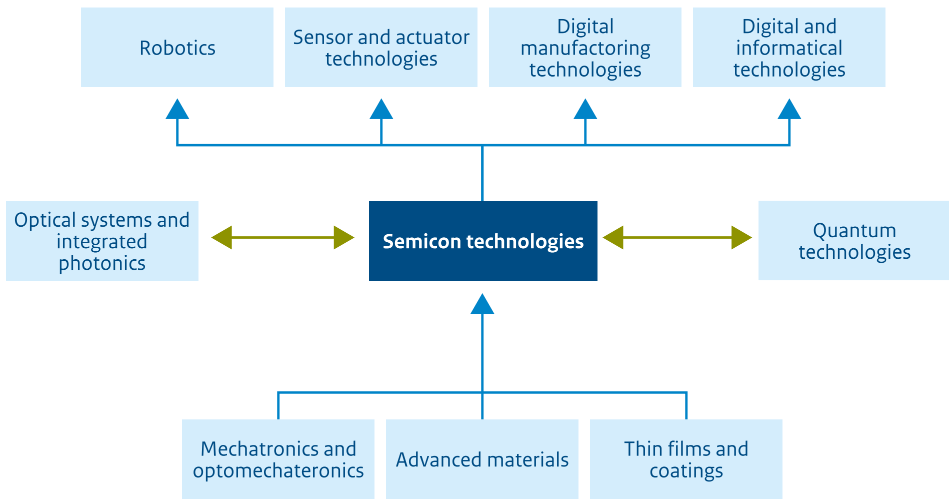
9.1.3 Related key enabling technologies

Within the Engineering and Fabrication Technologies cluster, *semiconductor technologies* complement key enabling technologies including *sensor and actuator technologies*, robotics, digital manufacturing technologies and *imaging technologies*, as these technologies are strongly dependent on semiconductor components. *Semiconductor technologies* also complement digital and information technologies, including AI, and can even be seen as an enabler, as *semiconductor technologies* are needed for (rapid) data processing.

Semiconductor technologies also complement *optical systems and integrated photonics* and mechatronics and optomechatronics. *Mechatronics and optomechatronics* are used to integrate mechanical and optical systems into the machines used to develop and produce *semiconductor technologies*. In such cases, *semiconductor technologies* can also be seen as a driver of further developments in this group of key enabling technologies.

Semiconductor technologies also complement *quantum technologies*. As is the case with *integrated photonics*, the industrialisation of *quantum technologies* depends on upcoming platform connections with more traditional chip technologies. The Advanced Materials technology cluster also complements *semiconductor technologies*. Research into and applications of advanced materials are an essential part of the ongoing development of *semiconductor technologies*.

Related key technologies



Source: TNO/NWO (2023) Recalibration of key technologies

9.2 Ambition

9.2.1 Main ambition

In 2035, the Netherlands will proudly occupy a strong, leading knowledge position and industrial position in chip design, production equipment and materials, and also in test and packaging technologies. These positions will have been strengthened and expanded by a flourishing SME sector, alongside the existing strong knowledge position and industrial position, a resilient ecosystem, the availability of high-quality talent and strong partnerships with other European parties. Growth will be driven by more intensive vertical chain partnerships in system design, heterogenous integration, flourishing European application domains and innovation challenges shared with the digital and energy transitions.

9.2.2 Sub-ambitions

The main ambition is divided into several sub-ambitions. In 2021, the government identified ten challenges to be addressed to strengthen our research and innovation ecosystems. The sub-ambitions are described in relation to these lines where relevant.

Long-term vision and relationship to investments in research and innovation

The POLARIS and NXTGEN HIGHTECH proposals from the National Growth Fund will result in a programme of measures to stimulate the *semiconductor technologies* sector in the medium term. The European ECS community and the Dutch HTSM Roadmap also provide direction. There are also opportunities to define the Netherlands' contribution more specifically, for example as part of European programmes. There is a need for a coherent story that integrates visions from the field and the government of the Netherlands. Involving SMEs will be challenging, as they have limited opportunities to assign employees to work on public-private partnership projects.

Sub-ambition: Long-term strategies at national level must be coordinated effectively and combined into a single national strategy and vision. The national strategy must take account of developments at European level. The Netherlands must adopt a clear position in relation to these developments.

Investments in research and test facilities

While some research and test facilities are available at R&D scale, the availability at precommercial scale is limited. There is a need for research and test facilities that can ease the transition from fundamental validated research to commercial implementation. Promoting the development of these facilities can also accelerate the development of new *semiconductor technologies*.

Sub-ambition: The ambition is to set up pilots and facilities that are of strategic importance for the Netherlands. These must focus on specialisms where the Netherlands has or can acquire a leading position in the market, and must complement the existing facilities in other European countries.

Involving users in research, innovation and market creation

Several important *semiconductor technologies* companies are present in the Netherlands. As a result, end users are heavily involved in research, innovation and market creation. Several of these companies indicate that they work together intensively with universities and that they are increasingly dependent on knowledge institutions as suppliers of new, fundamental insights. For example, PhD students increasingly work with the industry and there are opportunities to work more with 'bijzonder hoogleraren' (professors occupying an endowed chair). One major challenge is involving users outside the Netherlands, particularly users from Asia.

Sub-ambition: We will increase the existing involvement of users by focusing on enduring, long-term partnerships to share insights.

Developing, attracting and retaining (top) talent

There is currently a major shortage of qualified talent. While the title of 'engineer' is generally seen as prestigious in many countries, this is less so in the Netherlands. Admissions to study programmes are currently based on applications; the availability of study programmes is based on what students wish to study, rather than what our society needs. The Netherlands also has difficulty attracting women to study engineering. We can make better use of this untapped potential. Attracting international students is also important to meet the demand for labour. As such, most companies see the abolition of the expat scheme as a problem.

Sub-ambition: Future students must be offered a promising perspective: an attractive sector with a clear impact on our society. One way of achieving this is to offer additional guidance to help students during the transition to university education, as is the case in the United Kingdom in the form of a 'foundation year'. It is also important to attract a wide target group; we must attract more women and international talent. Sufficient structural funding must be available to recruit staff and PhD students to teach all new students.

Strengthening knowledge transfer and the valorisation process for greater impact

Many academic and industrial parties experience challenges when starting up: there are no customers, no financing and no experience at first. Pilot lines could help, although these are problematic at present as they cannot be loss-making. Setting up design platforms, as promoted by the Chips Act, is seen as an approach that may lower the barrier to entry. Efforts must also be made to facilitate career advancement for talent and promote collaboration.

Sub-ambition: It must become easier for academic and industrial developers to use pilot lines, as is the case in Germany, to set up pilot lines, to finance them and/or to have them managed by knowledge institutions. Initiatives that lower the barrier to entry should be promoted, including design platforms. It is also possible for a centralised centre to facilitate career advancement for talent and promote collaboration.

Organisational capacity of research and innovation ecosystems

There are opportunities to improve the organisation of the *semiconductor technologies* ecosystem.

Sub-ambition: We aim to combine the strengths and organisational capacity of the chip industry, as is already the case in quantum technology and photonics, for example. Multidisciplinary meetings, as well as both general and application focused research questions, can also contribute to this objective.

Links between ecosystems

There are currently various activities related to machine construction, chip design and packaging in the Netherlands. The links between these different ecosystems can be strengthened. This can be achieved by focusing on applications that bring these activities together, as well as research questions that involve multiple ecosystems.

Sub-ambition: We will foster stronger links between existing activities and ecosystems, driven by specific applications and research questions that involve multiple ecosystems. We also aim to ensure that activities in the Netherlands align better with international ecosystems, for example by setting up partnerships with international research institutions.

10 Cybersecurity Technologies

By 2035, the Netherlands has developed a competitive cybersecurity market with sufficient talent. Thanks to our multidisciplinary approach, we have also achieved a leading global position in innovative cybersecurity technologies. These technologies make an essential contribution to the security of infrastructures, as well as to IT and OT networks, the transition to post-quantum cryptography and more automated detection and defence through the use of AI. Research and more public-private partnerships, at national and international level, have strengthened the Netherlands' knowledge position and increased knowledge transfer. This makes cybersecurity an integrated part of Dutch sectors by applying security by design, security by default and cybersecurity in the supply chain in organisations and business chains. All these developments contribute to the Netherlands' digital security, resilience, autonomy and prosperity.

10.1 Definition

10.1.1 Importance of the key technology

In an increasingly digitalised society, cybersecurity is an essential prerequisite when it comes to protecting the Netherlands' national security, earning capacity and other societal interests.[101] *Cybersecurity technologies* help solve digital security challenges across all sectors of society. As a result of technological developments such as artificial intelligence (AI) and quantum computing, digital processes will become increasingly important, and our dependence on them will continue to increase. This makes society vulnerable to malicious actors and cyber incidents such as system failures (including critical system failures). In addition, technological developments offer new ways for malicious actors to carry out cyberattacks against organisations.

The Netherlands is facing a rapidly growing digital threat. For example, the 2023 Cybersecurity Assessment[102] (CSBN) found that there is an increasing threat from cyber activity by state actors, including efforts to influence public opinion, espionage, disruption and sabotage. This threat is evidenced by the growing number of digital attacks on operational technologies (OTs), with sectors such as healthcare, high tech, energy, transport and defence at risk of serious disruption.[103]

New key technologies are contributing to the growing digital threat as well. One example of this is the emergence of quantum technology. Quantum technology not only offers opportunities for innovations (including cybersecurity innovations), but also poses a threat to existing data encryption methods and could thus compromise the confidentiality of digital communications. Meanwhile, the rapid development of AI technology presents new challenges for detecting and defending against digital intrusions. As a result of these developments, there is a growing urgency to implement effective cybersecurity measures that offer a response to the technological and international trends of the coming years. Organisational measures, human skills and effective legislation are essential building blocks when it comes to enhancing national cyber resilience. Despite efforts to boost digital resilience, there is an imbalance between the increasing threat and the development of resilience.[104] This is why the government has developed the Dutch Cybersecurity Strategy 2022-2028[105], which sets out to safeguard the Netherlands' digital security by improving digital resilience and countering threats.

In addition to these cybersecurity measures, knowledge and innovation around *cybersecurity technologies* are needed to strengthen the Netherlands' digital resilience and earning capacity. Pillar 2 of the NLCS 2022-2028[106] highlights the need for targeted investments in knowledge and innovation development around *cybersecurity technologies*, as well as around their application in our economy and society to face new digital threats. This will increase our cyber resilience, reduce our dependence on foreign companies and solutions, and enhance the Netherlands' digital open strategic autonomy.[107]

The inclusion of a *cybersecurity technologies* agenda in the National Technology Strategy (NTS) supports these efforts. This agenda is based on Pillar 2 of the NLCS and thus aims to promote the development of knowledge and innovation in the field of cybersecurity. At the same time, it is important to place this agenda in a wider context and to consider it in relation to other issues. For example, in order to achieve the agenda's objectives, the cybersecurity labour market needs to become more attractive to new talent.[108] In addition, a multidisciplinary approach to cybersecurity challenges, combining technical and non-technical knowledge, is needed to make the right long-term choices. It is also important to seek cooperation with representatives of Dutch sectors that are undergoing major transitions, such as energy, logistics, chips and manufacturing, and the maritime industry. It is essential that cybersecurity principles such as *cybersecurity by design*, *cybersecurity by default* and *cybersecurity in the supply chain* are incorporated in these transitions, as this will ensure that the sectors in question become inherently cyber resilient.

10.1.2 Definition[109]

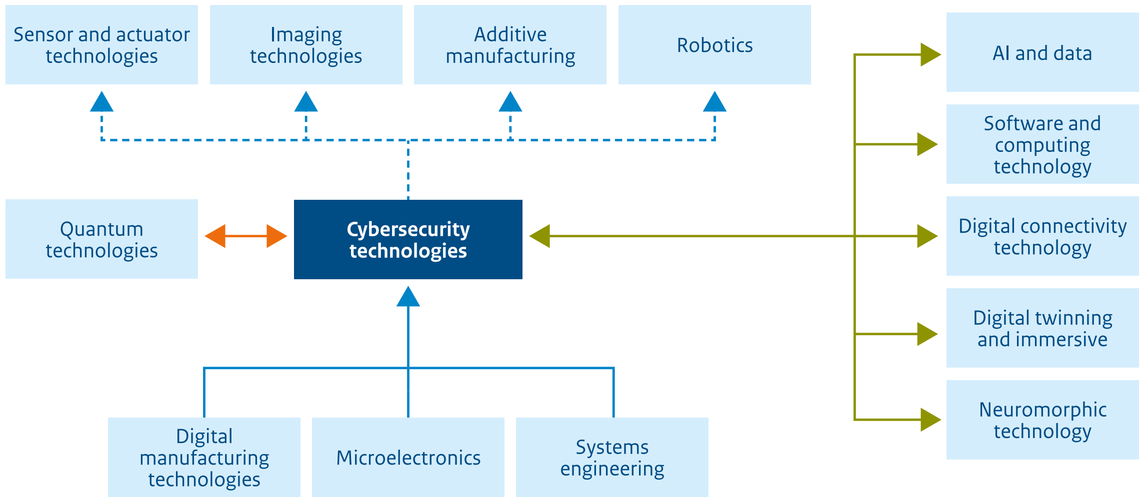
Cybersecurity technologies are digital technical applications designed to mitigate relevant digital risks. This includes managing the risk of damage to or failure of digital systems, as well as the availability, integrity and confidentiality of data. In addition, *cybersecurity technologies* focus on preventing cyber incidents. When cyber incidents do occur, *cybersecurity technologies* can be used to detect them, mitigate damage and streamline recovery. Acceptable levels of risk are often determined by a risk assessment.

10.1.3 Related key technologies

Cybersecurity is a prerequisite for the development and successful deployment of all key digital technologies. Particularly relevant in this context are the key technologies that belong to the Digital and Information Technologies cluster and that fall within the scope of the Digitalisation Knowledge and Innovation Agenda (KIA)[110]: *AI and data*, *software technologies* and *computing*, *digital connectivity technologies*, *digital twinning* and *immersive technologies*, and *neuromorphic technologies*. Due to their digital nature, products developed based on these key technologies will have inherent cybersecurity risks. At the same time, these key digital technologies are also essential for the development of cybersecurity applications. Consider the use of *AI and data* in automated detection systems, for example, or the use of software technology in software security applications. In the figure below, these digital technologies are connected by green lines.

The key technologies digital manufacturing technologies, microelectronics and *systems engineering* are required for cybersecurity applications. Key technologies such as *sensor and actuator technologies*, *imaging technologies*, *additive manufacturing* and *robotics* also need *cybersecurity technologies* to enable them. However, due to the digital component of these key technologies, cybersecurity risks need to be taken into account, and *cybersecurity technologies* play an important role. *Quantum technologies* pose a risk to existing cryptographic protocols, but they can also be used to develop new security methods (orange line).

Related key enabling technologies



Source: TNO Rapport Herijking Sleuteltechnologieën 2023 (kia-st.nl)

10.2 Ambition

10.2.1 Main ambition

By 2035, the Netherlands has developed a competitive cybersecurity market with sufficient talent. Thanks to our multidisciplinary approach, we have also achieved a leading global position in innovative *cybersecurity technologies*. These technologies make an essential contribution to the security of infrastructures, as well as to IT and OT networks, the transition to post-quantum cryptography and more automated detection and defence through the use of AI. Research and more public-private partnerships, at national and international level, have strengthened the Netherlands' knowledge position and increased knowledge transfer. This makes cybersecurity an integrated part of Dutch sectors by applying security by design, *security by default* and *cybersecurity in the supply chain* in organisations and business chains. All these developments contribute to the Netherlands' digital security, resilience, autonomy and prosperity.

10.2.2 Sub ambition

The main ambition is set out using relevant challenges from the government's strategy to strengthen research and innovation ecosystems.[111] For each challenge, a sub-ambition has been formulated that contributes to the main ambition.

Long-term vision and relationship to investments in research and innovation

There is still insufficient investment in cybersecurity research and innovation in the Netherlands. Moreover, the volume of both private and public investment projects is still too low. To remedy this, more coherence between research and innovation activities and effective cooperation between all parties involved in these activities are crucial. A multidisciplinary approach to knowledge and innovation development around cybersecurity – involving specialists from other fields of work and key technologies – ensures greater coherence as well as innovative insights and solutions. Innovators need critical market mass to be successful. As a major buyer, the government plays an important role in this context.

Sub-ambition: By 2035, a multidisciplinary approach has led to greater coherence between investments in cybersecurity and other disciplines, including key technologies such as quantum technology and AI, as well as non-technical disciplines such as behavioural science and economics. The government is a major buyer of key technologies.

Investments in research and testing facilities

Research and testing facilities are indispensable to cybersecurity innovation: good facilities enable research and help companies solve pre-competitive challenges. This also requires sufficient cybersecurity talent. Current facilities in the cybersecurity domain tend to focus on complying with laws and regulations, and on addressing cybersecurity threats and risks around key technologies. They are less concerned with exploiting the opportunities offered by key technologies. To address this, it is important that principles such as *security by design* are given due consideration by research and testing facilities for other key technologies. Data sharing also contributes to good scientific research.

Sub-ambition: By 2035, the importance of cybersecurity(*security by design* and *security by default*) is self-evident at research and testing facilities for various key technologies. The Netherlands also has sufficient facilities and the right infrastructure for cybersecurity research, making it easier for companies and academic researchers to conduct research and solve pre-competitive challenges.

Financing for startups and scaleups: early phase financing and growth

Compared to the US, where the leading cybersecurity companies are based, the EU invests relatively little in innovative cybersecurity startups and scaleups.[112] The funding required to scale up cybersecurity companies is often provided by foreign investors.[113] Promising cybersecurity startups in the Netherlands are quickly acquired by foreign parties, limiting the sector's development potential.[114]

Sub-ambition: By 2035, Dutch investors are more knowledgeable about cybersecurity. In addition, cybersecurity companies have sufficient access to venture capital, existing financing instruments are still being used effectively and there are no barriers in the internal market to sustainable growth in the cybersecurity sector. Cybersecurity companies have optimal growth prospects and more long-term investments are being made.

Involving buyers in research, innovation and market creation

Involving buyers in research, innovation and market creation is important for successful innovation in *cybersecurity technologies*. The current and potentially declining market is not yet sufficiently involved in cybersecurity research projects, and there is still insufficient cooperation between the scientific domain and the cybersecurity industry. This also leads to insufficient knowledge transfer: scientific research and knowledge are not being used to develop products that align with consumer needs and market opportunities. This is because SMEs do not have enough time to tackle long-term challenges around cybersecurity innovation. Moreover, barriers to data sharing are having a negative impact on research quality and opportunities.

Sub-ambition: By 2035, more Dutch market players are involved in research and innovation around *cybersecurity technologies*. Solutions are developed in a more demand-driven way, for example by giving PhD students the opportunity to gain industry experience and by involving business experts in research projects. Using a multidisciplinary approach, the cybersecurity principles *security by design* and *security by default* are a prerequisite for research projects around other key technologies. Other options for research project development and funding are also explored.

Skills and absorption capacity of SMEs

A lack of relevant skills and knowledge – and tight labour market conditions – are making it hard for SMEs to adopt the right cybersecurity measures. As a result, it remains difficult for SMEs to embrace new cybersecurity innovations. In addition, cybersecurity products and services are costly. This means that demand from SMEs for these products and services and the willingness to invest are low.

Sub-ambition: By 2035, there is more cooperation between SMEs, large companies, governments and knowledge institutions to increase the SME sector's knowledge and skills. Large companies are encouraged to share their knowledge with SMEs. Meanwhile, the scalability of *cybersecurity technologies* is being enhanced to increase the SME sector's access to more affordable cybersecurity products and services (for example through AI-driven automation).

Developing, attracting and retaining top talent

Attracting a wide range of cybersecurity talent – from technical specialists to people with a background in the humanities and social sciences – is a major challenge, partly due to severe labour shortages and competition from international companies. Retaining talent is difficult as well: many governments, companies and educational institutions are struggling to compete with large, resource-rich foreign companies. There should also be improved alignment between the needs of the education sector and the labour market.

Sub-ambition: By 2035, supply and demand between cybersecurity education and the labour market are better aligned, and the chain between the education sector and the labour market has been strengthened. This contributes to adequate education and research, improving the starting position of talented graduates. Continuing education and retraining are accessible and Lifelong Development programmes are actively promoted.

Including innovation in the development of laws and regulations

The laws and regulations around cybersecurity present certain opportunities, as organisations are required to implement more cybersecurity measures that will lead to the purchase of more cybersecurity products and services. However, this also means that purchasing organisations are only concerned with having the mandatory resources in place, without properly understanding their individual risks. In addition, technological developments are moving fast and laws and regulations are being overtaken by reality.

Sub-ambition: By 2035, innovation partners are involved at an early stage in the development and implementation of laws and regulations to ensure that cybersecurity innovation interests are given due consideration.

Annex – Description of the process of selecting priority key enabling technologies

How do we decide which key enabling technologies to prioritise?

The challenge is to select the technologies that have the greatest potential for the Netherlands. The selected priority technologies are based on a combination of qualitative and quantitative data about the existing position of the Netherlands in each key enabling technology, the expected impact of each technology on our national security, our current or future earning potential and the challenges faced by our society. In specific terms, the following aspects were considered:

- Which key enabling technologies make an important contribution to the current and/or future economic earning potential of the Netherlands?
- Which technologies are essential to address the challenges faced by our society?
- Which key enabling technologies contribute to our national security?
- Which key enabling technologies build on the Netherlands' existing strengths in science and technology, R&D and ecosystems?

During the past few months, we collected and analysed data for all 44 key enabling technologies in collaboration with various partners (TNO (Netherlands Organisation for Applied Scientific Research), NWO (Dutch Research Council), Elsevier and RVO (Netherlands Enterprise Agency)). The results of this analysis were then assessed by a large and varied group of experts and stakeholders from science, industry and investors.

Definition phase, September – December 2022

The first part of the process was to prepare a basic list of key enabling technologies. Although a similar list had been prepared in 2017 for the mission-driven innovation policy, the list was revised to take account of current developments in science and technology. This process, which was supervised by TNO and NWO, resulted in the 'Herijking sleuteltechnologieën' (Re-evaluation of key enabling technologies) report, which contained a list of 44 key enabling technologies divided into eight categories. We spoke to around 60 experts, primarily from science and industry, during several consultations to prepare this list. The advisory report by TNO and NWO was accepted by the key enabling technologies core and theme team, which advises the Ministry of Economic Affairs and Climate Policy, and by the Ministry itself.

Data analyses, January – June 2023

The Ministry of Economic Affairs and Climate Policy carried out analyses for each of the 44 key enabling technologies to identify how each of these technologies scores for each facet of the evaluation framework. The Ministry used one or more data sources for each facet of the evaluation framework.

- Earning potential of the Netherlands. The assessment used the draft results of the Groeimarktenstudie (Growth Markets Study). This study identified the areas with the greatest potential future value creation based on international market trends in combination with the Netherlands' strengths. The Ministry identified a preliminary, non-exhaustive list of twenty potential growth markets. This primarily focused on sectors that produce products with a high added value and a focus on exports. These sectors encompass the markets and market segments in which the greatest value creation is expected in the future and where there are opportunities to enhance the Netherlands' earning potential.
- Challenges faced by society. The Netherlands has a mission-driven innovation policy, with five central missions and 21 underlying missions. The Ministry assessed which key enabling technologies are most important to achieve these missions. An analysis was carried out to identify the extent to which key enabling technologies have been used in recent years in projects for particular missions, including projects from the MIT (SME investment incentive scheme for regions and priority sectors) scheme, the PPP (public-private partnership) allowance for research and innovation scheme and SBIR (Small Business Innovation Research) calls. The mission leader (the person responsible for implementing the mission) of each mission was then asked which key enabling technologies are essential to complete the mission.
- National security. The General Administrative Order (AMvB) defining the scope of the Investments, Mergers and Acquisitions Security Screening Act (VIFO) defines several technologies as very sensitive from the perspective of national security. This designation is made where there is a high degree of chain dependency on a technology throughout the entire technology domain (or even beyond), a high degree of uniqueness and where it is difficult to reproduce the technology, where there are direct (advanced) military or security applications and international requirements for the protection or security of the technology.
- Existing position. To understand which key enabling technologies build on areas where the Netherlands already has a strong knowledge position, R&D and ecosystems, Elsevier first carried out an analysis of the publications and patents related to each technology compared to other countries. The Field-Weighted Citation Impact (FWCI) scores and Relative Activity Index (RAI) scores were calculated for publications and the Patent Asset Index (PAI) was calculated for patents. The results were then compared with analyses that provide specific information about the existing innovative activities of companies and knowledge institutions. These included an analysis of WBSO (R&D tax credit scheme) awards, the financial performance of Dutch consortia in Horizon-2020 and the productivity of related SBI (standard industrial classifications) sectors.

It should be noted that, although these analyses are valid and usable, they do not in themselves provide a comprehensive answer to the question of which technology contributes the most to each element of the assessment framework. For example, the FWCI and RAI provide a useful picture of the scientific position of each technology, but not a comparative picture of the knowledge and expertise of industry as regards a particular technology.

The ideas and opinions about the national security aspect are still very much in development and it is not possible to definitively determine which technologies contribute the most to our national security. In general terms, the availability of data for each of the 44 key enabling technologies is a challenge.

Expert input, June 2023

A major stakeholder meeting with around 60 experts was held on 21 June to address the aforementioned deficiencies in the data analyses. In this meeting, the experts were asked to reflect on the results of the data analyses and to share their comments and criticisms. They were given the opportunity to indicate which results of the data analysis they recognised, which results they missed and which questions remained unanswered. The Ministry of Economic Affairs and Climate Policy combined this input to refine the results of the previous phase.

Selection shortlist, August 2023

The Ministry used the feedback from the experts and the data analysis to prepare a shortlist of nine priority key enabling technologies. The NTS project team prepared the advisory report based on the following principles:

- A priority key enabling technology (potentially):
  - has a major impact on the future earning potential of the Netherlands.
  - plays an essential role in resolving the challenges faced by our society.
  - is important for our national security.
  - already has a strong position in the Netherlands.

The above criteria are supported by qualitative information and are also accepted by experts and stakeholders from science, industry and investors.

- Various dimensions were analysed for each key enabling technology. The final assessment as to whether each key enabling technology should be included in the NTS did not use a formula that combined the various dimensions. Instead, a qualitative assessment based on various sources of information was made. The following rules applied:
  - A key enabling technology that scored higher for the various dimensions was more likely to be included in the NTS.
  - If a key enabling technology did not score highly for all four dimensions, it was still eligible for inclusion in the NTS if it makes a substantial contribution to one or more dimensions.
  - We aimed for an even distribution across the various technology clusters.
  - It was important that the prioritised key enabling technologies were at least somewhat broadly recognised during the round table discussions.

- A positive approach was adopted when selecting the priority key enabling technologies. In other words, the process considered which key enabling technologies should be prioritised, rather than which technologies should not be prioritised. We are therefore reasonably certain that the priority key enabling technologies are very important for the Netherlands, without discounting the possibility that other technologies may also be relevant.

- As we recognise that the key enabling technologies may be interrelated, the process of developing the agendas also considered the underlying technologies that support the prioritised technologies.

A number of technologies clearly met these principles. Additional input for other technologies was collected in the summer from experts from EZK, NWO and RVO.

The final outcome has been submitted for refinement to several external expert bodies with a broad overview of science and technology, including UNL, the 4TU, VNO-NCW, VH and the Kenniscoalitie (Knowledge coalition).

In stakeholder consultations and interdepartmental coordination, it became clear that it is important to designate cybersecurity technology as the tenth priority key enabling technology. This is in line with the social, economic and security importance given to cybersecurity in the Digital Open Strategic Autonomy Agenda[115] and the Dutch Cybersecurity Strategy[116]. A supplementary agenda has therefore been developed for *cybersecurity technologies*. This has been included in this version of the NTS.

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81 This vision will also devote attention to identifying and supporting upcoming technologies where the Netherlands can develop a niche or control point. These upcoming technologies can serve as the foundation for the innovations and ecosystems of tomorrow and beyond. It is also possible to focus on technologies such as synthetic cell biology, synthetic biochemistry, single cell technologies, epigenomics and/or new gene editing technologies.
82 These disciplines include biomolecular technology and, for example, bioinformatics, data mining, microfluidics and optics, as well as knowledge about legislation and regulations, valorisation and IP. Attention will also be devoted to making biobanks and cell lines available for applied and translational research. These facilities must be accessible and affordable for scientists, SMEs and startups that do not have access to complex and expensive equipment. By developing a campus where researchers, research facilities, companies and financiers literally sit at the same table, we can tackle the shortage of research and test facilities and also involve users and financiers in innovation and market creation. Realising facilities in areas where the distance to the market is relatively small will be prioritised.
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84 This national TTO can be set up based on the technology transfer department of the Flemish VIB: vib.be – Technology transfers at VIB. A national TTO can be a professional and efficient organisation that focuses on all aspects of technology transfers, including legislation and regulations, intellectual property rights, business development and support for the development of business cases.
85 These include developing business cases and business models, supporting IP applications, connections with financiers and navigating legislation and regulations. Preconditions: a shared, long-term vision is crucial to set up a national TTO (see sub-ambition 1). This TTO office must be embedded in a broader ecosystem organisation for *biomolecular and cell technologies* (see also sub-ambition 6).
86 Flanders has such an organisation, the VIB, which can serve as an example for the Dutch ecosystem. This independent research institutions, which combines all research into biotechnology, is a partnership between five Flemish universities. Alongside fundamental research, the institution also handles knowledge valorisation (see sub-ambition 5) and has a shared mission and a human capital agenda. A similar organisation in the Netherlands could help to bring the various islands together.
87 This organisation will take responsibility for a shared mission for these organisations and will coordinate between the various players. The organisation will also present a powerful and unambiguous message to the outside world. This will improve the business climate in the Netherlands and will also play a role in retaining and attracting top talent, financing, training and support for the business activities of researchers (see sub-ambitions 3 and 4).
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