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**TNO-report**

**TNO 2020 R10324**

# ERP Report 2019

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| Projectname | ERP Report 2019 Summary |

# Contents

# 1 Introduction

In this report we present the 2019 progress of TNO's Early Research Program (ERP) portfolio. In total 16 Full (four-year) ERPs carried out (see Table 1), focused on societal and economical grand challenges requiring a concerted effort of applied research, fundamental research and future private development. We thus continued our use-case-inspired research approach with equal emphasis on generating *cutting edge knowledge and technology*, together with research partners from academia, and on *building research ecosystems* with stakeholders and sponsors from industry and public organizations. Table 1 below lists these ERP's and provides for each of these a 2019 highlight.

*Table 1: Full ERP's 2019*

| **Full (four-year) ERP's** | | |
|---|---|---|
| Chapter | ERP-title | Highlight |
| 2 | Quantum Computing | Prepared the Quantum Inspire platform (www.quantuminspire.com) for a full launch at Hannover Messe 2020, including a 2-qubit spin chip (first-to-the world online availability) and a 5-qubit transmon device, showing Inspire's unique proposition as a public online accessible multi-hardware platform. |
| 3 | Energy Storage & Conversion | Demonstrated an integrated $CO_2$ capture/conversion methodology, explored the efficiency of this concept for very dilute $CO_2$ sources (i.e. air capture), and performed a detailed techno-economic evaluation of the developed process concept. |
| 4 | 3D Nano Manufacturing | In the frame of measuring smallest 3D details in next generations of chips: nearly completed two demonstrators for top-actuated subsurface measurements, with the probe being used for generating the signal as well as reading it. |
| 5 | Structural Integrity | Demonstrated the capability to detect dynamic strain signals in the range of µm/m at the spatial resolution of 1 to 10 m along the 93-m long sensing fibre. |
| 6 | Personalized Health | Implemented and validated TNO's platform for personalized diagnosis of inflammation.<br>Developed an interactive decision support tool for the systematic design of online interventions promoting behavior change. |
| 7 | Organ function on Chip | Optimized the throughput and handling conditions for a novel 3D printed microfluidic chip for easy application of human intestinal tissue in a micro-physiological system (needed to maintain tissue functionality). |
| 8 | Submicron Composites | Realized nanocomposite/nanoporous thermochromic $VO_2$ coatings on glass, which exceed the properties of best-in-class single-layer thermochromic coatings by far. |
| 9 | i-Botics | Developed a state-of-the-art tele-operated robotic hand for dexterous manipulation and intuitive control. |
| 10 | ExpoSense | Implemented a portable in-line chemical identification of particulate matter (3 patents). Developed a platform to first |

| | | |
|---|---|---|
| | | time combine global and local sensor data for personalized exposure modelling. |
| 11 | Frontiers-SatCom | Developed critical technology for multi-beam GEO satellite terminals capable of communicating with multiple ground stations and aircraft simultaneously. |
| 12 | Wise Policy Making | Described a conceptual design of the Expected Impact on Wellbeing Analysis (EIWA) tool. |
| 13 | STAR-PV | Developed a unique reproducible process (‘coring’) to drill circular samples from degraded areas of large substrates without damaging the PV device itself, thus enabling to study basic mechanisms on nanometer scale. |
| 14 | Large-Area Ultrasound | Demonstrated the first flexible printed ultrasound transducer and an 128-channel array demonstrator containing >12000 elements |
| 15 | Smart Batteries | Developed a first cell-level temperature sensing prototype to evaluate temperature sensors performance and integration and started development of a module-level prototype with battery pack manufacturer SPIKE. |
| 16 | Hybrid AI | Demonstrated a Hybrid AI method able to reduce discrimination in intelligent decision support systems while allowing for model transparency. |
| 17 | Decarbonisation | Aligned short, medium and long term possibilities, focus and goals between the Brightsite partners and additional representatives of Chemelot companies, resulting in initial roadmaps for each of the programs. |

In addition to the Full ERP programs we executed 5 Seed (single-year) ERP projects (see Table 2 below). Our policy is to yearly execute a similar set of such Seed ERP’s, of which a selection based on quality and outlook is promoted to Full ERP’s for the years thereafter. In 2019 the Seed ERP’s “Body-Brain Interaction” and “Social XR” have been promoted to Full ERPs from 2020 on based on such a qualitative selection process.

*Table 2. Seed ERP’s 2019*

| **Seed (single-year) ERP’s** | | |
|---|---|---|
| Chapter | ERP-title | Highlight |
| 18 | Body-Brain Interaction → Full ERP | Demonstrated for the first time that propionate exerts pronounced obesity-lowering effects and attenuates the development of the non-alcoholic fatty liver disease, affecting between 20% and 30% of the population in most countries worldwide (award for outstanding research at the EASL). |
| 19 | Social XR → Full ERP | Developed a multi-view, multi-sensor capture end-to-end demo system, running on top of a cloud-native social VR platform (Best Demo Award at the prestigious ACM Multimedia Systems Conference) |
| 20 | Bio-Nanotechnology | Conducted a successful proof-of-concept test which demonstrates that single-molecule detection of post-translational modifications of peptides is feasible. |

| | | |
|---|---|---|
| 21 | Pre-processing Plastics Waste | A technology development program for plasma assisted thermochemical recycling is defined to investigate the possibilities of this technology and find solutions for possible show stoppers. |
| 22 | Innovation Outlook | A modular data-driven framework has been designed that connects different foresight steps with methodologies, tools and techniques (recognized as 40th Future Research Methodology at AISF). |

We shared our plans and results in 2019 with many potential partners and stakeholders in the form of patents and other publications, conference presentations, posters and ERP dissemination events.

In the next chapters the progress in these ERPs is described in a concise format agreed on with the ministry of Economic Affairs and Climate, including a description of the setting of the research in national and international context, highlights of results obtained, cooperation's in the ecosystems pursued, use cases and contextual dynamics. The ERP plans for 2020 and beyond are described in 'TNO Early Research Program Annual plan 2020' (reference TNO 2019 R11669, dated October 31st, 2019).

# 2 ERP QuTech

| **Algemene gegevens** | |
|---|---|
| Title | QuTech 2019 |
| ERP/**Topsector**/Maatschappelijk Thema | High-Tech Systems and Materials |
| Contactpersoon TNO | Kees Eijkel, Rogier Verberk |
| Contactpersoon overheid | |

**Progress 2019**

**1. Summary**

QuTech has the ambition to develop the first working prototype quantum computer, as well as a demonstrator of 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 focusing on (different types of) a quantum computer, 1 focusing on quantum internet and 1 focusing on increasing the technology readiness level (TRL) of the (quantum) technology needed to realize 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

This roadmap's mission is to demonstrate topological protection of quantum information in a topological qubit based on Majorana bound states. So called zero state- or Majorana qubits have the potential of very long coherence times. The research in this Roadmap is focused first on improvements in materials, device technology, and measurement techniques.

Roadmap B: Fault- tolerant quantum computing

The mission of the FTQC roadmap is to achieve the grand goal of a scalable, fault-tolerant quantum computer, i.e. a system that uses quantum superposition and entanglement to reliably solve otherwise insurmountable problems by correcting the unavoidable errors from decoherence along the way. The roadmap's current qubit workhorses are silicon spin qubits and superconducting transmon qubits.

Roadmap C: Quantum communication and networked computing

The mission of the QINC roadmap is to build and apply fundamentally new network technology by enabling quantum communication between any two points on earth. Over short distances, such networks provide a scalable path to building large-scale quantum computing systems by networking small quantum processors into one big quantum computing cluster. Over long distances, a Quantum Internet will – in synergy with the 'classical' internet that we have today - connect quantum processors at a distance in order to achieve unparalleled capabilities that are impossible using classical communication.

Roadmap D: Shared Development

This roadmap's mission is to increase Technology Readiness Level (TRL) of technology needed for quantum computers and internet to the level that it can be adopted by business partners. To demonstrate that this TRL is achieved, quantum computer and internet proto-types of key components and demonstrators are built.

*Results 2019*

In 2019 the Quantum Inspire platform (www.quantuminspire.com) was prepared for a full launch at Hannover Messe 2020, including a 2-qubit spin chip (first-to-the world online availability) and a 5-qubit transmon device, showing Inspire's unique proposition as a public online accessible multi-hardware platform.

QBlox was started as a company commercializing room-temperature control electronics for qubits, with a license from QuTech (TNO+TUD). QBlox realized its first sales in 2019.

The first 2 city Quantum Link was prepared for launch in the first half of 2020. The underlying cooperation with KPN was shaped and signed. Within the Quantum Internet Alliance project, architecture is being built for Quantum Internet. QuTech plays a role in two EU-commissioned architecture studies with Thales and Airbus.
The NetSquid 2.0 quantum internet simulator was brought to a beta level, and prepared for open source access early 2020.

# 3 ERP Energy Storage and Conversion

| **Algemene gegevens** | |
|---|---|
| Titel | Energy Storage and Conversion |
| ERP/Topsector/Maatschappelijk Thema | ERP Energy Storage and Conversion (ESC) |
| Contactpersoon TNO | Pascal Buskens, Nicole Meulendijks |
| Contactpersoon overheid (eventueel) | - |
| | |

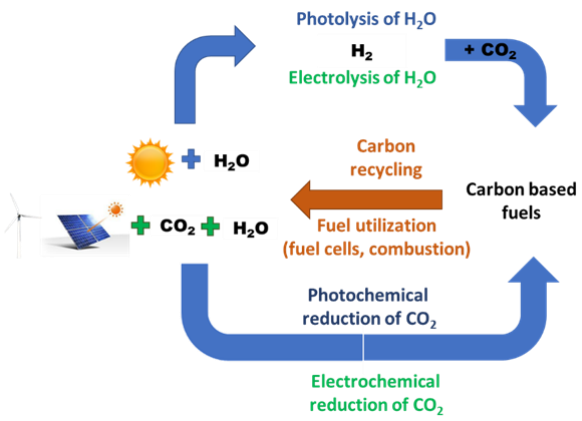
**Progress 2019**

## 1. Summary

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 methane ($CH_4$) 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. The ultimate goal is to provide technologies and concepts that can be scaled up to a technically efficient and economically feasible production process.

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 2019, we have successfully demonstrated an integrated $CO_2$ capture/conversion methodology, explored the efficiency of this concept for very dilute $CO_2$ sources (i.e. air capture), and performed a detailed techno-economic evaluation of the developed process concept. Furthermore, we have successfully synthesized and characterized materials (photocatalytic nanoparticles, photoelectrodes etc.) required for lab scale validation of selected systems for hydrogen production. We performed comparative quantitative studies on photo- and photoelectrochemical water splitting at lab scale, providing input for first technoeconomic feasibility studies. Technoeconomic feasibility studies of selected systems at lab scale were performed. We designed, developed, characterized and validated plasmonic metal nanocatalysts for the photohydrogenation of $CO_2$ to syngas (CO). A reactor concept tailored for $CO_2$ conversion with plasmonic catalysts and sunlight as energy source was established yielding a reaction cell for testing developed plasmon catalysts for the conversion of $CO_2$ to $CH_4$ and CO.

# 4 ERP 3D Nano-manufacturing Instruments

| **Algemene gegevens** | |
|---|---|
| Titel | 3D nano-manufacturing instruments |
| ERP/Topsector/Maatschappelijk Thema | ERP |
| Contactpersoon TNO | Peter Lucas (PM), Stefan Bäumer (LS), Rob Willekers (PMC owner) |
| Contactpersoon overheid (eventueel) | |

**Progress 2019**

**1. Summary**

There are already more connected devices than people on the planet and the demand for these devices is steadily increasing, driven by, for example, the internet of things (IOT), connected cars, augmented reality and cognitive computing. All of these products and applications rely heavily on semiconductor devices.

To accommodate the demands for ever smaller, faster and more efficient devices, the semiconductor industry is shifting away from planar device configurations towards 3D or stacked structures as well as new materials and -properties, still at ever shrinking pitches, see Figure 1. The semiconductor industry is therefore facing major challenges on manufacturing, metrology and testing.

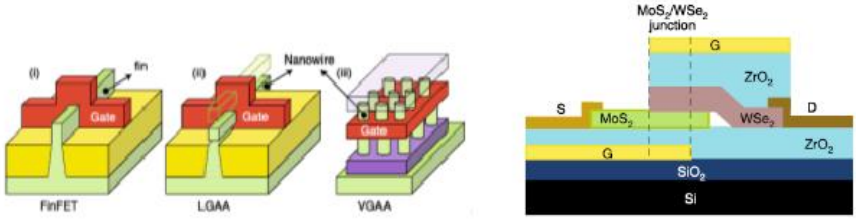



Figure 1 Developments in semiconductor manufacturing. Left, from two-dimensional configurations to three-dimensional. Right, sketch of a structure including new materials. Source: N.G. Orgji et.al. “Metrology for the next generation semiconductor devices”, Nature Electronics 1, 2018.

To enable the production of these new devices with sufficient yield, the development of (non-destructive) techniques are needed that are able to image, measure and characterize nanoscale production features and materials (properties).

Highlights of the 2019 research towards that goal include the following:

1. Subsurface measurements. We have nearly completed two demonstrators for top-actuated subsurface measurements. Here, top-actuated means the probe (cantilever and tip) is used for generating the signal as well as reading it. The goal is to experimentally validate these demonstrators in 2020.
2. Because of the smaller, more complex features and novel materials, the ‘conventional’ scanning probe microscopy (SPM) methods alone are no longer sufficient. We therefore studied AFM-IR (Atomic Force Microscopy Infra-Red), targeted at bringing spectroscopic technologies to nm’s spatial resolution. Following this feasibility study, in 2020 we start developing an improved AFM-IR tool using existing building blocks to be able to meet the accuracy demands for semicon applications.
3. When changing a cantilever/ tip for any SPM-based method, typically the operating parameters need to be adjusted because of changes in the cantilever/ tip mechanical properties, a time

consuming task which makes it difficult to use in a high volume manufacturing environment. We therefore performed research into how this operator dependency can be removed by developing an automated tuning strategy. We have shown that optimal topography imaging can be performed using an AFM independent of operator skills.

These technologies are being developed for important players in the semiconductor industry; for Dutch parties such as ASML, Nearfield instruments and other major industrial players such as Samsung, Intel, and Zeiss. This ERP is working closely together with academic partners such as the Delft University of Technology and the Technical University of Eindhoven. With the latter we recently signed a joined development agreement. For 2019, we have realized 31 different publications (posters, articles and conference proceedings) as well as 7 patent applications.

# 5 ERP Structural Integrity

| **Algemene gegevens** | |
|---|---|
| Titel | ERP Structural Integrity |
| ERP/Topsector/Maatschappelijk Thema | ERP |
| Contactpersoon TNO | Arjen Adriaanse, Henk Miedema |
| | |

**Progress 2019**

**1. Summary**

This early research program develops Digital Twin (DT) technology for Structural Integrity supporting design, management and maintenance of macro-structures. With the present state-of-the art, given the large number of aging structures to assess and structures to (re)design, costs are sharply increasing, and proper levels of safety are under threat of becoming unaffordable. We developed building blocks for DTs that will facilitate and optimize management and maintenance of *existing structures* and DTs that will improve *design of structures*. Main results are:

**DT existing structure**: the core components of this type of DT are material and structural models, sensor systems that give feedback from the structure to the models and learning algorithms, and machine learning algorithms that optimise the accuracy of the representation of the structure by the models based on sensor feedback. We made the following progress in building these components.

- A modelling approach for crack initiation has been compared with experimental data. The predicted fatigue crack initiation life is in good agreement with the data.
- Data from a field experiment on a concrete bridge have been analysed and together with laboratory experiments they show that our acoustic sensing method is sensitive to small variations in Young's modulus (for feedback on material elasticity in the structure).
- Our distributed fibre optic acoustic sensing (for feedback on cracks in the structure) was optimized with respect to signal quality, and the spatial resolution improved from 10 to 3 m. Tests of our fibre optic distributed strain sensing (for feedback on strain in the structure) demonstrated the capability to detect dynamic strain signals in the range of µm/m at the spatial resolution of 1 to 10 m along the 93-m long sensing fibre.
- Our algorithm for deriving weights (for feedback on weights of trucks passing over a structure) from dynamic strain data has been applied to data from calibration tests with a truck with known axle weights and dimensions. The fit between identified wheel configurations and loads, and the true values was reasonable. Deviations are understood and will be addressed.
- Several machine learning techniques that could be incorporated in the DT have been explored using experimental data on rivet fatigue failure. We identified the machine learning techniques that showed good predictions of test results, also in comparison to traditional FEM modelling.

**DT design of structure**: the design of a composite military vehicle, first focusing on the underbelly, is supported by modelling the expected behavior under loads, especially blast loads, and blast tests of specimen. New methods are developed for AI-supported selection of design alternatives.

- An investigation was made of AI supported design methods applicable at the lower levels (fine structure) of our multi-scale approach, so that the "classical" engineering design approach can be supplemented with an "AI-assisted" design approach, aiming at an improved efficiency and faster design process.

- To decrease computation time and enhance the model usage in the design process, a reduced strip model for composite components has been developed. Analyses times for this model are in the order of minutes instead of days for panel tests. It is sufficiently accurate so that it can be used for fast scanning the complete design space to select areas in that space for detailed analysis.
- For a novel fiber layer lay-up concept blast tests demonstrated superior blast-resistant behavior.
- The complete design space for a composite blast protector is very large. The number of layers, layer orientations, fiber and matrix material, geometry all influence the final efficiency of the protector. The performance function required for application of AI optimization, has been determined.

**Enabling technology**: computation time is a limiting factor for the models both in DT existing structure and DT design of structure. An online platform for objective comparison of advanced reliability algorithms was made and major international research groups participated in benchmarking their approaches with cases at the platform. Results will be analysed so that our reliability modelling can be optimized and outcomes will be disseminated internationally.

# 6 ERP Personalized Health

| **Algemene gegevens** | |
|---|---|
| Titel | Personalized Health (ERP 007) |
| ERP/Topsector/Maatschappelijk Thema | Early Research Programmes |
| Contactpersoon TNO | Dr. Marjan van Erk |
| Contactpersoon overheid (eventueel) | |

**Progress 2019**

**1. Summary**

There is a huge **increase** in **chronic lifestyle related diseases** while the current healthcare system is not equipped to **take care** of this problem. Lifestyle changes – comprising nutrition, exercise, stress and sleep – have a profound effect on disease progression. On the physiological level, these diseases are driven by metabolic and inflammatory disbalances. Fortunately, lifestyle changes can, to a certain extent, restore this disbalance and even lead to **remission of disease**. However, changing lifestyle is difficult; **personalization**, i.e. tailoring to individual needs and preferences, is an important factor for achieving **sustainable** healthy **lifestyle change**.

ERP Personalized Health (PH) focuses on (i) biological knowledge innovation and (ii) research methodology innovations for personalized health optimization. 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 generic driving mechanisms for lifestyle-related disease: low grade chronic inflammation, and specifically, on the healthy dynamics of this process and how that can be influenced with lifestyle (inflammatory dynamics). In 2019, we have:

1) identified 20 candidate biomarkers for diagnosing personal inflammatory dynamics and tissue-specific inflammation through an *in silico* systems biology approach
2) showed in mice that lifestyle interventions can reverse chronic inflammation in liver and adipose tissue as well as other obesity related pathologies, although effects were tissue and intervention specific;
3) showed the ability to detect fungi in atherosclerotic plaques both in mice as well as in humans and identified first nutraceuticals and ingredients with anti-fungal activity that may resolve intestinal inflammatory disease;
4) implemented and validated TNO's inflammation analysis platform and developed methodology to provide personalized diagnosis of adipose, vascular and systemic inflammation.

The work on inflammatory dynamics was published in a peer-reviewed review paper (van den Brink W et al. Front Nutr. 2019;6:129), It evaluates how metabolic challenge tests have been successfully applied to evaluate nutritional intervention effects on low grade inflammation as well as potential nutritional opportunities for optimizing inflammatory resilience.

The **research methodology innovation** work focuses on focuses on bringing together all knowledge and data relevant for personalized health optimization and connect this to the needs of citizens. In 2019, we have:

1) started the ontology incorporation for the knowledge on nutrition and behavior in the 'IRIS app', a research tool that provides personalised nutrition feedback and advice. This work was performed in collaboration with ERP Applied AI.
2) developed a tool that captures the behavioral change and maintenance models that are developed to predict compliance and adherence to a new lifestyle in a structured way by

using ontologies. This tool can be applied by researchers to choose the right behavioral change technique for the right context.

3) developed a first draft of an ethical legal framework ‘Gezond gebruik van gezondheidsdata’ that will guide ethical sharing of personal health data used for research purposes.

In 2020, this ERP will work towards integration of the different technologies developed in **biology knowledge innovation** and **research methodology innovation** and work towards a human Proof of Concept (hPoC) study in 2021, to showcase that personalization is effective in optimizing health.

The innovations from this ERP PH program will land in future PPS projects that will implement personalized health innovations in real-life.

# 7 ERP Organ-on-Chip

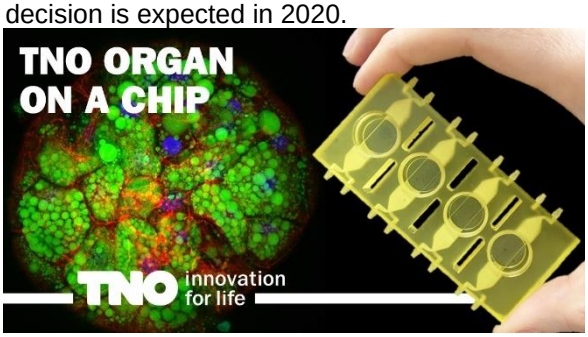
| General data | |
|---|---|
| Title | Organ-on-Chip |
| 'Topsectors' | LSH, A&F, HTSM |
| Contact person TNO | Ivana Bobeldijk-Pastorova, Evita van de Steeg |
| Contact person government | |
| | |

**Annual report 2019**

**Summary**

For both biological use cases, Liver and Gut, the aimed technology development as well as further extension of the network were achieved in 2019.

In addition, 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, TNO participated in several NWA consortia in preparation of grant proposals. Three of the proposals passed the first round and the final decision is expected in 2020.




New collaborations with academia were setup, with University of Jena, LACDR, UL. 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) improved design of a microfluidic chip suitable for gut, liver and other organ on a chip applications including integrated readouts for TEER and oxygen sensing, ii) several protocols for exposing the tissue in the gut chip to microbiota from different disease groups (host-microbiome interaction), iii) a stable diseased liver on a chip cell model, with first for validation steps with model pharmaceuticals and iv) improved protocols for 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. Three scientific manuscripts were published, two are in preparation.

The program succeeded in achieving the goals set for 2019: 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, after the first application of the gut on-a-chip mode in a B2B project we also had a first B2B application of our 2D liver fibrosis model that has been developed in 2018.

For 2020, we expect further validation steps of the technology, coupling of organ models for new applications, submission of the manuscripts and most importantly, more applications in the market.

# 8 ERP Submicron Composites

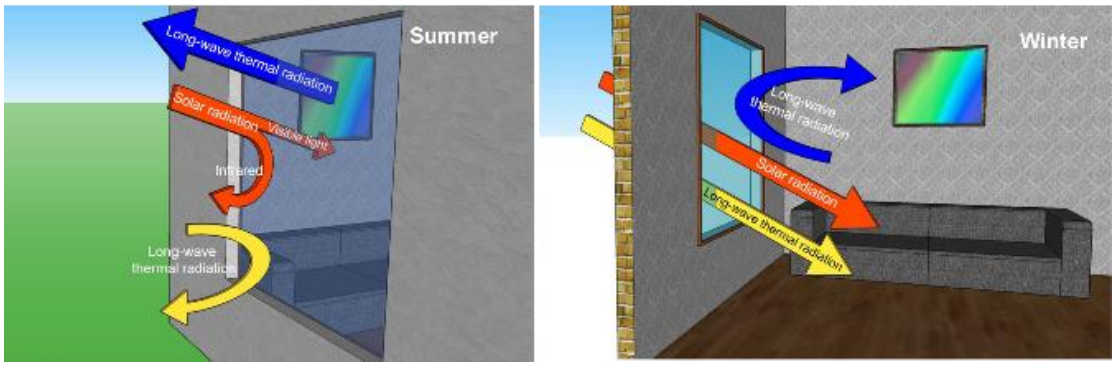
| **Algemene gegevens** | |
|---|---|
| Title ERP | Submicron Composites |
| Contact person(s) TNO | Pascal Buskens/Peter Wolfs |
| Contact person(s) Topsector / Government | n.a. |
| | |

**Progress 2019**

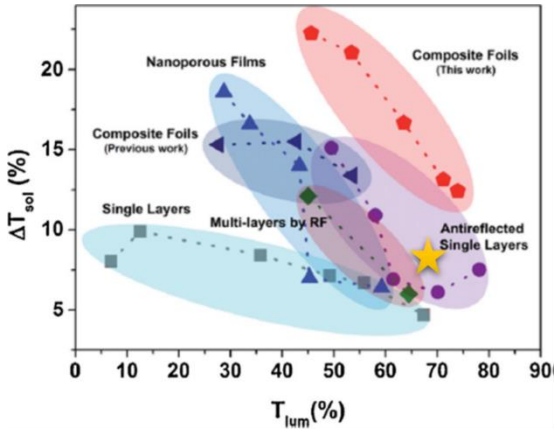
**1. Summary**

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 films, 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 2019, we have established a lab scale procedure for the production of thermochromic $VO_2$ powders with a monoclinic crystal structure. In addition, we have developed a procedure to include dopants in these powders for lowering the temperature of the metal-to-insulator switch from the intrinsic 68°C (undoped $VO_2$) to 30°C and lower (doped $VO_2$). Furthermore, we have reduced the particle size of these powders using bead milling to an average size of less than 100 nm, which is a key requirement for use as thermochromic pigments in polymer films. Additionally, we have demonstrated that we can prepare polymer nanocomposite film using model nanoparticles in polyolefin, using amongst others extrusion as processing technology. Furthermore, we prepared nanocomposite/nanoporous thermochromic $VO_2$ coatings on glass, which exceed the properties of best-in-class single-layer thermochromic coatings by far. Our single layer coatings (star in figure left) has a better balance between luminous transmission ($T_{lum}$) and switch in solar transmission ($\Delta T_{sol}$) than all single layer coating systems reported to date.




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 2019, we have investigated the first feasibility of 3D printing carbon fibre reinforced polymers to enable mechanical reinforcement in simple geometries.

We have optimized the processing conditions to improve the mechanical performance, and have produced several test products based on continuous carbon fiber FDM. In parallel, a specific application example of bicycle parts is being explored in the “100% Limburg Bike” project, together with regional industrial partners. Also, we have explored the feasibility of using the integrated carbon fibers as strain or temperature sensing elements. A patent application regarding this is in preparation. Improving the sensitivity and specificity of the sensing will be explored in more detail in 2020.

Furthermore, we have worked on validation of the process-structure-property relations and models to predict product performance and product lifetime, as developed in the period 2017-2018, in collaboration with Eindhoven University of Technology (TU/e). A computer app has been developed for the structure-property prediction of printed parts produced using DLP. This app makes usage of the most relevant results of the modelling of photocurable materials carried out within this ERP in the past year. The initial model developed in 2018 allowed for the warpage prediction of 3D printed parts using DLP. Additionally a new material model was added in order to capture better the effect of the boundary conditions during but also immediately after the printing process.

# 9 ERP i-Botics

| **Algemene gegevens** | |
|---|---|
| Titel | ERP Interactive Robotics |
| ERP/Topsector/Maatschappelijk Thema | ERP 013 i-Botics |
| Contactpersoon TNO | Nanja Smets |
| Contactpersoon overheid (eventueel) | |
| | |

**Progress 2019**

**1. Summary**

The ERP i-Botics aims to optimize human-robot interaction to perform different tasks in challenging, unpredictable and dynamic situations. We focus on direct tele-operation by humans (telepresence inspection, maintenance) and wearable robotics such as exoskeletons/ exosuits to enhance human capabilities.

The main ERP results in 2019 can be summarized as follows:

- **Bimanual manipulation**, we set up a state of the art tele-operated robotic hand for dexterous manipulation and intuitive control. In 2020 this set up will be expanded to a fully bimanual configuration.
- **Visually enhanced control** delivered a demonstrator showing the effect of low-bandwidths and multiple information streams to VR. Furthermore, we experimented with collecting sensor information using several distributed sources (so called 'multi-sensor multi-agent SLAM' technology). A concept report of this phase has been completed describing how we combined three different depth-sensors placed in different platforms with a 360 degree camera image and adjusted the resulting data geometrically according to the previously developed models. A literature study on the measurement of physical cues in the environment and subsequent incorporation of those in the VR environment has been prepared. We have collected the literature and will write the paper in 2020.
- **Exoskeleton / wearable robotics** mainly worked along two related lines:
    - *Arm support exoskeletons: we* explored the state of the art of exoskeletons that are being applied in realistic working situations and reported these findings in a literature review that is currently in press. We published the results of an experiment to study the amount of support provided by a passive arm support over a range of different arm postures exoskeleton (Skelex).
    - *Back support exoskeletons:* we proposed a regression-based model that can predict low-back load during lifting using a limited number of input variables. A full paper has been submitted to the journal of biomechanics, and is currently under review. Furthermore a podium presentation on this topic was given at the 3rd International Workshop of Spine Loading and Deformation.

  We also ran a number of experiments to evaluate the performance of the new version of Robomate: Collaborating with the IIT group, we evaluated low back loads during lifting while varying lifting technique, velocity and lifted weight. We are currently processing the data and will continue to work on this dataset in 2020. We have also extended the simulation model on multiple points, most importantly a more accurate model of the human body and the possibility to perform inverse dynamic analysis. This allows for the modeling of actuators and the calculation of joint reaction forces for potential exoskeleton designs.
- **i-Shield:** The results of the experiment of 2018 were published and presented at WorldHaptics 2019 in Japan. A position paper has been submitted about embodiment and the potential for tele-operation. A large embodiment experiment is being prepared for 2020, the (experimental) design of which is complex and time consuming.

- **Contribution to Avatar Xprize** with a consortium of partners (UTwente, Sensiks, Halodi, ETH Zurich and Haption) and organized a **Hackathon** to identify technology challenges and integration on new fun tasks for human-robot interaction.

# 10 ERP ExpoSense

| General data | |
|---|---|
| Title | Exposense |
| ERP | ERP |
| Contactpersoon TNO | Wilma Middel/Stefan Baumer |
| Contactpersoon overheid (eventueel) | |
| | |

**Progress 2019**

**1. Abstract**

The following main results have been achieved in 2019:

**Sensor development**. The micro-cyclone technology for concentrating particles and other chemical substances to a better measurable level has been refined and applied. The second major technology improvement which took place was the implementation of a portable in-line chemical identification of particulate matter (PM) and potentially other chemical substance in air. Being able to apply IR spectroscopy and making it portable is an achievement which found its recognition in three patent applications.

**Exposure modelling**. The application and integration of context sensors to monitor the pollution sources at a local level during a prescribed task increased the insight in how non-imaging sensor data have to be interpreted and what the relation between source, pollution and exposure is. Another technology milestone has been the integration of Lotos Euros and Urban Strategy Air module. For the first time global and local data can be combined to estimate a proper background on the local signals. With this information a better distinction between background and local sources can be made leading eventually to a better advice to individuals. On background one cannot react, whereas local sources can be avoided or actions for removal can be taken. This platform will be elaborated further to be able to accept measurement data of mobile sensors as well. Next to applications in this ERP and the field of Exposome, the newly developed system will have impact in the environmental monitoring activities of TNO at large: small satellite observations will benefit in a sense that new business models in marketing the data product could be investigated (rather than hardware only).

**Relation between PM exposure and diseases** were found through intensive automated literature studies. This milestone could provide the link between exposure levels and predicting possible health effect of the exposure. Without knowing the internal markers the advice given by personalized measured exposure data will be mostly on reaching governmental limit values, while with known effect on health the advice can be upgraded to personalized health advice.

# 11 Optical Satellite Communication

| General data | |
|---|---|
| Title | Optical Satellite Communication |
| 'Topsectors'/Societal Themes | HTSM Space Instruments, ICT |
| Contact persons TNO | Niek Doelman / Cristina Duque / Christa Hooijer/ Kees Buijsrogge |
| Contact person government | Mariëlle Beers Homans (EZK) |
| | |

**Program report 2019**

**1. Summary**

Satellite Communication by Optical waves offers various strong features to serve the needs of our Digital Society which requires an omnipresent, very high broadband and secure communication infrastructure. Next to the fiber-based terrestrial network and the wireless radio-frequency (RF) links through free space, there is a clear benefit of having **free-space optical** communication links between ground, air, sea and space. This ERP addresses the key fundamental and applied research questions for a network of free-space optical communication links. The main knowledge areas are: optics, photonics, beam propagation control, communication, network technology and quantum cryptography. 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 2019, system concepts and critical technology has been developed for:

- Ultra high data throughput (order 10 Terabits per second) links between ground and GEO-satellites,
- Multi-beam GEO satellite terminals capable of communicating with multiple ground stations and aircraft simultaneously,
- Free-space channels for bit/s rate quantum key distribution protocols,
- Light-weight, large-aperture telescope mirrors,
- Network protocols to orchestrate traffic over earth-to-satellite links with a minimum failover time,
- Deep-space mission links for data download.

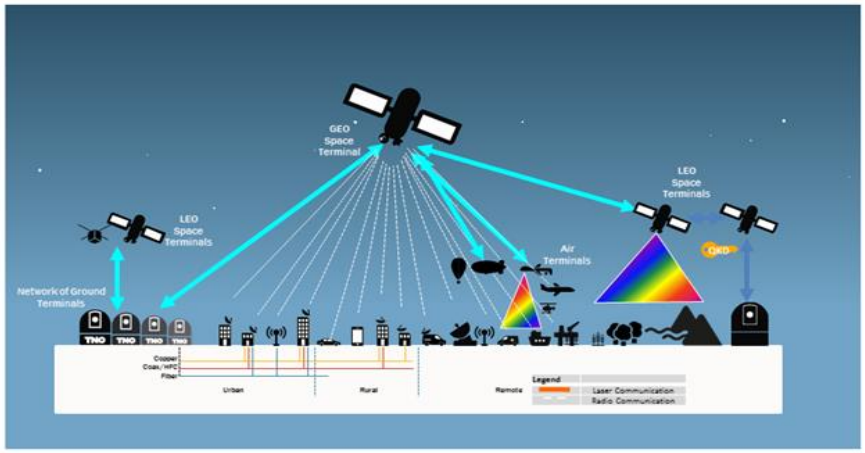



Figure 1 - Illustration of free space optical communication links.

# 12 ERP Wise Policy Making

| **Algemene gegevens** | |
|---|---|
| Titel | Wise Policy Making |
| ERP/Topsector/Maatschappelijk Thema | ERP |
| Contactpersoon TNO | Josephine Sassen |
| Contactpersoon overheid (eventueel) | nvt |

**Summary 2019**

**1. Bird's eye view of ERP Wise Policy Making in 2019**

The aim of this ERP is to develop a "Wise Policy Suite"; a suite of instruments and methods that support policy makers to assess the impact of policy options on wellbeing in advance (ex-ante). Furthermore the suite offers methods and tools that support unbiased and well-informed dialogue, thus providing a basis from which to engage in negotiations and decision making processes that are uncontaminated by vested interests or biased reasoning. With this Wise Policy Suite, policy makers will be able to quantify the impacts of different policy options on wellbeing (subjective, objective), and have fruitful dialogues about different policy options, with citizens and with other stakeholders. This will promote sustainable wellbeing in an integral way, based on scientific insights and legitimized by society.

The transdisciplinary approach in this research has led to the development of the first concept in this suite; the EIWA (Expected Impact on Wellbeing Assessment) tool. The EIWA-tool is a multi-criteria, multi-actor & utility-based analysis supporting the user in aligning wellbeing-parameters with policy-goals and providing a visual representation (a wellbeing landscape) of its expected impact on the sustainable wellbeing for society. Such a tool does not exist at this moment and its development would mean a great innovation in its field. EIWA could provide policymakers with grounded and substantiated information on the effects of policy options on wellbeing, thus creating legroom for discussing wellbeing effects in negotiations and providing accountability for decisions that prioritize wellbeing.

In 2019, the groundwork for developing the EIWA has been laid, and the first prototypes will be developed in 2020-2022. The scientific foundation that underlies EIWA has been brought together in several State-of-the-Art reports in various domains (explicated further in chapter 3 'results'). These state of the art inventories serve as the backbone for the conceptual framework of the EIWA tool. There is also a work-in-progress document that describes the innovative concept of EIWA itself, including functional requirements, conceptual design of the tool, methodology for quantification, and methodology for wellbeing questionnaire protocol.

In 2020-2022 this ERP will work on developing prototypes of an EIWA tool and researching options for Wise dialogue support tools. The main research topics are:

- Expected Impact on Wellbeing Analysis (EIWA): A minimal viable instrument that can bring ethical and long-term well-being considerations effectively in decision processes, in particular by augmented utility quantification supported by adequate data acquisition;
- Wise Tank (WT): Inventory of methods and tools to dynamically structure and support collective decision making processes, in particular by formal argumentation representation, argumentation mining and methods for capturing, analyzing, presenting and disseminating perspectives, rational arguments and expertise;

- Policy Practice: A case study in which above tools are tuned for use in policy processes in the field of Future Sustainable Urban Mobility System, and/or decision making on future Responsible Urban Surveillance Systems and/or on Energy Transition.

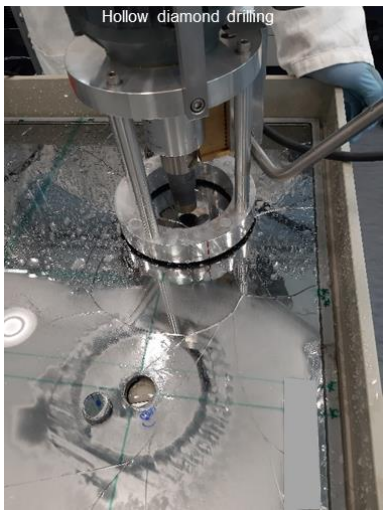
# 13 ERP STAR

| Algemene gegevens | |
|---|---|
| Titel | STAR: Sustainability And Reliability for PV and other (opto-) electric thin-film devices |
| ERP/Topsector/Maatschappelijk Thema | ERP |
| Contactpersoon TNO | Ando Kuypers (project mgr) Mirjam Theelen (lead scientist) Wim Sinke (Roadmap Solar Energy) |
| Contactpersoon overheid | |
| Participating units | ET (Solar Energy) IND (Flexible Freeform Products) CEE (Circular economy) |

**Progress 2019**

**1. Summary**

The mass deployment of durable photovoltaic (PV) electricity generation currently progresses at a pace of yearly installations of hundreds of square kilometers of PV, involving investments of many billions of euros per year. At the same time, two important factors which may impact the return on investments are constantly changing. PV devices are constantly improved in terms of power output efficiency by changing the way they are made (both their composition and manufacturing process). And at the same time, specifically also in the Netherlands, there is an increasing desire to limit the use of scarce land area for PV as much as possible, by integration in the built environment. This means that PV becomes part of surface areas that at the same time also have (often multiple) other functions (e.g. roof surfaces protecting against rain, hail, and wind) or are exposed to additional stress (e.g. waves and salt for PV floating on water). Maintaining a guaranteed life time (up to 30 years or more) under these constant changes of PV products and their exposure to additional stresses, requires more basic understanding of degradation mechanisms occurring in PV.




In 2019, we succeeded to create a very promising and innovative connection between outdoor PV degradation in the field and lab research on basic mechanisms. In collaboration with commercial parties (PV installers, field testing and product assessment) we have access to large sets of field exposed modules with known history. By diamond drilling (“coring”) we can now isolate samples from identified degraded spots on PV modules while keeping them intact. We can make electrical contacts, and study the samples in detail under controlled stress conditions. For crystalline silicon (cSi) PV modules we use this approach to study the effect of alternative types of encapsulation foils on the degradation of electrical contacts observed in presently used EVA-encapsulated modules. These foils prevent the basic mechanism that was identified for EVA, and are now studied by coring and accelerated life time testing. For thin film CIGS we focus on the stability of additives (like Na, K) which are increasingly used to improve the efficiency, and on the stability of the transparent electrical contact layer.

We identified specific effects of ingress from ambient atmosphere. Based on this, we demonstrated feasibility of 20% cost reduction in encapsulation by stabilizing the contact layer itself. We also found evidence that ingress of water increases migration of additives under electrical stresses (potential induced degradation) and that to some extent this degradation is reversible. For thin film Perovskite based cells we demonstrated record stability with a specific additive concentration. We improved our understanding of how to deal with partial shadowing of solar panels, which is specifically relevant for building integrated PV. We developed a system for mechanical reliability testing of stretchable electrical interconnects. Novel meander-type interconnection lines are studied, enabling reliable stretchable interconnects for integrated electronics in medical, PV and other applications. Finally, we drafted a position paper on sustainability of integrated PV.

# 14 ERP Large-area Ultrasound

| **Algemene gegevens** | |
|---|---|
| Titel | Large-area Ultrasound: making medical imaging safe and affordable |
| ERP/Topsector/Maatschappelijk Thema | HTSM Electronics (Hans Naus) |
| Contactpersoon TNO | Ton van Mol (DM), Jan-Laurens van der Steen (PL) |
| Contactpersoon overheid (eventueel) | |
| | |

**Progress 2019**

**1. Summary**

In 2019 we have demonstrated the first flexible printed ultrasound transducer, followed by an 128-channel array demonstrator containing >12000 elements, see also Figure 2. The transducer array was characterized in transmit and receive, 1) using a commercial source and 2) in pulse-echo mode.

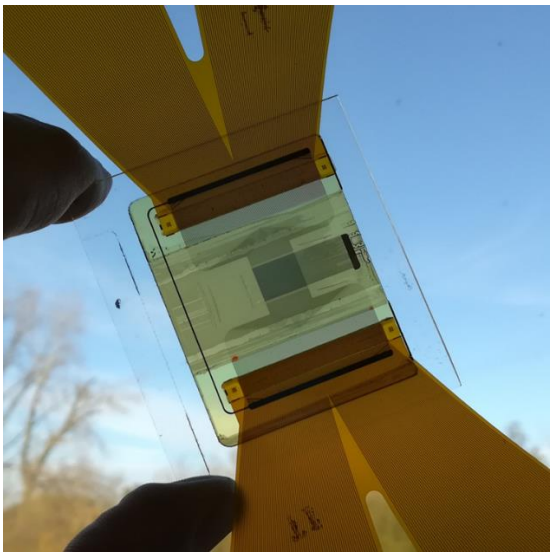


Figure 2 128-channel printed ultrasound prototype

In 2020 we will first focus on understanding and improving the transducer performance. The next step is to demonstrate the scalability of our fabrication process to large area (>10x10cm$^2$). In addition, we will develop know-how on how to efficiently read out large arrays of sensors (>1,000,000 elements), which greatly exceed the size of current state-of-the-art transducer arrays (~1000 elements).

In 2022 we want to be able to provide large-area ultrasound imaging solutions for different medical domains. Applications include hands-free 3D imaging, remote monitoring and multi-modal imaging to complement and eventually replace CT and X-ray as preferred imaging modalities during interventional procedures.

There are no major changes with respect to the original plan. The first key technology milestone is a dynamic imaging demonstrator, scheduled for 2020. This demonstrator shows technological

feasibility which enables us to engage with industrial parties. The size of this prototype (128 channels) is clinically relevant and can address first applications such as bladder monitoring and fetal heart rate monitoring. From the first milestone onwards, technology development will focus on scaling to larger area and readout strategies, in order arrive at a scalable technology platform by 2022.

In addition to technology development, we reached out to several experts in 2019. They confirmed that large area ultrasound can open up new applications in the medical domain that ultrasound technology today cannot address.

# 15 ERP Self-adapting smart batteries

| **Algemene gegevens** | |
|---|---|
| Titel | Self-adapting smart batteries |
| ERP | ERP 022 |
| Contactpersoon TNO | Pavel Kudlacek, Eric Meulenkamp |
| Contactpersoon overheid (eventueel) | Richard Roemers, Marc Hendrikse |
| | |

**Progress 2019**

**1. Summary**

This ERP strives to develop technologies for (i) cost-effective and seamlessly integrated printed temperature (and pressure) sensors for use in lithium ion battery systems and (ii) the corresponding battery management system (BMS) that turns the sensor information into benefits for battery system users and/or manufacturers. We investigate and develop required building blocks and verify their performance in a demonstrator smart battery module. Such smart batteries, which integrate the developed sensing and part of the control technologies on or in a battery cell, will simplify the BMS topology and allow more sophisticated strategies for control and management of future battery systems. The program is jointly executed by TNO Holst Centre and TNO Automotive.

The following objectives were reached in 2019:

(i) System requirements were defined and TNO acquired knowledge about battery system architecture, necessary building blocks, required accuracy of temperature sensors and potential benefits of battery sensing solutions. Also, the ERP team acquired hands-on experience with battery systems and sensors integration while building a first, simplified battery sensing prototype (completed Q2-2019 instead of planned Q4-2019).

(ii) The printed temperature sensor material was improved. The relative spread of sensor-to-sensor accuracy was reduced from 30% to less than 3%, which enables the ERP to do meaningful system integration and evaluation in the coming period.

(iii) BMS algorithms were developed for estimation of battery thermal state, state of charge and state of health, but the algorithms were not yet tested on a prototype. It is planned in the course of 2020 when a more sophisticated module-level prototype will be finalized.

(iv) Demonstration of benefits of our solution was identified as the key for attracting potential customers already in an early phase. Therefore, work on a prototype module, originally planned for 2020/21, was speeded up by teaming up with pack manufacturer SPIKE Technologies BV and a module-level prototype is now expected in Q1/2020.

(v) The ERP team devised a plan for commercialization of the results that focuses on Dutch battery ecosystem, which is centered around heavy-duty applications, single-person transport, and power tools.

(vi) Outreach started in Q2-2019 and market interest in our technology and its relevance were confirmed in discussions with potential customers. Concrete discussions with industrial partners about commercialization of the printed temperature sensors are taking place. Potential collaboration is being discussed with an Asian pack manufacturer.

# 16 ERP Hybrid AI

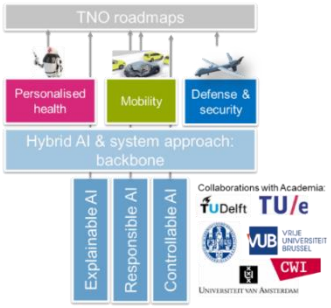
| **Algemene gegevens** | |
|---|---|
| Titel | Hybrid AI |
| ERP/Topsector/Maatschappelijk Thema | ERP |
| Contactpersoon TNO | Albert Huizing, Serena Oggero |
| Contactpersoon overheid (eventueel) | |
| | |

**Progress 2019**

**1. Summary**

Artificial Intelligence (AI) is rapidly becoming a transformative technology with an impact in almost every sector in society. Despite fast developments, AI-enabled systems are still unable to cope with new, unknown situations, unable explain their decisions to humans and unaware of their own (correct or not) functioning. Future AI-based Intelligent Systems need to acquire new capabilities to be able to act in the operational environments of the future and collaborate in a human society. For this reason the ERP Hybrid AI (HAI) has the following research lines with a long-term focus:

- *"Hybrid AI",* a combination of reasoning (based on knowledge) and learning (based on data).
- *"Controllable AI",* enable meaningful human control and self-awareness of intelligent systems;
- "*Explainable AI",* develop AI that can provide explanations to humans;
- *"Responsible AI",* make intelligent systems capable to operate according to the (western) ethical principles of responsibility.




Among other results achieved in 2019, the program realised a functional design for Meaningful Human Control. This design provides a generic approach to combine ethical and task-specific goal functions, self-assessment and self-management capabilities for an AI system that collaborates with humans. This framework is already used in concrete applications, e.g. in a project together with ABN-AMRO.

A second result of the program is a demonstration of personalized contrastive explanations for communication about diabetics to both patients and doctors. A third example of a result is a demonstration of a Hybrid AI method able to reduce discrimination in intelligent decision support systems while allowing for model transparency. In 2020 these technologies will be applied in use cases together with stakeholders such as MinJ&V, and MinSZW.

Another result is a machine learning tool that can balance fairness and prediction accuracy. We developed a pre-processing tool that can transform a dataset with protected attributes into a new representation by balancing group fairness with similarity with the original dataset. The new representation uses the original attributes, where the hot encoded categorical attributes are generalized into multiple categories. This new representation also enables transparency.

# 17 ERP Decarbonisation

| Algemene gegevens | |
|---|---|
| Titel | Decarbonisation |
| ERP/Topsector/Maatschappelijk Thema | ERP Decarbonisation |
| Contactpersoon TNO | Dick Koster, Marinke Wijngaard, Nicole Meulendijks |
| Contactpersoon overheid (eventueel) | - |
| | |

**Progress 2019**

**1. Summary**

The causal link between the exponentially increased $CO_2$ and other greenhouse gas emissions in the last 100 years and the accelerated global warming observed since then has meanwhile convinced most scientists and policy makers. Worldwide, governments and business communities have formulated objectives and measures to limit and, if possible, reduce the emission of greenhouse gases and associated effects on the climate. For the Netherlands the government has formulated the ambition to reduce greenhouse gas emissions at a national level by 49% by 2030 and by 90% by 2050 compared to 1990. In response to this ambition, TNO, Sitech Services BV, Maastricht University and Brightlands Chemelot Campus signed of a Letter-of-Intent in October 2018 to jointly investigate the possibilities for establishment of a sustainable technology oriented center at the Chemelot site in Geleen.

Chemelot Industrial Site is responsible for about 30% of the greenhouse gas emission in Limburg and contributes about 3% to the national emissions. Figure 1 shows the historical, current and necessary development of the reduction of greenhouse gas emission at Chemelot. This shows that a substantial reduction has already been achieved and is considered possible but that this will be insufficient to achieve the climate targets of 2050. Clearly new technological options will have to be explored, developed and applied to achieve these long term goals.

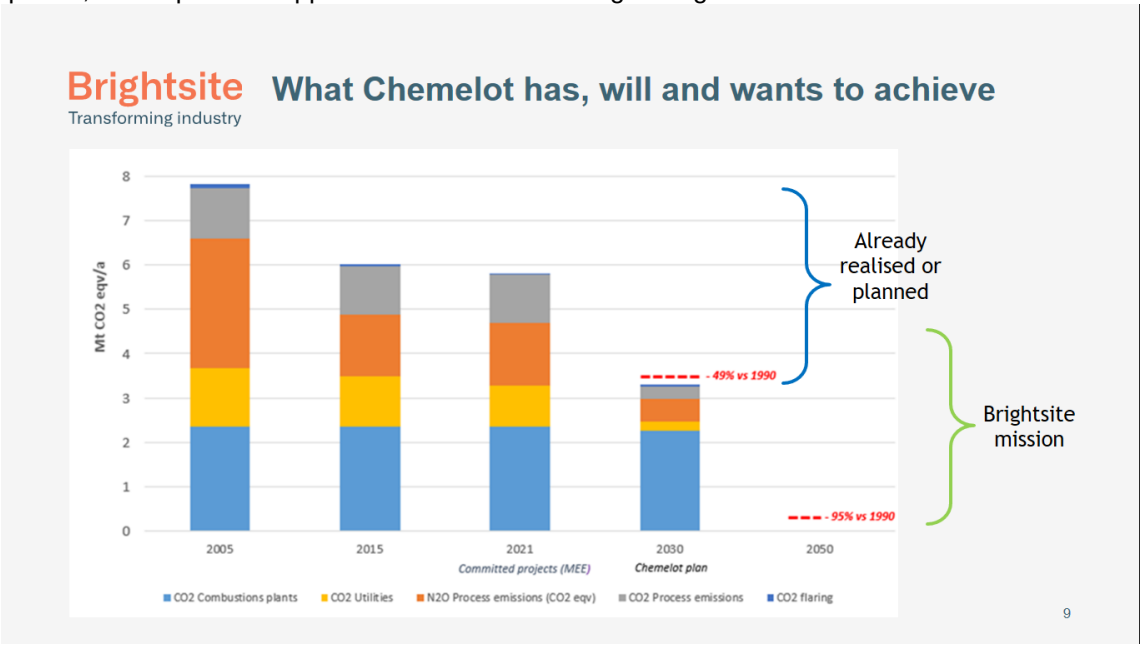



*Figure 1: Origin and options for reducing greenhouse gas emissions at Chemelot*

To investigate the possibilities, scope and framework of the establishment of a dedicated innovation center with the aim to apply existing knowledge and technology and develop and explore new options, each founding father made a representative available. In view of the possible regional impact, an additional grant of 300 k€ was received for this from the province of Limburg for funding of this quarter-maker phase. Based on the positive preliminary findings of the quarter-maker team, a Memorandum Of Understanding (MOU) was signed in January 2019 for the establishment of a "Brightsite" innovation center. For this a board with representatives of the founding fathers was established who signed a comprehensive Collaboration Agreement on behalf of their organizations on 28th June 2019. The Collaboration Agreement contained the head- and sublines of a work program resulting from exchange of information and feasibility studies executed by multi-partner program teams. For the execution of the associated work program Sitech Services, Maastricht University and TNO each committed 2 m€/year to make this possible. The TNO participation in the orientation and subsequent execution phase was made possible on the basis of the ERP-Decarbonisation funding which the TNO-board had made available for this. The focus and interrelation of the six main program lines is depicted in figure 2.

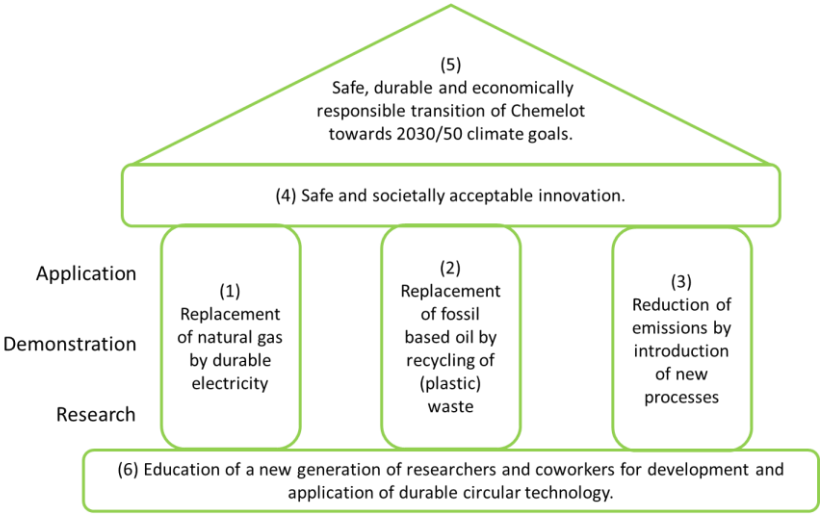



*Figure 2: Focus and interrelation of the six main Brightsite program lines*

For each of the program lines existing results and experience as well as new insights and ideas and obtained results were exchanged in various meetings and workshops (executed mainly in the 2nd half of 2019), with suitable representatives and experts of the partners. Based on this a further alignment has been established with respect to the short, medium and long term possibilities as well as towards the focus and goals recognized and to be pursued by the Brightsite partners and additional representatives of Chemelot companies. The results of this exercise was summarized in initial roadmaps for each of the programs.

In parallel to the technological scoping, the Brightsite organization was built to guide and fund the next steps along the technological roadmaps in 2020 and beyond. A management team was formed and has taken action to ensure project funding from Chemelot Partners and the ministry of economic affairs and climate, in addition to the support from the province of Limburg which provided an upfront contribution of 1 M€ for the execution of the transition phase until 1st July 2020.

# 18 SEED ERP Body-Brain Interactions

| **Algemene gegevens** | |
|---|---|
| Titel | Body-Brain interactions |
| ERP/Topsector | SEED ERP 018 |
| Contactpersoon TNO | Kieboom (PL); Kleemann (Prin Sc) |
| Contactpersoon overheid (eventueel) | |
| | |

**Voortgang 2019**

**1. Summary**

The ERP 'Body-Brain (BB) interactions' was initiated because the **interplay between organs of the body and the brain provide fundamentally new opportunities for optimization of performance and maintenance of health throughout life**. In 2019, two use cases were investigated: 1) BB-interactions between the gut/microflora and the brain in obesity and 2) BB-interactions controlling cognitive performance after exposure to multiple stressors. In parallel, mechanistic frameworks were developed for a) molecular and b) psycho-social BB interactions, both of which are currently drafted for publication. The work contributed to the establishment of a 4-year roadmap and also defined the type of enabling technologies and external research collaborations required with universities, hospitals, defense/NATO partners, private partners/companies.

The preclinical research on gut/microbiota-brain interactions revealed that a specific short-chain fatty acid (propionate) produced by the microbiota from dietary fibers improves metabolism and health state of inner organs (less liver fat, less adipose inflammation, reduction of obesity) and also modulated critical brain processes relevant for cognition (e.g. mitochondrial function and hypothalamic inflammation). Many health effects were specific for propionate because a reference fatty acid (caproic acid) had no effects. These findings were presented at three international conferences important for pharmaceutical (EASL, Sevilla and Discovery-on-Target, Boston) and nutrition (FENS, Dublin) to stakeholders and academia, and demonstrated feasibility and relevance of a preclinical BB platform. In parallel, we started a collaboration with Radboudmc and Rijnstate hospitals to elucidate for the first time the effects of weight loss on cognitive performance in a clinical trial with 150 obese participants. The trial includes a battery of cognitive tests and fMRI combined with extensive molecular profiling of organs, biomarkers and secreted factors that signal to brain as well as microbiota profiling (Vreeken et al., BMJ Open, 2019). An in-house human trial with volunteers exposed to combined metabolic and physical stressors (fasting and white noise) revealed clear BB interactions and allowed to generate a dataset for modelling/predicting cognitive performance under stressful conditions (manuscript in preparation and presentation at H-Workload, Rome). This contributed to establishment of a human BB platform for comprehensive analysis and quantification of BB interactions incl. predictive BB algorithms.

In 2019, this project had the status of a seed-Early Research Project (ERP) and it was explored whether the main research aim, that is to develop new in-depth knowledge and new technologies to measure and optimize the molecular and psycho-social interactions between body and brain, is feasible. Based on the results achieved and the plans presented the seed ERP has been promoted to a Full (4-year) ERP.

# 19 SEED ERP Social XR

| **Algemene gegevens** | |
|---|---|
| Titel | Social eXtended Reality (XR) |
| ERP/Topsector/Maatschappelijk Thema | ERP 019 |
| Contactpersoon TNO | M.S.A. Boen-Leo (PL); O.A. Niamut (Lead Scientist) |
| Contactpersoon overheid (eventueel) | |
| | |

**Progress 2019**

**1 Summary**

With the ERP Social XR, TNO aims to become an international leader in the field of photorealistic representation and communication between multiple people in networked virtual environments. TNO is building its technology base from 5G, Social Virtual Reality (VR), and haptic interactions into an integrated and fully-fledged facility for sharing Augmented Reality (AR)/ Mixed Reality (MR) /VR experiences across different locations and through sensory modalities beyond sound and vision. TNO can distinguish itself in this way from knowledge and market parties that mainly use AR/MR/VR to create individual, location-based experiences and applications, in which communication and other forms of interaction between people at remote locations hardly play a role.

Example of remote presence through holographic communication
(source: Oulu 6Genesis vision for 2030)

In 2019, this project had the status of a Seed Early Research Program (ERP). The primary goal of this Seed ERP was to develop an integrated Proof of Concept (PoC) of a shared and networked XR experience. As such, this project had a strong development and integration component. We used the PoC in demonstrations to interact with key partners and stakeholders and setup relevant collaborations. Furthermore, the integration efforts raised new research challenges that defined the outline for the complete and comprehensive multi-year ERP program.

By the end of 2019, this Seed ERP delivered the following:

- a real-time acquisition system for performing a volumetric scan of all participants;
- a draft architecture for an end-to-end transmission and rendering pipeline for volumetric video;
- new knowledge on the maximal allowable temporal mismatches between visual, auditory and tactile channels that still result in convincing (realistic) mediated experiences;
- a detailed technology development roadmap;
- PoC implementation that showcased TNO's advances in XR communication and the integration of the XR communication application, tactile interaction, and our cloud infrastructure and 5G networking platform. The PoC included a shared XR environment in which four participants (2 live, 2 pre-recorded) could engaged. Each live participant could see the other participants through a photorealistic volumetric representation within the shared XR environment and could interact using a vibro-tactile system.

The results were demonstrated and presented at key international academic and industry events, in particular ACM MMSys, IEEE VR, EuroVR, VR Days Europe 2019 and the XR4ALL Forum at Stereopsia 2019. We received the Best Demo Award at the prestigious ACM Multimedia Systems Conference for our showcase of "Multi-Sensor Capture and Network Processing for Virtual Reality Conferencing".

# 20 SEED ERP BioNanotechnology

| General information | |
|---|---|
| Title ERP | Bionanotechnology |
| Contactpersoon TNO | Rogier Verberk (DM), Aleksandra Jedynska (PL) Arnold Storm (lead scientist) |
| Contact person(s) government or topsector | Frank de Jong |

**Progress 2019**

**1. Summary**

This program aims to develop new technology for high-throughput detection and characterization of biomolecules at the single-molecule level. This technology has 'game changing' potential: the capability to fully characterize every individual molecule in a sample means that there is no detection limit anymore. Single-molecule protein analysis appears technically feasible and has a wide range of applications: biomedical research (biomarker discovery), diagnostics, detection of biological warfare usage and allergen research (human reactions to allergens, detection of allergens). Additionally, single-molecule technologies may enable archival-data storage in DNA.

This program focusses on development of new technology for single-molecule analysis of proteins, see Figure 1. The novel analysis approach was demonstrated first at TU Delft at a proof-of-principle level in 2016. Unique to this technology is its potential to quantify many different types of proteins with widely varying concentrations in one run. Additionally, single-molecule experiments can yield information inaccessible by regular measurements on a collection of molecules. Currently, analysis of 10-100 peptide molecules (short synthetic proteins) in one experiment is feasible. Final goal of this program is to realize a demonstrator in 2022 that is capable of detection and characterization of at least a million individual molecules in a liquid sample with a mixture of proteins. We work together with the Bionanoscience department at TU Delft that was started by professor Cees Dekker.

Additionally, we investigate whether existing or new single-molecule technologies may be applied for long-standing challenges in the semiconductor industry, e.g. data storage in DNA molecules.

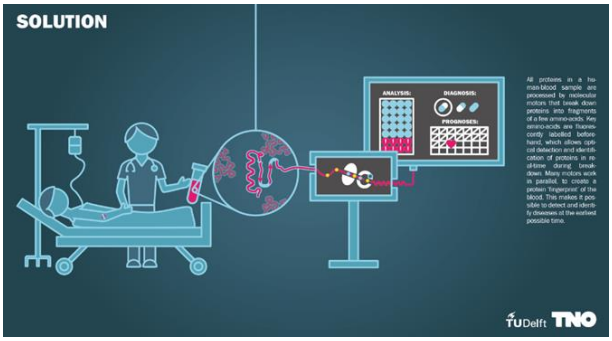



*Figure 1 Infographic to illustrate single-molecule proteome analyzer*

Key ERP results of 2019 are:

- Successful proof-of-concept test which demonstrates that single-molecule detection of post-translational modifications of peptides is feasible.

- Fluorescence imaging was demonstrated on TNO setup. The 2019 goal to implement multi-color, single-molecule imaging was not yet reached.
- A market and use-case analysis was performed.

# 21 SEED ERP Processing of Plastic Waste

| General data | |
|---|---|
| Title | Processing of plastic waste |
| ERP | Chemical industry, Circular Economy |
| Contact persons TNO | Esther Zondervan / Gerard van der Laan |
| Contact person government | n.a. |
| | |

Program report 2019

**1. Abstract**

The amount of plastic recycling should increase significantly to meet the requirements set in 'Rijksbrede Programma voor Circulaire Economie in 2050' and in parallel strong $CO_2$ reduction is necessary. The current recycling strategies are insufficient to close the plastic loop and to reduce $CO_2$ emissions. For this reason, new eco-systems and technologies have to be developed. This seed ERP combines different expertise of TNO to come up with innovative solutions.

As start the following results were delivered to focus our research:

- Current landscape of plastic use, waste streams and recycling technologies;
- Future scenarios for the use of plastics in 2050 (draft publication, to be finished at the beginning of 2020).

Plasma assisted thermochemical recycling is identified as a highly promising new technology that enables the efficient recycling of plastics that are difficult to recycle. One of the big advantages of this technology over the current thermochemical methods is that it doesn't emit any $CO_2$ in the process. This technology is at the moment investigated on lab scale size and needs to be further investigated and scaled up to enable introduction on a time span of about 10 years.

For monitoring thermochemical processes, several sensing methods were evaluated to determine if they could be applied for real time sensing of the process parameters. From this technology scan, Raman spectroscopy and optical emission spectroscopy (OES, plasma sensing) were identified as possible candidates. Initial tests showed promising results for optical emission spectroscopy to monitor contaminants in the process and product gasses, and for Raman to monitor the composition of the output.

# 22 SEED ERP Innovation Outlook

| **Algemene gegevens** | |
|---|---|
| Titel | Innovation Outlook |
| ERP/Topsector/Maatschappelijk Thema | ERP |
| Contactpersoon TNO | Arjen Goetheer |
| Contactpersoon overheid (eventueel) | |
| | |

**Progress 2019**

**1. Summary**

The long-term aim of the SEED ERP Innovation Outlook is to ensure that TNO is a key supporting player to research, industry and governments in their data-driven innovation strategy or policy development. With a new approach current expert-based practices in foresight and forecasting can be modernized to a hybrid forward-looking approach that creates a solid foundation for future anticipation. The goal for 2023 is a science-based operational data-driven forward-looking methodology that systematically supports technology and innovation decision making processes using big data and AI technologies. The forward-looking methodology extrapolates historical data to future developments, and focuses on modelling information dynamics (upcoming trends, patterns of information growth, convergence or divergence). This data-driven forward-looking methodology will lower costs and support the development of more efficient and effective strategies and enables more frequent, faster, and enriched insights into future technological and innovation developments and supports assessments of their potential impact on the (Dutch) economy/society, as well as the design of actionable strategies. The same methodology can also be used to monitor these trends and automatically detect deviating patterns or unexpected elements. The SEED ERP Innovation Outlook combines TNO expertise from eight TNO units and expertise groups on foresight analysis, scenario analysis, system dynamics, AI and big data analysis techniques and strategy development. The project started in 2019 as a continuation of the explorative study in 2018.
The following results have been achieved in 2019:

- A novel modular framework (see Figure 1) has been designed that connects different outlook steps with methodologies, tools and techniques. This unique systematic multi-disciplinary approach has been presented at international conferences. Its novelty and added value has been recognized and confirmed and the unique combination of foresight and data science expertise creates TNO thought leadership;
- A unique triple-bottom-line methodology based on Real Option Value (ROV) methodology has been developed to design actionable strategies and link output, societal impact, and investment outcomes;
- A data-driven AI-supported demonstrator (see Figure 2) has been delivered showing the potential of the new approach and can be used to showcase capabilities and attract new partners / clients;

- The framework is presented as TNOs innovative foresight approach and received requests for future collaborations (e.g. Fraunhofer ISI, ITRI Taiwan, RVO, Itonics, VTT, several ministries (I&W, EZ&K), Nelson Mandela University Business School, Volkswagen, foresight community).

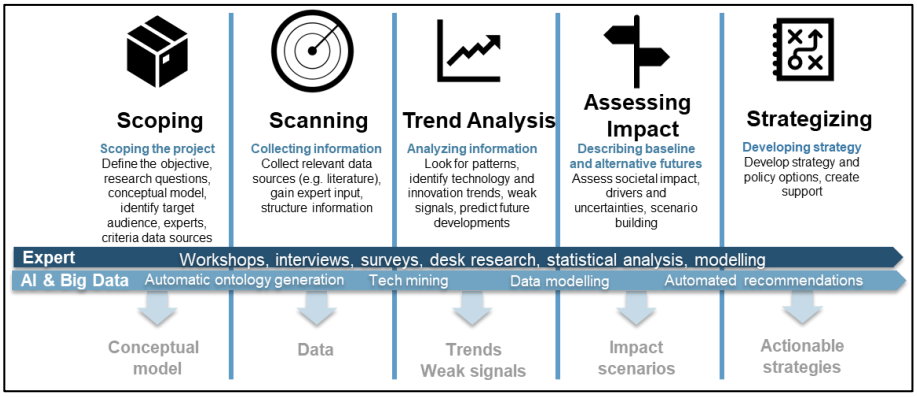



Figure 3: TNO (2019) Data-driven foresight framework & methodology

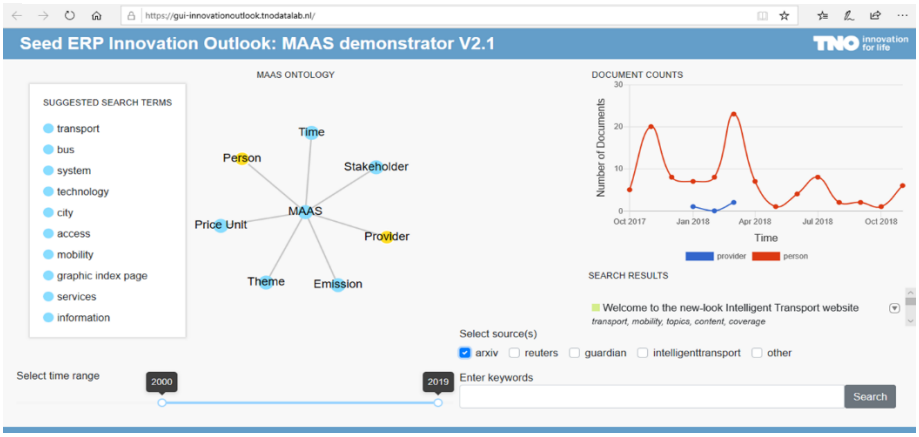



Figure 4: TNO (2019) Data-driven AI-supported demonstrator

As a consequence of the decision of the Science Board on the continuation of the SEED ERP alternatives options to follow-up on this project will be explored (e.g. establish strategic partnerships with partners such as Fraunhofer ISI, Itonics or external stakeholders, etc.). In addition, the finalization of two collaborative papers with Fraunhofer ISI will be delivered early 2020.