

# FLYWHEEL OF INNOVATION IN THE NETHERLANDS

“Everybody knew it couldn’t be done,  
until someone came along who didn’t know that”

**TNO** innovation  
for life

**STRATEGIC PLAN 2018 – 2021**



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# INTRODUCTION

Welcome to the 2018–2021 strategic plan for TNO, the Netherlands Organisation for Applied Scientific Research. This succeeds the current version, which was due to cover the years 2015–2018. As part of its policy to harmonize the planning periods of all members of the national Federation of Applied Research Organizations (TO2), the Dutch government has asked us to bring forward the starting date of the new plan by one year.

## BROAD EXTERNAL CONSULTATION

This plan has been compiled following extensive consultations with TNO's key stakeholders. We began with external stakeholders because our ambition is to look at TNO "from the outside in" whenever possible—in other words, to determine our research portfolio and programming in close co-operation with our clients and partners. Our interlocutors included the Ministry of Economic Affairs, the Council for Defence Research, other relevant government departments, TNO's own Strategic Advisory Councils (and their chairs in particular) and representatives of various national "top sectors" and "top teams". Naturally, we have also considered the recommendations of the Evaluation Committee for Applied Research Organizations in its subreport on TNO.

## INTERNAL CONSULTATIONS

Internally, too, the development of this plan has been an intensive process. A number of working parties helped in its compilation. It was also the subject of TNO-wide "webinar" and previous draft versions have been discussed repeatedly by the management team. The Staff Council and the Supervisory Board were also heavily involved.

We would like to warmly thank everyone who has devoted their valuable time to this exercise. It is in their constant quest for dialogue, their self-reflection and their ability to forge links that the strength of our innovation lies.

## COMPILATION

As mentioned above, this plan has been compiled looking "from the outside in". At the heart of what we as TNO do is impact: the practical application by others of the know-how we develop. To achieve that, our research portfolio and programming have to seamlessly match those of our clients and partners. Their specific agendas, as well as relevant external developments in general, therefore provide starting points for this strategic plan and our choices as TNO.

## ADAPTIVITY

A strategy is all about the choices we make as to what we want to be and do, and for whom. But we need to strike a note of caution here. Given the incredibly rapid pace of current social and technological development, our strategy should not be read as a blueprint set in stone for the next four years. It is far more important that TNO as an organization remain as flexible and market-focused as possible in order that we can always respond quickly and effectively to new advances and issues as they arise.

## PRECONDITIONS

For our strategy to succeed, a number of preconditions need to be met. The most important is that our state funding be maintained at the 2017 level, at the very least, for the next four years. In fact, together with our partners in the Knowledge Coalition, we are lobbying for additional public investment of at least €1 billion in order to further strengthen innovation in the Netherlands. After all, proper financing is essential in order to maintain and advance scientific know-how, to operate the cutting-edge facilities needed for outstanding research and to attract top scientific talent.

### ORGANIZATIONAL CHANGES

Since the beginning of 2017, preparations for two major changes have been set in motion: the merger of the TNO and ECN (Energy Research Centre of the Netherlands) sustainable energy portfolios within our organization (but under the ECN name) and the transfer of our food research work to Wageningen Research. Both are due to take effect on 1 January 2018. These developments have come too late for inclusion in the figures and scenarios presented in this document. However, the ambitions formulated for the “new” ECN (as part of TNO)—as reported to Parliament by the Minister of Economic Affairs<sup>1</sup>—are described under the subheading “Energy” in Section 4 of this plan. The resulting strategy is currently being developed jointly by TNO and ECN.

### PLAN STRUCTURE

This strategic plan is structured as follows.

- The executive summary presents the key points of our chosen strategy.
- Section 1 defines what TNO is, does and wants to be: our mission, ambitions, impact and core values.
- Section 2 outlines our positioning.
- Section 3 describes relevant developments and agendas.
- Section 4 outlines the resulting research portfolio and programming choices.
- Section 5 sets out our specific priorities for the next four years.
- Section 6 discusses our financial model for that period.

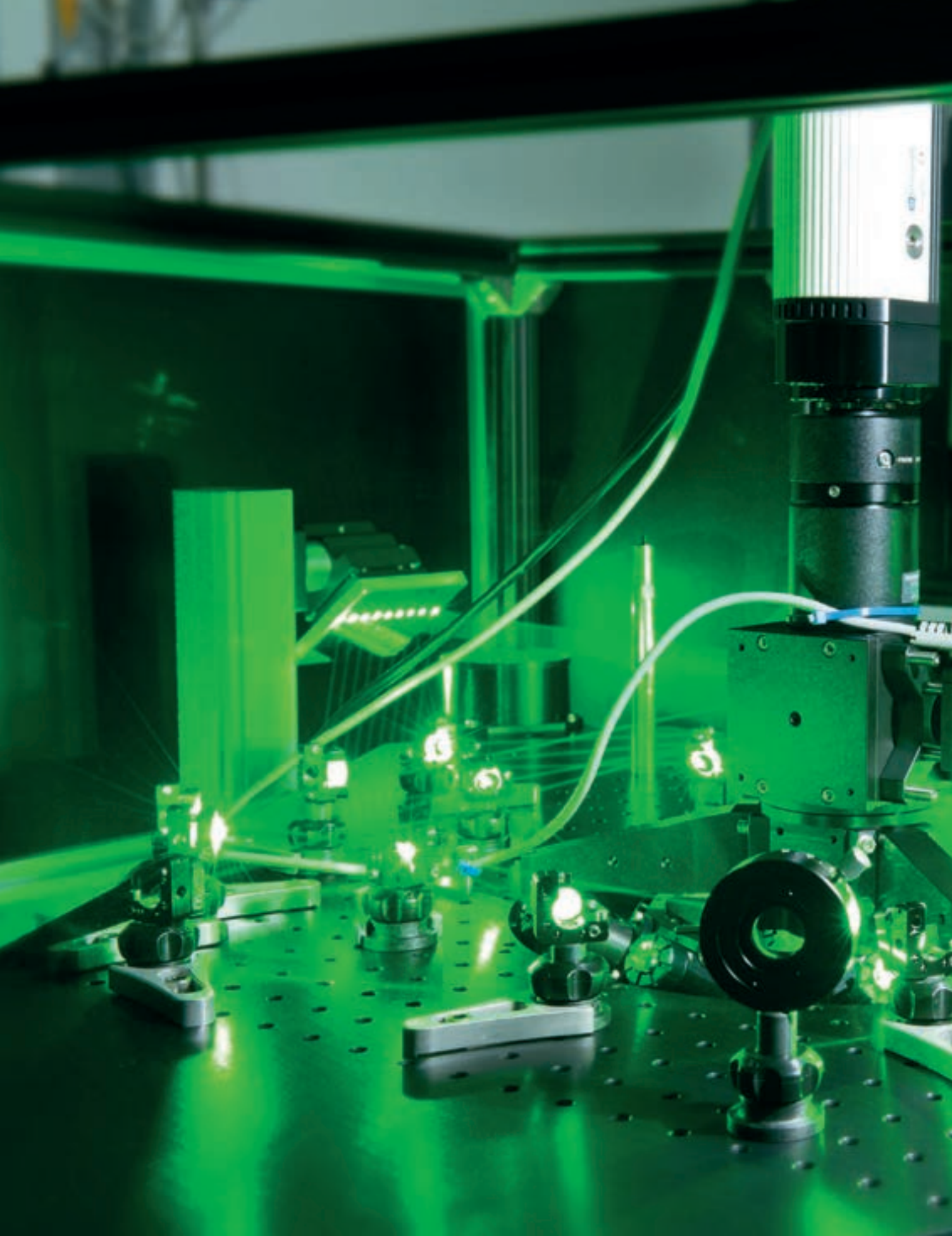
We are proud of the document in front of you. But, in the realization that the world is not going to stand still after the compilation of this strategic plan, I cordially invite you to keep plying us with your comments, suggestions and ideas. After all, only a well-anchored, broadly supported TNO has a “right to play” and the ability to keep on delivering the added value society expects of us. In the meantime, you can rely upon us to continue providing you proactively with good advice and with smart, unique and surprising solutions. In an ethical, professional and socially responsible manner. And upholding our slogan: **innovation for life!**

Enjoy reading our strategic plan!

On behalf of the Executive Board,

*Paul de Krom, Chairman and Chief Executive, TNO*

1. “De toekomst van de Stichting Energieonderzoek Centrum Nederland en de ontvlechting van het duurzame energieonderzoek en de nucleaire activiteiten” (“The future of the Energy Research Centre of the Netherlands and the separation of its sustainable energy research and nuclear activities”, 30 September 2016).







# EXECUTIVE SUMMARY

Change is as old as the world. But the pace of social and technological change is increasing faster today than ever before. Against this background, for TNO to keep adding value for its clients and partners it is essential that we constantly innovate and reinvent ourselves. In terms of our knowledge portfolio, programming, positioning and organization. Only then do we retain our “right to play” in the world of scientific research.

## EXTERNALLY-DRIVEN IMPACT

At the heart of our strategy is maximizing our impact: the extent to which the know-how we develop is actually put into practice. To achieve that, our programming and research portfolio need to align closely with the wishes of our clients and partners. So the starting points for our strategic plan are their agendas and relevant external developments in general.

## THOUGHT LEADERSHIP

TNO wants to take the lead in identifying social and technological trends and in providing smart, surprising solutions for the challenges they bring. We therefore intend to reinforce our position as a “thought leader”.

## DISTINCTIVE AND DYNAMIC PORTFOLIO

TNO’s focus is those areas in which we can excel because we are unique and distinctive. Besides harmonizing our programme with our clients and partners, this requires that we keep constantly developing and updating our research portfolio. As we are already doing: in the past five years, we have wound down and partially renewed about 30 percent of that portfolio, a process which will continue throughout the forthcoming strategic period.

## FIVE DOMAINS

At the strategic level, TNO research is concentrated in five domains.

- Industry, for a strong, internationally competitive business community.
- Healthy Living, for a fit, healthy and productive population.
- Defence & Security, for decisive action in an uncertain world.
- Energy, for faster progress towards a low-carbon energy system.
- Urbanisation, to innovate for dynamic urban regions.

## FOCUS

Within each of these domains, we particularly concentrate upon a number of priority areas. These are related to major social and technological trends about which TNO possesses a unique and distinctive fund of knowledge, or wishes to develop one (see table 3.2).

## CONNECTING PEOPLE AND KNOWLEDGE

As a public not-for-profit organization, and in line with our legal remit, TNO seeks to connect people and knowledge so as to create innovations that boost the sustainable competitive strength of industry and well-being of society. Accordingly, we want to reinforce and expand our strategic relationships with government ministries, leading industrial sectors, universities and the business community—from major companies to SMEs. To that end, amongst other things we plan to forge more broad, long-term alliances in the form of joint innovation centres.

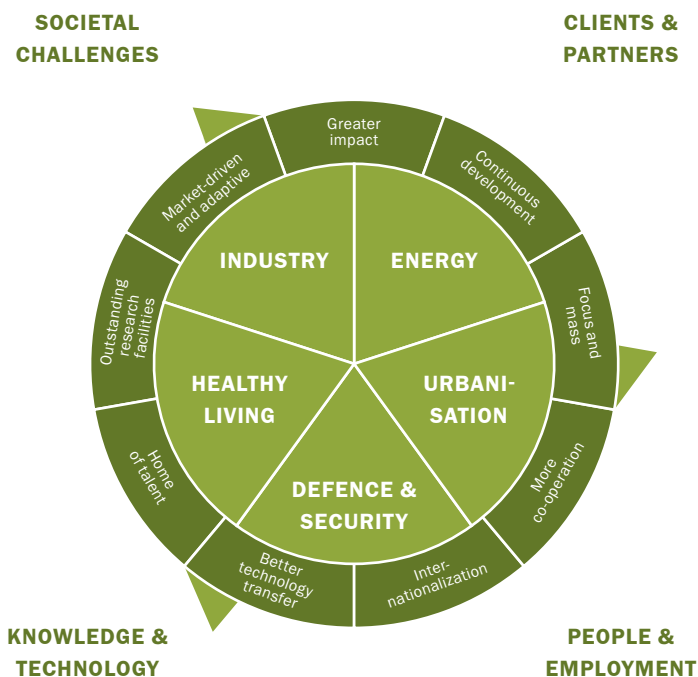


Figure 1 – TNO: the flywheel of innovation

### MULTIDISCIPLINARITY

Most true innovation occurs where different scientific disciplines meet under the umbrella of long-term alliances with sound underlying financing. That is where the critical mass needed to achieve maximum impact is created. For TNO, this means combining in-depth knowledge of particular scientific topics with the ability to develop multidisciplinary solutions. We therefore intend to further develop our systems-engineering know-how and ability, since they are essential in enabling us and our partners to achieve results that transcend traditional technological divides. At the same time, though, we still need to possess the specialist know-how required to create and apply our solutions in specific areas.

### FLYWHEEL OF INNOVATION

TNO wants to increase the amount of knowledge it shares with clients and partners. And the speed at which it is shared. That, after all, is the nub of our allotted role in Dutch society. So by 2021 we intend to become what we call the “flywheel of innovation” in the Netherlands. Not by doing or knowing everything ourselves, but by forming a network of solid relationships with partners who work with us to translate our know-how into complete and practical solutions.

### NINE PRIORITIES

The specific agenda contained on our strategic plan results in nine explicit priorities for TNO for the period 2018–2021, with key performance indicators formulated for each of them. They are:

- Increasing our impact, in both the public and the private sector.
- Ongoing development and renewal of our research portfolio.
- Bringing more focus and mass to what we do.
- Establishing more alliances.
- Further internationalization.
- Reinforcing and accelerating technology transfer.
- Creating a “home for talent”.
- Maintaining and developing outstanding research facilities.
- Forming an adaptive, market-driven organization bound together by clear core values.

Accomplishing these priorities should leave us in a consistently positive financial position, thus safeguarding the long-term continuity of our knowledge-building activities and facilities as well as creating room for further investment. ■





OUR FOCUS:  
**TO MAXIMISE IMPACT**

## } SECTION 1

# THE FLYWHEEL OF INNOVATION IN THE NETHERLANDS

## EIGHTY-FIVE YEARS OF TNO

TNO is 85 years old in 2017. Throughout that time it has been a vital part of the Dutch public-sector research infrastructure, making an important contribution to the creation and development of scientific know-how and innovation in the Netherlands. And so to economic growth and employment. TNO is an institution the nation can be proud of.

## RAPID CHANGE

Change is as old as the world. But its pace is increasing faster today than ever before. Ninety per cent of the Fortune 500 companies have disappeared from that list in the past 60 years. Fast-growing newcomers are rapidly pushing established firms into the background, in terms of technology, business models and market capitalization alike.

## THE LINK BETWEEN SCIENCE AND PRACTICE

Even for TNO, 85 years of successful applied research for the Netherlands provides no guarantee for the next 85 years. We have to prove every single day that we are still adding value for our clients and partners, be they commercial businesses, government departments or NGOs. And we can only do that by defining clearly and accurately where in the overall public-sector research and innovation system that value lies. Our answer: in our role as the link between science and practical applications and in our ongoing ability to adapt our knowledge portfolio, our programming and our organization to changing market needs.

## OUR MISSION

As well as in-depth scientific know-how, this role demands the skill needed to connect and combine different disciplines, systems and social sectors. Knowledge, after all, is becoming ever more dynamic and accessible. Not least due to information technology. So it is increasingly important that we use it astutely and effectively. It is in forging “smart” links across scientific and social boundaries that the strength of innovation lies. Which is why we want to remain a multidisciplinary applied research organization made up of motivated people working in fluid partnerships, coalitions and alliances. In that, we are unique in the Netherlands. It is what enables us to offer the solutions our clients are waiting for. For this reason, we only work on innovations when we have a crystal-clear answer to the question, “Who is going to use this, and what for?”. That is how we as TNO ensure that we always contribute to the success of our clients and partners and to a safe, healthy, liveable, competitive and sustainable Netherlands.

**MISSION:  
TNO CONNECTS PEOPLE  
AND KNOWLEDGE  
TO CREATE INNOVATIONS  
THAT BOOST  
THE SUSTAINABLE  
COMPETITIVE STRENGTH  
OF INDUSTRY AND  
WELL-BEING OF SOCIETY**

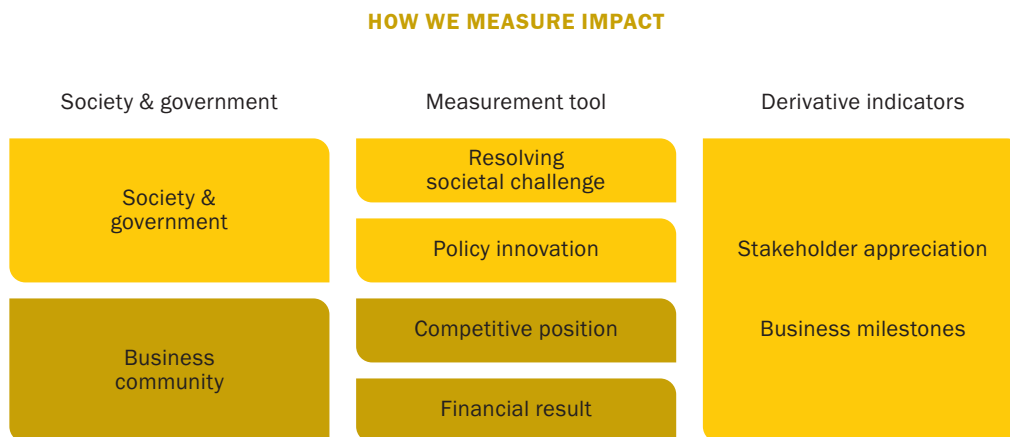


Figure 1.1 – How TNO measures impact

### OUR AMBITION

Throughout the world, there is a trend towards combining scientific know-how and its practical application at a small number of so-called “global knowledge hubs”. By concentrating learning close to businesses (including SMEs), government agencies and NGOs, these generate the dynamism and critical mass needed to be a front-runner in the worldwide innovation race. TNO wants to assist with the Netherlands’ ongoing development as one of those hubs. With our central position in the innovation “chain”—between pure science at one end and practical application at the other—and our solid grounding in the Dutch knowledge infrastructure, we intend to be our nation’s “flywheel of innovation” by 2021. Specifically, this means that TNO will: (a) be the driving force behind applied research and innovation in a number of clearly defined areas; (b) accelerate the process of innovation by connecting people and knowledge in an effective manner; (c) share as much know-how as possible with clients and partners; and (d) invest any financial returns in developing new knowledge and in establishing outstanding research facilities. In short, we want to be “the nation’s laboratory” for the creation, development and practical application of new ideas. And so play our part in forging an innovative society and in achieving the Dutch government’s goal of spending 2.5 per cent of GDP on research and development.

### IMPACT

TNO seeks to achieve maximum impact. By this we mean that as much as possible of the knowledge we develop is put to practical use by our partners and clients—and more generally by society as a whole, to help solve the major challenges it faces. Moreover, we want to increase our impact in the coming years. Not by doing or knowing everything ourselves, but by building relationships with partners who work with us to develop complete solutions. In so doing, we intend to focus upon those topics in which we can make a real difference. Topics in which we stand out. Topics with a scale sufficient enough that our knowledge and position give us the “right to play” with them. And topics which are multidisciplinary in nature, so that they also demand our skills in the field of systems engineering. We do what we do well, or we do not do it all.

**OUR AMBITION:  
BY 2021,  
TNO IS THE FLYWHEEL  
OF INNOVATION IN  
THE NETHERLANDS**



Figure 1.2 – TNO's mission, core values and brand values

Even more than in the past, in the next few years we intend to prioritize co-operation with leading clients and partners, with relevant government ministries, with universities and with other institutions of applied science, in the Netherlands and abroad. By 2021 we expect to be working strategically not just with the Dutch ministries of Economic Affairs, Defence, Social Affairs & Employment, and Infrastructure & the Environment as now, but also in strategic partnership with Security & Justice, with Health, Welfare & Sport, with Education, Culture & Science, and with others too. Moreover, the number of broad, long-term alliances—so-called joint innovation centres—we are involved in should have grown from the current eight to at least fifteen. We will also continue to play our part in bringing innovation to developing countries through our Innovation 4 Development programme.

### CORE VALUES

If we are to achieve our ambitions, we must realize that TNO is not a ship at the mercy of the waves but one sailing purposefully towards the future. A future we intend to help shape, in close consultation and co-operation with our clients and partners. This requires an open, flexible, inventive organization which comes up with considered solutions, looks for connections everywhere and is motivated to find the answers our clients and partners are waiting for. An organization staffed with top Dutch and international talent: people who do their jobs professionally, independently and honestly. Who appreciate the freedom and responsibility they are given. And whose personal ambition and social engagement motivates them to shape tomorrow's world with passion and pleasure. ■



**CORE VALUE: HONEST**

TNO staff are committed to integrity. Our good name depends upon it. For us, integrity means that the organization is guided by a set of positive core values and that our employees abide by them. Decisions are always based upon complete and correct information.

As far as possible, TNO is a transparent organization. Trust and respect form the basis for our open culture. There is always room to discuss difficulties and dilemmas, as doing so strengthens our integrity. We act decisively against abuses and injustices, and we protect those who report them

**CORE VALUE: INDEPENDENT**

Independence is the basis of TNO's success. We conduct our research objectively, advise companies and other organizations impartially and act as a neutral party in disputes and legal cases. Results are never subject to undue influence from commercial or any other interests.

**CORE VALUE: PROFESSIONAL**

The best results are achieved by working professionally, in accordance with clear guidelines, within reasonable time and monetary limitations. TNO undertakes high-quality research in a wide range of fields, combining its findings to produce new solutions for key issues of our times. For this reason, it is important that we question each other and that we share our ideas and opinions. That encourages quality and creativity. So too do evaluation, reflection and openness about legal, safety and environmental risks, as well as challenging inappropriate behaviour.

**CORE VALUE: SOCIAL ENGAGED**

TNO fulfils a role of social importance: connecting people and knowledge to produce innovations which durably enhance the competitive strength of companies and the welfare of our society.

## SECTION 2

# UNIQUE POSITIONING

## Distinctiveness

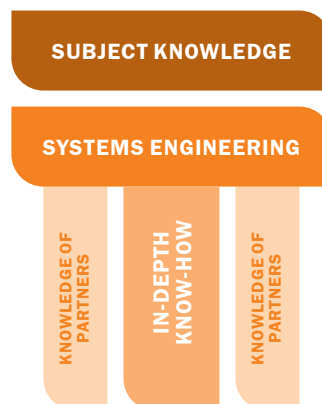
TNO's right to exist depends upon it adding value to the system of innovation in the Netherlands, in a recognizable, visible and unique way. This is no sinecure. Everyone at TNO has to work hard every day to maintain and reinforce our distinctive position, and so add that value.

### “T-PROFILE”

TNO is a multidisciplinary organization, and we want to remain one. What makes us unique is our combination of subject knowledge, specific in-depth know-how and systems-engineering abilities. It is these three features taken together, plus a thorough knowledge of our partners, which place us in an ideal position to develop practical innovations. Graphically, they form what we call our “T-profile”, as shown in figure 2.1.

## DOMAIN-SPECIFIC POSITIONING

As a public-sector research organization, TNO is always surrounded by many different knowledge and innovation partners. In close consultation with them and our clients, we always determine our exact role and positioning according to the characteristics—or in some cases the requirements, as with work for the Ministry of Defence—of the research to be undertaken. Relevant factors here include our relationship with the client or partner and the nature and maturity of the domain itself. Our position in respect of the apices of the triangle in figure 2.2 below therefore varies from domain to domain.



### ◀ In the T-profile:

- Subject knowledge is what we know about particular markets, client groups and ecosystems, including the challenges and players involved. This is needed in order to create appropriate innovations.
- Systems engineering is the ability, working with partners, to cross technological boundaries in order to devise integrated solutions.
- In-depth knowledge is the unique know-how we possess, which ensures that we are accepted as a domain partner and can make technological or social breakthroughs.

Figure 2.1 – TNO's “T-profile”

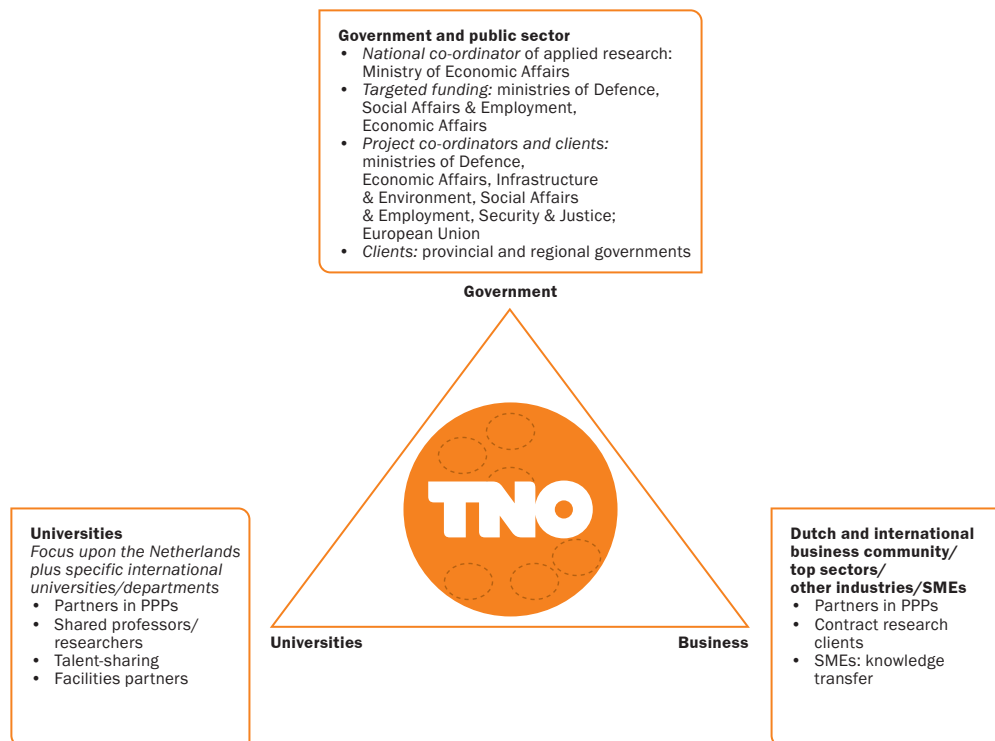


Figure 2.2 – TNO's positioning

### THOUGHT LEADERSHIP

Over the next few years, TNO intends to profile itself much more clearly as a “thought leader”. Our positioning enables—indeed, requires—us to help set the social agenda in the Netherlands and to suggest possible ways to resolve the great issues of our age. Drawing upon our in-depth scientific understanding of certain subjects, we aim to “feed” public debate with objective knowledge. This ambition also means revealing as much as we can of our expertise and know-how to clients, partners and prospects. The more widely TNO's capabilities are known, after all, the greater the contribution we can make to Dutch society and the national economy. We intend to pursue thought leadership by publishing even more widely in both scientific and non-scientific media, by encouraging our top scientists to become “standard bearers”—the public faces of their areas of expertise in the Netherlands, and even internationally—by more actively publicizing the results of our research and, in line with our core values, by reaffirming our status as the country's leading independent applied research centre in all the domains we work in.

### Clients and partners

We achieve impact through and with our clients and partners in a particular innovation domain. They can be classified into four groups: government, businesses and “top sectors”, universities and academic research bodies and other applied research organizations.

### GOVERNMENT IN THE NETHERLANDS AND EUROPE

As a public-sector research organization, TNO is engaged in a strategic relationship with the Dutch government. Our task is to maintain and build knowledge for the benefit of the nation, its society and its business community. We receive substantial government funding for this purpose, which we use to devise solutions to national challenges and to help the Dutch business community to implement successful innovations.

We assist government agencies with the development and implementation, of strategies, policies and standards. We also supply innovations in support of their public duties, sometimes backed by targeted state funding to build and maintain the necessary base of specific knowledge. Our aim is to further expand these activities.

Governments increasingly need independent professional knowledge partners to find answers to complex social questions and to support public initiatives. At the same time, however, many departmental innovation budgets have been reduced or decentralized in recent years. Social care is just one example. How government demand for TNO services is managed therefore requires new arrangements and agreements, which we need to reach amicably with the relevant agencies. As reiterated in the recent report by the so-called Schaaf Commission, the parliamentary commission of inquiry into applied research organizations, TNO has a significant contribution to make to Dutch society, with a high impact. How exactly this is provided and enhanced remains a subject for discussion with the relevant government departments.

Alongside the changing role of central government, there is also an increasing trend towards the regional organization and encouragement of innovative ecosystems. This is partly the result of a widely-shared conviction that large-scale public-private partnerships have a beneficial economic effect at this level. Examples include the metropolitan regions in Eindhoven, Rotterdam-The Hague and Amsterdam. TNO wants to support this development through centres of expertise such as so-called “joint innovation centres” and “field labs”, which link the national and regional knowledge agendas. We are already very active in regions like Eindhoven and Delft. In others, such as West Brabant/Bergen op Zoom (bio-based industry) and Leiden (bioscience), we are currently intensifying our engagement. We are also scouting potential new opportunities, including Groningen (energy, construction and cyber) and Geleen (smart materials), and hope to help develop these further in the coming years.

European Union research projects complement the national innovation and knowledge-building programme. Co-operation with counterparts and businesses throughout Europe facilitates the research exchanges needed to achieve international excellence and impact. In 2021 the EU’s current Horizon2020 research programme makes way for the ninth Framework Programme (FP9). For TNO this offers opportunities to better co-ordinate research as part of the national, regional and European programmes. Meanwhile, the increasing need for European security collaboration means that defence research is certain to be a new theme in the EU’s next Multiannual Financial Framework.

### **BUSINESSES AND TOP SECTORS**

Part of TNO’s mission is to improve the competitive strength of the Dutch private sector. To do this, we are working with businesses and with the “top sectors” defined by the Dutch government to develop innovative products and services which open up new markets because, for example, they are healthier, generate fewer CO<sub>2</sub> emissions, use less material or produce cleaner energy than current solutions.

As a result of globalization, companies today look all over the world for employees, business associates and know-how. When selecting research partners, too, they often adopt an international perspective. For TNO, this means that our knowledge base has to be distinctive and outstanding on the world stage as well as in the domestic arena.

# TNO: A UNIQUE MULTIDISCIPLINARY RESEARCH AND TECHNOLOGY ORGANISATION (RTO) IN THE NETHERLANDS

In order to be globally competitive, more and more regional and national alliances are forming in the Netherlands. These bring together companies of all sizes, government agencies and knowledge partners.

The Dutch government's "top sectors" policy aims to further strengthen industries in which the Netherlands is a global leader—by, for example, encouraging innovation through the implementation of public-private knowledge agendas. These key economic sectors and the system of public-private partnerships established within them will certainly continue to shape innovation efforts within the Dutch economy—and so guide TNO—for some years to come. As well as innovation along strictly sectoral lines, though, intersectoral co-operation is also increasing in importance.

SMEs represent a distinct market segment for TNO. We focus primarily upon those with an innovative business model, but are also happy to engage with others where possible. For example, we try to diffuse new know-how as rapidly as possible in partnership with universities of applied science and regional development corporations. The establishment of joint innovation centres conducting research across the entire spectrum of technological maturity—amongst them the Dutch Optic Centre (optics and optomechanics) in Delft and AM Systems (additive manufacturing) in Eindhoven—should open up new opportunities for SMEs.

## UNIVERSITIES, THE KNOWLEDGE COALITION AND NWO

Universities are the principal source of fundamental scientific knowledge and so are particularly important partners for TNO in our early research programmes. They are also becoming more and more anxious to "valorize" their results, a trend we view as providing the

ideal opportunity to build our relationships with them and combine our strengths. As we are already doing through a large number of alliances. For example, we are working closely with Delft University of Technology as a partner in the "high-tech incubator" Yes!Delft and with all four Dutch universities of technology as part of the Innovation Industries Fund. We also want to open First Dutch Innovations (formerly TNO Companies; see below: "Principal forms of research – Technology transfer") to university spin-offs.

Universities of applied science are important partners in disseminating knowledge to less technologically innovative SMEs. Since they provide more practical training and are present in every region of the Netherlands, they offer opportunities to accelerate the joint spread of relevant know-how.

In 2016, the Knowledge Coalition—comprising the Association of Universities in the Netherlands (VSNU), the Netherlands Association of Universities of Applied Sciences (Vereniging Hogescholen), the Netherlands Federation of University Medical Centres (NFU), the Royal Netherlands Academy of Arts and Sciences (KNAW), the Netherlands Organisation for Scientific Research (NWO), the national employers' confederation VNO-NCW, the SME representative body MKB Nederland and the Federation of Applied Research Organizations (TO2)—expanded the National Research Agenda (NRA) with 25 so-called "research pathways". The NRA will play a significant role in defining TNO's focus over the next few years and is also an important mechanism in facilitating public-private and public-public partnerships. Its research paths and the top sectors are mutually supportive and offer TNO good opportunities to work with partners to develop innovative solutions for major social challenges and to strengthen research in key technologies.

### APPLIED RESEARCH ORGANIZATIONS

Several organizations are actively engaged in applied scientific research in the Netherlands: Deltares (water and subsurface science), the Energy Research Centre of the Netherlands (ECN), the Maritime Research Institute Netherlands (MARIN), the Netherlands Aerospace Centre (NLR), Wageningen Research (WR) and TNO. All are members of the Federation of Applied Research Organizations (TO2). From 2018, ECN's sustainable energy activities are to be transferred to TNO and merged with ours, whilst our food research work is being taken over by the Dutch Food Initiative under the auspices of WR.

Since most have a specific scientific focus, the members of TO2 complement each other to form a multidisciplinary research community. The federation's strategic framework encourages this by emphasizing mutual co-operation at the basic programme level and the pooling of know-how, facilities and capacity, as well as collaboration with third parties. TNO would like to see TO2 further strengthened by, for example, sharing best practices and by establishing and implementing joint programmes.

At the European level, other research and technology organizations (RTOs) are relevant to TNO as potential knowledge partners. In the coming years we plan to forge at least one strategic partnership with a fellow RTO. Perhaps the most obvious candidate is Fraunhofer in Germany, as that country is an important industrial and trading partner for the Netherlands. At the same time we are investigating opportunities to join forces or to intensify existing collaborations in certain specific areas with such institutes as VITO and Imec in Belgium, VTT in Finland, Sintef in Norway, Tecnalia in Spain and/or SP in Sweden.

### Public financing: block grant and targeted funding

TNO helps to guide promising ideas and technologies through the so-called “valley of death”—the phase in the process of innovation at which ideas have advanced sufficiently to form the basis for a practical application but still involve too many uncertainties for market players to assume the full risk of their further development. The necessary research work is initiated in close consultation with clients and partners. The Dutch state's block grant to TNO provides the basic funding needed, topped up with contributions from clients and partners. How the block grant is used, be it for industrial research related to the top sectors or work on social themes, is specified in demand-driven annual programmes.

TNO is also required by law to maintain, enhance and upgrade the Dutch government's knowledge base in a number of research domains of national and public importance. These statutory tasks are financed by several different ministries, which allocate targeted funding for that purpose. The domains in question are:

- Defence. Under our strategic partnership with the Ministry of Defence, and where possible in collaboration with other parties (sometimes openly, sometimes confidentially), we maintain a defence-specific national knowledge base.
- Occupational health. On behalf of the Ministry of Social Affairs & Employment, we manage the MAPA working conditions programme.
- Geology. In our capacity as the Geological Survey of the Netherlands, we map the Dutch subsurface on behalf of the ministries of Infrastructure & the Environment and Economic Affairs and disseminate the resulting information in an innovative manner, for the benefit of society.

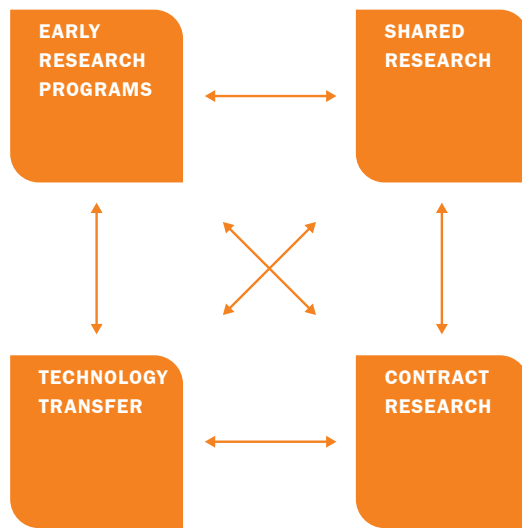


Figure 2.3 – Principal TNO activities

## Principal forms of research

TNO divides its research work into four main categories, which vary in their basic objectives, governance, financing and legal structure. They are: (1) early research programmes (ERPs); (2) shared research, meaning public-private and public-public partnerships and including joint innovation centres (JICs); (3) contract research; and (4) technology transfer.

### EARLY RESEARCH PROGRAMMES

ERPs are where scientific knowledge is substantially developed and expanded. On average, we have ten such programmes under way at any one time. When setting them up, we try to forge links with the outside world by co-ordinating them with stakeholders like universities and top sectors, establishing public-private partnerships or by identifying specific practical “use cases”. The basic funding for this kind of research comes from the ministries of Economic Affairs and Defence (where it is known as “high-risk exploratory research”) and is essential in maintaining and developing know-how in a phase when the market has yet to accept its relevance, or considers it too risky—as noted by the Advisory Council for Science, Technology and Innovation (AWTI) in its 2016 report, *Maintain the Basics*.

◀ In figure 2.3:

#### Early Research Programs

Research phase	Embryonic
Technology readiness level	3–5
Focus	Knowledge development: <ul style="list-style-type: none"> <li>– with partners</li> <li>– in PPS where possible</li> <li>– feasibility study</li> </ul>
Outcome	Insight into applications in various domains
State funding	ERP + targeted funding
Business model	Cost price

#### Shared research

Research phase	Growth
Technology readiness level	4–6
Focus	Knowledge development: <ul style="list-style-type: none"> <li>– with partners</li> <li>– in PPSs</li> </ul>
Outcome	Application in selected “use cases”, patents or spin-off technology
State funding	Research Co-operation Funds + targeted funding
Business model	Cost price

#### Contract research

Research phase	Mature
Technology readiness level	6–7
Focus	Application of knowledge: <ul style="list-style-type: none"> <li>– for individual private/public client</li> <li>– development and application of technology</li> </ul>
Outcome	Concrete product and/or service
State funding	n/a
Business model	Margin

#### Technology transfer

Research phase	Transfer
Technology readiness level	8–9
Focus	Exploitation of knowledge: <ul style="list-style-type: none"> <li>– IP license</li> <li>– spin-off (high tech start-up)</li> <li>– spin-out of mature technology</li> </ul>
Outcome	n/a
State funding	n/a
Business model	IP and sales revenue

<b>Name</b>	<b>TNO partners</b>	<b>Theme</b>	<b>Launch date</b>
<b>Aeolus</b>	Centre for Man and Aviation, Royal Netherlands Air Force	Human factors in extreme circumstances	2016
<b>AM Systems</b>	Eindhoven University of Technology (TU/e)	Additive manufacturing	2016
<b>Biorizon</b>	VITO, Green Chemistry Campus	Biobased aromatics	2012
<b>BMC (Brightlands Material Center)</b>	Province of Limburg, Brightlands Campus	Polymer materials	2015
<b>DOC (Dutch Optics Centre)</b>	Delft University of Technology	Optics and optomechanics	2016
<b>Holst Centre</b>	Imec	Flexible electronics	2006
<b>QuTech</b>	Delft University of Technology	Quantum computing and internet	2014
<b>Solliance</b>	ECN, Imec, Holst Centre, TU/e, Jülich Research Centre, University of Hasselt, Delft University of Technology	Thin-film photovoltaics	2010

Table 2.1 – Current joint innovation centres

### SHARED RESEARCH

Many innovations are the product of precompetitive collaboration, hence the term “shared research”. TNO wants to expand the use of both public-private and public-public partnerships as powerful means to achieve impact, and we foresee an increasing role for ourselves in shaping and taking part in these innovative initiatives. This can be done through projects, programmes or joint innovation centres (JICs): large-scale, long-term national or international alliances between two or more research centres, government agencies and/or companies, formed to undertake innovative, high-impact research around a clear programme in a specific technological field. At present, TNO is a partner in eight JICs. Ten more are in the pipeline, either as identified themes for new initiatives or in the early stages of their development.

### CONTRACT RESEARCH

Once client and partner requirements crystallize, TNO often receives requests to exclude third parties from subsequent research. For this to happen, we enter into contracts to find bespoke solutions with greater exclusivity than allowed for under public-private partnership arrangements: as a rule, developing and applying know-how in the form of a prototype, product or service—or, for government, concrete policy recommendations. However, this remains precommercial work: TNO does not undertake research which brings it into head-on competition with market players.

### TECHNOLOGY TRANSFER

This is the final phase of TNO’s involvement in the innovation cycle, when we “valorize” our knowledge in the form of licensing agreements and spin-offs. Once a technology is mature, the market can take it over. In recent years, TNO spin-offs and licences have made a substantial contribution to employment in the Netherlands.

Our intellectual property (IP) only acquires value when it is bought or licensed by paying customers, so from now on we plan to market it more aggressively. Conversely, TNO has a public remit to strengthen the knowledge position of the Dutch economy as a whole. This requires not only that we protect research findings with commercial potential, but also that—subject to reasonable conditions—we disseminate the knowledge we develop as widely as possible. In many cases, however, both are possible. After a patent has been applied for, for instance, we are free to publish a scientific paper on the breakthrough it covers. The knowledge is thus released, but its exploitation is protected. The basic principle we apply in such cases is, “open access where possible, restricted access where necessary”. Such restrictions are imposed if releasing IP might harm the Netherlands’ international competitive position or disrupt the market, say, or if it is needed for follow-up research. A more detailed IP strategy is to be developed in the near future.



“Business incubator” TNO Companies has always been an important means of bringing our innovations to the market through spin-off companies. With a portfolio of 27 firms employing more than 1100 people, until recently this organization was a wholly-owned subsidiary of TNO. In order to enhance its financial and commercial strength, we sold our majority stake to a carefully selected strategic partner, First Dutch. It has since been reorganized and renamed First Dutch Innovations (FDI).

This new arrangement offers a number of benefits.

- FDI is an active investor with a broader scope than TNO spin-offs alone, thus making its know-how available to other parties wanting to bring innovations to the marketplace.
- With a wider “pipeline” for potential spin-offs, FDI should be able to grow faster as a “launch platform”.
- The new organization is closer to the market and able to bring in outside commercial and financial expertise.
- Outside financing for growth, value creation and value realization has become available.

Meanwhile, TNO has introduced a new, more structured approach to technology transfer with better support during the formation of spin-offs and their preparations to enter the market. Staff are encouraged to bring promising ideas to the central technology-transfer team, which can then facilitate them. Step by step, interesting concepts are distilled into a business plan and, if necessary, an entrepreneurial backer is sought. After each step the project is assessed by a technology-transfer board made up of TNO personnel and outside experts, which also allocates resources to those with potential. This programme is to be improved and expanded over the next few years. ■

**COOPERATION  
IS CRUCIAL.  
THAT’S WHY  
WE FORM  
JOINT INNOVATION  
CENTRES:  
LARGE-SCALE,  
LONG-TERM  
NATIONAL  
OR INTERNATIONAL  
ALLIANCES**

## SECTION 3

# AGENDA FOR THE FUTURE

## SOCIETY'S CHALLENGES GUIDE TNO CHOICES

Every age presents its own challenges. TNO wants to help resolve those we as a society face today, and are set to face tomorrow. But we cannot do everything, nor do we want to. Choices therefore have to be made in respect of our research portfolio and programmes, in order to create the focus and mass needed to maximize our impact. What we do, we intend to do well.

This section explains how external challenges shape our choices concerning the specific domains TNO wishes to be active in, and the priorities we set within them. We then describe the areas—both scientific and social—in which we want to work on technological innovations. Finally, we set out how we are operationalizing those innovations in the form of early research programmes (ERPs) and joint innovation centres (JICs), and what facilities we use or want to develop in order to do so. Figure 3.1 illustrates this process.

## CHALLENGES AND AGENDAS

The great challenges of our times are encapsulated in the UN's sustainable development goals, in the EU's grand societal challenges, key enabling technologies (KETs) and Leadership in Enabling and Industrial Technologies (LEIT) programme and in the Dutch National Research Agenda (NWA). These agendas are summarized in table 3.1. Major recurring themes in all of them are climate change, sustainability, public security, work and well-being, with the digitization of society an important unifying enabler of solutions across all our domains.

These topics also resonate in the specific policy programmes of various Dutch government ministries, in the innovation agendas of the so-called "top sectors" and in the ambitions of individual companies and NGOs. Combining social and technological challenges, trends and developments, they are shaping the world of tomorrow and so also guiding TNO's knowledge portfolio and programme choices.

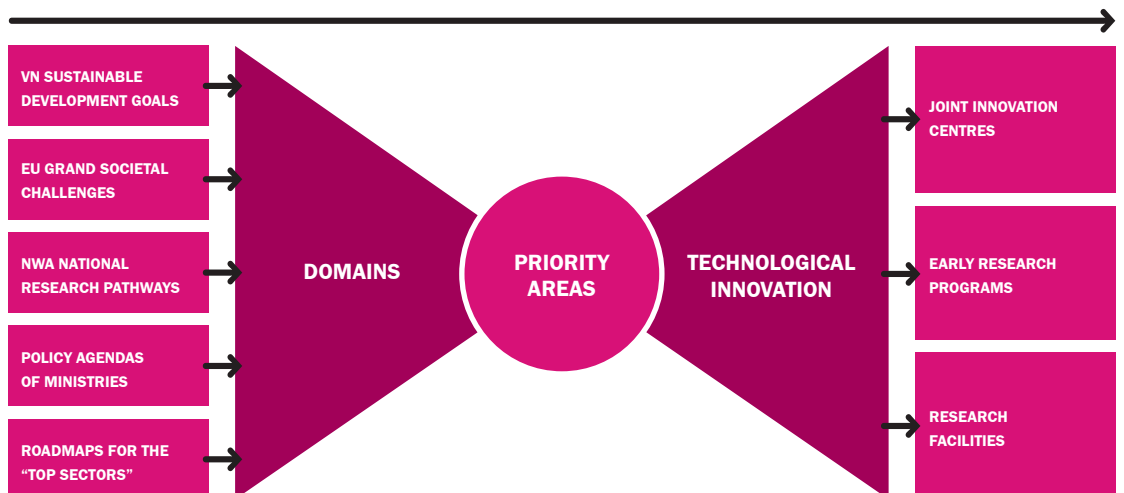


Figure 3.1 – From external challenges to TNO strategy

## TNO CHOICES: DOMAINS, PRIORITIES AND TECHNOLOGICAL INNOVATION

The areas TNO can and wants to be active in are defined by a number of factors. They include ...

- Key issues affecting the Netherlands and generally accepted as requiring urgent action: the energy transition, the cost and quality of healthcare, a safe, liveable, sustainable and resilient society, high-quality employment and so on.
- The policy agendas of government ministries and NGOs, and the roadmaps for the “top sectors”.
- TNO’s positioning in the system of innovation: the specific and distinctive strengths, experience and know-how with which we can achieve maximum impact.
- The extent to which our know-how connects different scientific disciplines to facilitate the development of comprehensive solutions in collaboration with our partners.

### UN sustainable development goals:

1. No poverty
2. Zero hunger, sustainable agriculture
3. Good health and well-being
4. Quality education
5. Gender equality
6. Clean water and sanitation
7. Affordable and clean energy
8. Decent work and economic growth
9. Sustainable industry, innovation and infrastructure
10. Reduced inequalities
11. Sustainable cities and communities
12. Responsible consumption and production
13. Climate action
14. Protection of life below water
15. Protection of life on land
16. Peace, justice and strong institutions
17. Partnerships to achieve the goals

### EU grand societal challenges:

1. Health and well-being
2. Food security and the bioeconomy
3. Secure and clean energy
4. Smart and green transport
5. Climate and raw materials
6. Innovative societies
7. Secure societies

### EU key enabling technologies:

1. Micro and nanoelectronics
2. Nanotechnology
3. Industrial biotechnology
4. Advanced materials
5. Photonics
6. Advanced manufacturing technologies

### EU Leadership in Enabling Industrial Technologies

1. ICT
  - ICT KETs (Photonics)
  - Future Internet (5G PPP)
  - Robotics & autonomous systems (SPARC)
  - Advanced & cloud computing
  - Content (Big Data Value Association)
2. Nanotech
3. Biotechnology
4. Advanced Manufacturing
5. Space

### NWA National Research Agenda:

1. The “Blue Route”: water as a path to innovative and sustainable growth
2. Building blocks and materials and fundamentals of space and time
3. The circular economy and efficient use of raw materials: sustainable circular impact
4. Sustainable production of safe, healthy food
5. The energy transition
6. Health research: preventive and curative medicine
7. Growing up, parenting and education
8. Art: research and innovation in the 21st century
9. Environmental quality
10. The living past
11. Logistics and transport in a dynamic, innovative and sustainable society
12. Materials “Made in Holland”
13. Measurement and detection: anything, any time, anywhere
14. NeuroLabNL: the centre for brain, cognition and behavioural research
15. The origins of life—on earth and in the cosmos
16. Towards a resilient society
17. Personalized medicine: putting the individual first
18. The quantum/nanorevolution
19. Regenerative medicine: a game-changer on the way to general use
20. Smart industry
21. Smart, liveable cities
22. Sport and exercise
23. Sustainable development goals for inclusive global development
24. Between conflict and co-operation
25. Value creation through managed access to and use of big data

Table 3.1 – External agendas

With these factors in mind, we have decided to focus upon five domains and set clear objectives in each of them.

- Industry, for a strong, internationally competitive business community.
- Healthy Living, for a fit, healthy and productive population.
- Defence and Security, for decisive action in an uncertain world.
- Energy, for faster progress towards a low-carbon energy system.
- Urbanisation, to innovate for dynamic urban regions.

Each of these domains is a world in itself, so even greater focus is needed within them. In close consultation with the relevant stakeholders, we have defined a number of research priorities per domain. These are specific topics around which we will be concentrating our efforts in order to make a worthwhile contribution. They are listed in table 3.2. As with our choice of domains, these priorities have been defined by comparing key issues in the external agendas with TNO's positioning and specific strengths.<sup>2</sup>

To approach these priority areas in a way that produces tangible solutions, we intend to concentrate our innovation activities around a limited number of technologies in each—technologies essential to finding those solutions and in which we excel. They are listed in table 3.3, together with TNO's unique focus in that field and the associated strategic instruments: input from ERPs (or, in the case of work for the Ministry of Defence, from “high-risk exploratory research”) and the Netherlands Enterprise Agency (RVO), “grand alliances” (JICs) to enhance our proposition and impact and, in the final column, significant investments we hope to make in major research facilities. ■

2. Appendix 1 summarizes how external agendas have shaped our choice of domains, research priorities and specific technological innovations for the coming years, as well as listing the “top sectors” and ministries associated with each priority.

**COMBINING SOCIAL  
AND TECHNOLOGICAL CHALLENGES  
TO GUIDE TNO'S KNOWLEDGE PORTFOLIO  
AND PROGRAMME CHOICES**

Industry	Healthy Living	Defence and Security	Energy	Urbanisation
<p>Breakthrough technology for industrial innovation:</p> <ul style="list-style-type: none"> <li>– nanotechnology and quantum computers for greater computing power;</li> <li>– 5G with a wide spectrum of applications;</li> <li>– renewable raw materials;</li> <li>– photonics and optics for observation and communication in space;</li> <li>– functional new materials, including nanomaterials;</li> <li>– smart-industry concepts based upon the internet of things, artificial intelligence, big data and robotics.</li> </ul>	<ul style="list-style-type: none"> <li>– Fit and healthy young people</li> <li>– Longer working lives</li> <li>– Biomedical health: innovative treatment strategies and new medicines</li> <li>– Health technology and digital health</li> <li>– Personalized health interventions</li> </ul>	<ul style="list-style-type: none"> <li>– Information as a target and a weapon, and information-intensive operations</li> <li>– Unmanned and autonomous systems and human-machine teaming</li> <li>– People and mindset in the armed forces and other security providers</li> <li>– Modern fighting ability, escalation dominance and protection</li> <li>– Resilience in the face of major social upheaval</li> <li>– Opportunities and threats from new technology</li> </ul>	<p>Our energy priorities are to be decided during the course of 2017, as part of the process of merging the sustainable energy activities of ECN and TNO</p>	<ul style="list-style-type: none"> <li>– Mobility: scaleable, safe co-operative and self-driving vehicles</li> <li>– Infrastructure and buildings: self-learning industrial concepts</li> <li>– Environment: more accurate monitoring and local management for proactive quality improvement and resource exploitation</li> <li>– Systemic approaches for more liveable cities and greater adaptivity</li> </ul>

Table 3.2 – TNO research priorities for 2018–2021, by domain

TECHNOLOGICAL INNOVATION		STRATEGIC INSTRUMENTS		
Field of technology	Unique TNO focus	Partnerships (JICs)	Early research programmes and high-risk exploratory research	Research facilities
Nanotechnology and quantum technology	Nanometrology; nanopatterning; laser satellite communications; bionanosensors; adaptive optomechanics; quantum components (processors, sensors), quantum cryptography; nanosensors and quantum sensors; nanomaterials for protection and signature reduction; additive manufacturing	DOC; QuTech; Holst	Quantum Computer & Quantum Internet; 3D Nanomanufacturing; Optochemical Sensors; Bionanosensing; Engineering the Subsurface; Quantum Algorithms; Nanosensors and Quantum Sensors; Innovative Materials for Protection and Signature Reduction	Van Leeuwenhoek Laboratory (VLL): enlarging cleanroom capacity, VLL equipment (eg. calibration for satellite instrumentation); Dutch Optics Centre; Physics and Electronics Laboratory; Ballistics Laboratory
Hybrid energy systems	Power to gas; heat networks; thermochemical and underground storage; flexible fuels; solar foil; integrated photovoltaic cells	HESI; Solliance; Holst	Energy Storage & Conversion	Delft Ocean Technology Centre; Smart-Large optimization and demonstration facilities; upgrade of MEC Building laboratory
Smart and green materials	Aromatics from biomass; electrochemistry; green energy materials; metamaterials for protection and signature reduction; additive manufacturing	Biorizon; BMC; Voltachem	Energy Storage & Conversion; Submicron Composites; Smart and Green Materials; Innovative Materials for Protection and Signature Reduction	Chemical energy storage and conversion lab, BioRizon-ADAPT, ADAPT pilot facility for bio-aromatics, Lab for sustainable procestechology, Fysisch en elektronisch lab, Ballistics lab, Pyrotechnics lab

Field of technology	Unique TNO focus	Partnerships (JICs)	Early research programmes and high-risk exploratory research	Research facilities
Smart megastructures	Large-scale instrumentation with high-resolution sensors; predictive models		Structural integrity	Delft ocean technology centre, Smart-large optimization and demonstration facilities, upgrade MEC building lab
Media synchronization	VR, AR and tactile internet; advanced and cloud-based information systems; distributed storage and processing; 5G internet; internet of skills	EIT Digital	Media Synchronization	
Artificial intelligence	Propagation of uncertainty; uncertainty and adaptation; causal interference; frame autonomy; model-based software refactoring; cognitive enhancement; self-learning systems; big-data harvesting; self-explaining analysis	EIT Digital	Making Sense of Big Data; Artificial Intelligence; Big-Data Analytics	
Robotics	Remote-controlled maintenance robots; exoskeletons; autonomous systems; artificial intelligence; robot swarms; human-robot interaction	iBotics	iBotics; Autonomous Systems; Human-Machine Teaming	Interaction Robotics Laboratory

Field of technology	Unique TNO focus	Partnerships (JICs)	Early research programmes and high-risk exploratory research	Research facilities
Neuro-technology/ medical technology	Cortex sensory interfaces; non-invasive imaging techniques (radar, infrared, ultrasound) for examining organ function, including the brain's; detection and identification of bio-engineered life forms	NeuroTechNL; i3B	Human Enhancement; Synthetic Biology	Interaction Robotics Laboratory
Subsurface engineering	Modelling and forecasting surface effects of underground activity	GeoERA	Structural Integrity	
Valorization of data and metadata	Business and value models for advanced data; generation, validation and interpretation of satellite and climate data (ACTRIS)	EIT Digital	Making Sense of Big Data; Big-Data Analytics	
Inside the human body	Human microbiotics and its effects (antibiotics); allergies and food-ingredient risks; “organ-on-a-chip” modelling; total exposure and exposomic effects; biometrics; threats from bio-engineered life forms	Metabolic Health Innovations; Neurotech-NL	Organ on a Chip; Personalized Health; Synthetic Biology	Biomedical Accelerator Mass Spectrometry Laboratory (AMS2); Inside the Human Body; CBRN High-Tox Laboratory



Field of technology	Unique TNO focus	Partnerships (JICs)	Early research programmes and high-risk exploratory research	Research facilities
Inside the human mind	Causal links between the microbiome, physiology and cognition; biomarkers of cognitive and mental condition; individual behaviour and intervention effectiveness; cognition and behaviour; cognitive and mental enhancement	iBotics; Aeolus; i3B; Neurotech-NL	Human enhancement	Desdemona+, Interaction Robotics Laboratory
Integrated social-system modelling and forecasting	Multilevel energy optimization; self-organizing logistics; sustainable business models; integrated urban models and forecasts (technological, business, behavioural); responses to social engineering; psychological and information operations	Labour JIC, Leiden	Complexity; Opponent Modelling	Hybrid Energy Systems Integration (HESI) Laboratory; Real-Life Safety Methodology Research Facility; Hybrid Warfare Laboratory

**Table 3.3 – Technological innovation at TNO, with strategic instruments.**

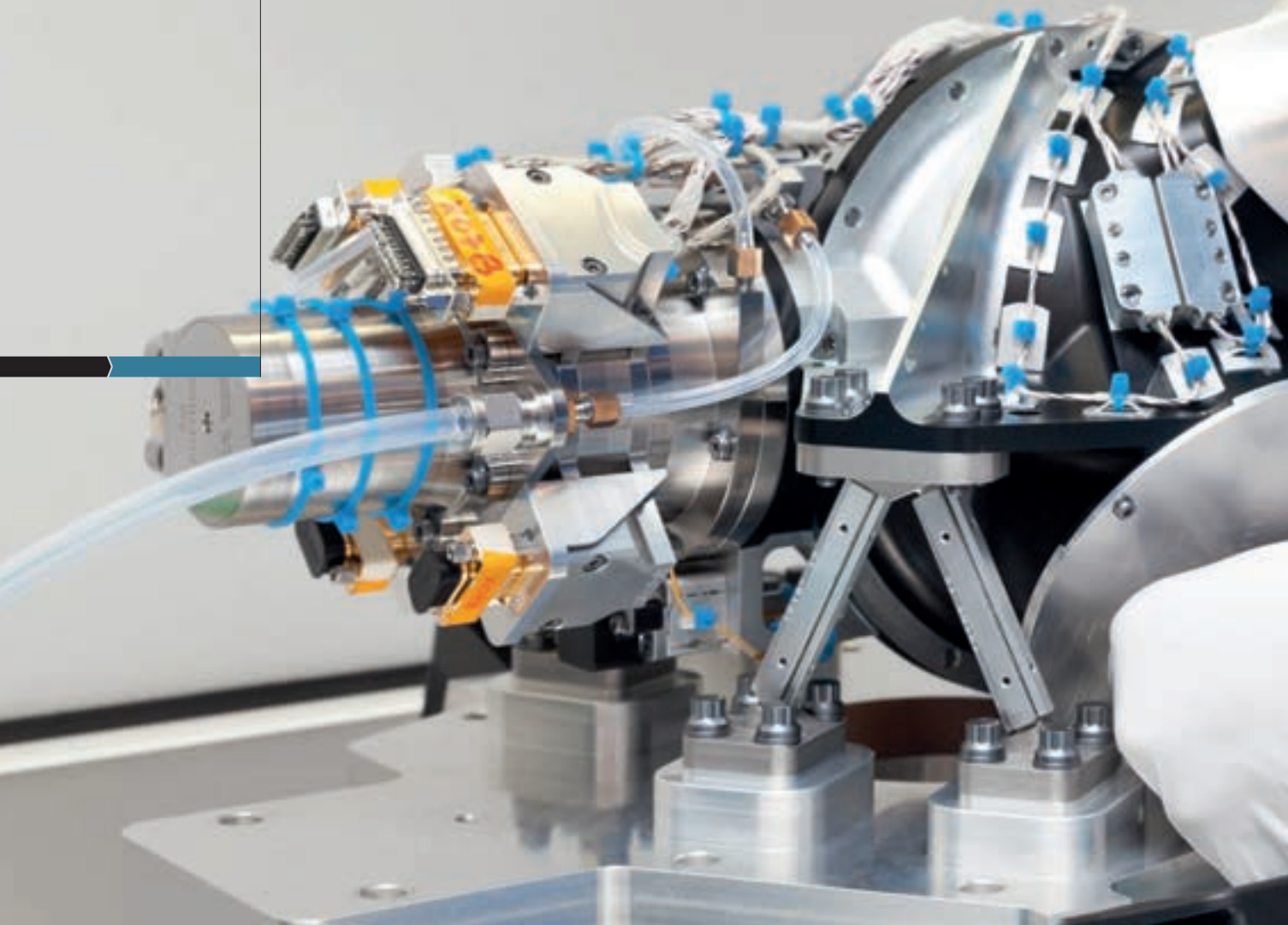
The priorities and technologies described above do not represent TNO's entire portfolio, only those areas in which we expect to focus our innovative activities during the next few years. We will also remain active in fields in which we are already unique and relevant—such as maritime and offshore technology—and in those where we are entrusted with statutory tasks, including certain parts of the Defence and Security domain. Even in these areas, of course, constant innovation is essential. ■

## SECTION 4

# DYNAMIC KNOWLEDGE INNOVATION

As described in the previous section, TNO's strategic programme is shaped by the major challenges facing society. These define the domains we are active in, our choice of research priorities and the specific innovations we are pursuing. In this section we set out TNO's specific ambitions in each domain, describe our priorities in more detail, introduce our most important clients and partners and explain what technological innovations we plan to work on.

These are our substantive choices for the years ahead, the topics we plan to "run with". But we live in a rapidly changing world, and sooner rather than later it is likely to present us with new social challenges—and new technological opportunities. In response, and in close consultation with clients and partners, we are quite prepared to adapt our research portfolio and programme accordingly.





# INDUSTRY

## A STRONG, INTERNATIONALLY COMPETITIVE BUSINESS COMMUNITY

### OUR AMBITION

Dutch industry is amongst the best in the world. Together with its suppliers and related services like IT support, it accounts for a substantial proportion of the nation's exports and creates high-value employment. And it is a vital link in solving the major challenges facing our society. TNO is playing its part to further advance Dutch industry by developing key technologies with the aim of building a strong, internationally competitive business community and so increasing employment and maintaining national prosperity.

### OUR CONTRIBUTION: RESEARCH PRIORITIES FOR THE COMING YEARS

Society's great challenges also represent new opportunities for "smart" industry. The need to improve sustainability is a proving an ever heavier burden for this sector, but also provides a source of inspiration for new materials, products, processes and services. The arsenal of possibilities is expanding all the time thanks to development in the so-called "key enabling technologies", such as photonics, nanotechnology, quantum technology and advanced production and ICT solutions. The trick, though, is to bring these to the point where they can be implemented industrially. Many innovations in this domain have a digital component ("smartness" and the "internet of things"). And it is becoming more and more usual that they are the product not of one company, but of cocreation—in public-private partnership constructions like "innovation hubs" and "field labs", for example. With the resulting turnover and profit are shared through novel business models. This is the playing field on which TNO operates. In this domain we have chosen the priorities listed below, as they serve the needs of industry and society as well as building on our strengths.

### PRIORITIES FOR THE COMING YEARS

Breakthrough technology for industrial innovation:

- nanotechnology and quantum computers for greater computing power;
- 5G with a wide spectrum of applications;
- renewable raw materials;
- photonics and optics for observation and communication in space;
- functional new materials, including nanomaterials;
- smart-industry concepts based upon the internet of things, artificial intelligence, big data and robotics.

### NANOTECHNOLOGY AND QUANTUM COMPUTERS FOR GREATER COMPUTING POWER

The demand for more powerful yet more energy-efficient communication networks, computers and IT systems offers interesting opportunities for the Dutch high-tech equipment industry, in such segments as semiconductors. TNO is supporting this sector by developing and applying nanotechnology and quantum technology. We are also working on innovative, DNA-inspired nano and optics solutions for healthcare and for use in space exploration and astronomy.

### 5G WITH A WIDE SPECTRUM OF APPLICATIONS

The new 5G standard will comprise a collection of technologies bringing together a number of currently irreconcilable functions. For example, a huge increase in bandwidth combined with extremely high speed and reliability plus an explosive rise in the number of connected devices. On behalf of the telecommunications sector, TNO is developing and patenting the necessary technology. We also want to be a leader in 5G standardization and are working on new applications which will need it. This is being done within public-private partnerships like 5Groningen, with a focus upon rural applications, and ArenA for urban ones.



### RENEWABLE RAW MATERIALS

Our research in this area focuses on renewable raw materials such as biomass, waste and carbon dioxide, as well as on sustainable power generation for “greener” industrial processes and chemicals production. Another area of interest is improved functionality for materials and chemicals to deliver greater intrinsic sustainability when they are actually in use. Here, we believe, lies the key to a futureproof processing industry and the introduction of new products providing higher added value.

### PHOTONICS AND OPTICS FOR OBSERVATION AND COMMUNICATION IN SPACE

Photonics is becoming a key technology for the Dutch space industry. To help maintain its global lead in earth and atmospheric observation instruments, TNO is pioneering the creation of compact devices for small satellites. And to ensure that the growing data streams they generate are processed safely and reliably, we are developing laser-based systems for communication between satellites and ground stations. These will also facilitate applications on the 5G network. Another area we are investigating is the potential of quantum computing and communications in space.

### FUNCTIONAL NEW MATERIALS, INCLUDING NANOMATERIALS

The transition to sustainable energy generation and storage is presenting industry with new opportunities. For example, TNO is working on novel “thin-film” solar cells and is exploring the integration of solar cells with heat-regulating windows in buildings and vehicles. Using the same thin-film technology, we are also pioneering new forms of energy storage: innovative batteries and systems to convert sunlight into synthetic fuels—functions which exploit the properties of materials at the atomic and molecular nanolevels.

### SMART INDUSTRY CONCEPTS BASED UPON THE INTERNET OF THINGS, ARTIFICIAL INTELLIGENCE, BIG DATA AND ROBOTICS

TNO’s focus here is the digitization of manufacturing processes, products and systems. We are integrating data (big data, artificial intelligence), adding smart functions to products (sensors, user interfaces, the internet of things), creating novel applications for 5G wireless networks and pioneering new ways for systems to conduct transactions between themselves (blockchains). Using digitally controlled production processes (3D printing, additive manufacturing, smart robots and so on), we are also creating new forms of efficient, high-quality short-run and one-off fabrication. And we are supporting the establishment of new business models for commercial ecosystems comprising suppliers that develop and make products in conjunction with original equipment manufacturers (OEMs), who in turn evolve into solution providers leasing their products. In this field we are paying particular attention to innovative networks of established SMEs, start-ups and scale-ups seeking to develop their own products, make them cost-effectively in small numbers and sell them bundled with related services.

### CLIENTS AND PARTNERS

Our principal clients and partners in this domain are:

- Businesses active in high-tech manufacturing, space technology, telecommunications and chemicals, including parts of the “top sectors” high-tech systems and materials, information and communications technology and chemicals.
- The public sector, including the ministries of Economic Affairs, Education, Culture and Science and Defence, as well as the European Commission and its research programmes.
- Research institutes: the four Dutch universities of technology (Delft, Eindhoven, Twente and Wageningen), other universities, applied research organizations (NLR, ECN) and partners abroad (Fraunhofer, Imec, VITO).

TNO's efforts here will focus upon structural and programmed co-operation with these partners, in the form of field labs, joint innovation centres, innovation hubs, consortia undertaking European framework programme projects and public-private partnerships, since we are convinced that this—far more than conducting individual projects—is the best way to tackle the huge innovation challenges we face. Established examples of joint initiatives include the Holst Centre, Solliance, QuTech, Biorizon, the Brightlands Materials Centre and the AM Systems Centre, and more are in the pipeline. In extending this approach, we are particularly committed to regional alliances like Smart Industry's thirty field labs. The most recent initiatives to emerge are related to the electrification of the chemicals industry (Voltachem), blockchain technology (trust in transactions between parties unknown to each other) and the new 5G mobile network.

In addition, we support the Ministry of Economic Affairs in developing its industrial policy and the associated instruments. For the Ministry of Education, Culture and Science we are exploring ways of increasing participation by Dutch businesses, especially SMEs, in “big science” projects like the ITER fusion reactor and CERN nuclear research centre.

#### TECHNOLOGICAL INNOVATIONS

- **Nanotechnology:** 3D/additive manufacturing, nanometrology and patterning, nanoparticle synthesis and macromolecular self-assembly are all playing their part in fulfilling our ambition to build products layer by layer, or even atom by atom, so that the exact functionality required can be obtained in an industrial manner. Biological knowledge is being used to develop new nanoinstruments.
- **Quantum technology:** Quantum calculation (for speed) and quantum communication (for encryption) are set to result in major breakthroughs in the management and security of data streams.
- **Photonics:** Aspheric, adaptive and free-form optics are bringing complete control over photons and electromagnetic waves ever closer, and steadily increasing the resolution and accuracy of sensors and measuring devices.
- **Media synchronization:** Augmented and virtual reality, are—as a result of the parallel developments in the internet of things, data/AI and embedded systems—going to play an important role in content creation and in services like remote maintenance. 5G is an important priority for the next few years, in

terms of both the underlying technologies and the new services it could make possible, in such areas as automated driving, media and entertainment.

- **Valorization of metadata:** TNO is using blockchain technology to enable safe, reliable transactions and data-sharing within technological ecosystems. New service-based business models are in development, in such areas as satellite climate data for cities.
- **Smart and green materials:** With our knowledge of process technology, we are developing chemical building blocks (aromatics) from biomass and waste. And by electrifying chemical processes we are making the production of chemicals more sustainable and enabling the conversion of carbon dioxide into energy carriers. Additive manufacturing is helping in the development of smart materials for use in building, vehicles and so on.
- **Hybrid energy systems:** We are working on ultrathin-film deposition and patterning for sustainable energy generation and storage using perovskite solar cells, innovative batteries and solar fuels.
- **Robotics:** Together with sensors and optical measurement methods, robotics is playing its part in the smart-industry revolution by enabling one-off fabrication for the same unit price as mass production and so helping to bring manufacturing back to the Netherlands.
- **Artificial intelligence:** As well as smart sensors and communications, the digitization of manufacturing is creating demand for deep-learning technologies for data interpretation and self-guiding systems.
- **Inside the human mind:** In the future, people will co-operate more and more intensively with computers, robots and self-guiding systems. This requires a good understanding of cognitive and mental attitudes in the workplace, and of intervention possibilities. ■



# HEALTHY LIVING

## A FIT, HEALTHY AND PRODUCTIVE POPULATION

### OUR AMBITION

We want a fit, healthy and productive population. To help achieve this, the innovations we develop focus upon four “Ps”:

- Prevention: better than cure.
- Prediction: forecasting using scientifically proven methods.
- Personal: health, lifestyle and intervention advice tailored to the individual.
- Participation: involving people in society and work, and interesting them in the quality of their living and working environment.

### OUR CONTRIBUTION: RESEARCH PRIORITIES FOR THE COMING YEARS

Ensuring that everyone, young and old, can play an active part in society whilst at the same time keeping healthcare affordable yet high in quality as the population ages. That is the greatest challenge we face in this domain. The government is shifting more and more of the responsibility for healthy living and social participation to the individual, and they in turn want to decide what is good for them personally. Local authorities have been given new tasks in this area, and commercial businesses are responding to the changes with new healthcare services. TNO is supporting both the public and the private sectors with technological and social innovations to promote healthy living and working, a contribution deliberately aligned with the knowledge and innovation agenda of the “top sector” life sciences and health and with the Ministry of Social Affairs & Employment’s (SZW) 2018–2019 knowledge strategy.

### PRIORITIES FOR THE COMING YEARS

- Fit and healthy young people.
- Longer working lives.
- Biomedical health: innovative treatment strategies and new medicines.
- Health technology and digital health.
- Personalized health interventions.

### FIT AND HEALTHY YOUNG PEOPLE

TNO is developing new and effective approaches to keep children healthy, both physically and mentally. Directly, but also through their surroundings: home, school, neighbourhood and community support services. Over the next few years we want to ensure that every child is given a healthy start in their first thousand days of life. To that end, we are working with partners in the child and youth healthcare and youth policy arenas.

### LONGER WORKING LIVES

In the coming years we plan to develop interventions and instruments to help prepare both employers and employees for the tasks of the future and the professional skills they require. For example, we are investigating the repercussions of workplace automation and revealing how human-robot interaction is creating new opportunities to extend working lives and to enable workforce participation by all.

To promote health and safety at work, we are developing sensors to measure exposure to hazardous substances and developing the exposome. By facilitating immediate interventions in high-risk situations, this work paves the way for bespoke solutions and better control—a research priority which corresponds with the themes “Future of work” and “Decent work, longer working lives” in the SZW 2018–2019 knowledge strategy.

# TNO SHORTENS THE LENGTHY PROCESS OF DEVELOPING NEW DRUGS





### BIOMEDICAL HEALTH: INNOVATIVE TREATMENT STRATEGIES AND NEW MEDICINES

In partnership with pharmaceutical companies, we are working on methods and models to better predict the effectiveness of medicines. And new in-vitro techniques such as “organ on a chip” make it possible to conduct medical experiments—with stem cells, for instance—outside the body.

In this way TNO is helping to shorten the lengthy process of developing new drugs, to reduce the need for animal experiments and to cut the risk that, in the final phase, human clinical trials, the products turn out not to work after all.

Thanks to microdosing and non-invasive sensors, it is also possible to take measurements directly from human subjects. This enhances the accuracy of predictions about the effects of a medicine upon a particular patient, so that we can establish which therapy best suits each individual. Meanwhile, recent developments in systems biology are making it easier to study the possible effects of pathogens and toxins in a more integrated manner, and to treat them at the individual level. Our work in this area focuses mainly upon intestinal health and metabolic conditions such as diabetes and its complications.

### HEALTH TECHNOLOGY AND DIGITAL HEALTH

New technology is encouraging many consumers to take greater control over their own health. The rapid rise of wearables featuring health apps continues, a trend which calls for both technological and practical innovation on our part in support of providers. TNO’s contribution includes Stresscoach, to enable the early detection and treatment of overexertion.

We have identified four factors crucial to increasing the impact of health technology and digital health: personalized design, valid and reliable predictive models, advanced data profiling and guaranteeing privacy and security. TNO is focusing on systems integration and on developing fact-based models and applications.

### PERSONALIZED HEALTH INTERVENTIONS

The principal challenge facing the Dutch healthcare sector in the next few years is to combine quality improvement with cost control. To make health interventions better and more effective, TNO favours an integrated approach combining the latest medical know-how with good technical and IT support and changes to patient lifestyles and behaviour. Our contribution includes new insights into child and youth healthcare, extending working lives, biomedicine and health technology, and we are working with a wide range of healthcare stakeholders and other partners (insurers, retailers, sports organizations, technology firms and IT businesses) in multi-stakeholder projects, public-private partnerships, joint innovation centres and European alliances.

### CLIENTS AND PARTNERS

Our principal clients and partners in this domain are:

- In the commercial sector, the pharmaceutical and biotechnology industries, health-service providers, industries with high health-and-safety risks and Rotterdam Mainport.
- The “top sector” life sciences and health.
- NGOs like the Netherlands Organisation for Health Research and Development (ZonMW) and the Bill and Melinda Gates Foundation.
- In government, the Dutch Ministry of Social Affairs and Employment, and the Ministry of Health, Welfare and Sport.
- In Europe, the European Commission (Horizon 2020) and EIT Health.
- Local authorities.
- Alliances with universities and research centres: Leiden University Medical Centre, Utrecht University Medical Centre, Utrecht University, VU Amsterdam, Wageningen University and Research, the Institute for Human Organ and Disease Model Technologies, the Centre for Care Technology Research and the National Organization for Scientific Research.

Our strategy for the coming years is to establish and build broad alliances in the following areas.

- Labour-market issues related to longer working lives: flexible employment, qualification obsolescence and technological innovation (robots, digitization).
- The first thousand days of life, which lay the foundations for a healthy future, both for individuals and for society as a whole.
- Metabolic syndrome and diabetes.
- Products and services at the crossroads of medical technology, IT and data, such as glucose sensors and Stresscoach, as well as the clarification of data and algorithms.

#### TECHNOLOGICAL INNOVATIONS

- **Artificial intelligence:** The development and application of deep-learning technologies to map and interpret health data for translation into reliable advice for professionals and patients.
- **Robotics:** Industrial exoskeletons are a promising innovation for human enhancement in the fields of work and health, particularly in support of physical capacity.
- **Valorization of data and metadata:** Identification of harmful effects using systems biology, text mining and network analysis; real-time monitoring of risks (sensing, omics, impact assessment, toxicology, exposure modelling, dynamic safety) and effective behavioural interventions drawing upon feedback.
- **“Inside the human body”:** Human microbiotics and the effects of substances like antibiotics; immune health and allergies; “organ-on-a-chip” models; overall external burden and its effect upon the body (exposome).
- **“Inside the human mind”:** Causal links between the microbiome, physiology and cognition; biomarkers of cognitive and mental condition; individual behaviour and intervention effectiveness.

- **Modelling and prediction of integrated social systems:** A development important for the creation of integrated dashboards (child health, longer working lives, smart work) and for regional innovations in the social domain—the latter requiring further integration of what we know about efficient and effective transfers (decentralization) of responsibility for the interrelated fields of youth, employment and social services. ■

# DEFENCE & SECURITY

## DECISIVE ACTION IN AN UNCERTAIN WORLD

### OUR AMBITION

Together with our partners, we aim to produce groundbreaking solutions for the complex security challenges of today and tomorrow.

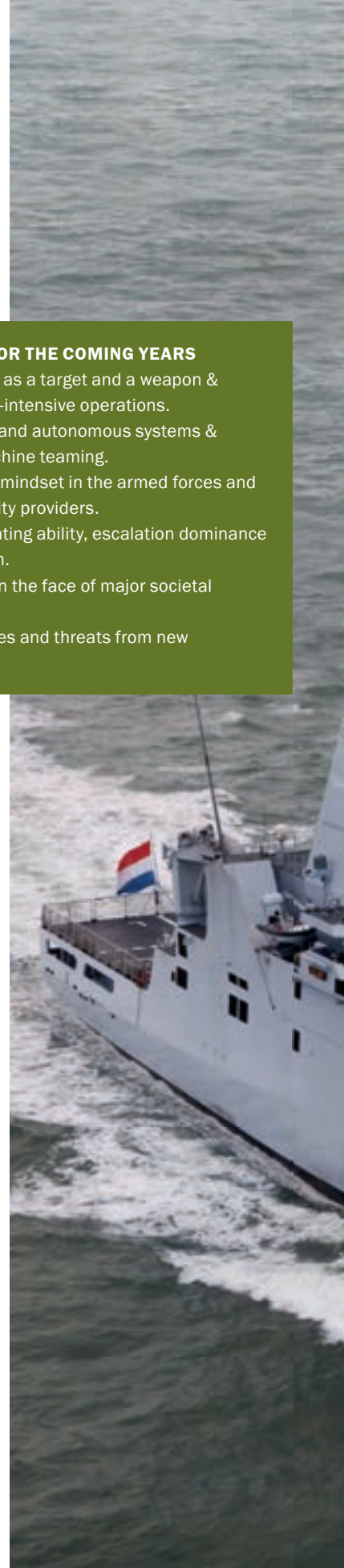
### OUR CONTRIBUTION: RESEARCH PRIORITIES FOR THE COMING YEARS

Security is a basic need in our society. However, the geopolitical security situation has become uncertain. Tension is growing on Europe's external borders, and even within them social cohesion is not the given it used to be. Massive refugee flows, ruthless international terrorism, blanket propaganda, state-sponsored cyberattacks, deadly attacks in our capital cities, multinational-like organized crime ... The scale and form of the threats to our prosperity and well-being have taken Europe by surprise. Governments and companies are struggling to counter these assaults on all we hold dear. TNO's ambition, therefore, is to be part of a "golden ecosystem" developing innovative, cost-effective solutions to keep us one step ahead of the threats and risks. Drawing upon our in-depth knowledge of technology, people and organizations, we and our partners are working on products and services to make society safer and more resilient. And to support ongoing innovation in our armed forces and other security providers.

### PRIORITIES FOR THE COMING YEARS

- Information as a target and a weapon & information-intensive operations.
- Unmanned and autonomous systems & human-machine teaming.
- People and mindset in the armed forces and other security providers.
- Modern fighting ability, escalation dominance & protection.
- Resilience in the face of major societal disruption.
- Opportunities and threats from new technology.

OUR AMBITION:  
TOGETHER WITH OUR PARTNERS,  
WE PRODUCE  
**GROUNDBREAKING SOLUTIONS**  
FOR THE **COMPLEX SECURITY CHALLENGES**  
OF TODAY AND TOMORROW







The strategic agendas of our stakeholders and partners around the world have shaped six priorities for our defence research over the next few years.

- Information technology, from big data to cyber, is now a decisive factor. As well as information-guided operations, command and control, (digital) investigation and law enforcement, TNO is working on both the protection of our own information and offensive cyber to disrupt hostile information processes.
- Autonomous systems and artificial intelligence have numerous potential applications in this domain. TNO's research focus here includes swarm robotics and the crucial interaction between people and autonomous systems.
- Despite all the technological advances in this area, people still have a vital role to play. Our specialisms in the human factors aspect of defence and security are agility and resilience, performance in extreme conditions, ability, collaborative behaviour and training.
- When the worst comes to the worst, military operations require decisive action. Our work in such areas as scaleable, configurable munitions and new directed-energy weapons enables tailored deployment of weaponry whilst keeping collateral damage to a minimum. TNO technology also helps give troops (and police officers, etc.) the best possible protection.
- Increasing globalization and digitization is making our society more vulnerable. TNO combines a good knowledge of possible threats with a thorough understanding of technological, organizational and social interrelations, and of the potential impact of disruption—know-how we are applying to protect critical infrastructure and to counter hybrid threats, for example.
- All in all, new technologies offer almost countless possibilities. That makes it all the more important that TNO carefully chart the security opportunities and threats associated with advances in biotechnology, nanotechnology, IT and robotics, so that we and our stakeholders can map our future direction accordingly.

At TNO, we deal not only with technological innovation, but with social and cultural innovation as well. Our know-how is put into practice in defence procurement, new combat tactics, more effective organization and enhanced human performance. Whether they are acquiring new aircraft, replacing naval vessels, deploying new interoperable land warfare systems or introducing information-led policing, in all these fields we are ready to stand shoulder to shoulder with our stakeholders.

#### CLIENTS AND PARTNERS

Our principal clients and partners are:

- The Dutch government, principally the ministries of Defence and of Security & Justice.
- The defence and security industry, in the Netherlands and abroad.
- Foreign governments and international organizations.
- Research institutes, government laboratories and universities.
- Public-private partnerships.

TNO is guided by the agendas and ambitions of our stakeholders. Our special strategic relationship with the Dutch Ministry of Defence and the Council For Defence Research's role in the governance of TNO's defence division are enshrined in law, in the TNO Act. Because of the importance to national security of the defence knowledge base, we maintain a wide-ranging knowledge infrastructure—expertise, capacity and facilities—on behalf of the Ministry of Defence. Our defence division is an integral part of TNO, but has its own budgeting and accountability systems. Nevertheless, we remain in open contact with the rest of the world and conduct a substantial amount of work in the wider defence and security domain. The knowledge shared through these activities broadens and deepens our fund of relevant know-how, and keeps it affordable for the ministry. During the period of this strategic plan, we intend to further expand our relationship in specific areas, as a research and innovation partner, with the Ministry of Security & Justice, the National Police and other front-line security organizations. Our ambition here is to help uphold the rule of law by deploying technology and innovation to every link in the security chain. We also aim to work with the ministries of Foreign Affairs and Economic Affairs, in many cases across departmental boundaries.







The international component of our work multiplies our contribution to the national agenda and will become even more important over the next few years. Intergovernmental co-operation with the United States, Canada, Germany, the United Kingdom, Norway and Sweden is being intensified, as is our participation in NATO research panels. Within the EU we are tackling the grand challenge of building a secure society and aim to play a significant role in the European Defence Agency (EDA) and the forthcoming Preparatory Action on Defence Research. The latter is precursor to an intended new European defence research programme focusing upon joint investment to close so-called “capability gaps”, as part of the ninth EU Framework Programme. To strengthen fulfilment of our statutory and public remit, we also mean to forge more partnerships with Dutch and international companies. At our branch office in Singapore, we are developing activities which should have a multiplying effect in respect of both local and Dutch agendas.

Our knowledge-building and innovation activities rely upon close co-operation with partners. Within the national defence and security research infrastructure, we plan to intensify co-operation with the Netherlands Aerospace Centre (NLR), the Maritime Research Institute Netherlands (MARIN), the Netherlands Defence Academy, the Netherlands Police Academy and others. We are also active within the relevant industrial “top sectors” and the Hague Security Delta ecosystem, and intensifying relationships with strong knowledge partners in allied nations. In a changing innovation system, we are placing more emphasis upon joint, shared and open research which also encompasses the business community. A good example of this is the “Netherlands Radarland” initiative. JIC Aeolus, the joint innovation centre for human performance in extreme conditions, is being joined by JIC Cyberworks, a strong cyber-related ecosystem in the Hague region. Field labs and research centres in such areas as real-time intelligence and hybrid warfare are improving our connections with the defence and security domain, too.

### TECHNOLOGICAL INNOVATIONS

In a rapidly changing world, TNO has to continually update its knowledge portfolio and explore new areas of application. High-quality research facilities are vital to this. We can only maintain our leading knowledge position in such areas as operations research, organizational sciences, individual and team performance, radar, sonar, data processing, ballistic and CBRN (chemical, biological, radiological

and nuclear) protection by innovating on a daily basis. And rapidly emerging themes like information technology and information operations, offensive and defensive cyber, autonomous systems, technology for precision and directed-energy weapons will require substantial investment. To keep making a difference here, we are exploring future security applications of nanotechnology, quantum technology, information technology, robotics, biotechnology, neurotechnology, behavioural science and cognitive science, in part drawing upon knowledge available elsewhere at TNO.

In these areas, we intend to focus upon certain specific themes. For example, quantum cryptography and quantum sensors (such as quantum radar) for military purposes, nanomaterials and metamaterials for protective use and signature correction, and green energetic materials—including their 3D printing. Artificial intelligence with self-explaining analytical tools and an understanding of uncertainties should help with the analysis of heterogeneous big data in the military domain. AI will also be a crucial factor in the success of our work on advanced autonomous systems, where we are taking a particular interest in their interaction with each other and with people. Synthetic biology holds out exciting opportunities, too, but also entails potential threats; in addition to obtaining insight in the dangers posed by modified life forms, our ability to detect and identify them could literally be a matter of life and death. Meanwhile, biotechnology and neurotechnology hold out hopes in the field of human enhancement: improving our cognitive and mental capabilities. Cognition and behaviour in the broader sense are an important focal area as well, not least in the fact that they feed into our work on the modelling and forecasting of social systems. In the context of hybrid warfare, for example, our interests here include such topics as opponent modelling, psychological operations (psy-ops), information operations (info-ops) and responses to social engineering.

In our strategy we are guided by the defence knowledge portfolio review performed in 2016 by the Ministry of Defence and its knowledge partners—subject, of course, to the necessary resources being made available by the incoming government after the general election of March 2017. ■

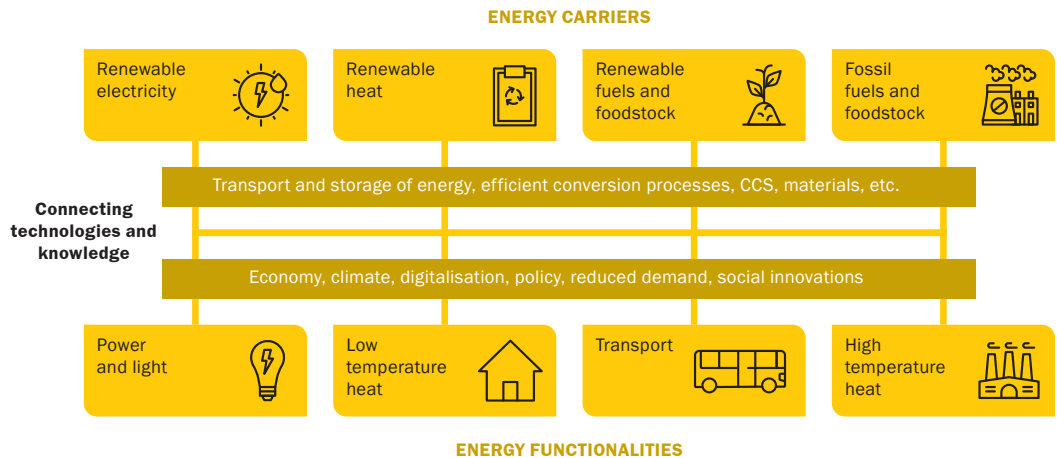
# ENERGY

The aspiration of the unit 'ECN part of TNO'<sup>1</sup> is to work with knowledge institutions and the private and public sectors to expedite the country's energy transition. The ultimate goal is a CO<sub>2</sub>-emission-free energy system for the Netherlands by 2050. The energy transition also offers the Dutch private sector an opportunity to lead the way and to export their innovative products, thus contributing to the global energy transition.

Progress towards the energy transition must be expedited if we are to meet the Paris climate targets. The challenge is to cut CO<sub>2</sub> emissions by expediting the phased introduction of renewable energy and smoothly phasing out fossil energy, while ensuring that the energy supply remains secure, available and affordable. Energy conservation is also an important tool. The energy transition demands major technical and social changes that will impact all sectors of the economy, as well as public sector bodies and members of the public.

The transition to a CO<sub>2</sub>-emission-free energy system will require technological, social, and policy innovations. By combining their energy research in this area, ECN and TNO are jointly aiming to become a top European player in the development and application of this knowledge and technology. We plan to achieve this by taking on the challenge of implementing the energy transition, together with the Dutch private sector, various research institutes and the public sector.

One part of the ECN part of TNO unit's two-pronged mission is to expedite the country's energy transition, the other part involves strengthening the Netherlands' competitive position. The ECN part of TNO unit independently performs leading international research. Ours is an agenda-setting, initiating and supporting role for the public and private sectors, as well as for community organizations.



1. In 2018, a joint venture 'ECN part of TNO' is established. This combines Foundation ECN's (the Energy research Centre of the Netherlands) renewable energy activities with those of TNO.



## OUR CONTRIBUTION: EIGHT ROADMAPS

New low-CO<sub>2</sub> energy-generation methods impose new demands on the transport, storage and use of energy. Conversely, changes in energy use will have a major impact on energy demand. One example is the switch to electric vehicles. The figure illustrates the energy transition's playing field, in which energy carriers are interconnected by energy functionalities.

This is based on the energy functionalities that feature in the Dutch government's Energy Agenda. These functionalities are supplied with energy by different energy carriers. For example, renewable electricity serves the Power & Light functionality, but it can also serve Transport, Low-Temperature Heat and High-Temperature Heat. Technology for the transport, conversion and storage of energy, for example, is needed to link energy carriers to energy functionalities. Also, if the energy transition is to succeed, innovations are needed in areas such as the economy, behaviour and policy.

The ECN part of TNO unit has formulated a set of **eight coherent roadmaps** (long-term research programmes). Five of these roadmaps focus on individual energy functionalities, while the other three serve to connect the different energy functionalities. The figure shows the eight roadmaps, with the three connecting ones intersecting the others. This gives the ECN part of TNO unit a very broad-based portfolio. Within these roadmaps, the ECN part of TNO unit has selected a limited number of tangible key focus areas where we are striving to achieve a leading international position. Each of these areas is of great importance to the Dutch economy.

### 1. Towards an abundance of SOLAR POWER

Solar energy (photovoltaics or PV) is fast becoming one of the cheapest and most widely used forms of energy generation. The ECN part of TNO unit's efforts in this area include the development of new solar cell technology that combines high yields with low costs. In addition, the ECN part of TNO unit is attempting to make solar panels even more widely applicable. This could involve integrating solar power technology into building structures and infrastructure, and developing energy storage technology. We are doing this in partnership with the Dutch private sector. The technology used to produce solar cells and solar panels is a major Dutch export product.

### 2. Towards the large-scale generation of WIND ENERGY

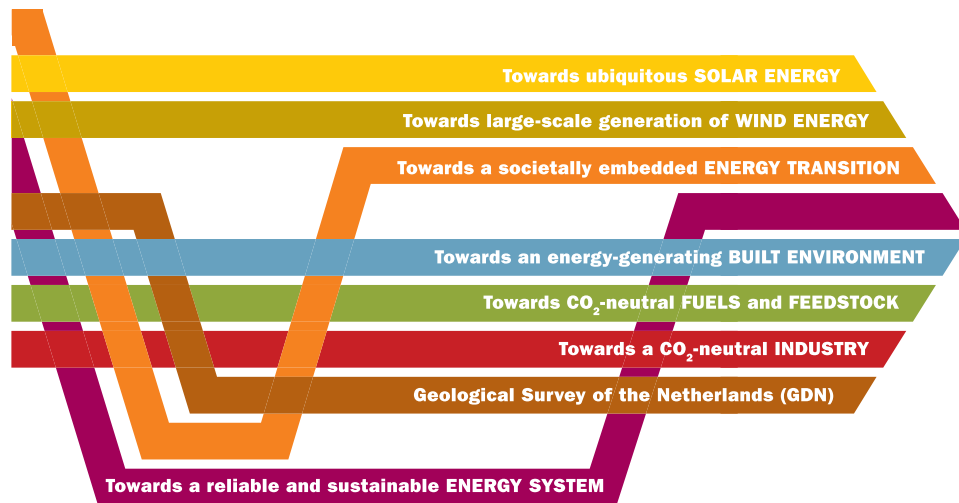
For the Netherlands, wind energy (especially offshore wind energy) is one of the most important forms of renewable electricity production. The ECN part of TNO unit is developing expertise that will soon enable offshore wind farms to produce unsubsidized electricity at competitive rates. One of the most important ways to reduce the costs of offshore wind energy is to develop larger turbines. The ECN part of TNO unit is developing new expertise for this very purpose, ranging from how these structures are anchored to the seabed to the aerodynamics of the wind turbine's blades, and from turbine maintenance to connecting them up to the national grid. The government uses this basic knowledge to shape its policy, while the private sector uses it to develop products and services. Dutch companies are global players in the construction of offshore wind farms. One of the ECN part of TNO unit's unique research facilities—which many large manufacturers use—is equipped to test a wide range of prototype wind turbines.

### 3. Towards a broadly supported ENERGY TRANSITION

The transition to a CO<sub>2</sub>-emission-free energy system will require changes in the economy, in business models, in legislation and in consumer behaviour. In close cooperation with the other roadmaps, the ECN part of TNO unit is developing expertise in the field of social and behavioural sciences. The new ECN part of TNO unit has in-depth knowledge spanning the entire energy system. We use this knowledge to formulate well-founded views on specific parts of the energy system, which contribute to the public debate. The ECN part of TNO unit supports public sector bodies at all levels in the energy transition. Trade associations, community organizations and the private sector are also knowledge consumers.

### 4. Towards an energy-producing BUILT ENVIRONMENT

Homes and offices use a lot of energy, for heating and cooling, for example. The Netherlands aspires to replace the use of natural gas in the built environment with renewable alternatives. The first step towards making the built environment more sustainable is to conserve energy by renovating buildings, to use smart technology and to bring about behavioural changes among the residents. In addition, the supply of heat must make more use of renewable sources. One approach involves electric heat pumps, another option is geothermal energy. Together with building experts from other parts of TNO, the ECN part of



Eight roadmaps from ECN part of TNO

TNO unit is developing technology such as heat pumps, innovations for heat and cold storage, and district heating systems. The ECN part of TNO unit is also developing the expertise required to transform buildings into net energy producers. This could involve the smart integration of solar energy into building structures, for example. The construction sector is a natural partner here, as are companies that produce appliances and components and sell them in the Netherlands and elsewhere.

### 5. Towards CO<sub>2</sub>-neutral FUELS AND RAW MATERIALS

Any far-reaching reduction in CO<sub>2</sub> emissions will require a major transition in the transport sector, which is now largely based on petroleum-based fuels. Electric vehicles are important option for passenger transport. Heavy freight, shipping and aviation will all require CO<sub>2</sub>-neutral liquid fuels in the years to come. The ECN part of TNO unit is developing technology for fuel production based on biomass and electricity (power-to-fuels). Fuel production is closely related to the production of sustainable feedstock for the chemical industry. The petrochemical industry is one of the cornerstones of the Dutch economy, so making it more sustainable is a major challenge for the Netherlands.

### 6. Towards a CO<sub>2</sub>-neutral INDUSTRIAL SECTOR

Industry uses high-temperature heat for its production processes. Generating this heat produces substantial CO<sub>2</sub> emissions. The ECN part of TNO unit is developing solutions to make the high-temperature heat supply more renewable, such as heat pumps, green gas and ultra-deep geothermal energy. We are also working on energy conservation and on new production processes that emit far less CO<sub>2</sub>. These include renewably-

generated electricity and sustainable raw materials. Finally, the ECN part of TNO unit is developing expertise in the capture and storage of CO<sub>2</sub>, for various industrial processes. The unit is cooperating closely with energy-intensive industries, such as the steel industry, the chemical industry, the food industry and the equipment manufacturing industry.

### 7. Towards sustainable use of the SUBSURFACE

Knowledge of the subsurface plays an important part in the Dutch energy supply. The Netherlands Geological Survey (GDN) maps the subsurface's natural capital, such as energy, groundwater, building materials and underground storage spaces. The GDN also plays an indispensable part in advising on, and asking questions about, safe gas extraction, about the shutting down and reuse of existing wells, and about opening up geothermal energy as a source of renewable heat. The GDN also provides insight into natural risks that often manifest themselves as water-related issues in our low-lying country, such as subsidence and soft soils.

### 8. Towards a renewable and reliable ENERGY SYSTEM

Due, in part, to the rapid growth in solar and wind energy, the supply side of the energy system is undergoing profound changes. If the energy supply is to remain secure, reliable and affordable, we will soon need new knowledge and technology for the transport and storage of energy. In addition, the energy system is becoming more and more interwoven. For example, electricity can be converted into heat and hydrogen, and used for the production of raw materials. It is very important for any decisions concerning the system

to be future-proof. The ECN part of TNO unit provides assistance in weighing up the choices involved in the integration of renewable energy systems. It also explores ways of increasing the flexibility of energy generation and use, while developing technology in the field of energy conversion and storage.

### CLIENTS AND PARTNERS

The ECN part of TNO unit can only help to expedite the energy transition if it cooperates intensively with fundamental research projects, and with the private and public sectors. The ECN part of TNO unit will work closely with private sector organizations specializing in the generation, distribution and use of energy. We are strongly anchored in the manufacturing industry, the energy-intensive industry and the offshore industry. The ECN part of TNO unit sees consultancies as important partners in its efforts to make knowledge available to the market. We also share our knowledge with many different public sector bodies, from local authorities, provincial authorities and ministries to multinational organizations such as the UN and the EU. We cooperate intensively in projects involving various knowledge institutions at home and abroad. In this way, the ECN part of TNO unit makes the best possible use of knowledge that has been accumulated elsewhere. The ECN part of TNO unit has formal links (involving part-time appointments) with Delft University of Technology, Eindhoven University of Technology, Utrecht University, the University of Groningen, the Hanze University of Applied Sciences, the University of Amsterdam and the NWO Institute AMOLF. Its main foreign partners are Fraunhofer and Helmholtz in Germany, SINTEF in Norway, DTU in Denmark, NREL in the US, and IMEC in Belgium.

The Energy Top Sector—which includes knowledge institutions and the public and private sectors—is a prominent stakeholder for ECN. Within the framework of Top Sector public-private partnership projects, we develop innovations with numerous companies (including SMEs) and knowledge institutions. Together with private and public sector organizations within this Top Sector, the ECN part of TNO unit is also involved in drawing up the National Research Agenda for the energy transition.

In the upcoming years, the goal is to strengthen the unit's formal links with the private sector, with universities and with the NWO (the Netherlands Organisation for Scientific Research) by setting up long-term, mission-driven, research and innovation programmes. In the area of thin-film solar energy, the unit has already benefitted from its participation in Solliance, a joint venture in which foreign knowledge institutions work alongside various universities and large corporations.

Finally, one of this strategy period's major goals is to embed energy research more strongly within TNO. To this end, the ECN part of TNO unit will expand existing joint innovation programmes at the interfaces with other parts of TNO, and set up new ones. The areas involved are construction, industry, mobility and the circular economy.

**ONE PART OF THE  
ECN PART OF TNO'S  
UNIT'S TWO-PRONGED  
MISSION  
IS TO EXPEDITE  
THE COUNTRY'S  
ENERGY TRANSITION,  
THE OTHER PART INVOLVES  
THE NETHERLANDS'  
COMPETITIVE POSITION**

## TECHNOLOGICAL AND SOCIAL INNOVATION

During this strategy period, the ECN part of TNO unit will bring numerous technologies and knowledge areas a step closer to maturity, at which point they will have a genuine impact on the energy transition and on the economy as a whole. The ECN part of TNO unit is endeavouring to achieve a leading international position with regard to the following innovations—each of which will be given priority in this strategy period:

### ► Tandem solar cells

Two existing types of solar cells can be combined to create an entirely new solar cell with an efficiency of 30%. The ECN part of TNO unit is developing technology to combine bottom cells of crystalline silicon with a top cell consisting of thin layers of Perovskite solar cells. Highly sophisticated deposition techniques are being developed for this purpose.

### ► Wind turbines generating more than 15 MW

Offshore wind farms need larger wind turbines to cut costs even further. The blades of turbines with capacities in excess of 15 MW are so large that completely new aerodynamic models are needed to design them. Larger turbines also require lighter materials and need to be more strongly anchored to the seabed.

### ► Making fuels and raw materials from seaweed

Seaweed grows very rapidly, its cultivation does not compete with scarce farmland, and it has a high sugar content. This makes it an ideal starting material for biofuels and a great source of raw materials for the chemical industry. The ECN part of TNO unit is developing new technology to efficiently convert seaweed into fuels and other valuable raw materials.

### ► Social innovations

The public's role in the energy system is changing dramatically. Rather than being just energy consumers, they are increasingly becoming energy producers. As a result, the government and the energy companies need to rethink their approach. The ECN part of TNO unit is developing expertise about the public's behaviour in terms of energy. It is also developing scenarios to effectively manage the new role of 'energy prosumer'.

### ► Heat pumps

There is a need for new forms of heating, both in buildings and in industry. The ECN part of TNO unit is developing thermoacoustic and magneto-caloric heat pumps capable of upgrading unusable residual heat







to a temperature level at which it is of practical use to industry. We are also researching ways of converting electricity into heat at very high efficiencies.

► **Information technology and regulations**

The energy system will become even more complex. For instance, the supply of renewable energy and the demand for energy will both show increasing variation over time. This means that new IT tools will be needed to bring supply into line with demand. The ECN part of TNO unit is developing the knowledge required to effectively manage this complex challenge by means of regulations.

► **Electrochemistry to produce renewable fuels and raw materials**

Renewable electricity will increasingly be used in industry and in the production of renewable fuels. The ECN part of TNO unit is working with a number of private sector organizations to develop new technology for hydrogen production, based on electrolysis. It is also developing technology capable of producing fuel directly from sunlight.

► **Ultra-deep geothermal energy**

High-temperature heat from the subsurface is an important option as industry moves towards renewable heating. It would require geothermal wells up to eight kilometres deep, much deeper than the ones that are usually drilled in the Netherlands. The ECN part of TNO unit is developing the expertise needed to use this new energy source safely and cost-effectively.

► **New concepts for energy storage**

The storage of renewable energy is an increasingly important consideration. It is the only way to guarantee supplies in the face of varying demand, and to bridge the differences between seasons. The ECN part of TNO unit is researching new materials and methods for the storage of both heat and electricity.

► **4D modelling of the subsurface**

The ECN part of TNO unit is developing new monitoring techniques, strategies and computer models to identify fluctuations in the subsurface, and to better understand its behaviour. Take the Groningen gas field, for example. These techniques make it easier to determine the impact of various extraction and mitigation scenarios, in terms of the anticipated seismicity and soil subsidence. ■

## SECTION 5

# ORGANIZATION AND MANAGEMENT

For TNO to make its intended contribution to the Dutch innovation landscape as a public-sector research centre, agile and effective management and organization are essential. In recent years we have optimized our matrix organization and successfully completed several effectiveness-raising programmes. In 2017, however, we say farewell to the matrix. At this stage its drawbacks, which include sometimes unclear access for our clients and partners, a consensus culture and a lack of overall responsibility, have ceased to outweigh the benefits of a unified TNO facilitating multidomain innovations. We now wish to evolve into an organization within which people can achieve their full potential by being given, and accepting, the greatest possible responsibility. This new TNO should seek focus, mass and impact and achieve lasting, positive financial results.

The final decisions needed to create this new organization are being taken and implemented during the course of 2017. The current effectiveness-raising programme, Focus, which is concerned mainly with integral cost-price control, will continue into 2018. At the same time we will also be putting more effort into performance coaching.

We have defined nine policy priorities to develop as a high-impact research centre. These are primarily the product of recent audits and evaluations.

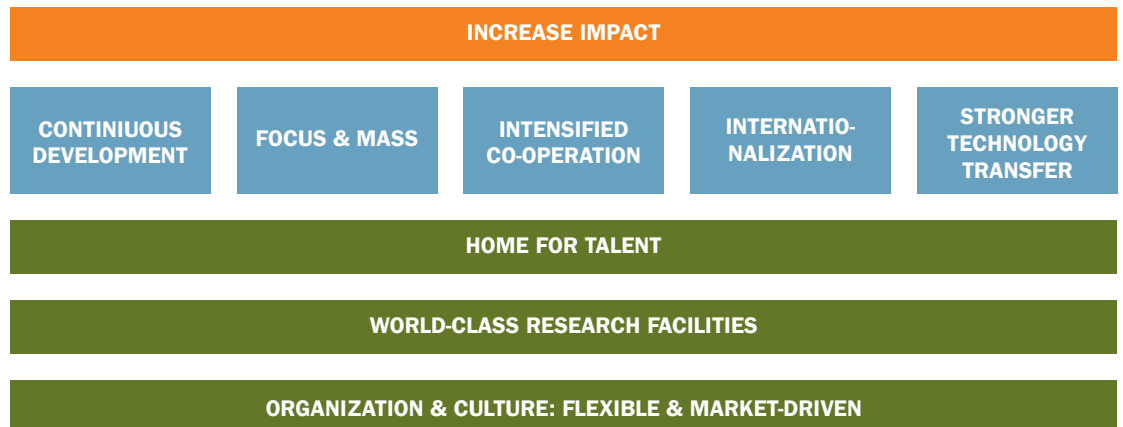


Figure 6.1 – TNO priorities, 2018–2021.

### PRIORITY 1. INCREASE IMPACT

Impact is the yardstick of our success. It can be expressed in many different ways. A 2016 study by the European Association of Research and Technology Organizations (EARTO), for example, showed that every euro of state funding spent on applied research institutions like TNO generates a return of €3.80 for society. In general, though, the exact contribution our know-how and innovations make in resolving major social issues is hard to measure. Their widespread application often follows only many years later. In many cases, moreover, the final outcome is the combined product of many different contributions, by TNO and others. Over the next few years, then, we intend to make our precise impact more quantifiable by calculating it explicitly at four levels (see also figure 1.1).

- Specific contributions to the resolution of social issues.
- Implementation of policy innovations by public-sector partners, or strengthening the competitive or financial position of commercial clients.
- Business milestones: the completion of specific underlying steps in knowledge-building and innovation.
- Client, partner and auditor satisfaction with TNO's contribution to the resolution of their issues.

Finally, we will continue to invite stakeholders to regular meetings at which they are free to reflect openly upon our performance and the quality of our products.

- KPI. In 2021 TNO has introduced an effective system to quantify its impact. Ideally, this has been developed on a pan-European basis in order to enable comparisons with other research centres.

### PRIORITY 2. CONTINUOUS DEVELOPMENT

To keep our research portfolio relevant and up to date, we manage it actively and involve our stakeholders. We monitor external developments around challenges facing society, market demand and technology on a constant basis. We create scope to move into new areas by expanding our activities where the market is ripe for them and winding them down where demand from our stakeholders is declining. In every case we assess whether the value we do or can add is substantial enough (looking at turnover and/or impact) and whether there is sufficient market demand for the final product (looking at the so-called “multiplier”<sup>3</sup>).

We concentrate more emphatically upon developing multidisciplinary innovations. This makes systems engineering more important, so we strengthen this capability. In principle, areas of expertise which are too small and too monodisciplinary are wound down—unless, that is, state funding is provided to maintain them. By focusing our use of the public funds available to us in this way, we endeavour to increase the multiplier slightly.

- KPI. Lifecycle-based portfolio management is introduced in full.
- KPI. Multiplier rises from 2.8 to 3.0.<sup>4</sup>

### PRIORITY 3. FOCUS & MASS

We ensure that we are distinctive by concentrating upon those areas in which we have a substantial contribution to make. We grow in what we are good at and wind down those activities which do not play their full part. With the possible exception of our statutory tasks, this translates into a minimum size for those subdomains we are active in (so-called “roadmaps”) and those areas of expertise we maintain. We also plan to reduce the number of small standalone projects we undertake, so that we can put the bulk of our attention and efforts into larger multidisciplinary programmes with more impact.

- KPI. Minimum turnover per “roadmap”: €15 million.
- KPI. Minimum staffing level per area of expertise: approximately 10 full-time equivalents.
- KPI. Number of projects is halved, average project size is doubled.

3. Total turnover divided by the available Research Co-operation Funds (Samenwerkingsmiddelen Onderzoek, SMO; excluding ERP resources and VAT compensation). The multiplier varies by domain, depending upon the nature of the underlying challenge (social or economic), TNO's position in the triple helix (e.g. whether or not we have a statutory task) and the maturity of an area of expertise.

4. This is the average objective for TNO as a whole.

#### PRIORITY 4. INTENSIFIED CO-OPERATION

Successful innovations which resolve issues facing society only come about through co-operation. TNO believes that public-private partnerships like joint innovation centres (JICs) are the best way to accelerate innovation, as the success of ventures like the Holst Centre and Solliance demonstrates. Our goal is to engage in even more public-private partnerships in the coming years, and to enable companies to contribute more extensively in this context. The number of JICs should therefore increase from eight in 2016 to at least fifteen in 2021. Under the title “Orchestrating Innovation”, we are clustering our knowledge and expertise in this area to help establish such wide-ranging alliances. We particularly intend to strengthen collaboration with universities as they are important partners in many of our activities, from early research to technology transfer. Another priority is closer co-operation with other applied research organizations in the Netherlands and elsewhere.

- KPI. Company contributions in public-private partnerships rise from €36M naar €40M<sup>5</sup>.
- KPI. Number of JICs rises from eight to 15–20.
- KPI. Improved co-operation with universities and applied research organizations.
- KPI. Strategic partnership with at least one European research and technology organization.

#### PRIORITY 5. INTERNATIONALIZATION

TNO can only help build knowledge for the Netherlands, and so contribute towards our nation’s prosperity and competitiveness, by working with leading international research institutes, companies and government bodies. The know-how we develop for or with partners abroad also benefits the Dutch business community and helps to resolve issues in our own society. As scientific research is becoming more and more globalized, so too is TNO. The results will include a higher proportion of international employees, the transition to English as our working language and a rise in the percentage of turnover generated from clients and partners abroad. Depending upon the nature of the specific market, we use a variety of channels to secure international assignments: in-house business development, local agents and branch offices. At present, there are three such offices, in Aruba, Qatar and Singapore. Our aim for the next few years is to make these permanently self-sustaining.

- KPI. Each roadmap has at least two of the world’s top ten 10 relevant companies or government bodies as clients.
- KPI. A quarter of new personnel are international.
- KPI. English is the working language at TNO in 2021.
- KPI. International turnover increases by 2 percentage points a year.

#### PRIORITY 6. STRONGER TECHNOLOGY TRANSFER

TNO is putting more effort into technology transfer in order to produce greater economic impact. Our objective for 2021 is to bring between five and ten spin-offs to the market each year. We also intend to enhance valorization of know-how through licensing agreements, increasing their contribution to turnover to at least 2 per cent. With the additional funds raised by the sale of shares in First Dutch Innovations, we are further expanding our technology-transfer programme and intensifying collaboration with investment funds, universities and regional development corporations. Alongside First Dutch, important partners in this field include Yes!Delft—in which we own a minority stake—and the Innovation Industries Fund. Ultimately, our investments should generate revolving returns in the form of licensing income and revenue from selling shareholdings in spin-offs.

- KPI. Between five and ten spin-offs per year.
- KPI. Licensing income rises from approximately 0.8 per cent of turnover to at least 2.0 per cent.

#### PRIORITY 7. A HOME FOR TALENT: GROW IN, GROW OUT

TNO wants to be an attractive employer for outstanding scientists. Our highly talented workforce is the backbone of the organization. We consider ourselves very fortunate to have so many top people on the payroll—people who make a difference in their areas of expertise and so underwrite our success. And who serve as our standard bearers in the world.

We strongly encourage internal staff mobility, in part to ensure the constant cross-pollination of know-how and methods. Our employees are expected to gain experience in different fields, and to help them do that we apply the “grow in, grow out” principle. For as long as someone works at TNO, they add value to the organization and it adds value to them as a working scientist. We facilitate and support their constant professional development with an explicit focus upon the next step in their career, whether that be within TNO or elsewhere. To this end, we actively employ tools like job-market scans.

5. Only shared research, i.e. exclusively contract research.



Our workforce has increased in diversity in recent years, but not enough. Employing more women and more international staff is therefore an explicit objective for this strategic period. By offering challenging work and modern contract terms, we intend to remain in the vanguard of non-profit R&D employers in the Netherlands and so keep recruiting the talent we need from this country and elsewhere. Colleagues who leave us are treated as alumni, and we hope that they will always remember TNO as an important phase in their career. Because we regard them as our best ambassadors, we are establishing an active alumni programme.

- KPI. TNO remains one of the top five non-profit R&D employers in the Netherlands.
- KPI. “Grow in, grow out.”
  - Internal career advancement: staff mobility within TNO doubles.
  - External career advancement: 90 per cent of staff leaving TNO regard it as an important phase in their career (from exit interviews).
- KPI. Forty per cent of TNO employees in 2021 are women.

#### **PRIORITY 8. WORLD-CLASS RESEARCH FACILITIES**

High-quality facilities are essential to our work. We can only undertake cutting-edge research and extend our unique knowledge position if our laboratories and equipment are some of the best in the world. And if, because of that, they attract outstanding Dutch and international scientists. After all, the best talent goes where it is given the best support. Our clients and partners, too, choose TNO very much because of its excellent facilities and infrastructure.

We intend to strength our portfolio of facilities over the next few years. Naturally, this will require the kind of investment envisaged by the Minister of Economic Affairs in his 2017–2021 Strategic Agenda for Facilities at Applied Research Organizations (Strategische Agenda Onderzoeksfaciliteiten TO2 2017–2021).

To fulfil our commitments to this strategy, we are investigating opportunities to purchase and/or operate major facilities jointly with other partners and so strengthen alliances, accelerate innovation and share the financial burden.

- KPI. Completion of investment plans.
- KPI. Major research facilities (worth more than €2 million) are shared with partners.

#### **PRIORITY 9. ORGANIZATION & CULTURE: FLEXIBLE & MARKET-DRIVEN**

To make TNO even more effective and efficient as an organization, it is vitally important that we be recognizable to our clients and partners as a public-sector research centre, that we respond quickly and capably to enquiries from the market and that we be flexible enough to accommodate a constantly evolving research portfolio. We also need to create an environment in which our employees feel at home, make the most of their potential and achieve great things. To do this, we are currently metamorphosing from a complex matrix organization into a far more market-driven entity. Even once this transition is complete, we will continue to develop and advance, both organizationally and methodologically—for example, by continuing our programme of performance coaching for constant improvement. For our strategy to succeed, we must be an organization perfectly aligned with our market, our role and our activities.

- KPI. Our stakeholders recognize the TNO of 2021 as a more flexible, market-driven organization.
- KPI. Our average score in staff engagement surveys is consistently higher than 7 out of 10. ■

**OUR HIGHLY TALENTED WORKFORCE  
IS THE BACKBONE  
OF THE ORGANIZATION**

› SECTION 6

# HEALTHY FINANCIAL MANAGEMENT



Good financial performance is essential for the continuity and vitality of our organization.

**STATE FUNDING**

This strategic plan is based upon the assumption that TNO’s state funding will continue at its present level for at least the next four years. Together with our partners in the Knowledge Coalition, however, we are lobbying for additional public investment of at least €1 billion in order to further strengthen innovation in the Netherlands.

**MULTIPLIER**

Using the state’s contribution as our basic funding, TNO seeks to define and secure research contracts—usually in the form of collaborative arrangements cofinanced by our clients and partners. It is our duty to use the public money we receive as effectively as possible, striking the right balance between this source of income and revenue from the market. The relationship between the two is expressed by the so-called “multiplier” (see Section 5). By improving our portfolio management, we intend to increase the average value

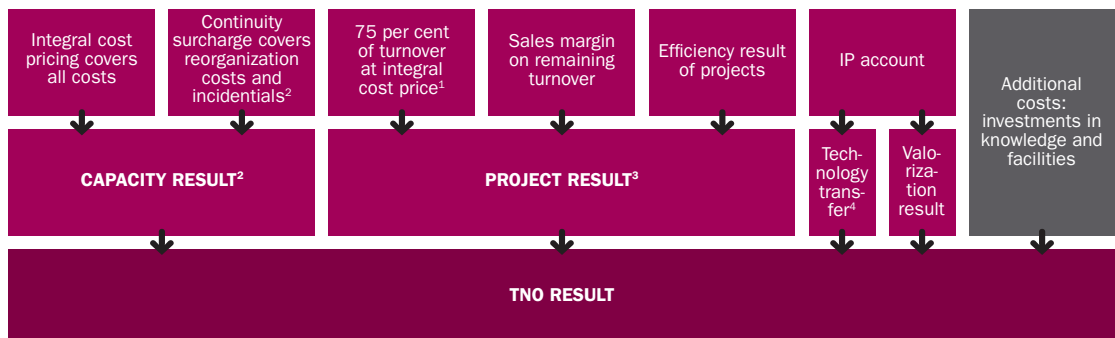
of this indicator from 2.8 to 3.0 in the next four years. Anything much higher than that, though, would indicate too great a reliance upon orders that the market could actually finance itself to a large extent.

**TURNOVER**

Generating turnover is not an objective in itself, but it is needed to maintain the basic knowledge base demanded by TNO’s clients and partners. And to create impact. Assuming that our state funding remains at its current level and the multiplier increases slightly, thanks in part to international growth, we aim to increase our turnover from €425 million in 2016 to approximately €450 million in 2021.

**FINANCIAL PERFORMANCE**

Figure 6.1 shows TNO’s financial model.



1. A similar structure is in place at TNO’s Defence division.  
 2. The current continuity surcharge has been agreed up until the end of 2018.  
 3. More will be invested in technology transfer in the next few years; after 2021, these activities must record a surplus to enable revolving investment.

Figure 6.1 – TNO’s financial model.

TNO's target bottom-line operating surplus is modest as a proportion of turnover, at about 1 per cent. A positive result is necessary in order to maintain a healthy financial position. In our current model, however, even a small fluctuation in turnover could seriously affect our final result. Our objective, then, is to report an average annual operating surplus of about €5 million over an extended period.

A substantial proportion of TNO's activities—some 75 per cent—are financed at cost price. This means that that financing does not cover certain costs, such as any mismatch of capacity with available work and reorganization costs resulting from active portfolio management and market volatility. In the above model, this causes a negative capacity result. The Ministry of Economic Affairs therefore allows us to impose a continuity surcharge in order to partially recoup these costs and incidentals. In the long term, though, careful ongoing portfolio management will have to minimize any reorganization costs

The above model allows only limited financial scope for renewal. Modest investments in knowledge-building and research facilities can be funded from the operating surplus, but there is no room for major capital investments. These would thus require additional government funding.

#### IMPROVED PERFORMANCE AND KPIS

Between now and 2021, we aim to optimize our financial performance within the limits imposed by our mission and our model. We intend to do this first by further refining our operational and financial management in such areas as portfolios and operational performance, as well as by reducing the amount of vacant property we have in order to prevent a negative capacity result. Secondly, we will be increasing the procurement margin in contract research by introducing value-based pricing wherever possible. This should lead to a positive project result (project revenues exceed project costs). Finally, we will be doing more to generate income from the licensing of our intellectual property. Since the costs of maintaining IP are fairly high, though, it will take some considerable effort to keep the "IP account" in the black over the next few years.

The focus upon operational performance should ensure that any rises in our cost prices remain below the rate of inflation, so that as much as possible of every euro we spend goes towards achieving impact.

Our most important financial KPIs for the forthcoming strategic period are as follows.

- KPI. Annual operating surplus consistently exceeds €5 million.
- KPI. Inflation outstrips rises in cost prices.

#### RISKS

We perceive the principal external risks to the success of our strategy as being:

1. TNO's "right to play". An evolving innovation system is making it increasingly important that we clearly define our position in the market, so that clients and partners know exactly when and why to call upon us. A number of the priorities described in Section 5 should help us hone our positioning and so retain our "right our play".
2. Continuity of state funding. As described above, the state provides TNO with its basic funding. We have assumed that this will continue at its 2017 level, but no promises have been made in that regard. After the general election of March 2017, the new government will establish its own policy for research and innovation. Should this involve a significant change of direction and reduction in our funding, it will become impossible to implement this strategic plan.
3. Economic developments. The state of the economy always strongly influences the readiness of commercial businesses, in particular, to entrust research assignments to TNO and to participate in joint projects with us. Sound financial and operational policy, plus dynamic portfolio management, are therefore essential to ensure that our organization keeps pace with market requirements.
4. Limited financial solidity. Our business model is based heavily upon orders fulfilled at cost price: some 75 per cent of them. And our margins on the remainder are small. This makes us vulnerable, with few buffers to absorb setbacks caused by, for example, a sudden drop in orders due to an economic slowdown or the limited internal mobility of our specialists between different scientific disciplines. Or by project risks, which will increase as TNO focuses more upon larger projects, with more and more of them undertaken by consortia, and because clients are more frequently demanding performance guarantees. Here again, good financial and operational management is the best way to keep these risks under control. It is important that project risks always be carefully identified, assessed and managed—in the case of the very biggest projects, at board level. ■

**AIM:**  
EVERY EURO WE SPEND  
GOES TOWARDS ACHIEVING **IMPACT**

# APPENDIX 1

UN	EU	NRA	Top sector	Ministry
UN 8, UN 9	GSC 6, KET 1, KET 2, KET 4, KET 5, KET 6, LEIT 1, LEIT 2	NRA 18	HTSM	EZ
UN 8, UN 9	GSC 6, LEIT 1	NRA 20, NRA 25	HTSM, ICT	EZ
UN 8, UN 9, UN 12	GSC 2, GSC 5, GSC 6, KET 3, LEIT 3	NRA 3, NRA 12, NRA 23	Chemicals, Energy	EZ
UN 8, UN 13, UN 14, UN 15	GSC 5, GSC 6, KET 5, LEIT 5	NRA 2, NRA 15	HTSM	EZ
UN 8, UN 9, UN 12	GSC 3, GSC 6, KET 1, KET 2, KET 4, KET 5, KET 6, LEIT 1, LEIT 2, LEIT 4	NRA 12, NRA 20	HTSM	EZ
UN 8, UN 9, UN 12	GSC 6, KET 4, KET 5, KET 6, LEIT 1, LEIT 4	NRA 13, NRA 20	HTSM, ICT	EZ
UN 3, UN 10, UN 11	GSC 1	NRA 6, NRA 7, NRA 14	LSH	VWS
UN 3, UN 8, UN 10, UN 11	GSC 1, LEIT 1	NRA 6, NRA 14, NRA 16, NRA 20	HTSM	SZW
UN 3	GSC 1, LEIT 1	NRA 6, NRA 14, NRA 17, NRA 19, NRA 25	LSH	VWS
UN 3	GSC 1, LEIT 1	NRA 6, NRA 16	LSH, HTSM	VWS
UN 3	GSC 1, LEIT 1	NRA 6, NRA 17	LSH, ICT	VWS
UN 16	GSC 7, LEIT 1	NRA 16, NRA 24	ICT	Defence, V&J
UN 16	GSC 7, LEIT 1	NRA 24	HTSM, ICT	Defence, V&J
UN 11, UN 16	GSC 7	NRA 24		Defence, V&J
UN 16	GSC 7, LEIT 1	NRA 24	HTSM, ICT	Defence, V&J
UN 16	GSC 7, LEIT 1	NRA 16, NRA 24		Defence, V&J
UN 16	GSC 7, KET 4, LEIT 1	NRA 18	HTSM, ICT	Defence, V&J
UN 11, UN 13	GSC 4, LEIT 1	NRA 11	Logistics, HTSM	IenM
UN 9, UN 11, UN 13	GSC 5, LEIT 1	NRA 1, NRA 21	HTSM, Water, Energy	IenM
UN 6, UN 11, UN 12, UN 13	GSC 1, GSC 5	NRA 1, NRA 3, NRA 21	HTSM, Water	IenM, EZ
UN 11	GSC 1, GSC 4	NRA 9, NRA 16, NRA 21	HTSM	IenM

**UN:** United Nations sustainable development goals, **GSC:** European Union grand societal challenges, **KET:** EU key enabling technologies, **LEIT:** EU Leadership in Enabling and Industrial Technologies domains, **NRA:** National Research Agenda pathways

For key to numbering, see table 3.1

Domain	Research priority	Technological innovation
Industry	Nanotechnology and quantum computers for greater computing power	Nanotechnology and quantum technology, photonics
	5G with a wide spectrum of applications	Media synchronization, valorization of metadata
	Renewable raw materials	Smart and green materials
	Photonics and optics for observation and communication in space	Nanotechnology and quantum technology, photonics
	Functional new materials, including nanomaterials	Nanotechnology and quantum technology, hybrid energy systems
	Smart-industry concepts based upon the internet of things, artificial intelligence, big data and robotics	Media synchronization, valorization of metadata, artificial intelligence, robotics, photonics, inside the human mind
Healthy Living	Fit and healthy young people	Modelling and prediction of integrated social systems
	Longer working lives	Robotics, modelling and prediction of integrated social systems
	Biomedical health: innovative treatment strategies and new medicines	Inside the human body, inside the human mind
	Health technology: medical technology and digital health	Media synchronization, neurotechnology/biotechnology
	Personalized health interventions	Artificial intelligence, valorization of metadata, inside the human mind
Defence & Security	Information as a target and a weapon, and information-intensive operations	Artificial intelligence, nanotechnology and quantum technology
	Unmanned and autonomous systems and human-machine teaming	Artificial intelligence, robotics
	People and mindset in the armed forces and other security providers	Inside the human mind, inside the human body
	Modern fighting ability, escalation dominance and protection	Artificial intelligence, robotics
	Resilience in the face of major social upheaval	Modelling and prediction of integrated social systems
	Opportunities and threats from new technology	Artificial intelligence, robotics, nanotechnology and quantum technology, neurotechnology/biotechnology
Energy		
Urbanisation	Mobility: scaleable, safe co-operative and self-driving vehicles	Media synchronization, modelling and prediction of integrated social systems, inside the human mind, robotics
	Infrastructure and buildings: self-learning industrial concepts	Smart megastructures, artificial intelligence, inside the human mind
	Environment: more accurate monitoring and local management for proactive quality improvement and resource exploitation	Valorization of metadata, inside the human body
	Systemic approaches for more liveable cities and greater adaptivity	Modelling and prediction of integrated social systems, valorization of metadata, inside the human mind

**HTSM:** High-Tech Systems and Materials, **LSH:** Life Sciences and Health, **ICT:** Information and Communication Technology, **EZ:** Economic Affairs, **VWS:** Health, Welfare and Sport, **V&J:** Security and Justice, **SZW:** Social Affairs and Employment, **I&M:** Infrastructure and the Environment







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COLOPHON

Text: TNO

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