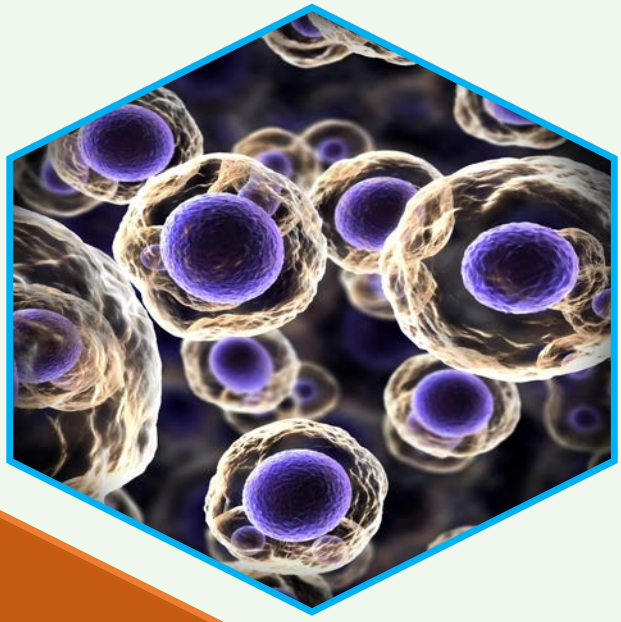
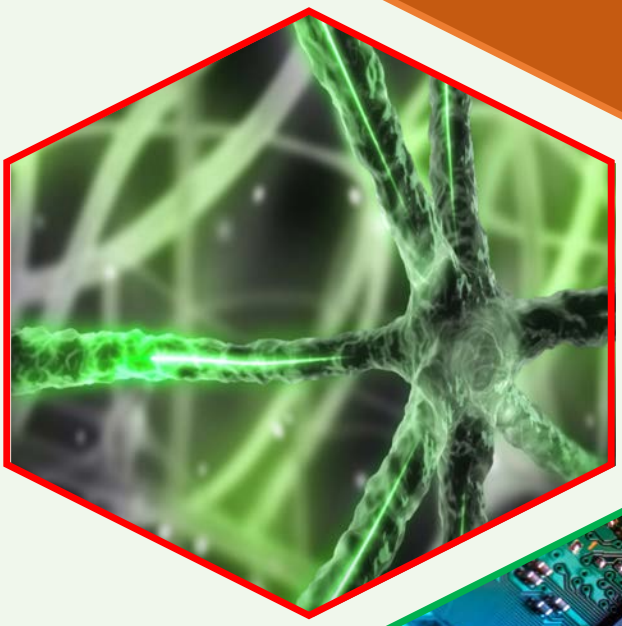
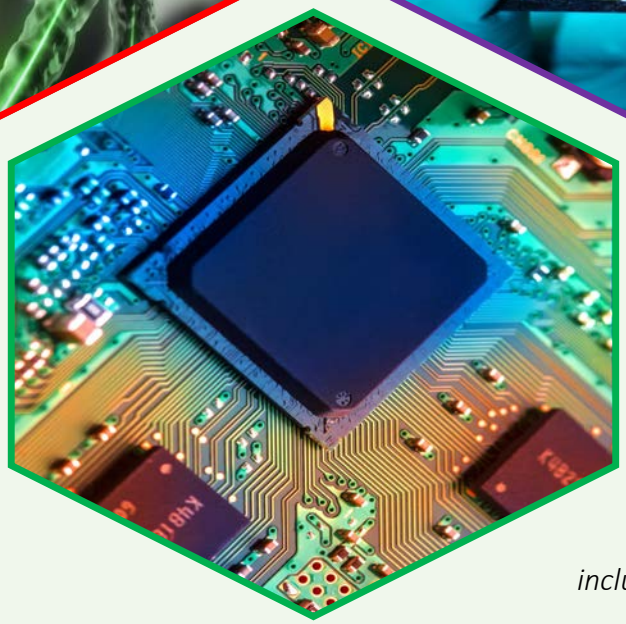


NANO4SOCIETY

NANOVISION 2030
NANOTECHNOLOGY as KEY-ENABLING TECHNOLOGY for THE NETHERLANDS





English version
includes COVID-19 research themes

Executive Board NanoNextNL

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prologue & content

PROLOGUE

This vision (nanovision 2030) is a multi-year plan for the knowledge and innovation agenda around the key enabling technology, nanotechnology. The foundation is the selective continuation of the national FES programme NanoNextNL, supplemented by the input of a wide range of stakeholders. The initiators are the NanoNextNl and MinacNed foundations, an industry organisation within FHI. This encompasses the entire chain secured, from science - spinoff - startup – SME's - large companies - end user.

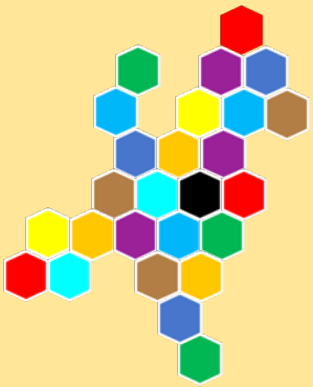
Nanovision 2030 is a clear indicator of the position and application that nanotechnology occupies as a key enabling technology for solving societal challenges. This aligns with the four themes the Netherlands has chosen, *health and healthcare*, *energy and sustainability*, *agriculture, water, and food*, and *security*, and in line with the European Green deal.

The programme outlined here, Nano4society, can make vital contributions to these mission-driven innovations. It combines excellent technology development with a dedicated governance system to safeguard that its outcomes will contribute to solving societal issues.

As illustration of the dynamics and flexibility/agility of the nanotech community, a special section on nano-solutions for the "Corona-challenge" is added.

Prof.dr.ir. Albert van den Berg, chair NanoNextNL

CONTENT NANO4SOCIETY



introduction

1.1 A NANOVISION FOR THE FUTURE

How will we view technological progress in 2050? A lot can have changed in a time frame of 30 years. Are the social challenges, as we identified them in 2020, still valid or are we facing new challenges? Now, when we look back to 30 years ago, to the early nineties, we were at the beginnings of nanotechnology. The first years as an exotic phenomenon with possible applications in electronics, the past 15 years as driver of various applications in medical technology, energy materials, CMOS transistors, quantum electronics, photonics and nutrition. These possibilities came about because we started viewing technological change differently. Distant concepts came closer and could become reality as a result of nanotechnology. Watching and manipulating at the nanoscale has led to new materials and insights into chemical processes. The food-technology and medical world gratefully make use of this. By assigning the national programs in the field of nanotechnology, the market grew in particular. Infrastructure on the one and scientific breakthroughs on the other hand have led to a technology that is rightly reckoned to be a key technology. One can even say that many named key technologies make use of nanotechnology. The term nano-inside is therefore justified. Nano's role is not always visible, but essential for its impact. Nano forms an essential building block of many applications and solutions for sustainable developments.

Nanotechnology is at the stage where industry-wide implementation of this technology is approaching, with safety guaranteed and where social acceptance is a fact. As already analysed in NanoNextNL, it is insufficient to only work on knowledge product development to meet these goals. The impact will only really become substantial when the solutions are applied by the business on a large-scale.

It remains speculative, of course, but will humans live longer, safer, more sustainably and healthier in 2050? Has the quantum computer made its entrance? Do we no longer only communicate via electrons but mainly through photons? Are the materials so intelligent that they fully adapt to the circumstances or completely provide us with sustainable energy? Will the food and food production of that time be such that the expected deficits are a thing of the past? Will our safety be guaranteed by a conditioned environment? Or to name an important objective: is cancer now history? These are questions where there are, perhaps fortunately, no ready-made answers. It is clear that the progress of technology, such as nanotechnology, plays an essential role here.

This nanotechnology agenda is a vision for development through connecting scientific agendas with innovative ones the challenges, integrating a component of societal relevance and recognizing the need for cooperation between science and business. An action plan for the Netherlands to be a leader in nanotechnology.

key technologies

1.2 NANOTECHNOLOGY

Key enabling technologies are strategically important because they provide the development of new goods and services and the restructuring of industrial processes necessary to modernize the industry and to improve research, development and to secure the innovation base. For challenges such as affordable healthcare, sustainable energy, healthy food, clean (drinking)water and secure information exchange for a more and more connected, but also aging population, innovations are required that are acceptable from an environmental and citizen perspective. Nanotechnology is considered one of the most important key technologies that underpin the innovations in the 21st century. It is indispensable for generating new knowledge. Just as how quantum technology and photonics are actually applications that emerge and depend on nanotechnology's progress. This is also underlined by recently awarded Nobel Prizes to Nanotechnology Researchers: in 2016 to, among others, Ben Feringa in the field of nanochemistry, in 2017 for Cryo Electron Microscopy and this year, to nanomaterial science lithium batteries.

Nanotechnology has a broad basis and extensive infrastructure that is needed for many nanotechnology specializations and can also be used for research, development and training.

1.3 RELATIONS

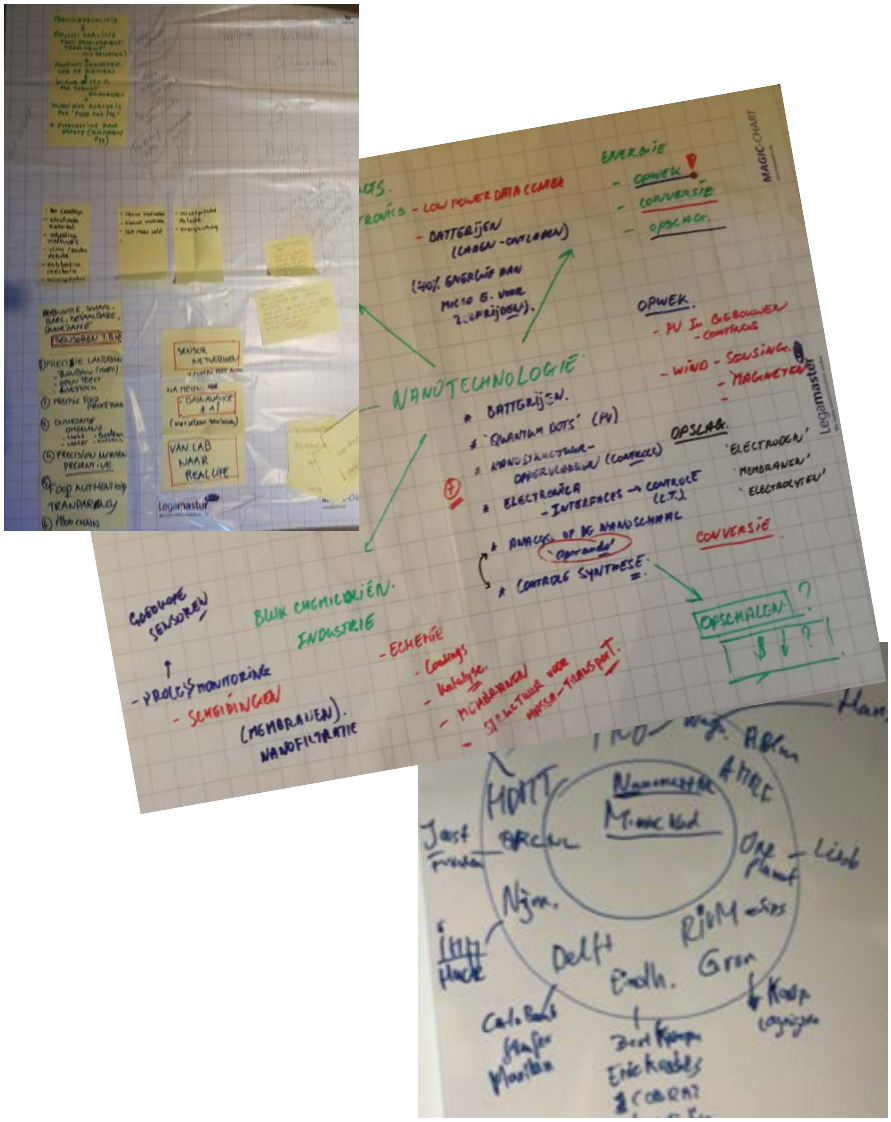
In addition to nanotechnology, the following stands for Nano4society technology clusters: quantum technology, advanced materials, biotechnology, photonics, micro- and nano-electronics and measuring detection technology. From the cross-over nature of the program it focuses on exploiting the potential of virtually all technology clusters. There is a clear relationship and alignment with these technology clusters.

realisation

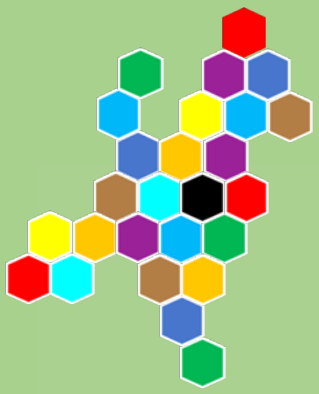
1.4 FORMATION

After completing the FES NanoNextNL program, with the goal of creating an ecosystem for nanotechnology in the Netherlands, the participating partners have considered a (selective) continuation of the program. This Manifesto was created by a close collaboration between MinacNed and NanoNextNL. Recently, several workshops have been held where science and business were represented. They have all contributed to the realization of this Manifesto through these workshops and interviews

After drafting multi-year plans, the wish arose to create economic, social and political support for nanotechnology by means of a thorough plan. The boards of NanoNextNL and MinacNed as well some other stakeholders have helped to edit this Manifesto. The active contribution of a broad representation from the sector has resulted in a widely supported plan for the future.



nano ned



initiatives

2.1 NETHERLANDS NANOLAND

Because investments were made at an early stage in the scientific foundations of nanotechnology with national programs MicroNed, NanoNed (and NanoImpuls) and also collaborations with business in NanoNextNL and associated nationally coordinated infrastructure NanoLabNL, the Netherlands has a unique global leadership position. With the acquired knowledge and expertise, we are able to make an essential contribution to the solutions for current and future societal challenges. Meanwhile, nanotechnology is in the standard toolbox of companies and in the capillaries of both the scientific and higher professional education institutes and TO2 institutes. In addition, it has resulted in a large number of spin-offs, start-ups and scale ups that underline the social and economic relevance of doing business internationally and ensure the export of unique products and services with nanoinside. All these economic activities underline the social and economic relevance of the ecosystem. The expectation for the return on Investment is excellent from both impact and finance. With this, the development of nanotechnology has not come to an end. New developments lead to new value chains, where the role of nanotechnology can be essential.

2.2 NANONEXTNL FOUNDATION

NanoNextNL's mission is to create sustainable economic and social value accelerated through developing and commercializing innovative nano- and micro-technologies, and by constituting a sustainable ecosystem of researchers, entrepreneurs and policymakers.

To achieve this, 13 universities, 8 medical centers and 12 knowledge institutes have collaborated with more than 90 multinational, SMEs startup partners in intertwined joint research programs. NanoNextNL is made possible by government support from the Economic Fund Structural reinforcement (FES) and investments of academic and industrial partners. External interim and final evaluations concluded that the results, with respect to scientific output and business development and value creation, exceeded the goals set by more than 1,200 scientific publications with an average high citation impact well above the world average and an expected value creation multiplier of 4 compared to usual investments. In addition, the commercial impact is underlined by 127 patents, 23 new business cases and 18 new start-ups. Furthermore, 230 PhD projects have been completed successfully. Last but not least, NanoNextNL has set a new standard in the area of responsible "Safe by Design" by raising awareness of the risks involved in the R&D phase which should be considered when products based on nanotechnology are manufactured.

MinacNed
Association for Microsystems and Nanotechnology

companies

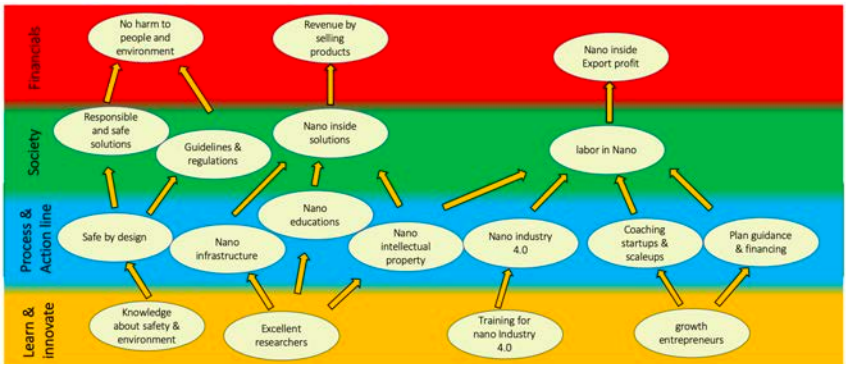
2.3 MARKET ORGANISATION MINACNED

MinacNed is the association for the companies and institutions in the field of nano and micro technology that create economic value and impact from and for the Netherlands. MinacNed has existed for 15 years and originated from Minac and MicroNed. MinacNed is one trade association within FHI. This makes the entire chain of science - spinoff - startup - SMEs - large companies - end user secured.

MinacNed is, together with NanoNextNL, the initiator of Nano4society, in which business and knowledge institutions work together on the roadmap and initiatives in the field of the key technology Nanotechnology.

The members of MinacNed are aware of the possibilities of micro and nanotechnology. They believe that through the power of technology and cooperation, social issues can be solved. They work together to realise technology applications to face societal challenges. This collaboration is cross-cutting, international and creates added value for the world and the people who live there. For the parties involved this means additional economic activity and increasing the chance of global impact on society. In the MinacNed ecosystem, knowledge is shared and parties are brought together through networking events. Development and application of nanotechnology and the emergence of international markets are accelerated due to this. By collaborating, a greater focus is formed on the potential of micro and nanotechnologies and can increase the total market and impact of the products. The collaboration leads to worldwide visibility and impact, which can be converted into sustainable profitable activity.

MinacNed organizes its activities on topics which are worked on in clusters. This way, they make it possible to reduce the conduction of animal experiments, analyse DNA faster and cheaper, have medications work better and to target the issue more effectively, to diagnose diseases earlier, make more efficient energy sources, help to eradicate the use of fossil resources, and to increase the yield of food production, etc ..



2.4 CONSORTIUM NANOLAB.NL

NanoLabNL is a collaboration of six laboratories spread across five locations. In Amsterdam- the AMOLF institute; in Delft the locations are the Kavli NanoLab and the Else Kooi Lab of TU Delft and the Van Leeuwenhoek Laboratory of TNO as an associated partner; in Eindhoven the NanoLab @ TU/e of Eindhoven University of Technology; in Enschede the MESA + NanoLab of the University of Twente and in Groningen the Zernike NanoLab of the University of Groningen.

NanoLabNL plays a central role in research, development and the embedding of nanotechnology. Equipment and expertise are available at the six locations for nanoscale manufacturing microreactors, MEMS and electronic and optical components for diverse applications. There are also diverse facilities available at the five locations for general nanoscale fabrication. In addition, each facility offers unique equipment and expertise for items like the fabrication of *quantum devices,* surface analysis, lithography and microfluidics. This approach, with facilities being geographically dispersed and complementary, has proven to be particularly effective.

On top of fundamental research in areas such as photonics, electronics, new materials and quantum technology, the facilities are also used for the commercialization of research by developing and testing prototypes and production of test series. Businesses, including start - ups, have access to equipment and expertise. They are also part of the *NanoLabNL community*. Long-term cooperation has led to the emergence of a unique ecosystem for research, development and commercialization that generates numerous innovations and provides employment to thousands of people.

In addition, NanoLabNL also facilitates research that is in line with the knowledge questions formulated within the top sectors and the National Science Agenda. Examples of this are nanostructured materials, regenerative medicine and the development of the quantum computer (QuTech). The initiative created in 2019 - PhotonDelta- will also be largely facilitated by NanoLabNL.

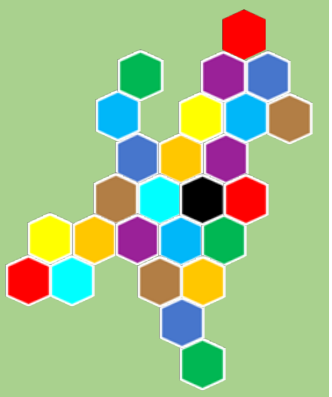
NanoLabNL has also taken the initiative to set up the EuroNanoLab consortium, which provides the facilities for research and links the development of key technologies in Europe. The ultimate goal is a Europe-wide infrastructure for nanotechnology, in which the participants each expand their own expertise and make it available. This way, they enlarge the spectrum of possibilities and technologies.

Infrastructure for nanotechnology

The scientific excellence of the locations and the effect of such high-quality ultra-modern facilities also reflected in the number of individual scholarships: 1 Nobel Prize; 9 Spinoza laureates; 16 Simon Stevin laureates; 47 VICI receivers; 2 ERC Synergy grants; 27 ERC Advanced Grants; 10 ERC Consolidator Grants; 30 ERC Starting grants. 4 Dutch 'Gravitation' programs are granted with substantial participations of researchers from the nanotechnology domain.

In Europe, the active role that the Netherlands has is in several work packages within the European Graphene Flagship which is made possible by the NanoLabNL facilities.

Future investments will have to continue to keep the facilities "State-of-the-Art". In the next 10-15 years, there are still plenty of opportunities to take advantage of nanotechnology. The Netherlands is well positioned to fully utilize new discoveries in the field, especially in the field of quantum and photonics.



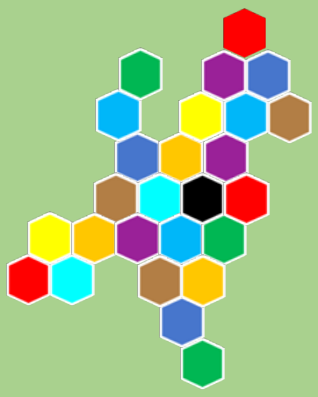
partners

2.5 ADDITIONAL INITIATIVES

Several organizations have been involved as strategic partners in the creation of NanoNextNL because they have adjacent or overlapping positions in nanotechnology. These partners, despite changing strategies and organizational positions, still have an important share of the development and application of nanotechnology. At TNO, who recently has merged its broader energy related activities with those of ECN, the Holst Center and Solliance have shared their retained research-based roles in the specific areas of flexible electronics, autonomous sensors and solar cell production technologies. In addition, Brightland Materials Center (BMC) has been established. The M2i organisation still fulfils its public-private matchmaking role, although it will soon be positioned as a wholly owned subsidiary of the holding company TUDelft Services BV. TIFN, Wetsus and ISPT organisations have maintained their roles in the field of food, water and process technology, while the former CTMM and TI-Pharma have merged into the new Lygature organisation that manages public-private partnerships to provide pioneering solutions in medical technology and pharmacotherapy.

During the implementation of NanoNextNL, the TI-COAST and hDMT organisations were established, which have similar functions for analytical science and represent the "organ-on-a-chip" area. More recently, The PhotonDelta organisation has taken a central position in the field of (integrated) photonics and a new organisation is created around the Electrochemical Energy Conversion & Materials initiative (ECCM). A very recent initiative is OnePlanet, where Radboud University, RadboudUMC, Wageningen University and IMEC collaborate on micro/nano solutions for agri-food and health related challenges.

After scientific successes in the field of quantum physics by Kavli Delft and TU/e, the Netherlands plays an important role in the global development and industrialisation of quantum computing and quantum technology. To stimulate these developments, QuTech, a consortium of TU Delft and TNO, was founded with important (international) private partners such as Microsoft and Intel. The development of a quantum computer makes extensive use of nanotechnology. Together, quantum and nano form a route within the national science agenda under the name of quantum/nano revolution and the (NAQT) National Agenda Quantum Technology.



society

2.6 RESPONSIBLE BUSINESS

To ensure that innovations meet the requirements and wishes, made from both the government and society, and to ensure the safety of people and the environment, risk governance is required. In the field of nanotechnology, the Netherlands has an internationally leading position to achieve competent risk management. Concepts developed in the Netherlands such as Green Deals, Safe by Design and Safe Innovation Approach are building blocks to develop risk management.

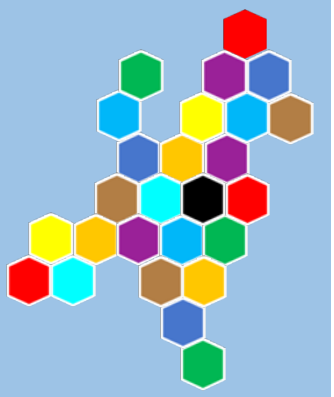
At the moment, however, there is still a lack of structure and instruments to promote technology development, social challenges and risk management to take place in conjunction. This gets in the way of an efficient approach to achieve mission goals. In addition, this also hinders the valorisation, because it is up to a lot of uncertainties which make investors reluctant.

Nano4society is the first partnership that not alone focuses on knowledge development and valorisation of knowledge, but at the same time offers an infrastructure in which participants are involved in developments in risk management and social acceptance to achieve an efficient and targeted innovation process. There will have to be much more co-creation by the participating stakeholders, but also the creation of 'trustworthiness' and 'trust' among stakeholders is critical to moving forward in the implementation of nanotechnology.

The Netherlands holds a very prominent position at both EU and global level in the area of the risk management of nano technology. Organisations such as RIVM, TNO and WFRS university groups form a powerful representation of the Netherlands in international activities. In various compositions, they are setting the agenda in the vast majority of H2020 projects in this area. RIVM is also NL representative in the OECD-WPNM, it provides direct expertise to European agencies such as ECHA and EFSA, and is internationally recognised as an initiator of concepts such as Safe by Design and Safe Innovation to support the achievement of objectives in the areas of climate, the circular economy and zero pollution.

RIVM is currently leading a prestigious H2020 risk management project, called Gov4Nano, in which both the societal aspects and the risk governance aspects are brought together.

The Ministry of Infrastructure and Water Management (minIenW) has now set up a program to extend beyond the field of nanotechnology initiatives to implement Safe by Design.



nano4society

3.1 NANO4SOCIETY

Nano4society is an umbrella program that focuses on identifying, clarifying and putting technological developments in perspective. It offers a platform for stakeholders to co-create and using its four substantive pillars based on the themes chosen by the Netherlands, to want to make an important contribution to mission-driven innovations. With this, Nano4society delivers essential contribution to challenges on all four major social themes: *health and care*, *energy and sustainability*, *agriculture, water and food*, and *safety*.

The Nano4society agenda is a follow-up to previous very successful programs NanoNed (including Nanoimpuls), and NanoNexNL. Where NanoNed laid the groundwork for exploring the then infancy of nanotechnology, NanoNextNL clearly sought and made the connection with the industry, partly through the strong link with MinacNed: more than 50 companies joined, and an active nano-network with representatives from the knowledge establishments, knowledge institutes, large and small and medium-sized enterprises and the government. This created an excellent foundation in the form of an intended *ecosystem* in support of achieving objectives in the areas of climate, the circular economy and zero pollution. The aim is to take steps in addition to knowledge development in the areas of security, regulation and social embedding and acceptance. Nano4society can build on the toolboxes that were developed in NanoNextNL, such as the Safe by Design toolbox and aspiration to FAIR databases.

With the strengthening of cross-sectoral connections, the road to market introduction and financing of new applications in the field of nanotechnology can be found even better. This will cause the industry to being increasingly encouraged to invest in research and development while in interaction with the market. To make this possible there is a need to bring (groups of) SMEs, larger companies with significant R&D activities in the Netherlands and research centers together. In particular smaller companies need to develop close relationships to provide sufficient body and continuity for larger national organizations and international clients in this domain. Additionally, one tight cross-linking in the Dutch ecosystem can prevent that startups lose their added value for the Netherlands after an 'exit' from financers after being sold to a foreign party.

The present Manifesto is focused on identifying the most promising applications and associated partners from the joint ecosystems to seize and build on common opportunities.

The activities connect with the Dutch mission-driven research domains: Nano4health, Nano4sustainability, Nano4agrifood and Nano4security.

The research activities are in line with the *European Green Deal*, a set of initiatives by the European Commission with the overarching aim of making Europe climate neutral in 2050.

nano4society

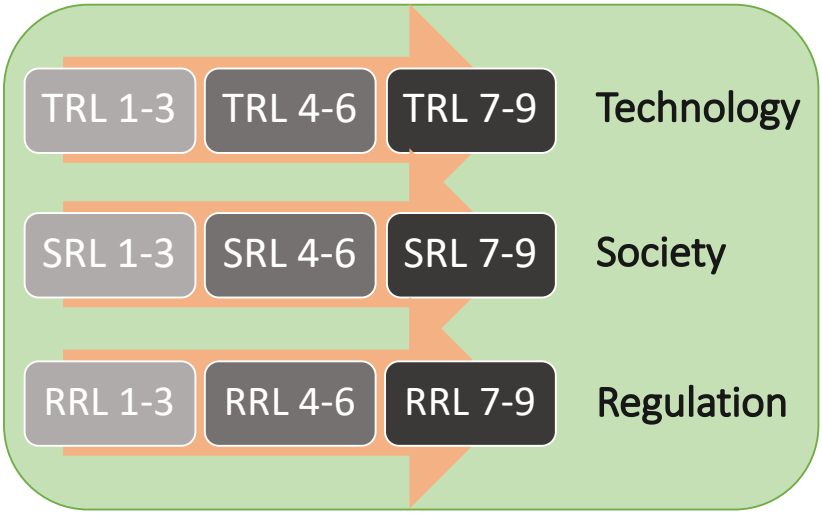
BUSINESS CASE

A new toolbox is needed to provide insight into the state of affairs regarding technological development, societal acceptance and regulatory embedding. The latter may include: standardization, normalization, internationally accepted guidelines and guidance's (both in OECD and in ISO). For this, in addition to the so-called technology readiness levels (TRLs), society readiness levels (SRLs) and regulatory readiness levels (RRLs) are being developed and brought together in one system.

NanoNextNL has resulted in companies that are currently virtually fully develop their services and products from the Netherlands and also produce here. These companies have a very high percentage of export. In many cases more than 80% of turnover. The added value for the Netherlands' revenue model for high-tech SMEs is then also high. A good Return on Investment both financially and from impact on society is high for this category of companies.

The value chain of research into impact could be further strengthened by advancing the technology to a higher TRL and RRL level. Scaleups will be required to serve global markets who use nanotechnology in their products so they must be able to produce large-scale. For this, the value chain and the ecosystem must be further developed by continuing to invest in research and development across the chain across all levels of TRL and RRL.

The issues from society on the four different themes require multidisciplinary cooperation, offering par excellence opportunities for the Netherlands. The Dutch open and direct culture ensures efficient and powerful teams that can work well together. Through organizing such collaborations around well-defined challenges with impact on society it is plausible that with targeted cooperation at world level, distinctive results can be achieved.



nano4health

3.2 LIVING HEALTHY LONGER

Nano4health focuses on the theme of health and care in particular. Nanotech enabled solutions make sure that people live high quality lives longer and are able to take care of themselves, with tailor-made care. Five more quality adjusted life years (QALY's) is a feasible ambition with the key being nanotechnology. The laboratory will increasingly go more and more to the people instead of people going to the laboratory, monitoring will take place more in the home environment, due to nanotech. Medication and treatment can be performed by nanotech-based microfluidics and lab a-chip solutions are more adapted to the individual (personalised medicine).

Nanotechnology based DNA analysis systems are used for analysing the whole genome, intestinal flora, cancer cells and much more. Organ-on-a-chip is expected to ensure faster drug development and reduction of animal testing.

Nanotechnology allows for better drug delivery and contrast agents for imaging techniques.

Nano-mechanically tuned materials and structural properties reduce rejection processes with implants, make wearable medical measuring and monitoring instruments possible and patient-friendly.

Due to the presence of HT-SME and a clear market demand for solutions, the chance of impact in the short and medium term is high. The time to market is mainly determined by regulation and financing.

ECONOMIC PERSPECTIVE

The ecosystem that has emerged has led to a large number of HT-SMEs with scale up potential and a good basic infrastructure that make the chance of economic impact very large. The mostly medical character of research and products creates a high demand for thorough research, validation and risk management. These are necessary to transform an innovation into a marketable and approved product. Timelines of 15 years of research and development are more of a rule rather than an exception. Investment into the already created ecosystem is therefore necessary to make use of the already existing investments made from the Netherlands to reap the benefits. The highly specialized market can also be developed in the short term (0 - 7 years) for medical research with instruments and devices to be provided. Through cooperation with prominent individuals, Medical Centers within the program are expected to have good market access.

With sufficient investments, the export potential for the Netherlands is preseverable and will make the sector an even more important resource of scale ups and export revenues. Many markets and market segments in which nanotech is the key to growth are growing a lot faster than the average market. Market growth of more than 15% is no exception.

PERSPECTIVE

What does the future of healthcare look like in 2050? A healthcare that keeps people healthy instead of *cured*. Would it be possible for every citizen to have a virtual twin (*Digital Twin*) in which all medical and health information has been processed? Nanotechnology is essential for gathering that information: nanotech based ultrafast DNA analysis, ultra-sharp medical images (PET-MRI, CT etc.) obtained with nanoparticles, nanosensors such as swallowable sensor pills, organs on chip of own cells, personalised and targeted administration of medications. These techniques make a big cost reduction in healthcare possible: with a *Digital Twin* many diseases can be *prevented*, the citizen can live a much better and longer independent life, while with organs on chip the costs and development time of drugs will greatly reduce. As the first step in disease prevention, a *Digital Twin* can play a major role through targeted tailor-made advice.

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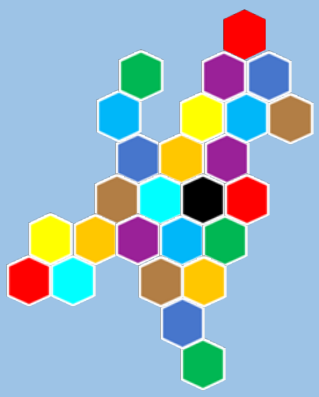


nano4security

3.3 SECURE SOCIETY

Nano4security will be of great added value for safety in the Netherlands, where technical innovations can also be tested at an early stage for expected product safety, impact on the environment and health, and social capacity.

Nanoforensic research: development of nanosensors, applicable for example with DNA research and nano-based sensors for detection of minute amounts of relevant substances in traces. Nano for food safety: for the health of consumers, and food security, for sufficient food and waste prevention.

Nano for safe clothing: development of protective clothing against aggressive substances and weather factors that meet contemporary health and safety standards.

Nano and fraud: developing methods of identification and authentication features on products; nano-based solutions for tracking and tracking products (track and trace) and technology for protecting sensitive communications for example via quantum communication.

Nano-enabled quantum security (secure internet). Nano for safety in traffic and living and working environment: optimal usage of new materials to make processes more efficient or combine functions; develop methods and tools in order to be able to measure unwanted or harmful substances.

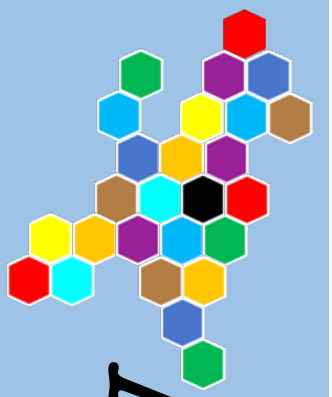
ECONOMIC PERSPECTIVE

The security sector offers plenty of opportunities for new companies. The sector will monitor developments in all technologies which are an influence on the safety of people and nature and must seriously follow and assess their impact. Reactions to these (possibly threatening) developments will also have to come from high-tech innovations. There seems to be a willingness to invest in technology, if it is applied in a result-oriented manner.

The Nano4security program builds on the NanoNextNL and therefore also makes use of the results achieved there. As a result, the technological maturity for some innovations is already reasonably high and are even used here and there. The size, complexity and the dynamics of the professional field however, also require more in-depth research to achieve the desired results. Because the program is embedded in an ecosystem of knowledge institutions and companies (large to small) the flow of results will go smoothly. In addition, it is linked with several large and, in part, already ongoing initiatives thus ensuring that the outcomes will be optimal. Additionally, assessment plays an important role in successful integration.

PERSPECTIVE

Security will become an increasingly important point of attention in the future. How do we get a grip on the advancing digitization and how we prevent unencrypted data from falling into the hands of others? How can we protect ourselves in the future against terrorist biochemical attacks? As citizens, do we keep a grip on the multitude of medical data being generated growing greater in size? Can we protect our own DNA code? What about food safety? In many cases, future nanotechnologies provide the solution. Nanophotonic data encryption plays an important role in the future, as do nanobiosensors that can identify a virus or micro-organisms extremely fast. But we may possibly get a fast “nano-inside” handheld DNA test or new nanocoatings in the future which protect surfaces from bacteria.



nano4sustainability

3.4 ENERGY TRANSITION

Lithium-ion batteries are the most popular rechargeable today batteries, as they have become the main power source for many applications, such as portable electronics, electrical tools and hybrid/all-electric vehicles. although enormous effort has been devoted to investigating the electrochemical performance of a large number of lithium-based materials, current rechargeable batteries show an energy density, longevity and safety which are still far below the theoretical capacities. None of the current rechargeable batteries can completely meet all challenging requirements for our current energy storage.

New research directions aimed at understanding ionic diffusion and electron transport and the regulation of reversible electrochemical reactions are crucial for developing batteries with strong improved energy storage and longer life. Nanotechnology and advanced materials, including innovative techniques for the making and shaping materials are the most important technologies because they enable intervention on the critical nano length scale.

In addition, research will be carried out to use nanotechnology for the reusability of materials, more sustainable use of energy and developing alternatives to plastics and insulation materials.

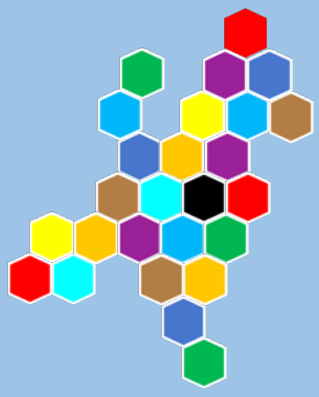
ECONOMIC PERSPECTIVE

In the field of sustainability, one will have to adapt to new standards. The climate agreement provides guidelines that will not be achieved without the innovative contribution that nanotechnology offers us.

A more conscious and efficient use of energy shows that other forms of energy flows are needed. The sector is going to work on standards that have a positive influence on people and nature. The entrepreneurs and ministries in this sector are joining hands for this and the willingness to invest in high tech solutions is big. The technological maturity for some innovations is already reasonable high and current applications are starting to come. The size, the complexity and dynamics of the professional field however, also demand more in-depth research to achieve the desired results. Because the program is embedded in an ecosystem of knowledge institutions and companies (from large to small), the flow of results will go smoothly. In addition, it is connected to a number of large initiatives, some of which are already in progress, thus utilisation of the results will be optimal.

PERSPECTIVE

How do we ensure a sustainable energy supply in 2050? Can we increase efficiency using nano technology, by say 50%? Can we reduce the capacity and the weight of batteries by a factor of 5 or 10 so that electric flying may also become possible? Or do we need to move to radically new nanoquantum concepts here such as *"spin batteries"* which, in principle, can be charged and discharged infinitely with almost unlimited energy content? Closer to home are innovative nano-electrochemical breakthroughs to make hydrogen from sunlight or electricity. A very different area is that of *Brain Inspired Computing*, where the unimaginable energy efficiency of the human brain serves as an example for totally new innovative calculation concepts that allow us to follow the trend of breaking through more and more energy-guzzling data centers.



nano4agrifood

3.5 HEALTHY AND SAFE FOOD

Nano4agrifood & water will be of great added value to people and nature. Good food and clean water are essential for the health and well-being of humans. However, it must be tuned to the needs of the body, individual preferences and sustainably produced. Nanotechnology is crucial in this. Nanosensors complete the range of parameters used in the primary production and post-harvest processing that must be monitored in order to optimise processes. Process innovations based on nanotechnology, such as membrane technology in separation processes, lead to more sustainable and circular production. Nanostructured ingredients, nutrients and pesticides ensure better delivery and therefore less loss and side effects. This all ultimately leads to optimal food quality and safety, less food waste and sufficient and pure water to the consumer with an as small as possible ecological footprint.

Food is a nanostructured material and also its processing in the body takes place at the nanoscale. Therefore, the possibilities of nanotechnology are used to realise better product properties and/or new functionalities ("Food/body interaction"), which fit in a preventive health care concept.

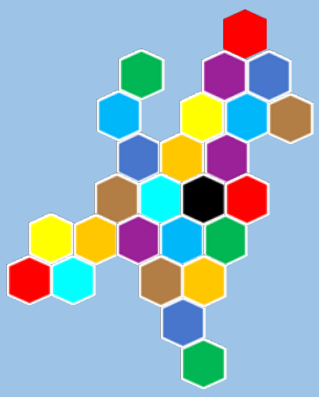
As a Key-Enabling Technology (KET), nanotechnology will hardly ever be visible directly in the end result, but it is essential before that. The program aims at utilisation and, if necessary, expanding the capabilities of nanotechnology to provide one sustainable way in our need for high quality food and clean water, and thus provide a healthy and enjoyable life safeguarded also for future generations.

ECONOMIC PERSPECTIVE

The agricultural and food sectors are permeated by the fact that something has to change radically because of the burden on nature and our environment. The entrepreneurs in these sectors are all looking for opportunities to improve that and many have their hope pinned on high-tech applications to provide relief. The willingness to invest in this is substantial.

PERSPECTIVE

Can we sustainably continue to provide the growing world population with food? Can we soon be artificially making meat based on vegetable proteins and switch from animal to vegetable protein? We already see an important role for micro-nanotechnology in the production and processing of food, and the Netherlands has global leadership thanks to advanced technology in this area. Micro and nanoemulsions for the texture of food, nanomembranes for protein-scale separation, nanoscale processing of vegetable proteins, but also for instance, nanosensors to precisely control vertical cultures, nano-indicators that determine whether food is still safe to consume and therefore reduce waste or swallowable nanopills or organs on a chip that determine per person precisely what and how much of the food is being absorbed into the body. Here too, a personal *Digital Twin* can give every citizen perfect, tailored advice.



safe by design

3.6 MISSION-DRIVEN INNOVATION POLICY

The government is facing the “double challenge” to associate policy goals around societal challenges and economic growth. This has led to an increasingly loud desire to putting societal challenges at the center of innovation policy. This mission-driven innovation policy aims to resolve social challenges, and endeavours in these areas strengthen competitive position and achieve economic growth. Social missions often require a combination of changes in technology, institutions (rules of the game) and behaviour.

To ensure that innovations meet the requirements and wishes made by both the government and society to safeguard the people and the environment requires so-called risk governance. In a world in which many transitions are involved, the need for a flexible and a resilient form of risk governance is of great importance. The need for this has previously been indicated for topics such as artificial intelligence and "the 4th industrial revolution", but it is certainly under discussion for key technologies. The Netherlands has a leading international position in the field of nanotechnology to achieve so-called agile risk governance. Concepts developed by the Netherlands such as Green Deals, Safe by Design and Safe Innovation Approach are building blocks to develop agile risk governance.

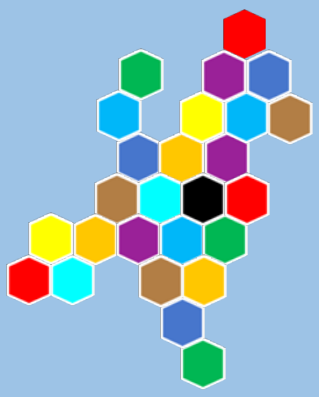
At the moment, however, there is still a lack of structure and instruments to promote technological development, social challenges and agile risk governance to take place in conjunction. This hinders an efficient approach to achieving mission goals but it also hinders the valorisation of knowledge because it leads to a lot of uncertainties that make investors reluctant.

Nano4society is the first partnership that not only focuses on knowledge development and valorisation of knowledge, but also an infrastructure in which participants are involved in developments around risk governance and social acceptance to in this way to achieve an efficient and targeted innovation process. This approach fits in perfectly with the preconditions that are required to achieve successful mission-oriented innovation. There must be much more mention of *co-creation* by participating stakeholders and consumers, but also the creation of 'trustworthiness' and 'trust' among stakeholders is critical to moving forward in the implementation of nanotechnology.

The Nano4society organisation builds on the foundation for the ecosystem that is laid in NanoNextNL. Nano4society is one organised ecosystem in which research institutions, companies and government reinforce each other. The setup of one system and associated infrastructure to provide knowledge and to consider innovation tasks integrally with social and public values will increase the chances of application and enable implementation of innovation.

HUMAN HEALTH NANO

Nanomaterials are already produced in large quantities and it is expected that in the coming decade, there will be many new nanoproducts on the market every year to come. It is important for companies to produce sustainable products that comply with regulations. To avoid regulatory difficulties and negative market perception of nanomaterials, clear conclusions and communication about health risks of nanomaterial are necessary. This will help support the commercial success of research and innovation in the sector of nanomaterials in Europe. Knowledge is being developed together with TNO and others to help industries take the safety of their (nano) product into account during the development phase. Innovative tools, guidance and training contribute to risk management within the industry, especially in this situation where clear guidelines are missing.



fundamentals

3.7 DEVELOPMENT BASIC COMPETENCIES

The foundation of Nano4society is laid by a number of basic technologies and competencies necessary for multiple missions and applications. In the Netherlands, we have a clear strength in most of those areas both in the field of knowledge but also in the form of businesses. The strength of a coherent and overarching Nano4society program is that it enables the cross-pollination between the different missions, and offers space for developments that are necessary to the mission-driven research. Two important basic competences are elaborated elsewhere: the shared developments in the field of corporate social responsibility (Safe by Design), and the joint management and use of infrastructure (NanoLabNL). In the field of relevant basic technologies, there will be collaboration with initiatives in other key areas, such as with Materials in the field of (artificial) nano-materials, biotechnology in the field of molecular and systems biology and with photonics in the field of nano-photonics and devices. In a number of specific Nano technology basic technologies, there are excellent opportunities for further development through strong knowledge and business infrastructure that we have in the Netherlands.

For example, this concerns:

nano and microfluidics, needed for hand-held diagnostics and organ-on-a-chip like developments in Nano4health but also for water and food applications;

production equipment for e.g. thin layers and nano-devices for applications in all missions;

nano-analysis equipment used for inspection and metrology for nano-materials, thin layers, nanoparticles and nanodevices for applications in all missions;

nano sensors that can be widely deployed on applications in agrifood, water and health.

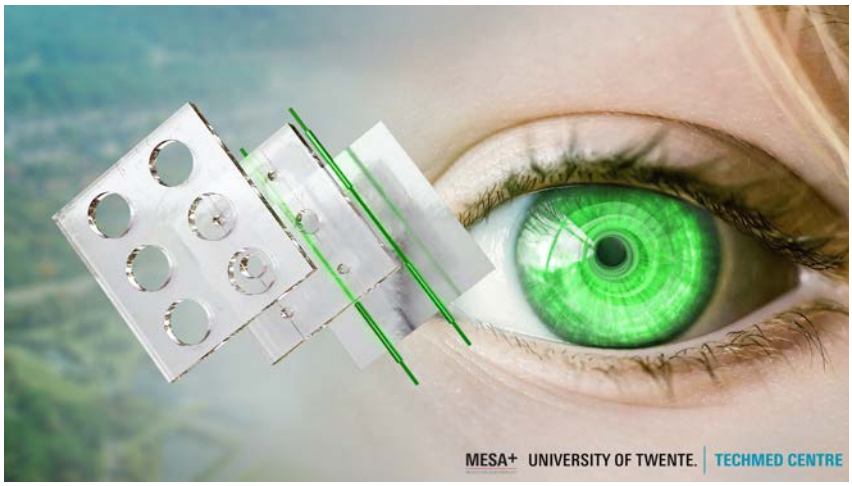
missions / **technologies**	agriculture water, food	health & care	safety	energy & sustainability	along with key technology
nano-fluidics					
molecular and synthetic biology					biotechnology
Nano-sensors					
nano-photonics & devices					photonics
nano-analytical & production equipment					
(artificial) nano-materials					materials

questions

4.1 NANO-INSIDE

Nanotechnology can contribute as key technology to various social issues. Oftentimes, the developments within nanotechnology are essential to take important steps. Within the Nano4society program innovation lines are set out where knowledge institutions, business and industry civil society organisations work together to find solutions. These innovation lines do fall under the four missions, but are largely overlapping. Below, a number of applications in which nano will play an important role are listed.

- Developing organ-on-a-chip systems that mimic diverse interacting organ systems for better understanding of diseases, testing of medications, food, cosmetics, chemicals etc. and for example, personalising treatment (*example eye on chip, see picture*).

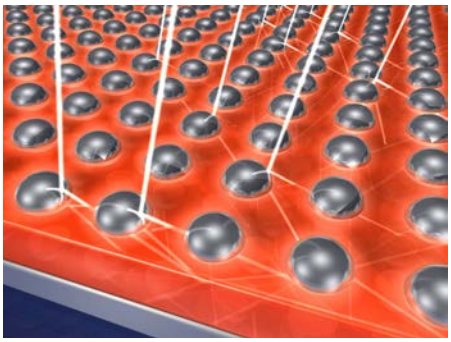


- Organ-on-a-chip systems that lead to a reduction in animal testing and possibly to a faster and safer route to make products available (shorter time to market).
- Designing new techniques and developing nanoparticles for cell-specific drug delivery and active drug targeting for, among other things, imaging techniques.
- Application of nanosensors combined with self-management by (home) monitoring of health through wearables and insideables.
- Applying (functional)nanosystems that control the behaviour of tumors which reprogram the microenvironment of tumor and thus inhibit growth.
- Developing preparation techniques involving atomic control about the composition and structure of materials can be realised.
- Influencing at the nanoscale, with advanced techniques and artificial intelligence methods (self-learning machines), from the physical and chemical properties of materials to improve these properties.
- Integration of the properties of electrons, photons, ions, spins, phonons, etc. that act specifically at the nanoscale, efficiently integrate into sensors and devices to improve sensitivity and applicability in health and intensive agriculture, but also for low power communication and energy storage.

questions

NANO-INSIDE (continued)

- Use semiconductor technology to connect devices and circuits that go beyond conventional scaled CMOS technology (More than Moore).
- Development of energy-efficient ICT devices and circuits such as alternatives to the current energy-intensive computer architecture, for example, based on neuromorphic techniques which are based on the efficient functioning of the human brain.
- Use integrated photonics for developing extremely sensitive optical sensors. Combining electronics and photonics in integrated circuits.
- Developing sensors based on the quantum properties superposition or entanglement that lead to higher sensitivities and lower detection limits.
- Realising photovoltaic cells with a higher efficiency than conventional cells based on stable, durable, non-toxic and recyclable materials.



Nanophotonic design for improved photovoltaics (Albert Polman, AMOLF)

- Nanotechnology for safe clothing: protective clothing against aggressive substances and weather factors that meet health and safety standards.
- Nanosensors for sustainable food production and monitoring of food products.
- Study of food-body interaction with regard to efficient absorption of food, allergies, digestive problems.
- Determination of nano indicators that determine whether food is still safe to eat to consume and thus reduce waste.
- Membrane technology for water filtering and separation processes which lead to a more sustainable and circular production.
- Optimisation of ingredients, nutrients and pesticides that provide quality and ensure the safety of food and water.
- Nano-electrochemistry for energy conversion.
- Nano-based batteries, ionic diffusion and electron transport and the regulation of reversible electrochemical reactions. Nanomaterials that are reusable, durable in the use of energy or are a sustainable alternative to plastic.

programs

ENERGY & SUSTAINABILITY:

Nano-electrochemistry for energy conversion;

nanomaterials for batteries and solar cells;

nanomembrane technology for CO_2 capture;

nanoelectronics (Green ICT).

AGRICULTURE

Nanosensors, for sustainable food production and monitoring of food products;

nanoscale adjustment of properties of ingredients

HEALTH

Personalised medicine with lab-/organ- on-a-chip and microfluidics technology;

nanotech based **DNA analysis** techniques;

(home)monitoring of health (**wearables**, **insideables**).

SECURITY:

Nanodevices for quantum computing and encryption (**nano-photonics**);

nano-based data storage technology (DNA encoding);

nano for forensic research.

WATER & FOOD

Food-body interaction: efficient absorption food, allergies, digestive problems;

membrane technology for water filtering.

programs

VALORIZATION

Continuation of the developed and successful valorization program of NanoNextNL (**evaluation Technopolis**).

SAFE BY DESIGN:

Safe by Design: risk management, risk analysis and (eco)toxicity of nanotechnology.

CARE

Animal-free research;

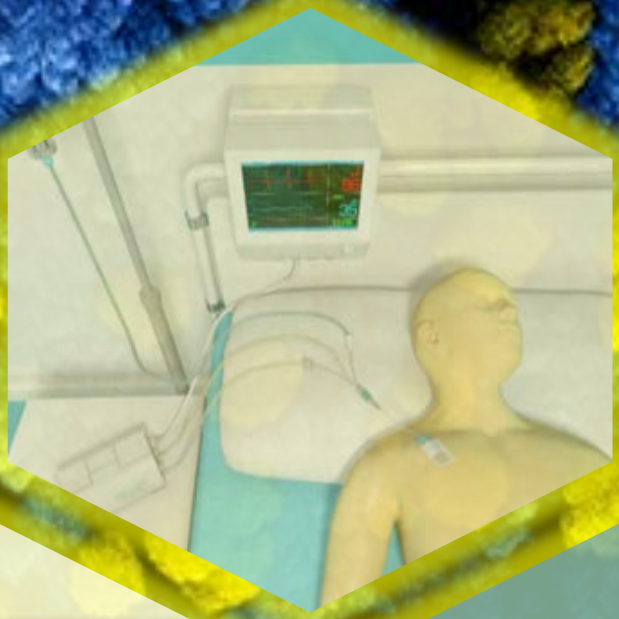
Organ-on-a-chip for development of medications;

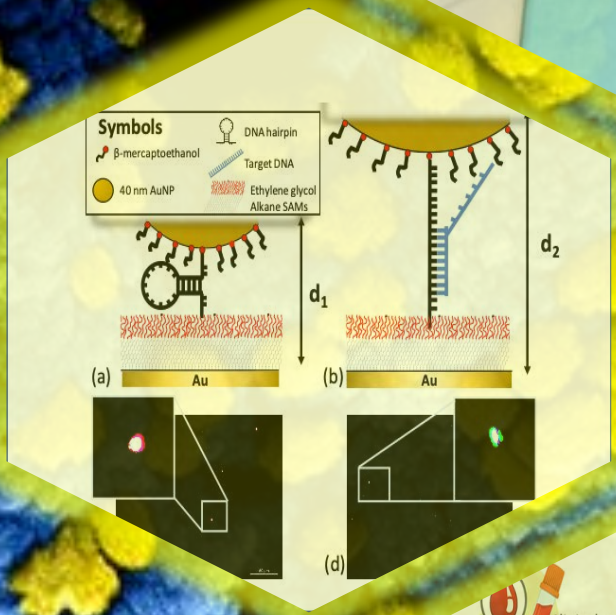
nanomedicine; targeted drug delivery and nanoparticles for enhanced imaging.

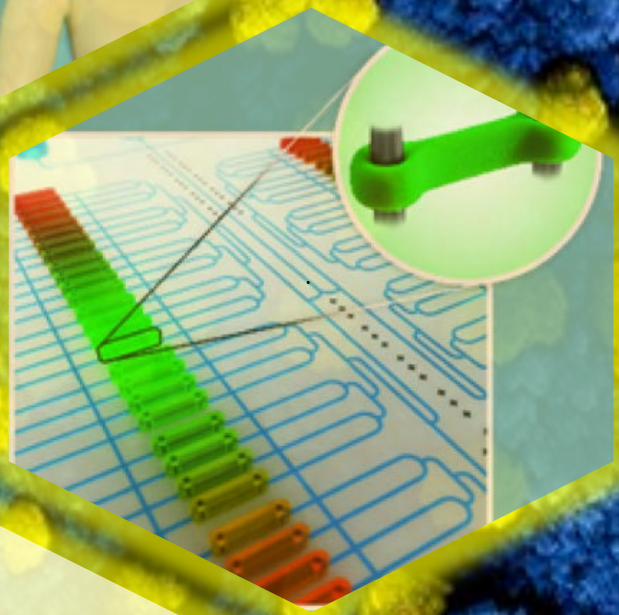
RISK GOVERNANCE

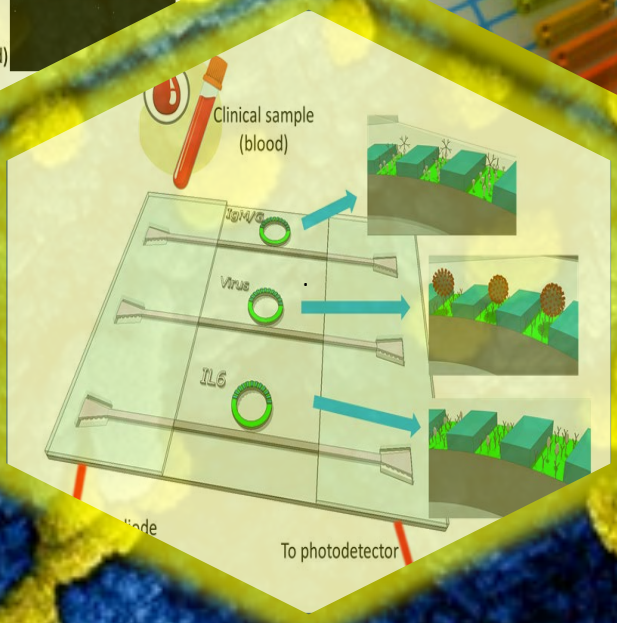
Signalling relevant developments, sharing knowledge, stimulating collaboration within Nano4society, missions and stakeholders.

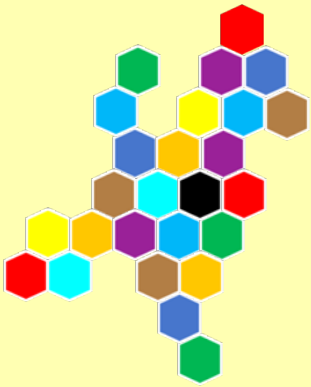
COVID-19




Symbols
β-mercaptoethanol
40 nm AuNP
DNA hairpin
Target DNA
Ethylene glycol
Alkane SAMs
d1
d2
(a)
Au
(b)
Au
(d)




Clinical sample
(blood)
TNFα
Virus
IL6
To photodetector



SARS-CoV-2

4.2 COVID-19 RESEARCH PROGRAMS

A good example that shows that nanotechnology can make a significant contribution to rapidly emerging societal challenges is the outbreak of the SARS-CoV-2 virus. Early diagnostics, targeted medicine, organ-on-chip, etc. are examples in nanotechnology that are strongly linked on virus detection and analysis. COVID-19 brings uncertainty, but also opportunities for Dutch companies in nanotechnology. This highlights the enormous innovation potential in the sector. Since the outbreak of the SARS-CoV-2 virus, several existing research programs and new ideas are being utilized in the health sector in particular. Activities of the past years are now becoming urgent. A selection of activities is summarized, most of these have their origin in the NanoNextNL national program. Most research here presented is carried out in collaboration between universities, institutes and SME's.

Continuous COVID-19 patient Cytokine Storm monitoring (TU/e)

Developing a biosensing technology, based on Biosensing by Particle Mobility for the continuous monitoring of patients. Focus is on monitoring the inflammatory markers, which is crucial for patients who are at risk of Cytokine Release Syndrome or Cytokine Storm.

Optical SARS-CoV-2 multiplexed sensor (various)

Building a multiplexed optical sensor based on microring resonators. The device will simultaneously detect the SARS-CoV-2 virus, the presence of IgG/IgM antibodies and of IL-6 cytokines, which are markers for severe inflammation. The sensor will deliver the test results within minutes of loading the sample (i.e., blood serum or plasma).

Rapid SARS-CoV-2 virus detection using Nanoparticle LSPR (UT)

Optical single sensing-step DNA sensor using hairpin-DNA has been developed. The read-out is based on the displacement of gold nanoparticles (AuNPs) attached to hairpin-DNA relative to an Au-surface upon target binding and observed by darkfield microscopy as a color change from red to green. This detection method is exploited for the detection of several genomic diseases and pathogens, like SARS-CoV-2.

Serum test for SARS-CoV-2 antibodies (Interfluidics)

Utilizing a screening platform, based on Surface Plasmon Resonance imaging, for patient sera in high throughput (96 simultaneously) for antibodies of a single recombinant part of the virus. The ratio IgG/IgM response can be measured for obtaining the status of COVID-19.

Nanotechnology-based ultra-rapid COVID-19 test kit (SPEKTRAX)

SPEKTRAX strives to democratize medical diagnostics by making it more accessible and affordable throughout the world. They have developed a proprietary testing method, based on existing laser, groundbreaking nanotechnology, and modified Raman spectroscopy, that is able to detect which molecules are present in a liquid sample. We utilize nanotechnology to enhance the signal of a Raman laser, which enables us to see at a molecular level what kind of composites are present in a throat or nostril swab. As a result, we can rapidly detect the presence of a virus, but currently, we focus solely on COVID-19.

SARS-CoV-2

COVID-19 RESEARCH (continued)

Painfree Nanovaccination (Rivas, UT)

Deploying worldwide vaccines, such as required for the COVID-19, would benefit from requiring less vaccine volumes, particularly for prime-boost protocols that entail several injections. A portable prototype for the effective delivery of a jet, size of a hair, with controlled depth and volume and with minimal damage to the skin is under development.

Organs-on-Chips for better COVID-19 treatment (hDMT)

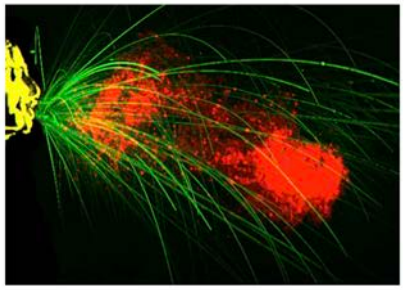
Why does the disease lead to such serious complications in one patient, but not the other? What is the most promising target to develop a new drug? Are there new types of treatments that are potentially effective? And are such experimental treatments actually safe? In order to quickly provide answers to these questions, organ-on-chip studies that realistically mimic the patients' bodies will be utilized.

Lab-on-chip applications for SARS-CoV-2 (Micronit)

Besides next generation sequencing and in vitro diagnostics offer Lab-on-a-chip systems serology opportunities. Analyzes that show the presence of antibodies against a particular virus in the blood, indicate whether there has been an infection in the past and may also potentially indicate the degree of antibodies measure. There is a great need for such accurate tests, which can monitor the immunity of individuals.

Respiratory droplet spreading (Lohse, various)

To mitigate the COVID-19 pandemic, it is key to slow down the spreading of the deadly Corona virus. This spreading occurs through virus-laden droplets expelled at sneezing, coughing, singing, speaking, or even breathing. Unfortunately, surprisingly little is known on the characteristics and fate of such droplets. Fluid dynamics and flow physics will be used to solve these key questions.



High-speed imaging visualization of the sneezing process: in yellow the head, in green the trajectories of single large drops, which behave ballistically. On the other hand, the turbulent jet of humid, warm air containing many small and tiny droplets of saliva and mucus is seen. The cloud of these droplets can remain in the air for many minutes (from Lydia Bourouiba, MIT)

Functionalized nanomembranes for SARS-CoV-2 virus detection (WUR)

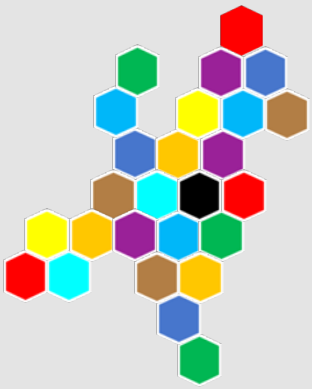
Functionalization of the membrane through layer-by-layer modification which adds layers that are in the nanometer range to the membrane surface leads to attachment of the virus to the membrane surface where it then readily can be detected. Further functionalization with e.g. silver nanoparticles can even lead to inactivation of the virus. Since the concentration of viruses is in general very low, a relatively large amount of air, or liquid needs to be treated in such a way that the virus is either concentrated, or accumulated on the membrane.

Rapid Virus Detection Assay – RAVIDA (TUD)

Rapidly spotting viruses in body fluids, based on microfluidics combined with surface enhanced Raman spectroscopy for the detection of antibody-antigen reactions. Due to the microfluidic system, which guides the fluidic streams that carry the virus to the bioconjugated antibodies, the incubation period will shorten. The goal is to obtain the result of the assay within 15 minutes after sampling a patient.

financials

5. BUDGET



Indication of required average **annual** funding (**tot**) needed is in M € for the period of 2020-2023 to realise the Dutch ecosystem and what is committed (**com**) by the various stakeholders. This budget has been drawn up for knowledge and innovation agenda KIA 2019.

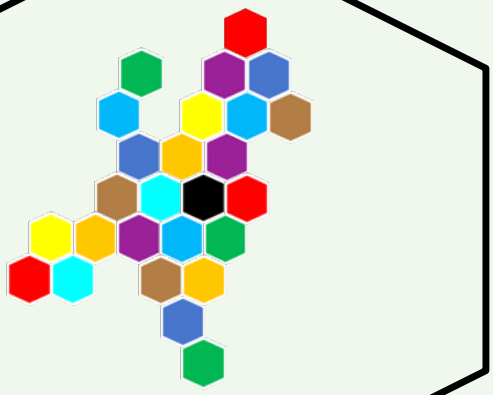
	health		security		agrofood		energy	
	tot	**com**	**tot**	**com**	**tot**	**com**	**tot**	**com**
Private	10,5	3,5	3,0	1,0	10,5	3,5	6,0	2,0
PPS toeslag	1,8	0,7	0,5	0,2	1,8	0,7	1,0	0,4
TO2	0,7	O,4	0,2	0,1	0,7	0,4	0,4	0,2
NWO	4,2	2,8	1,2	0,8	4,2	2,8	2,4	1,6
Uni/HO	5,3	4,2	1,5	1,2	5,3	4,2	3,0	2,5
Regionaal	3,5	1,8	1,0	0,5	3,5	1,8	2,0	1,0
Departementen	8,8	-	2,5	-	8,8	-	5,0	-
EU	5,3	3,5	1,5	1,0	5,3	3,5	3,0	2,0
ROMs & InvestNL	8,8	1,8	2,5	0,5	8,8	1,8	5,0	1,0
Anders	1,4	-	0,4	-	1,4	-	0,8	-
Totaal	**50**	**19**	**14**	**5**	**50**	**19**	**29**	**11**

COLOPHON

This Dutch nanovision 2030 is the result of consulting experts in the field of micro and nanotechnology with regard to the entire chain of science, spin-off, start-up, SMEs, large companies and end users.

Editorial: Dave H.A. Blank & Albert van den Berg

Design: ID'S 4 ALL SUPPORT FOR STARTUPS



nano4health

nano4security

nano4society

nano4sustainability

nano4agrifood