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TNO report

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ERP Rapportage 2018, Resultaten

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Contents

1 Introduction

In this report we present the 2018 progress of TNO's Early Research Program (ERP) portfolio. In total 10 ERPs were carried out (see Table 1) - at the heart of societal and economical grand challenges - where we believe a concerted effort of applied research, fundamental research and future private development will be of great impact. We therefore continued our use-case-inspired research approach with equal emphasis on generating *cutting edge knowledge and technology*, together with research partners from academia, and *building research ecosystems* with stakeholders and sponsors from industry and public organizations.

Table 1: Early Research Programs 2018

nr	**ERP-title**	**ERP-status**	**Lead Scientist**
1	QuTech, Quantum Computing	PROGRAM	Richard Versluis
2	Energy Storage and Conversion	PROGRAM	Pascal Buskens
3	3D Nano Manufacturing	PROGRAM	Stefan Bäumer
4	Structural Integrity	PROGRAM	Henk Miedema
5	Making Sense of Big Data	PROGRAM	Wessel Kraaij
6	Complexity	PROGRAM	Ardi Dortmans
7	Personalized Health	PROGRAM	Jildau Boumans/André Boorsma
8	Organ function on Chip	PROGRAM	Evita van de Steeg
9	Submicron Composites	PROGRAM	Pascal Buskens
10	i-Botics	PROGRAM	Jan van Erp
11	BioNanotechnology	SEED	Arnold Storm
12	Applied AI	SEED	Albert Huizing
13	ExpoSense	SEED	Stefan Bäumer/Anjoeka Pronk
14	Optical Satelite Communication	SEED	Niek Doelman

In the next chapters the progress in these 10 ERPs are presented the abstracts of the report which is presented to the ministry of Economic Affairs and Climate, explaining the setting of the research in national and international context, and the highlights of results obtained. The plans for 2019 and beyond are described in the 'TNO Early Research Program Annual plan 2019'.

In addition to these 10 programs we started 4 ERP 'seed'-projects to explore the potential of strengthening our knowledge positions on Artificial Intelligence, Bionano devices, Chemical sensing (of exposome), and Laser satellite communication.

The ERP portfolio is focused on building the future knowledge base of TNO. At the same time we constantly look for opportunities to leverage our research with the efforts of others, to gain mass and jointly generate a higher pace of development.

For five programs we have established (the seed for) strategic, program based cooperation:

- Quantum computing / Quantum internet: QuTech (partner TU Delft),
- Personalized Health (Centre for Metabolic Health and Lifestyle (partner LUMC),
- 3D Nano Manufacturing (NOMI, partner TU/e High Tech Systems Centre),
- Submicron Composites: Brightlands Materials Centre (BMC, partners Chemelot Campus, TU/e, UM),
- Interaction Robotics (i-Botics, partner UT).

We shared our plans and results in 2018 with many potential partners and stakeholders in the form of patents, publications, conference presentations and posters, and ERP dissemination events.

2 ERP QuTech / Quantum Computing

General data	
Title	QuTech / Quantum Computing
'Topsectors'/Societal Themes	HTSM Nanotechnology
Contact person TNO	Garrelt Alberts, Peter Werkhoven, Rogier Verberk

QuTech has the ambition to develop the first working prototype quantum computer, as well as a demonstrator quantum internet. These new concept are gamechangers in the ICT sector and will have an tremendous effect on society. The envisioned developments cover many TRL's, multiple disciplines, and thereby about 15 years. To manage the developments, several roadmaps are defined: 2 focussing on (different types of) a quantum computer, 1 focussing on quantum internet and 1 focussing on increasing the technology readiness level (TRL) of the (quantum) technology needed to realise QuTech's ambition. TNO's role is to do applied research, increase TRL of the Quantum Computer and Internet systems and bring QuTech technology to society.

Roadmap A: Topologically protected quantum computing
Main objective: braiding with Majorana's in 2020 in order to create qubits with the potential of very long coherence times.

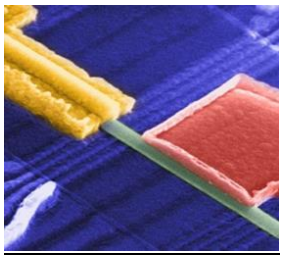


Figure 1 Majorana device

To demonstrate Majorana braiding, the nanowire crosses will need to be integrated in a superconducting circuit with a microwave resonator and several Josephson junctions. In 2018 a nanofabrication process was developed which will allow for the creation of complex 2DEG-superconductor devices and a well behaving heterostructure (InSB 2DEG) with a Hall bar was manufactured. An atomic layer deposition (ALD) process of oxide gate dielectrics, AlOx, was developed to be used in superconductor - semiconductor quantum devices.

Roadmap B: Fault- tolerant quantum computing
Main objective: a 49 qubits device in 2020, controlled with surface code driving. Two principle types of qubits are under investigation.

The transmon qubits are relatively speaking the most advanced type of qubits. In 2018 a design improvement of transmon chips was established, to improve the

functionality of both Intel and QuTech chips. This year, the best chip manufactured demonstrated 6 functional qubits (out of 7).

Figure 2 Transmon qubit

Spin qubits may intrinsically have longer coherence times, and also use surface code protection for scalable operation. In 2018, TNO set up successfully semi-routine fabrication of many of the preliminary steps to build full devices. A full development line was also setup to use purified Silicon as substrate material. A new ALD tool was purchased and setup to improve the quality of devices. The QTT software tool for autocalibration of spin qubits was released to be used by a wider community.

Roadmap C: Secure Quantum Internet
Main objective: a 4 city demonstrator network in 2020.

The fourth type of qubit is based on the N-V color centres in diamond. In 2018 experimental demonstration of NV spin-photon entanglement after frequency conversion has been completed. This is an essential step towards remote entanglement based quantum communication using NV centres in diamond. Furthermore, several nanofab processes of NV centres have been optimized, improving the performance of the NV centres.

Figure 3 Quantum Internet proof-of-principle at TU Delft campus

Roadmap D: Shared Development
This roadmap aims for increasing technology readiness level (TRL) of technology developed at QuTech by co-creating technology with scientist as well as product engineers from companies. The increase in TRL is required to transfer QuTech technology to industry and society. In 2018 major steps are made in the development of the full stack generic quantum computer platform. On all subsystems significant progress is made. On hardware level a clear design for both the few qubit as well as for the 10 qubit system is ready, known and detailed out. This resulted in having clear requirements, interfaces and Bills of Materials for the procurement of all hardware including electronics. According to plan the full hardware including facilities reach readiness in august 2018 (www.quantum-inspire.com). The quantum internet demonstrator project the choice has been made for a single click protocol enabling the high entanglement rate of 2 Hz. All equipment for 2 quantum nodes has been purchased and design of the quantum node has been patented. Breadboards of several

subcomponents in the design have been produced to validate the individual components. Although both design and validation has proved tougher than expected, all results indicate that the individual components seem to work and there is no indication that the components together would fail. The experience in breadboard building will be used to build the quantum nodes which started Q4 2018

Figure 4 Generic quantum computer.

3 ERP Energy Storage and Conversion

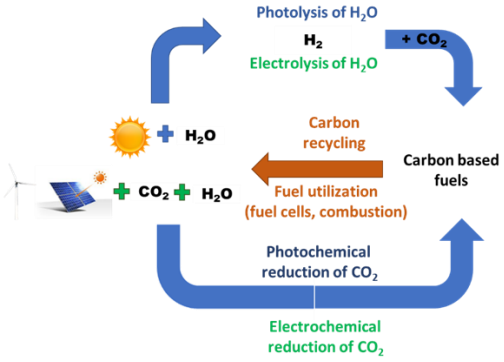
General Data	
Title ERP	Energy Storage and Conversion
Contact person(s) TNO	Pascal Buskens/Peter Wolfs/Nicole Meulendijks

Energy conversion and storage becomes increasingly important to realize the vital transition from fossil fuels to sustainable energy. In recent years, we made good progress in our search for new conversion and storage processes, resulting e.g. in the development and validation of plasmonic catalysts to reduce CO_2 to CH_4 using sunlight as energy source, and the development of a process and reactor concept for the reduction of CO_2 to formic acid using renewable electricity as energy source. We strongly collaborate with industry (e.g. via VoltaChem and the Brightlands Chemelot Campus and Site) and academia (e.g. Utrecht University, Leiden University, Delft University, Hasselt University and DIFFER), and will continue our developments in close collaboration with these partners and national and regional governments. Our focus is on the development and validation of concepts and processes at a technology readiness level of 2-4 that use electricity from renewable sources (solar, wind) or sunlight directly to convert CO_2 to C1 chemicals and fuels containing one carbon atom.

Routes to come to technically and economically viable technologies and processes are pursued, and feasibility will be demonstrated on laboratory scale (up to TRL 4). Focus is on processes that convert CO_2 into C1 fuels and base chemicals. For fuels, the ultimate goal is to provide technologies and concepts that can be scaled up to an efficient production process at a cost of max. 800 Euro/ton.

To date, we have identified two attractive routes towards hydrocarbon based fuels. These two routes are highly interconnected. The first route (indirect) is based on generation of renewable hydrogen, and the subsequent reaction of this hydrogen with CO_2 towards hydrocarbons. The second route (direct) is based on the direct conversion of CO_2 and water towards hydrocarbons. The technologies related to these routes are based on electrochemistry (direct: electrochemical reduction of CO_2, indirect: electrolysis of water) and on photochemistry (direct: photochemical reduction of CO_2 with water, indirect: photolysis of water to cost-effectively generate green hydrogen and subsequent use of that for hydrogenation of CO_2).

In 2018, the successful proof of principle of a paired electrolysis concept that has the potential to make the CO_2 electroreduction economically attractive by both reducing the CAPEX and OPEX costs as well as increasing the valuable products of the reaction has been shown. Studies on the potential of photowatersplitting as a technology to produce H_2 at lower costs than the conventional route via electrolysis clearly elucidated which systems have the potential to produce hydrogen at lower cost than electrolysis (≤ 2 €/kg), and therefore contribute to a positive business case for CO_2 hydrogenation. For photochemical conversion of CO_2 to C_1 chemicals/fuels using sunlight as energy source, in 2018, we managed to successfully demonstrate the concept of plasmon catalysis for photochemical hydrogenation of CO_2 to methane.



More information:
https://www.tno.nl/nl/samenwerken/expertise/early-research-programma/
http://www.voltachem.com/
http://www.grensregio.eu/projecten/co2-voor-energie-opslag-enop

4 ERP 3D Nanomanufacturing

General data	
Title	3D Nanomanufacturing
Topsector	HTSM
Contact person TNO	Stefan Bäumer, Rob Willekers, Rogier Verberk, Peter Lucas

There are already more connected devices than people on the planet and the demand for these devices is steadily increasing: IOT, connected cars, immersed reality (virtual and real world augmented). All of these products and applications rely heavily on semiconductor devices. To meet the needs for ever smaller and faster devices, the semiconductor industry is shifting from planar device configurations to 3D or stacked structures, such as multi-gate logics (e.g. FinFETs, Gate-All-Around FETs, and nanowires) and 3D NAND memories with still shrinking pitches, see also Figure 5.

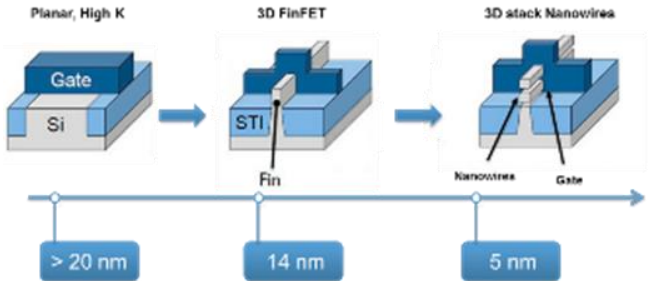


Figure 5 Moving from planer to 3D configurations at an ever shrink pitch.

Following the shrinkage, manufacturing processes are changing as well: EUV lithography will become widely adopted, next to new (selective) etch and deposition technology, for manufacturing the smallest features. To develop and control the manufacturing processes it is essential that new metrology tools are developed. Optical metrology is reaching its limit and cannot see through the new materials needed for the EUV processes. Therefore Scanning Probe Microscopy (SPM) and Subsurface SPM metrology are needed to facilitate the newest nodes in the semiconductor industry. To support the semiconductor industry, the ERP 3D nanomanufacturing has developed and is developing key technologies for amongst others:

- Quantitative subsurface metrology to detect up to > 20 µm deep structures with a resolution of < 3 nm.
- True 3D metrology of advanced semiconductor devices aiming at 1nm resolution for new nanowire and gate all around devices as well as stacked memory.
- High throughput, robust and reproducible scanning probe microscopy (SPM) for nanometrology applications down to < 10 nm resolution.
- Efficient, flexible and fast mask-less nanopatterning for < 100 nm structures.

The first three items are aimed at high-throughput detection of potential manufacturing flaws of semiconductor devices. The last item will enable flexible, yet high-throughput, patterning for e.g. integrated optics.

Some highlights of 2018 are:

1. First measurement results for a new sub-surface actuation scheme based on photo thermal acoustic imaging. With this technique potentially deeper buried structures can be imaged, which will be needed for amongst others alignment purposes.
2. Photo-thermal actuation of cantilevers: the measurement included identification of sub-surface anomalies for 6 nm fins with a newly developed demonstrator as well as fin height estimations and overlay measurements on industry samples (ODM wafers).
3. Shown feasibility of very fast maskless nanopatterning at, at least, one order of magnitude faster than current state-of-the-art systems.
4. First measurements on mice liver cells. It is believed the physical properties of living cells can facilitate research into the efficacy of newly developed drugs.
5. TNO spin-out company NFI has adopted the parallel AFM technology and is developing it into a commercial tool. This will allow NFI to serve the most important players in the semiconductor industry with high-throughput SPM.

These technologies are being developed for important players in the semiconductor industry such as Samsung, Intel, ASML and Zeiss. This ERP is working closely together with academic partners such as the Delft University of Technology and the Technical University of Eindhoven, where there exists a joined development agreement.

Next to the semiconductor applications, this ERP is porting and expanding the key technologies for applications of nanometrology to the bio and/ or health industry. The possibilities of organ-on-a-chip to you-on-a-chip are fascinating, appear endless and will have a tremendous impact on society.

Over the last four years the program has 48 patents filed, 34 invited lectures delivered, 166 conference posters presented and 30 journal papers published.

5 ERP Structural Integrity

Title:	Structural Integrity
Contact TNO:	Henk Miedema

ERP Structural Integrity aims to safeguard structural integrity of macro structures while reducing maintenance costs and maximizing the availability of the structures. The main goal is optimising the operation and maintenance of a structure by knowing its present state and being able to predict its future state (Condition-Based Maintenance, CBM). Knowing the present state and predicting the future state of a structure requires advanced models and new sensing technologies. Both are being developed in ERP SI, which was driven by the following 4 use cases.

-*Concrete bridge*

Full probabilistic reliability assessment with non-linear FEM (NLFEM) for modeling structural response, and efficient reliability analysis methods for assessing probability of failure have been enabled by (i) improving robustness and computation-efficiency of reliability analysis methods, (ii) developing a stochastic approach to modelling corrosion defects in reinforced concrete structures, and (iii) developing methods for quantifying model uncertainty in NLFEM. All elements were integrated in a tool for assessment of baseline safety of existing bridges. In addition, methods have been designed for incorporating testing and monitoring data in condition assessment modelling, aiming at reduction of model uncertainty and improvement of accuracy. A similar concept of data assimilation has been developed and for the first time successfully applied for detection of hidden damage through numerical modelling combined with field data. Finally, we set up and performed a large field experiment to demonstrate our results so far.

-*Offshore wind support structure*

A software model for condition assessment for an individual structure has been realized and is validated using actual measurement data from an offshore wind park. The tool is efficient and reliable. The core of the probabilistic model for the condition evaluation for an entire wind park has been programmed. The models and probabilistic relations between input parameters and response calculations are operational. The variations and uncertainties associated with the soil are addressed. The theoretical framework for giga-cycle fatigue has been established, describing the relation between stress cycles and fatigue crack initiation as well as the relation stress cycles and crack growth. The failure models and associated parameters are validated with tests and can be used to calculate the critical fatigue crack length.

- *Well integrity*

A quantitative risk assessment methodology for the prediction of post-abandonment well leakage and for evaluating integrity of a well before reuse (CO_2 storage, geothermal) has been realized. Our fundamental approach to the geomechanical modelling was further developed and applied to wells in the North Sea. The reactive transport model developed for CO_2 storage and conventional gas wells was applied to simulate a set of CO_2 storage scenarios for a North Sea field. We have made possible the exploration of scenario's (microannulus width, permeability values, reservoir pressure, chemical interactions). The model was

adapted to incorporate methane leakage from a shallow gas pocket. The risk assessment workflow and Bayesian Believe Network (BBN) have been brought to a level that it can be used in practice.

Composite vehicle

We made significant steps to enable the use of fibre reinforced composite materials in blast resistant vehicle structures. We alternated modelling the performance of the composite materials with first ¼ scale and later ½ scale tests for which we developed the setup. Our materials performed well in these tests. Materials (fibers, epoxy) that appear to be suitable for large scale application in the vehicles have been found.

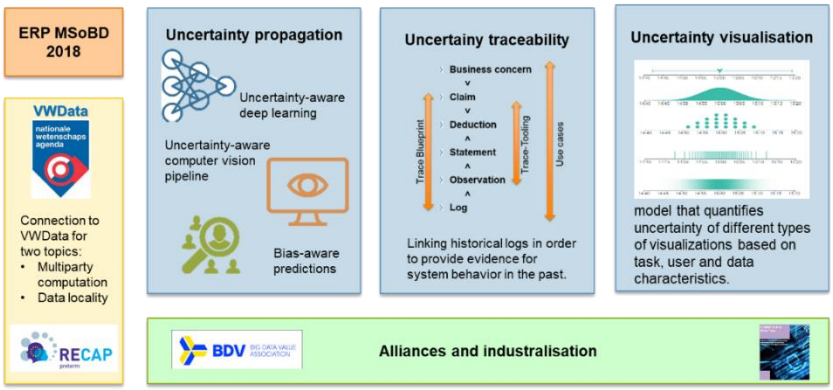
6 ERP Making Sense of Big Data

General data	
Title	Making Sense of Big Data
'Topsectors'/Societal Themes	HTSM, LSH, Agro, Logistics
Contact person TNO	Wessel Kraaij, Judith Dijk

The term Big Data is used for collections of data so large and complex that it becomes too difficult to process using on-hand data management tools or traditional data processing applications. The goal of the ERP is to create top capabilities (tools, models, methods) that enable a stakeholder to design and implement a data-driven-innovation in a multi-stakeholder setting.

In the first two years (2015-2016), this ERP explored the complete big data value chain, including data governance, analysis and distribution. In 2017 the ERP focused on three topics within the big data value chain: Uncertainty, multi-stakeholder collaboration and Information Centric Networking. In 2018 we focused mainly on **Uncertainty;** the other topics were handed over to other programs within TNO.

The technology line ***Uncertainty*** has continued to focus on tackling ***real-world challenges*** in big data where multiple, unstructured, relatively "ambiguous" (belonging to different domains or contexts) datasets are used. Three different types of uncertainty were investigated: 1) Uncertainty propagation 2) Data traceability and data quality assurance and 3) Visualization. Within the ERP, we have shown the effects of these uncertainties for big data applications and we developed methods and tools for big data applications and big data technology that can handle these uncertainties. The research also resulted in a large number of publications. These results contribute to a better understanding of the impact of uncertainties and data quality in a data driven innovation.



Within the ERP Making Sense of Big Data strong collaboration with various partners outside TNO is key. One of the goals of the ERP was to strengthen these collaboration and to build a national and international ecosystem. This

resulted in joint projects in the NWA route Responsible Value Creation, COMMIT2DATA and the European BDVA.

7 ERP Complexity

General data	
Title	Complexity
Topsector	TKI Logistics, TKI Chemistry, TKI Energy
Contact person TNO	Ardi Dortmans; Esther Zondervan

Early Research Program (ERP) Complexity builds new knowledge and networks on the topic of complexity science, with focus on models for technical systems with human decision making. The 2 pillars in ERP Complexity are 1) self-organisation in logistics and 2) value creation by sustainability.

Self-organisation in logistics
Four joint projects with universities and industrial partners are in progress about the possibilities offered by new (ICT) technologies to plan and execute transport of goods in networks with reduced environmental loads. Within these projects, the following outstanding results were obtained:

1. a decision support system was developed for better understanding of self-organisational properties of the maritime ship handling chain, from port arrival to departure;
2. a mathematical framework that can solve synchromodal transport problems from sea harbours to further inland;
3. a database was started with traffic and logistic data to enable a streamlined logistic system with improved transport efficiency from and to the harbour of Rotterdam;
4. a prototype solution for a use case based on commodity trading on existing blockchain technology, supporting data sharing in complex organizational networks.

Value creation by sustainability
Value creation by sustainability focused on the transition towards a more sustainable economy where combinations of new technologies, new value creation approaches and human behaviour are critical to realise the disruptions needed. In this area both the material transition and the energy transition are equally important.

For energy transition, a value case methodology was further developed to version 2.0 to support stakeholders in the energy domain to prepare for or to anticipate on the changing dynamics in energy markets and business. Furthermore a Transactive Energy Marketware model was developed to allow for demand /response real time market, a large scale control of the distribution grid level, taking into account end-user devices, and grid level constraints, and different involved parties (market operators, aggregators) to operate on the same grid.
Two new joint projects were started with universities and industrial partners.

For the material transition, **the main activities focused** on new plastics recycling technology based on dissolution technology. This technology is especially useful for those types of complex plastics that cannot be mechanically recycled. Life cycle assessment showed a high environmental impact and the economic assessment showed that the technology is economically viable.

From these activities **two new projects were started in the small NWA route circular economy**. One on the recycling of multilayers and on the circular use of building materials.
The ERP Complexity ends at 31 Dec 2018. The projects in collaboration with universities and industry will be continued in 2019 according to plan with funding from ERP/demand-driven programs. New activities are continued in the demand-driven programs.

8 ERP Personalized Health

Titel	Personalized Health
ERP/Topsector/Maatschappelijk Thema	Early Research Programmes
Contactpersoon TNO	Dr. Marjan van Erk

ERP Personalized Health focuses on biological knowledge innovation and research methodology innovations for personalized health optimization. The fact that lifestyle interventions can be used to prevent health problems is clear. Lifestyle – comprising nutrition, exercise, relaxation and sleep – is vital to good health and to staying healthy and can be part of treatment of (lifestyle-related) diseases. Personalisation, i.e. tailoring an individual's needs and preferences, is an important factor for achieving sustainable healthy lifestyle habits. The innovations in this ERP result from 2 focus areas: biology and research methodology and are targeted towards personalisation, lifestyle and health. These innovations are a pivotal part of the envisioned disruptive change that will result in a higher quality of life and lower healthcare costs.

The **biological knowledge innovation** focuses on one of the major driving mechanisms for lifestyle-related disease: inflammation, and specifically, on the healthy dynamics of this process and how that can be influenced (inflammatory dynamics). In 2018, the work on inflammatory dynamics resulted in a review paper, which includes a summary of 12 studies describing inflammatory biomarker responses upon a nutritional challenge test as well as potential opportunities for optimizing inflammatory resilience. Furthermore, in 2018, we developed an *in silico* systems biology approach to identify candidate biomarkers for inflammatory dynamics and tissue-specific inflammation; we designed a study to apply TNO's existing PhenFlex challenge concept for assessing inflammatory dynamics; and we gathered first insights into new markers of inflammation, related to the intestinal mycobiome (fungi), that can be analyzed in a novel mycobiome screening platform for inflammatory disease.

Methodology innovation work focuses on the generation of new personal health advice models, that exploit a wide range of relevant biological knowledge, the subject's personal health story, and the stories of others. In 2018, the architecture for these personal health advice models was developed and a first version of a personal health advice system was designed and implemented in a research tool, IRIS app. In addition, the behavioral change and maintenance models were developed to predict compliance and adherence to a new lifestyle.

Research innovation work focuses on building the fundaments of a prototype research and health community in order to initiate, facilitate, and to test "personal health data valorization" . This community will empower citizens to achieve a sustainable lifestyle change. The fundaments developed in 2018 include health valorization requirements, personalised dietary advice and behavioral maintenance interventions, which were built into the IRIS app. Next, this app will be implemented in a research setting.

In 2019, this ERP will work towards a proof-of-concept on improved inflammatory robustness measured by innovative plasma biomarkers and proof-of-concept on

reversal of organ inflammation (biology innovation) as well as a next version of the personalized health advice model that implements the output of 2018 and 1-2 health data communities in which the innovations will be implemented and tested.
The innovations from this ERP PH program will land in future PPS projects that will implement personalized health innovations in real-life.

9 ERP Organ Function-on-Chip

Title	Organ Function-on-Chip
'Topsectors'/Societal Themes	LSH, A&F, HTSM / Work & Health, Defense
Contact person TNO	Ivana Bobeldijk-Pastorova, Evita van de Steeg

Over the last 4 years, the ERP Organ function on-a-chip evolved from a seed ERP (2015) into a full ERP (in 2017). For both use cases, Liver and Gut, important technical developments as well as extension of the network were achieved in 2018.
In 2018, TNO was an active strategic member of hDMT, a national pre-competitive institute focusing on state-of-the-art technologies around organ on-a-chip. Membership in this network group emphasizes TNO's right to play in this area.
New collaborations with academia were setup, with University of Utrecht (joint postdoc), University of Leiden, Academic Medical Centre for biology (joint postdoc), University Medical Centre Groningen. Further industrial collaborations are currently being explored together with business developers. The program is currently discussing collaboration with Catapult Drug Discovery in the UK. The internal collaborations between Metabolic health research, Optomechatronics, Equipment for additive manufacturing, Microbiology and systems biology, were further strengthened by joint development of microfluidic systems and readout methods. The main results achieved were i) design and 3D-print manufacturing of a microfluidic chip suitable for gut, liver and other organ on a chip applications, ii) several protocols for stable culturing of cells in the gut model, using the newly developed chip iii) a stable diseased liver on a chip cell model, ready for validation and iv) prototype flowcell for biological application of AFM as well as first results of measuring physical properties of cells with AFM. The results achieved were disseminated through many poster and oral presentations at scientific events as well as during several business trips to pharma and nutrition companies. Two scientific manuscripts are in preparation, one in review and one has been published.

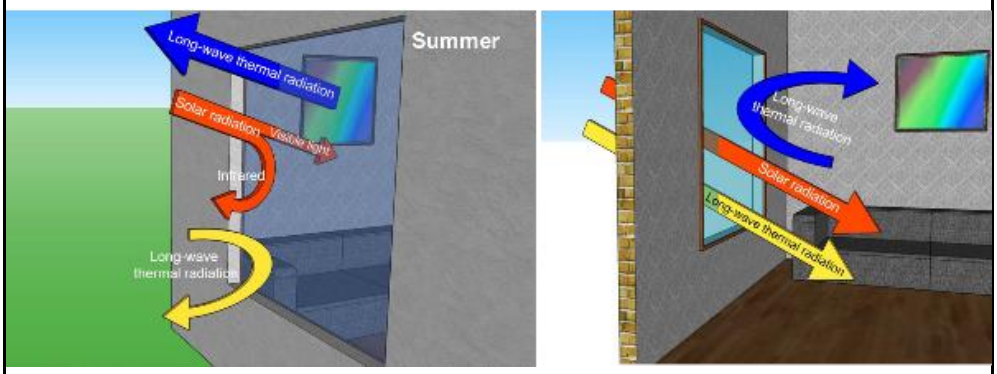
The program succeeded in achieving the goals set for 2018: bringing the development of advanced in-vitro models a major step further. We designed and fabricated a new chip for multiple applications, and in collaboration with Roadmap Biomedical Health, the first gut on-a-chip model is currently being optimized for market applications together with industrial partners.
For 2019, we expect further development of the technology, validation of the developed models, coupling of organ models for new applications, submission of the manuscripts and most importantly, applications in the market.

10 ERP Submicron Composites

General Data	
Title ERP	Submicron Composites
Contact person(s) TNO	Pascal Buskens/Peter Wolfs

The overall goal of this ERP is to develop and validate concepts for achieving control both over nanostructure and chemical composition of materials. Since both jointly determine the material's properties, gaining control over nanostructure and chemical composition enables the development of materials with tailored functionality. Furthermore, in specific cases we aim to progress from static monofunctional materials to active and adaptive materials, since such functionalities have a higher added value. We will demonstrate the knowledge gained within the framework of this ERP in selected use cases related to materials for sustainable buildings and additive manufacturing, as chosen in collaboration with the Brightlands Materials Center (BMC) and its partners. Within the framework of this ERP, we aim at facilitating a successful transfer of technologies delivered by academia at a TRL level of 2-3 to the applied research activities on a TRL level of 4.

In line with the BMC program Sustainable Buildings, we selected infrared regulating polymer foils, and coatings or materials that capture light on large surface areas and guide it to a position where it can be used e.g. in combination with photovoltaic modules. Both materials have the potential to contribute to improving the energy efficiency of buildings, which is highly relevant in view of European, national and regional ambitions regarding energy neutrality in the built environment.
In 2018, we started with the IR regulating polymer foils. We successfully developed the synthesis procedure for monoclinic VO_2 nanoparticles with a particle size below 100 nm, and even below 50 nm (the latter is important to avoid substantial scattering in the visible). We also characterized their thermochromic switching behaviour (i.e. phase transition). Finally we developed the procedure for model particles to be dispersed in polyolefin foils resulting in a random particle distribution. The next step is to apply this procedure to the actual synthesised VO_2 nanoparticles.



In line with the BMC program Additive manufacturing (AM), we aim to develop new materials and processes for the production of parts with high mechanical reinforcement as well as integrated thermal and dielectric functionalities, based on AM of fibre reinforced polymers. An example of an automotive part, that requires resistance against high thermal as well as high mechanical loads, which is the base of this use case, is an inlet manifold. Traditionally, these manifolds are made from metals, but the use of polymer composites allows the production of light-weight alternatives. In 2018, we successfully demonstrated the ability to integrate and position nanoparticles and fibres in 3D printed polymer parts. Ergo, we have proven the concept that we can integrate nanoparticles/fibres in 3D printed polymer parts, and that we can control where to position them within the part. This provides us with a high level of control over the material's composition and nanostructure, which allows us to start tailoring the properties of 3D-printed products. Moreover we successfully validated the material predictive models for such parts.

The next step is to show the first feasibility of 3D printing carbon fibre reinforced polymers to enable mechanical reinforcement in simple geometries.

11 ERP I-Botics

Algemene gegevens	
Titel	I-Botics
ERP/Topsector/ Maatschappelijk Thema	ERP
Contactpersoon TNO	Jan van Erp, Chris Jansen, Nanja Smets

Het ERP i-botics programma genereert kennis die nodig is om robot systemen te maken die de mens zo intuïtief mogelijk kan aansturen, alsof de menselijke operator één is met het robotsysteem. Dit kan zowel een robotsysteem zijn waarmee een mens op afstand kan handelen en waarnemen alsof hij ter plekke aanwezig is (telepresence teleoperatie), als een op het lichaam gedragen robotsysteem (exoskelet) dat fysieke ondersteuning biedt bij bewegen of extra kracht levert. Na afloop van dit programma kunnen op basis van deze kennis zulke systemen gebouwd worden, voor bijvoorbeeld expert-onderhoud/inspectie op afstand in de olie- en gas industrie, en til-ondersteuning in maakindustrie/logistiek.

Het primaire doel voor 2018 betrof onderzoek naar de benutting van perceptuele informatie om zo de interactie tussen robot en mens zo intuïtief mogelijk te maken; zowel voor teleoperatie als exoskeleton ondersteuning. Als een mens een object oppakt is een rijkdom aan perceptuele informatie (met name zicht en gevoel) beschikbaar (en nodig!) om zo'n beweging goed uit te voeren. Denk hierbij aan bijvoorbeeld drukpunten op de vingertoppen, minieme huidverschuivingen door beweging, spierspanningsveranderingen door zwaartekracht, etc. Wanneer deze beweging via een robot wordt uitgevoerd (teleoperatie) moet een adequate vertaling plaatsvinden van de informatie die de robot kan waarnemen (met sensoren), naar informatie zoals de mens die kan interpreteren (via zintuigen) op afstand. 2018 heeft inzicht gegeven in hoe die vertaling het best kan plaatsvinden. Op basis daarvan is een robotarm/hand -opstelling gebouwd die door een operator aangestuurd kan worden. De operator gebruikt hiervoor een hand-exoskelet voor krachtterugkoppeling (denk aan mechanische handschoen), met tril-elementen daarin voor overige haptische terugkoppeling.

Naast deze perceptieve kant van interactieve robotica is onderzoek gedaan naar een cognitief/emotionele kant: onder welke voorwaarden voelt een tele-operator eigenaarschap over een robot arm/hand, zogenaamd body ownership. Anders gezegd, waarmee kunnen we bewerkstelligen dat de robot arm/hand voelt alsof het je eigen arm/hand is? De resultaten wijzen uit dat body ownership ook voor een robotarm gevoeld kan worden, onder de voorwaarde dat de tactiele en visuele ervaring overeenkomen. De hypothese die we vervolgens gaan toetsen is of de taakprestaties ook echt verbeteren wanneer dat gevoel van 'ownership' aanwezig is.

Intuïtieve aansturing en gevoel van 'ownership' worden gehinderd wanneer de communicatie over en weer tussen robot en operator vertraagd is, zoals bijvoorbeeld door draadloze communicatie over grotere afstand. In 2018 is een volledig virtuele representatie van de robot omgeving gemaakt waarmee de vertraging en tijdelijke uitval van de communicatie (deels) wordt ondervangen. Deze virtuele representatie wordt actueel gehouden met

(enigszins vertraagd binnenkomende) videobeelden afkomstig van sensoren van de robot.

Voor exoskeletten met industriële toepassing zoals til-ondersteuning is onderzocht of spieractivatie zoals geregistreerd in de spieren van de operator een voorspelling kan zijn voor de bewegingsintentie van de operator. Met deze informatie kan het exoskelet nog reactiever aangestuurd worden. Om vervolgens de juiste krachthoeveelheid te kunnen toevoegen of te doseren moeten de krachten goed geschaald kunnen worden. Kennis hierover is opgebouwd met een literatuurstudie. Deze kennis zal het komende jaar ook benut kunnen worden in de aansturing van de mechanische handschoen (hierboven genoemd).

Naast bovengenoemde onderzoek naar spieractiviteitmeting als indicatie voor de menselijke bewegingsintentie, is ook de afstemming tussen mens en exoskelet geoptimaliseerd (ter verkrijging van shared control), en is een model gemaakt waarmee de impact van een exoskelet op de mens bepaald kan worden (bijvoorbeeld ter voorkoming van blessures).

12 SEED ERP Bionanotechnology

Algemene gegevens	
Titel	Bio Nanotechnology
ERP/Topsector/ Maatschappelijk Thema	ERP
Contactpersoon TNO	Rogier Verberk, Sandra Guns, Arnold Storm

The seed ERP Bionano aims to develop a new technology for high-throughput detection and characterization of proteins at a single-molecule level. The capability will likely enable breakthroughs in e.g. biomedical research, diagnostics, chemical analysis and environmental monitoring. In 2018 a set-up for single molecule protein fingerprinting has been designed and built. Additionally progress has been made to design a transmission model that calculates the optical performance based on the choice for laser, prism, objective lens, filters and camera. Proof-of-concept experiments together with TUDelft (Chirlmin Joo lab, Department of Bionanoscience)) have been started, and will continue in 2019.

13 SEED ERP Applied AI PM

General Data	
Titel	Applied AI
ERP/Topsector/Maatschappelijk Thema	ERP
Contactpersoon TNO	Serena Oggero, André Meyer-Vitali

Some of the problems associated with current applications of AI in the real world occur because AI systems are designed to conduct very specific tasks in a known environment but are unable to carry out tasks that require (slightly) different skills. Furthermore, unexpected changes in the environment and situations that have not been foreseen by the designer of an AI system can lead to unsafe behaviour with (sometimes lethal) consequences. Another factor that hampers the acceptance of AI is the lack of transparency that is related to the inability of current AI to explain its decisions to human users and/or co-workers. In addition to technical and human factors, the application of AI in society also requires ethical and legal issues such as accountability and liability to be addressed.

The objective of the seed ERP Applied AI in 2018 is to investigate new concepts and methods for explainable AI (XAI), to explore legal concepts for meaningful human control of systems based on AI, and to define the lines of research for the next phase of the ERP Applied AI.

In 2018 the following results have been achieved.

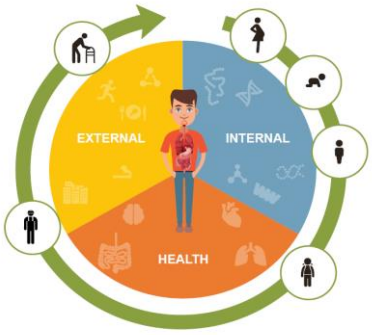
- A theoretical framework called PeCoX (Perceptual and Cognitive Explanations) was developed. The PeCoX framework underlines the need for both symbolic (logic, rule-based, explicit models, etc.) and sub-symbolic (machine learning, bio-inspired algorithms, reinforcement learning, etc.) to obtain an effective system that can explain itself and conduct conversations that include explanations specifically targeted towards a specific human. The PeCoX framework also addresses the requirement of adequately validated explainable AI (XAI) methods. The integrated XAI methods are system independent; meaning that they can be used by most AI systems in a plug-and-play manner.
- An example-based explanation method LEAFAGE (Local Example And Feature importance-based model Agnostic Explanation) has been developed that is able to extract an explanation for a prediction made by any black-box Machine Learning model. The results showed that LEAFAGE explanation performed overall better than the current state-of-the-art method LIME (Local Interpretable Model-agnostic Explanation) on non-linear models, in terms of local fidelity. The user-study evaluation showed that the participants overall perceived receiving explanations concerning a prediction as more helpful than providing no explanation for the goal of decision making. However, when the participants were tested about their gained knowledge after seeing an explanation, no significant advantage was found compared to providing no explanation.
- To explore potential answers for legal questions concerning meaningful human control and liability, initial ideas about the attribution of legal personhood to AI-based autonomous systems have been formulated.
- The next phase of the ERP Applied AI has been defined with the following research lines:

- *Controllable AI*:. enable meaningful human control and self-awareness of AI;
- *Explainable AI*: enable AI to provide meaningful explanations to humans;
- *Responsible AI*: enable AI to operate responsibly in society according to the (western) ethical principles;
- *Hybrid AI*: develop methods that integrate symbolic reasoning and machine learning to support controllable AI, explainable AI and responsible AI.

14 SEED ERP ExpoSense

General data	
Title	ExpoSense
'Topsectors'/Societal Themes	Chemical industry, LSH, Occupational / Environmental Health
Contact persons TNO	Stefan Bäumer / Anjoeka Pronk / Ingeborg Kooter

Our health is strongly impacted by the environment we live in. Development of adequate measures for the reduction in the burden of disease requires a better understanding of the relation between environmental exposures and its impact on human health. This seed ERP ExpoSense combined measuring and modelling expertise with the aim to acquire information on the personal environmental exposure of people at defined time and position.



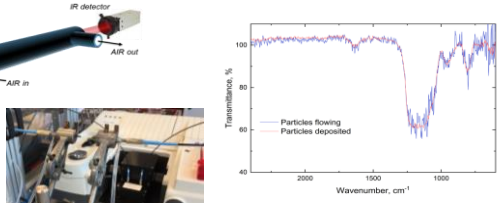
The Exposome

Focus area of the seed ERP ExpoSense is on particulate matter (PM) as a relevant environmental pollutant. PM, often measured as PM10 consisting of the mass of total particles smaller than 10 □m, and complex by nature. Human (anthropogenic) activities, such as agricultural operations, industrial processes, combustion of wood and fossil fuels, construction and demolition activities etc. are important sources. PM is responsible for about 4% of the disease burden in the Netherlands.

The technical challenges are found in several areas: current portable sensors are not reliable enough (no accurate measurement parameter) and cannot distinguish the chemical composition of PM. Therefore better sensors for PM are needed, which in addition can also chemically classify PM. Second, for estimating personal exposure, sensors and exposure models work hand in hand. Current exposure models are using data which are delivered in daily intervals. Making these models fit for accepting hourly updates and in the future even faster updates poses a challenge which is tackled in the ERP. The faster updated models together with sensor input will ultimately be able to give quasi instantaneous personal advise on PM exposure risks.

Results of the ExpoSense exploratory project are:

Sensor development: A first proof of concept of particle sensing in a hollow waveguide leading to not only classification of PM but ultimately to chemical identification of PM.



Modelling: Updating dispersion models from daily to hourly values. Using these models exposure along roads could be predicted in a first field study (TNO YouTube film)

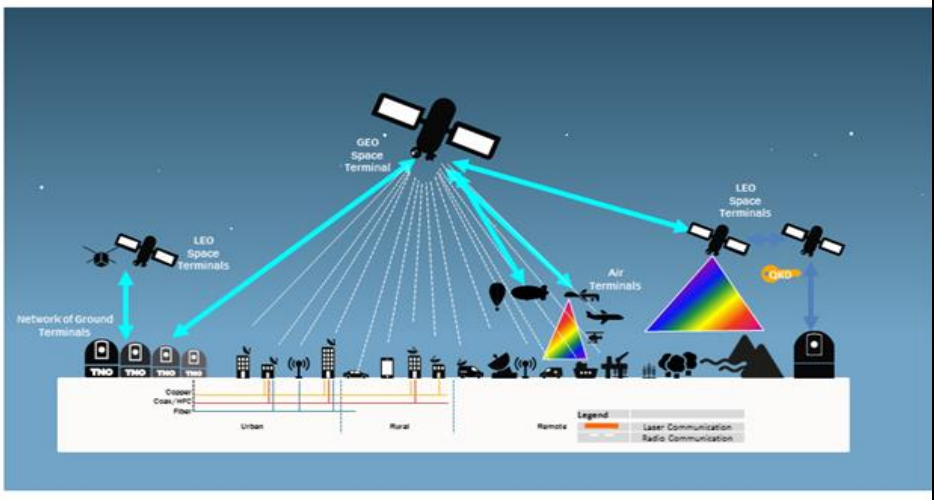
Eco-system: The eco-system including NWA start-impulse “Meten & Detecteren”, TI-COAST, and cooperation with the Exposome hub of Utrecht University has grown. Furthermore there are firm links to the roadmaps of Prevention, Work & Health (HL) and Environment and Sustainability (CEE). TNO business development is attracting first customers for the propositions developed in the ERP.

15 SEED ERP Optical Satellite Communication

General data	
Title	Optical Satellite Communication
‘Topsectors’/Societal Themes	HTSM Space Instruments, ICT
Contact persons TNO	Niek Doelman / Cristina Duque / Kees Buijsrogge

Our Digital Society will require an omnipresent, ultra-high broadband and secure communication infrastructure, which fully supports the information-oriented character based Cloud Computing, the Internet of Things, the Internet of Everything and High-speed Connectivity. Satellites play a key role in the overall communication infrastructure.
Satellite Communication faces the disruptive transition from radio-frequency waves to optical waves. Optical communication offers various strong advantages together with a number of technological challenges. The main challenges are: distortion due to atmospheric conditions and clouds, extreme high precision laser pointing, development of photonic devices (high power and space qualified), low mass and low volume satellite optics and extreme secure encryption.
This project addresses the key fundamental and applied research questions for optical satellite communication, with an emphasis on Terabit per second optical links, secure links by quantum encryption, multi-point communication and deep-space communications links. Various university and industrial partners are involved. The multi-year plan is to realize laboratory demonstrators of critical technologies with research partners, followed by further development towards products with industry partners. In the upcoming years the research eco-system will be further matured with the underlying aim to create a strong technology and market position for Dutch industry.
In 2018 this ERP produced the following results:

1) a design and proof of principle breadboard of a bulk multiplexer. A bulk multiplexer is an essential component of the future high throughput ground stations. The bulk multiplexer is able to combine several optical laser with modulated data while preserving the fidelity of the data to be transmitted.
2) Quick scan study of a low elevation wave front sensor used in atmospheric precorrection. Low elevation angles are important to establish a longer link between a ground station and a moving Low Earth Orbit (LEO) satellite. This technology is specially sough for Quantum Key Distribution (QKD) satellite links where the acquisition time of the keys lowers the error rate and enables the acquisition of longer (safer) keys.
3) Concept design of a multibeam terminal for a Geostationary Satellite capable of multiple user terminals simultaneous communication.


GEO
Space
Terminal
LEO
Space
Terminals
LEO
Space
Terminals
Air
Terminals
QKD
Network of Ground
Terminals
TNO
TNO
TNO
TNO
Copper
Coax / HFC
Fiber
Urban
Rural
Remote
Legend
Laser Communication
Radio Communication

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