UNLEASHING THE POWER OF SMALL

NANOLABNL, THE NATIONAL NANOTECHNOLOGY INFRASTRUCTURE IN THE NETHERLANDS

EXECUTIVE SUMMARY

How a sustained nanotechnology infrastructure can prepare the Netherlands for a role in global transitions

NanoLabNL: the national open-access infrastructure for nanoresearch and nano-innovation

NanoLabNL is the Netherland's national facility for nanotechnology and one of the leading consortia of its kind in Europe. Its open-access infrastructure for R&D at the nanoscale is utilised by over 1300 researchers and more than 90 companies. It thus hosts many public-private partnerships. NanoLabNL is co-ordinated as one infrastructure while its facilities are distributed over five cities: Groningen, Enschede, Amsterdam, Delft and Eindhoven. Each of the cleanrooms in NanoLabNL is a hub where nanoscientists such as quantum engineers, smart-materials designers and medical scientists from both academics and industry meet to fabricate, characterise and experiment with nanodevices. Some do fundamental research; others focus on product development. Without this infrastructure, they could not even dream of doing new research or developing new devices.

NanoLabNL is indispensable if the Netherlands wants to play a role in global transitions

NanoLabNL hosts key enabling technologies that are at the heart of several huge transitions that society faces today: towards clean energy, a safe society, personalised health care and sustainable agriculture. The aim is to solve huge societal challenges with innovations rooted in fundamental research. NanoLabNL is a crucible for performing such groundbreaking research, for training new generations of skilled high-tech workers and for developing innovative products. If the Netherlands wants to play a part in the impending global transitions, NanoLabNL is indispensable.

Only one way to perform competitive nanoscience

The promises offered by nanotechnology are emerging from the continuous and uniquely rapid development of high-end equipment. This means there is only one way to perform competitive nanoscience: by continuously investing in equipment that is at the absolute forefront of performance. This is simply too costly to do without public funding, yet it has become increasingly difficult to secure the necessary investments in a sustainable manner. Therefore sustainable funding and embedment in national policy is crucial.

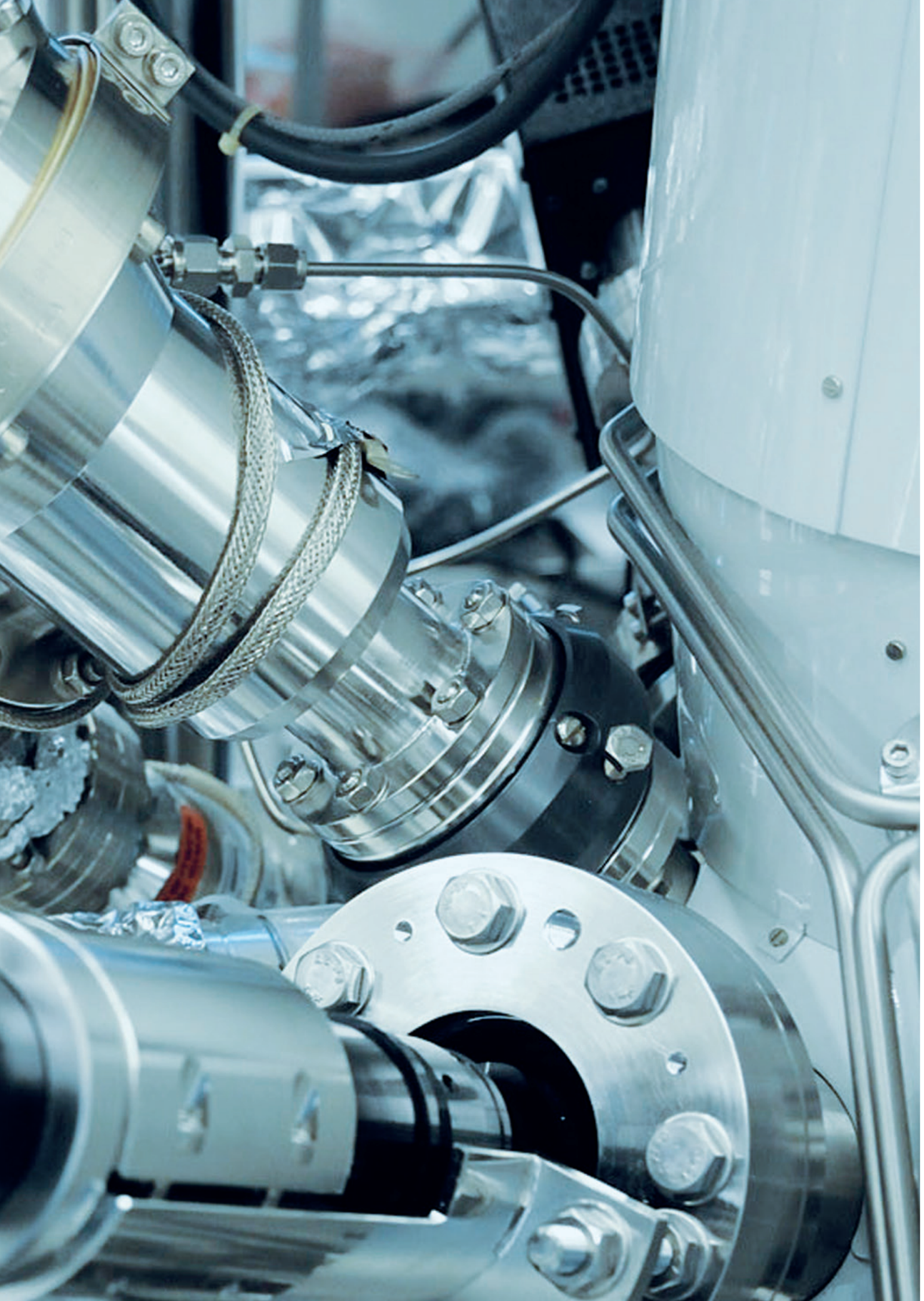
Backbone for public-private ecosystems, talent magnet and driver of frontier research

If its level of excellence is sustained, NanoLabNL can form the backbone for vibrant public-private ecosystems, enabling the Netherlands to come up with the innovations the world needs now. It is a magnet for talent and a driver of frontier research. Moreover, being centrally co-ordinated and building on existing infrastructure, NanoLabNL delivers this in an efficient and effective way.

NanoLabNL is open to strategic partnerships

It takes a great diversity in strength and expertise to face up to today's technological and societal challenges. Therefore, NanoLabNL reaches out to partners beyond its current ecosystem, be they from research, industry or government. Do you see an opportunity to join forces? Please get in touch! NanoLabNL is ready to play an integral part in any co-ordinated national effort that can employ the power of small.

NANOLABNL Key to a vibrant public-private ecosystem



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HOW CONTROLLING THE VERY SMALL CAN HELP WITH HUGE TRANSITIONS

Vast possibilities

Small things can still be very strong. While modest in land mass and population, the Netherlands scores high in international innovation rankings. One key enabler of the current Dutch competitiveness is an increasingly rapidly expanding branch of science that operates on a tinier-than-tiny scale: Nanotechnology. It involves the growth and sculpting of matter at a scale of 1 millionth of a millimetre, the level of atoms and molecules. When you go this small, nature starts behaving in surprising new ways. If one were to crumble a lump of gold into nanoparticles, for instance, their colour would not be yellow but red, purple or green, depending on their exact sizes. In essence, the physical and chemical properties of matter change radically when it is controlled at the nanoscale. This phenomenon not only offers fascinating science that can revolutionise our understanding of matter, it also opens up vast opportunities for technological innovations – innovations that will help us solve urgent societal problems and create sustainable economic value.

Science and technology that make use of the power of small – including quantum technology, photonics and advanced materials science – are at the heart of some of the huge transitions the world needs to make. These include transitions towards clean energy, a safer world, more effective and affordable health care, and sustainable agriculture that can feed a growing population. Concrete products include superefficient solar cells, compact batteries for storing energy, safe global communication networks supported by quantum encryption, vastly improved communication and computing using light to handle big data flows at low power consumption, nanosensors that can detect just about anything from cancer to explosives, smart filters for clean water and food production, early diagnostics through ‘lab-on-a-chip’ technology or personalised medical treatment thanks to ‘organ-on-a-chip’ technologies.

Well-positioned for a prominent role

The Netherlands is well positioned to play a prominent role in global transitions thanks to its first-rate universities, highly trained workforce and excellent track record in innovation.
Many of the scientists and engineers working on key enabling technologies experiment and develop things at the nanoscale. They do this because they need the ‘special effects’ that can only emerge on such a small scale, because they want to manipulate a material at the most fundamental level, or simply because they want to miniaturise devices and components. Nanotechnology is therefore a primary enabler for scientific and technological progress. And luckily, the Netherlands is excellently equipped for R&D at the nanoscale, thanks to its well-co-ordinated infrastructure: NanoLabNL.

WHAT IS NANOLABNL ?

NanoLabNL is the national infrastructure for nanotechnology in the Netherlands, providing an open-access infrastructure for R&D at the nanoscale. The network of facilities is distributed over seven labs in five cities: Zernike Nanolab in Groningen, MESA+ Nanolab in Enschede, AMOLF NanoLab in Amsterdam, Kavli Nanolab, Else Kooi Laboratory and TNO Nanolab in Delft and NanoLab@TU/e in Eindhoven.

NanoLabNL offers the use of facilities to universities, research institutes, start-ups and industry. The seven laboratories are managed as one infrastructure to co-ordinate investments, supplement and enhance each other’s work and exchange best practices. Thanks to this co-operation, the Netherlands as a whole can provide the infrastructure for the full spectrum of nanoresearch, both fundamental and applied, as well as proof-of-concepts, demonstrations and small-scale production. Together, the available tools, processes and techniques facilitate a range of research from biotechnology to integrated photonics and from quantum engineering to photovoltaics.

Cinzia Silvestri on how a start-up was born in NanoLabNL

Dr Cinzia Silvestri is CEO and co-founder of Bi/ond, a start-up company developing organ-on-a-chip technology at the Else Kooi Laboratory.

‘By spending time in the Else Kooi Laboratory, talking to people involved in a myriad of different fields from biomedical to quantum computing, you realise how a single material can be multipurpose. Organs-on-chips have been built with a rudimentary technique. We thought: why not bring in an added value with microelectronics?

‘Doing microelectronics is like cooking. Once you master the basic techniques, you can push the boundaries – like adding exotic ingredients to a traditional dish – thus building bridges between different fields. Creating an organ-on-a-chip using the fabrication technology of mass-produced computer chips results from this out-of-the-box thinking.

‘Applying microelectronics to consumer technology is nice, but it is even more rewarding to use it to reduce animal testing and create personalised medicine. The first time I saw heart cells beating on our chip, I found it unbelievable! It gives you satisfaction to know that you are working towards a greater good.’

David Reinhoudt on the roots of NanoLabNL and why it is a collective undertaking

Prof. David Reinhoudt is emeritus professor of supramolecular chemistry, former director of the MESA+ Institute at the University of Twente and a co-founder of NanoLabNL.

‘I think NanoNed was the first large, multidisciplinary research programme in the Netherlands. Multidisciplinarity was still rare when we started out, in the nineties. But to make any progress in the nanofield – to make a lab-on-a-chip for instance, or a medical sensor – you need chemistry, physics, electronic engineering, optics, mathematics, social science, etc. So for purely scientific reasons, different groups had to work together in order to do nanoresearch anyhow. That multidisciplinary aspect was and still is typical of nanotechnology.

‘Another reason to pull together was that the infrastructure needed to do research at the nanoscale was so expensive that it was impossible for any one university to buy it. For that reason, Hans Mooij (of Delft), George Robillard (of Groningen) and I ventured out together. When we got the large subsidy from the ICES-KIS fund in 2004, we co-ordinated who would buy what devices. We had a good rapport; we did not begrudge each other our success. It worked out fine, and it should continue to work out fine.’

2

NANOLABNL: MAKING A LITTLE GO A LONG WAY

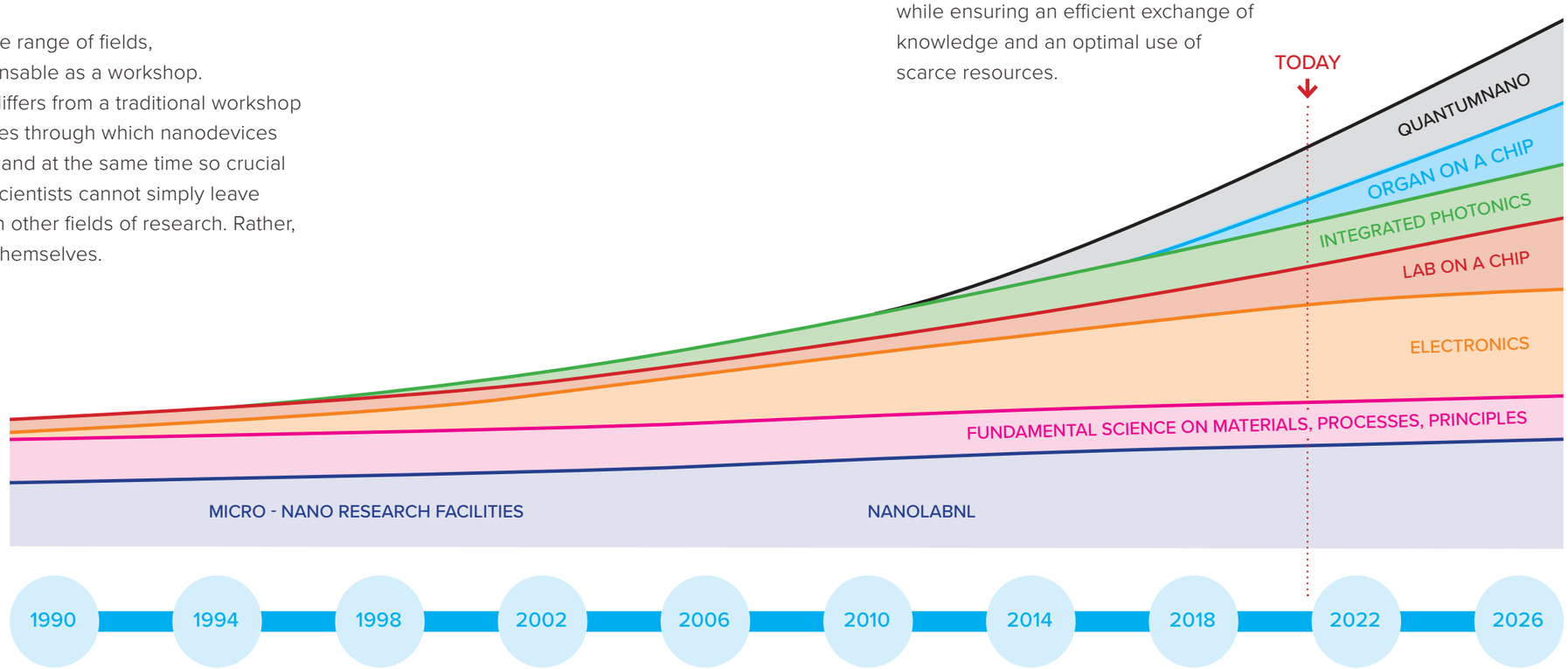
More than the sum of its parts

The number of different areas that nanotechnology serves – from materials for energy to biotechnology and from quantum engineering to integrated photonics – is far too large for a single location in the Netherlands. Some 1,300 researchers each year need direct access to local facilities. What makes their science excel is an immediate turn-around of device fabrication, characterisation and experimentation, which together form the cycle of development.

To the various researchers in this diverse range of fields, nanotechnology facilities are as indispensable as a workshop. Nonetheless, a nanofabrication facility differs from a traditional workshop in two essential ways. First, the processes through which nanodevices are made are so challenging to control, and at the same time so crucial for the functioning of the devices, that scientists cannot simply leave them to skilled technicians, as is done in other fields of research. Rather, they need to perform those processes themselves.

A second unique property of a nanofabrication facility is that the groundbreaking promises offered by nanotechnology emerge from the continuous and uniquely rapid development of the capabilities of high-end equipment. This equipment development is fuelled in great part by the extreme speed at which the semiconductor industry advances. Thus there is only one way to perform competitive nanoscience: by continuously investing in equipment that is at the absolute forefront of performance.

The challenges that these two characteristic aspects of a nanofabrication facility pose are best met through co-ordination and collaboration. NanoLabNL does just that, by offering facilities that provide the needed local access while ensuring an efficient exchange of knowledge and an optimal use of scarce resources.



Applications of nanotechnology emerging in different areas over time

Source:
Dutch Roadmap Nanotechnology

Wiebke Albrecht on the importance of state-of-the-art experimental infrastructure

In May 2021, Dr Wiebke Albrecht started her Hybrid Nanosystems group at the Amsterdam research institute AMOLF, one of the NanoLabNL locations.

‘My specialisation is studying single nanoparticles with a combination of optical techniques and advanced electron microscopy. It is fundamental research, but the nanoparticles I study are extremely promising as enablers of new technologies. Once we understand their behaviour, we can use them for a wide range of applications: from hypothermic cancer therapy to solar harvesting.

‘To me, state-of-the-art cleanrooms are a key feature of AMOLF. If we want to cross new boundaries in nanofabrication and nanocharacterisation and test new ideas, we need cutting-edge technology. I like the way AMOLF stays ahead of new technological developments, and I will be a part of that myself by co-creating new equipment with specialised tech companies. In this way we will not only be able to follow the technology, but also drive it.

‘I think it’s amazing that through NanLabNL and other Dutch networks, expensive infrastructure is made accessible. Ideally you would collaborate on a supranational scale, but you have to start somewhere. It’s a good thing that this is happening, and it’s also one of the reasons why the Netherlands is a good place to do research.’

Albert van den Berg on the unique character of NanoLabNL

Prof. Albert van den Berg is professor of lab-on-a-chip technology at the University of Twente and chairman of Nano4Society, a research programme strongly associated with NanoLabNL.

‘NanoLabNL offers national coverage, ensuring that researchers in each location have access to the right equipment. This makes the Netherlands unique. Where other countries have more internal competition between the laboratories, there are no competitors here. Everyone collaborates in NanoLabNL. By networking and perhaps by being more efficient, we can maintain similar facilities more cost-effectively than other countries do.

‘NanoLabNL has many benefits. Its first priority is educating young people, second comes inventing and developing new technology, third is valorisation: bringing new technology to the market. If only half of these valorisations is successfull, we are doing well! NanoLabNL is like a flywheel, continuously reinventing itself.’

Through smart specialisation, NanoLabNL is more than the sum of its seven parts – not only in cost-effectiveness, but also in putting together minds and expertise. NanoLabNL's leaders are all internationally renowned scientists who are capable of looking far ahead. They can recognise the lines of research that hold promise for the next decades and furnish the labs accordingly, so that their users can always be at the forefront of science.

While all seven laboratories naturally have similar basic facilities, each one has its own specialisation and key areas of strength. Expertise in quantum technology is concentrated in Delft, for instance, while Eindhoven focuses on integrated photonics and Twente specialises in lab-on-a-chip research. Amsterdam has great strength in nanophotonics, and Groningen a longstanding programme on nanomaterials science.

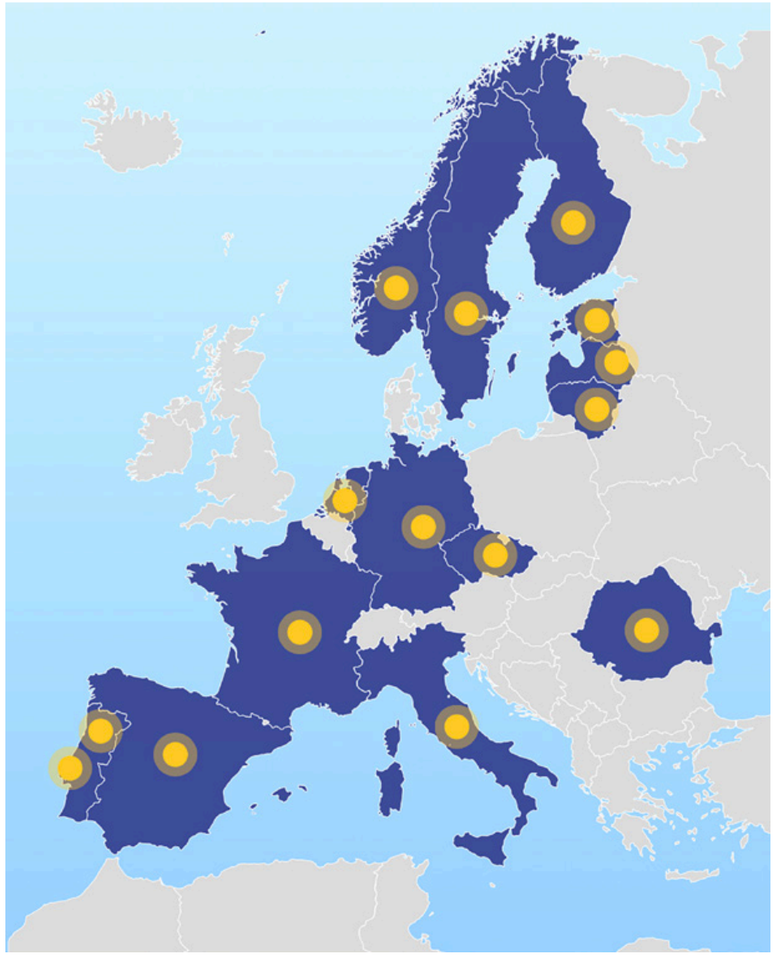
Single access point

Co-creation is a core Dutch strength, and NanoLabNL embodies it perfectly. From the beginning, NanoLabNL's leaders have cherished the national network's open-access model, ensuring easy admittance and synergy. Each of the seven laboratories taking part in the national network is located on a university campus, close to students and academics and also close to many small and large high-tech companies. Regular users of one lab may occasionally need to use expensive equipment at another lab. They can book the equipment online, along with support from experienced local users. All labs share a single online access point to all equipment and to the expertise available in the network. It is accepted practice that the intellectual property rights for whatever is discovered in one of the local labs go to whoever made the discovery.

NanoLabNL is the backbone of a well-organised national public-private ecosystem. It serves not only science but the private sector as well. Tech companies can work together with scientists within public-private partnership programmes, or they can use NanoLabNL's highly specialised cleanrooms to test new product lines. Young start-ups are encouraged to use the nanolabs as well, which gives them a chance to start at a high technological level long before they can afford their own labs. In the nanolabs, students and postdocs thus work alongside engineers from private companies, each with their own objectives, but together pushing the limits of what the combination of talent and high-end equipment can do.

International anchoring

NanoLabNL is not only a national access point, but an international one as well. In 2017, together with its French, Swedish and Norwegian sister-organisations, NanoLabNL helped establish EuroNanoLab. This European network currently offers an online one-stop-shop and open access to nanotechnology research facilities at 44 cleanrooms in 15 countries.



EuroNanoLab at a glance

EuroNanoLab is an initiative to establish a large scale nanofabrication research infrastructure distributed throughout Europe

Talieh Ghiasi on the attractions of the Top Master of Nanoscience programme

Talieh Ghiasi is a PhD student in the physics of nanodevices (spintronics), working in the group of Prof. Bart van Wees at the University of Groningen.

‘I received my bachelor’s and master’s degrees in Tehran, in solid-state physics. In 2014, I came to the Netherlands to start the ‘Top Master of Nanoscience’ programme at the University of Groningen. It is quite a well-known programme, with a specific scholarship. Students become familiar with the multidisciplinary aspects of nanoscience, including mesoscopic physics, chemistry, biology and nanomedicine.

‘I chose to work with Prof. Bart van Wees because I was most interested in specialising in the physics of nanodevices. We address fundamental physics questions, but those also have direct applications. With spintronics, we are working on a replacement for electronics as we know it. It is going to make our electronics high-speed and ultracompact, with less heat dissipation. These spintronic devices not only have great impact in memory and sensory systems, but they also provide revolutionary advances in information-transfer technology.’

Guus Rijnders on what he is most proud of

Prof. Guus Rijnders is professor of inorganic materials science at the University of Twente and chair of NanoLabNL.

‘What strikes me personally the most is that when I walk through the labs, I see top researchers at the peak of their careers mingling freely with young researchers and people from companies. They have built their own ecosystem in which young people are being trained by more senior researchers. Together, they do great work. It could result in a new finding that leads to an excellent article in a scientific journal, or it could lead to a new product that goes to market. It is as if we are constantly putting new train wagons on the rails: each one starts out as fundamental research but could eventually lead to a marketable product. And while that is happening, we keep putting new wagons on the rails. It is the combination of all this that makes me proudest: being at the heart of excellent science and innovations.’

3

HARVESTING FRUITS FROM NANOLABNL

Talent magnet and key supplier of skilled researchers

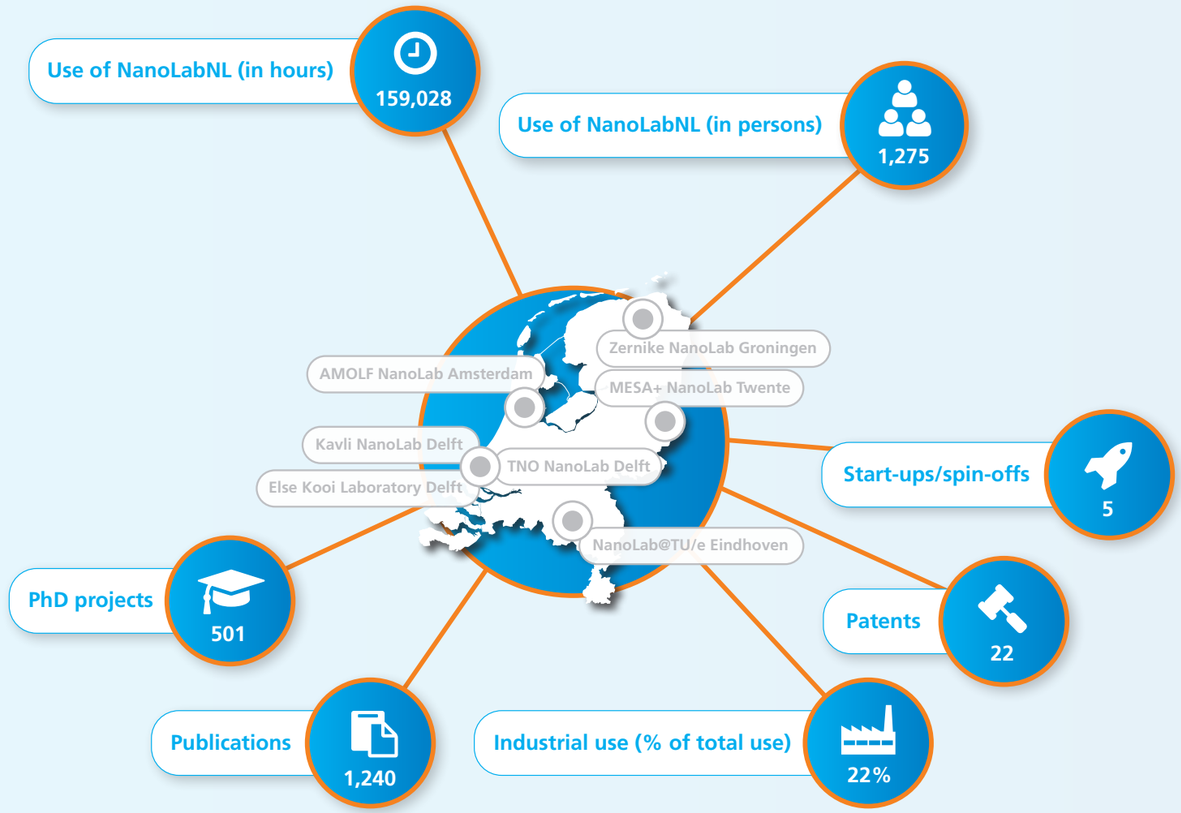
NanoLabNL is a perfect example of a core value in the Dutch academic system: the intertwining of research and education. Besides being a place of exciting research, the NanoLabNL network is the national incubator for new generations of highly skilled researchers, providing them with hands-on experience in designing, creating and testing at the nanoscale. These young researchers are greedily absorbed by academia and the high-tech industry, or they end up launching their own start-ups. This well-trained workforce is known to be one of the factors that makes the Netherlands an attractive business climate for foreign investors. In addition, NanoLabNL's world-class cleanrooms are a veritable talent magnet. From all over the world, they draw promising tenure-trackers to the Netherlands who wish to use the infrastructure for their research. In turn, this kind of groundbreaking research attracts smart and sought-after young researchers from all over the world who keenly consider the available expertise deciding where to do their PhD or postdoctoral research. Many of these researchers will remain in the Netherlands and become a national asset in the face of global competition.

Research at the frontier

NanoLabNL's infrastructure has led to scientific breakthroughs that could eventually provide new solutions to the world's challenges. This is demonstrated by the awards won by research done in the nanolabs and by the fact that the Netherlands ranks ninth worldwide when it comes to the number of patent applications at the European Patent Office.

Facts & Figures

Averages per year, 2013-2020



Ronald Hanson
on the emergence of nanotechnology applications

Prof. Ronald Hanson is the former scientific director of QuTech, the centre for quantum technology co-founded by the Delft University of Technology and TNO, and chairman of the supervisory board of Quantum Delta NL.

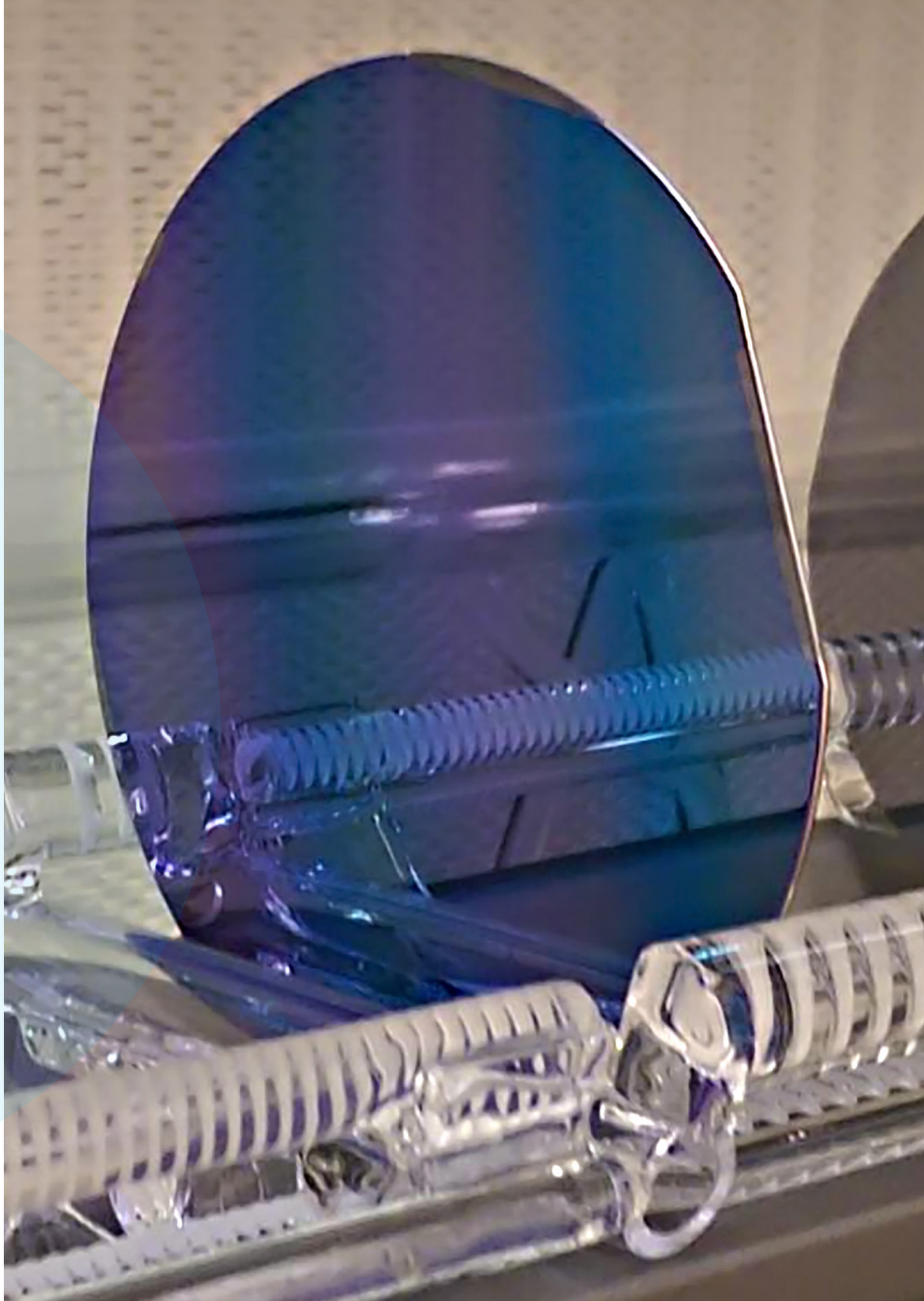
‘The development of nanotechnology research has progressed in three phases. In the beginning, we focused on studying fundamental phenomena. In phase two, we developed applications based on those phenomena. We are now in phase three, where completely new research areas have emerged from nanotechnology research done in the Netherlands, such as quantum technology and biomedical applications.

‘Currently, we are not only able to make nanostructures, but also to apply them. And various applications are beginning to emerge. It takes time to develop a new technology like nanotechnology to the point where you understand what you can do with it and what its added value is compared to existing technology. Nanotechnology has been developed over the past 10 to 20 years and is currently a key enabling technology for many new applications, with quantum technology already having become a key enabling technology itself.’

Simon Groeblacher
on the attraction of the Dutch nanolabs

Prof. Simon Groeblacher is professor of quantum physics at Delft University of Technology

‘The availability of the broad range of facilities in the different NanoLabNL labs was one of the main reasons I came to the Netherlands. With my group, I am studying the quantum behaviour of massive mechanical systems coupled to a laser field inside an optical cavity. The mechanical oscillators range from hundreds of nanometres to several millimetres in size. They all need to be fabricated in a completely controllable environment so as not to destroy the very fragile quantum nature of these devices. The cleanroom facilities in Delft provide a unique environment and are a key ingredient in the success of my lab.’



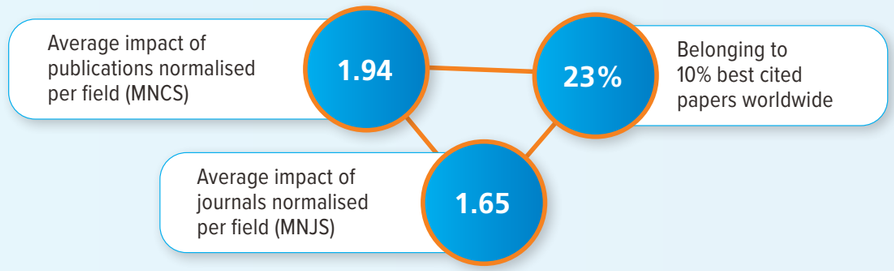
NANORESEARCH PROGRAMMES

The NanoNextNL research programme (2010-2016) established a solid public-private collaboration aimed at applications of nanotechnology, with 130 participating companies. Since then, several high-tech collaborative research programmes targeting societal challenges have emerged, all of which depend on the NanoLabNL research infrastructure. These include Nano4Society, the National Agenda for Quantum Technology, PhotonDelta, the Netherlands Organ-on-Chip consortium hDMT and related routes in the Dutch Research Agenda.

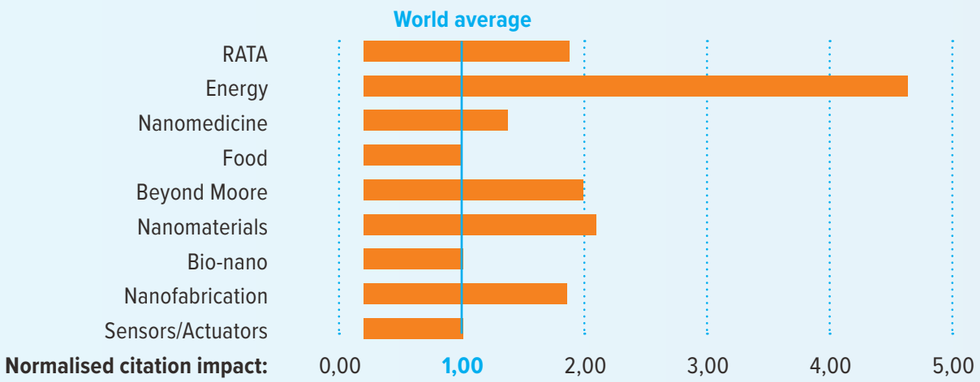
Technology-driven research in NanoNextNL has led to top science with very high impact

Citation impact of NanoNextNL publications

- Close to 900 publications (until March 2016)
- Over 140 published in high impact journals, impact factor >10
- 443 analysed (published in 2010-2014)



Citation impact of publications from NanoNextNL themes *(Source: CWTS, 2016)*

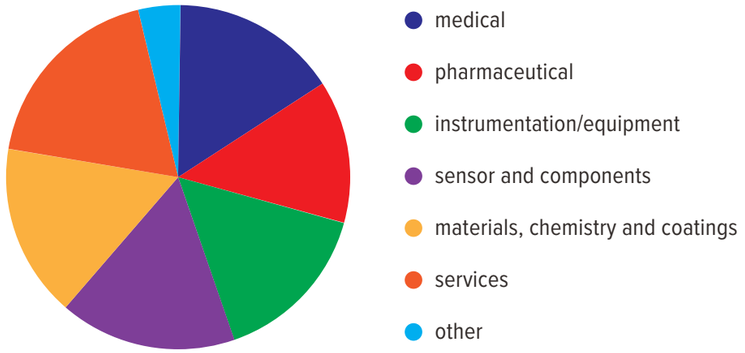


Among the scientific successes made possible by the Dutch nanolabs so far is the work of Bart van Wees, who in 2016 was awarded a Spinoza Prize – the most prestigious Dutch prize for scientific achievement, considered the highest honor in Dutch science – for his nanoscale electronic devices that make use of the quantum mechanical properties of electrons and may prove to be much faster and more energy-efficient than traditional electronics. Van Wees developed these devices in the nanolab in Groningen. Ronald Hanson likewise received a Spinoza Prize for having successfully entangled particles separated from each other by 1 km. He did so with devices made in the nanolab in Delft. His findings may eventually aid in the development of the quantum computer. Marileen Dogterom won the Spinoza Prize 2018 for her investigations of the cytoskeleton of a living cell, an important step towards building a human-made cell in the lab. The NanoLabNL cleanroom facilities in Delft and AMOLF enabled her to study biological structures in a controlled way. These celebrated researchers are just a few examples that demonstrate the excellence of the facilities at NanoLabNL.

Start-ups, driving innovation ever further

Sometimes nano-trained graduates have an idea so revolutionary that large companies are not ready to embrace it yet. So they start their own enterprise in the vicinity of lab facilities. Each of the Dutch nanolabs is a hub where young companies can use nanofabrication devices that they could never afford to purchase themselves. This enables them to develop innovative products. On average, NanoLabNL produces six high-tech start-ups per year over a wide range of fields.

Business orientation of NanoLabNL's commercial users



Start-ups related to NanoLabNL are active in a wide range of application areas.

Source: Business Orientation NanoNextNL, Enabling MNT, by Henne van Heeren

Marc Hendrikse on the power of our economy

Dr Marc Hendrikse, formerly CEO of high-tech company NTS-Group, is figurehead of the Top sector High-tech Systems and Materials.

‘The power of our economy is that we use insights from fundamental research to build key technologies, and through cooperation between universities, institutes for applied science and industry, we convert these into innovations that eventually produce ample economic value.

‘Now we are slowly beginning to see towards which applications we’re heading: photonic computer chips, ultrafast data centres, labs on chips, organs on chips. We are approaching market introduction with these technologies – something we would never have been able to do if we had not taken that first step and invested in fundamental research, including building advanced nanolaboratories. But to think that nanoscience has reached its goals would be a huge mistake. We are world leaders in technology development, but if we do not carry our investments in nanoscience through to the end, our competitors will run off with the economic gain.’

Constantijn van Oranje-Nassau on the importance of technology hotspots

Constantijn van Oranje-Nassau is an envoy of TechLeapNL.

‘Labs play an important role as the physical access point to high tech. They are hotspots of technology development. COVID-19 showed how critical the access to labs is for many companies that are in their early phases and cannot finance their own labs. The quality of the labs determines the quality of their results.

‘The lab alone is not enough, however, especially if it is highly specialised. Innovation thrives on the interaction between people from different disciplines, so that ideas will arise on how to use an extremely advanced technique to solve a specific problem in another sector. Therefore it is important that labs are embedded in a broader innovation environment where different disciplines meet and new ideas can emerge.’

Elham Fadaly on the role of NanoLabNL in her celebrated research

Dr Elham Fadaly recently obtained her PhD cum laude at Eindhoven University of Technology (TU/e). Her discovery of light emission in silicon was proclaimed Breakthrough of the Year 2020 by *Physics World*.

‘My doctoral research on the fabrication of nanomaterials for optoelectronic applications has attracted attention because it could potentially lead to the development of the first silicon-based laser, or spark a second revolution in silicon technology, bringing silicon photonics within reach.

‘The cutting-edge facilities in NanoLabNL have been a key enabler for the success of my experimental research work, particularly in reaching undiscovered territories in the field of nanomaterials fabrication. The accessibility of and training on a wide range of advanced fabrication and characterisation tools played a crucial role in my career as a researcher. They allowed me to expand my understanding of theoretical concepts via experimenting with them in the lab and testing new innovative ideas directly.

‘Working in the nanolab at TU/e while having access to the facilities in other NanoLabNL sites nationwide has been an excellent opportunity to connect and benefit from top-notch researchers in academic institutions and start-ups working in the NanoLabNL network.’

Pieter Duisenberg
on the Netherlands as a delta of knowledge

Pieter Duisenberg RC is president of the VSNU, the Association of Universities of the Netherlands.

‘I believe in a world where the winner takes all, even though this is not always a very nice world. In a globalised environment, physical boundaries have become irrelevant. For knowledge and research this means that If you want to excel you have to be number one or number two as quality goes. Then you will attract talented people and companies. If you are not the top, then people and companies will not make this choice.

‘It is important that we position the Netherlands as a delta of knowledge, the place to be if you want to innovate. The whole world should know: team.nl stands for cocreation, international pioneering and entrepreneurship. That should be our branding. NanoLabNL could contribute hugely to this positioning. In this way they can server a broader interest than only science.’

SUCCESSFUL START-UPS

Some examples of established companies that have evolved from the nanolabs and have become true flywheels for fast innovation:

By now well-established high-tech companies, **Lionix** and **Micronit** both started 20 years ago in the MESA+ nanolab at the University of Twente. Lionix has grown into an international supplier of customised photonic chips and microfluidics. Micronit currently employs over 100 people and offers lab-on-a-chip and MEMS solutions to industrial clients.

VSParticle spun off from the nanolab at the Delft University of Technology in 2014. This producer of machines for making and handling nanoparticles currently has over 20 employees.

High-tech company **Delmic** develops revolutionary microscopy techniques to visualise biological processes and materials for energy conversion. Born out of the nanolabs of Delft and Amsterdam, it continues to collaborate with academic partners and industry giants such as Thermo Fisher to pioneer new breakthroughs.

Giving industry a competitive edge

As specific nanotechnologies approach commercialisation, NanoLabNL is increasingly home to high-tech companies as well. In fact, the labs are an ideal ecosystem to stimulate or even spark public-private partnership programmes. NanoLabNL's open-access facilitates informal meetings between students, academics and industry representatives from various disciplines. This fosters creativity and facilitates a smooth technology transfer. It also allows graduates to find jobs that match their skills and interests.

ASML, for instance, based near the nanolab in Eindhoven, is the global leader in manufacturing nanolithography machines for the semiconductor industry. It not only benefits indirectly from the nanolabs through well-trained researchers, but it also makes use of facilities directly. Sometimes ASML commissions tailor-made components for small series. For example, a series of sensors that the Else Kooi Laboratory in Delft was commissioned to develop ended up in machines used for extreme ultraviolet lithography (EUV). ASML has a strategic partnership with the Eindhoven University of Technology, supporting the operation of the world's only 3-inch InP wafer 193nm scanner.

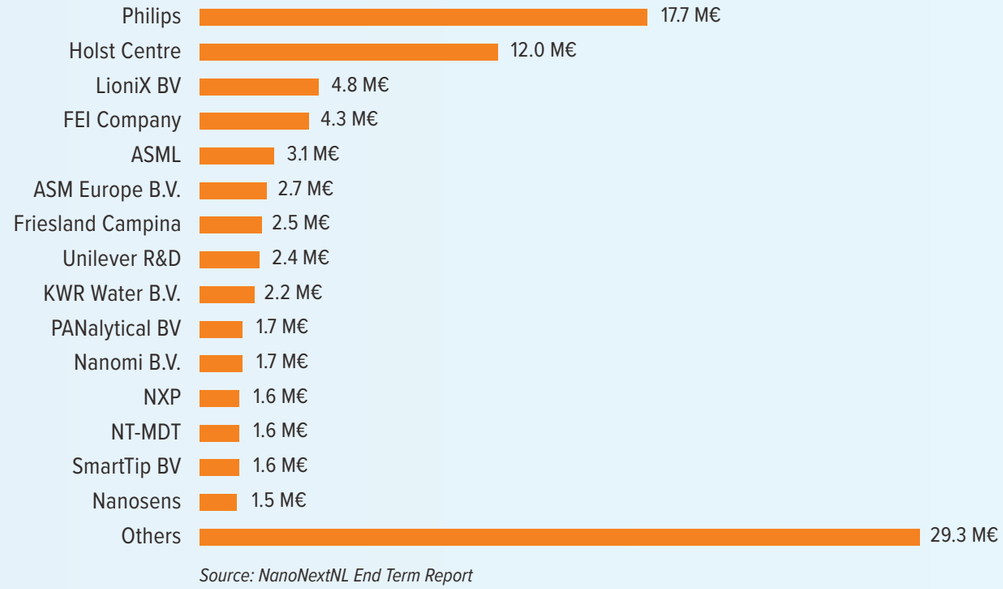
NanoNextNL's industrial research led to a 4-fold return-on-investment

Return-on-investment

When extrapolating the expectations on the return-on-investment, the 91 M€ invested in industrial NanoNextNL research (subsidy + matching) would generate >400 M€ in the years to come:

Financial investments

A total of 110 companies were involved in NanoNextNL. Their total budget for this programme was 91 M€ of which 40 M€ was subsidy.



Source: NanoNextNL End Term Report

The companies that took part in the NanoNextNL research programme also included other large multinationals such as Philips, DSM and Unilever as well as smaller high-tech industrial members of the branch organisation MinacNed. In PhotonDelta, 15 companies are currently collaborating with Dutch universities and TNO in public-private partnerships that require state-of-the-art research infrastructure in the cleanrooms for nanoresearch. These are just a few examples of the many large and small companies that profit from NanoLabNL's infrastructure.

Jos Benschop on the benefits of NanoLabNL for ASML

Prof. Jos Benschop is senior vice president of technology at ASML, the world's leading producer of chipmaking machines, based in Veldhoven, Netherlands.

'The primary benefit that NanoLabNL has for companies such as ASML is that it generates well-trained people with hands-on experience in nanotechnology. People who have not just created powerpoints, but who have actually realised devices, after having designed and measured them. This is the primary reason why we need the infrastructure. Secondly, the infrastructure is also important for our research. We use the results of academic research groups and collaborate with them. They perform research for us in the nanolabs; they are either embedded in NanoLabNL or associated with it.

'In the past, a lot has been invested in nanotechnology infrastructure in the Netherlands. This was a good choice. If you want to remain at the top level in science and technology, you have to keep investing. It would be incredibly stupid to let it pass away.'

Marileen Dogterom
on the ‘projectification’ of funding

Prof. Marileen Dogterom is professor of bionanoscience and department chair at the Delft University of Technology and Medical Delta professor at Leiden University.

‘The present funding system in the Netherlands does not provide a stable base for research infrastructures. They have to acquire funding every few years, and whoever is the “hottest” at that point in time has the best chance. It is fine to finance research in a project-based structure, for this fits how research works. But financing large infrastructures as if they were projects does not match their character, nor does it match the needs of long-term research programmes that need such infrastructures.

‘Nanoscience is still cutting-edge, but this has become less apparent. Instead of being a revolutionary new technology, it is now more of a standard need for many scientists, like microscopes. Those were also revolutionary at one time, but not anymore. But they, too, keep getting better and better, and we will always need them.’

Inviting new guests

With a voucher system, NanoLabNL invites companies that are unfamiliar with nanotechnology to make use of its infrastructure and technical assistance. It also offers consultancy services to companies that suspect nanotechnology could help to improve their products.

HIGH-TECH SOLUTIONS FOR SOCIETAL CHALLENGES

Public-private research that originated in the nanolabs has proven to be successful.

- In Eindhoven, researchers managed to create light in silicon, a breakthrough that could be scaled up in industry.
- Indium phosphide photonic integrated circuits and TriPleX were developed in the nanolabs in Eindhoven and Twente. In PhotonDelta, these technologies are used for several applications including precision farming, medical scanners, sensors for aircraft wings and 5G telecommunication.
- Since it was founded in 2014, Dutch national icon QuTech – the advanced research centre for quantum computing and quantum internet – has been joined by Microsoft and Intel. Microsoft and QuTech are currently frequent users of the nanolabs in Delft.
- In the Twente nanolab, thin nanolayers are fabricated that end up in the optical components of Zeiss that, in turn, are used in ASML scanners. Finally, research institute ARCNL, in which ASML is a partner, makes frequent use of NanoLabNL's Amsterdam facilities to produce ever-smarter and ever-smaller technology.
- Philips and the universities collaborating in NanoNextNL developed a sensitive method for detecting kidney or liver disease on the spot with a single finger prick. The start-up LipoCoat coats contact lenses with dirt-repellent nanocoatings.

Dutch Research Agenda

NanoLabNL plays a crucial part in the Dutch Research Agenda, the scientific framework for contributions to the solution of urgent societal challenges. In particular, it is indispensable for the routes 'Quantum/nano revolution', 'Materials made in Holland', 'Personalised medicine', 'Energy transition', 'Smart industry', 'Building blocks of matter and foundations of space and time', 'Measuring and detecting' and 'Value creation by responsible access to the use of big data'.

The battle against COVID-19

Unexpectedly perhaps, nano-based companies even play a part in the battle against COVID-19. Photonic technologies that originated in the nanolabs are being used in detecting the virus and creating immunity against it. Nanoresearchers are working on an ultrarapid COVID-19 test kit that will make diagnostics more accessible and affordable throughout the world.

IN CONCLUSION

Nanoscience and nanotechnology in the Netherlands currently form an extraordinarily productive and internationally acclaimed knowledge ecosystem. Besides being an important centre for nanoscience, NanoLabNL is also indispensable for high-interest key enabling technologies including quantum technology, lab-on-a-chip and organ-on-a-chip technologies and photonics. The labs are a necessary condition for performing groundbreaking fundamental research, training new generations of skilled high-tech workers and developing innovative products. All these things, in turn, are vital if the Netherlands wants to play a prominent role in the huge and necessary transitions the world is currently facing.

Investments in NanoLabNL guarantee a relatively high return. For one thing, both the material and social infrastructure for doing top nanoresearch is already in place, For another, the organisation of NanoLabNL guarantees maximum efficiency and minimum overlap. To stimulate a Dutch contribution to global transitions, NanoLabNL is very happy to offer advice to and exchange expertise with any initiative that works towards the same goal.

René Penning de Vries
on new opportunities

Dr René Penning de Vries is chairman of PhotonDelta, a network for the development of photonic applications.

‘Quantum technology, photonics and applications of surface modifications at nanometre scale are going to take off massively. We need to support that with excellent research. In the absence of continued investments, we will slowly start missing out on new opportunities. Internationally, many parties, e.g. in China and America, have ambitions. We have solid expertise in certain areas, and we should take advantage of that. If not, we will become a small player, similar to what we saw in football with Amsterdam’s team, Ajax.

‘Our strength in the Netherlands is our ability to make those connections. We can see the advantages. We are strong in cooperation throughout the entire network, from fundamental research to applications. If you only do fundamental research, you can publish in *Nature* or *Science*, but it won’t generate many more benefits.’

Michel de la Bachelerie on the importance of European sovereignty at minimal costs

Prof. Michel de Labachelerie is research director of the French CNRS laboratory Femto-ST and chair of the EuroNanoLab consortium.

‘At an international level, nanotechnology is progressing quickly, especially in Asia. It is important to understand the competition and ensure European sovereignty in the capability to do research. NanoLabNL and other European labs should be able to maintain reasonable know-how to be able to face future problems. Invest in nanotechnology to have at least the know-how to fabricate it; afterwards, you can decide if it is economically worthwhile to manufacture it here or not.

‘Our research could be very new, breakthrough research. When you invest, focus on equipment that can be used in such basic and exploratory research of high risk and expected high gain. For that is the first thing. In the Netherlands, the NanoLabNL network can help to reduce the costs of the investment by avoiding duplications. This makes NanoLabNL of high value to the country. The same goes for the French and Swedish networks set up in 2004, and the Norwegian network, which followed the same example, in 2008.’

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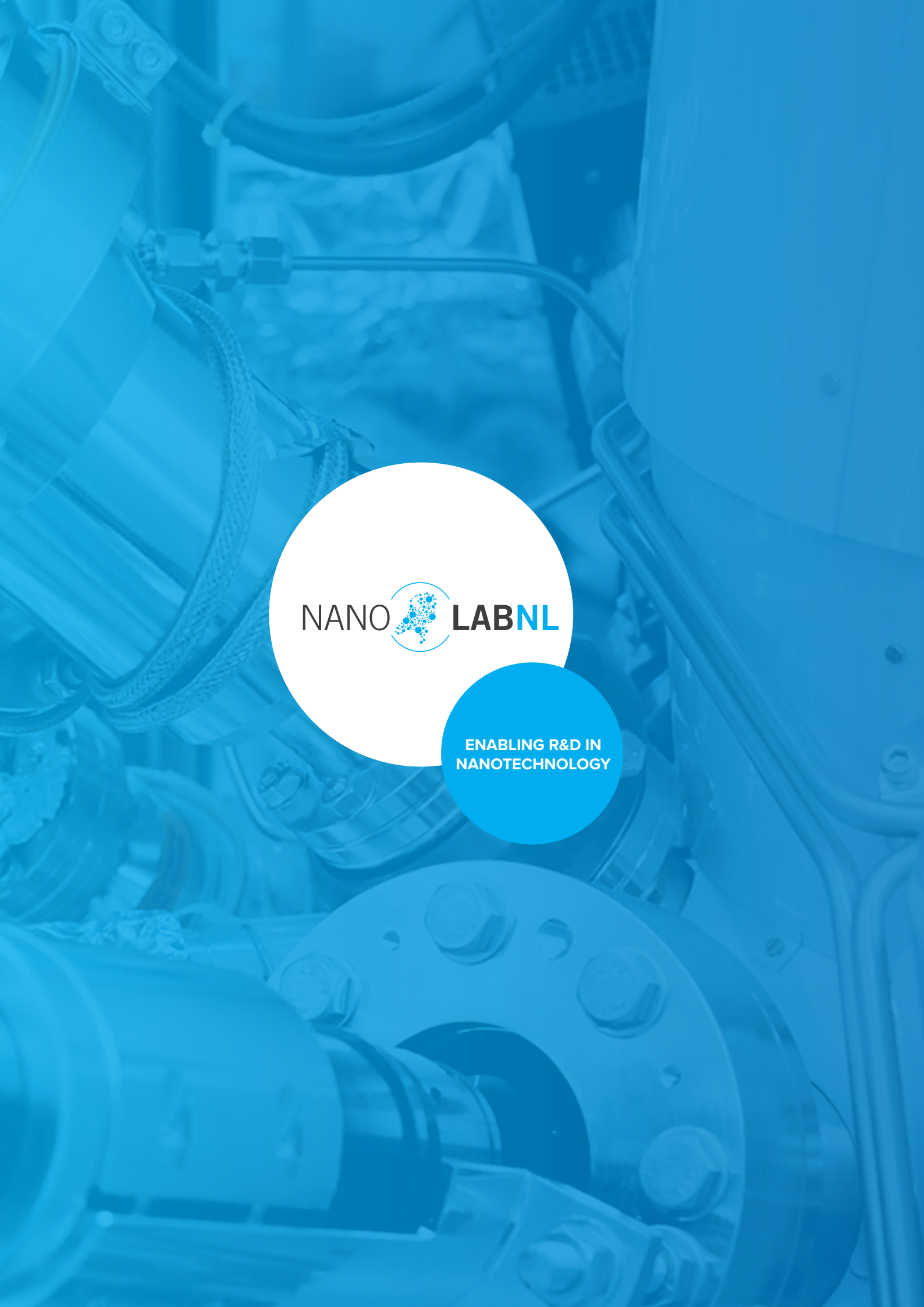
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