Titel	**Sustainable Chemical Industry (P603)**
Missie/ Topsector	Chemie
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Programma jaar 2020 - Samenvatting

In line with the needs of society and specifically the chemical industry and with the ambitions of the Topsector Chemie, TNO's program Sustainable Chemical Industry focuses on developing technology and new business models in three mission-driven Public Private Partnerships being Biorizon, Voltachem and Brightlands Materials Center, whilst exploring novel topics like digitization and recycling in relation to these partnerships. In 2019 also the Public Private Partnership Brightsite was erected in which technology will be demonstrated. Furthermore the potential of photon chemistry will be further explored within this VP building on the results obtained in the ERP Energy Conversion & Storage.

We will, for the period 2020-2023, continue to strengthen these partnerships and further embed them in regional, national and international innovation ecosystems.

Biorizon

In 2023 a pilot line at TRL7 level will demonstrate the integrated production of both novel and existing renewable, bio-aromatic products to such an extent that the market introduction of several applications of bio-aromatics will be supported. In 2020 several unit operations will be tested at TRL5 in order to validate and trouble-shoot the technology, improve process conditions, and provide samples to end users for application development with existing industrial users.

VoltaChem

The program line Power-2-Chemicals aims to have demonstrated by 2023 paired electrosynthesis of key plastic intermediates and high value chemicals together with industry and academia. By the end of 2020 we aim to have tested our continuous flow reactor for paired electrosynthesis of chemical building blocks on bench-scale (TRL4), made the preparation for validating the technology in an industrial environment (TRL5), investigated multiple electrochemical routes and started working on non-aqueous electrosynthesis. Furthermore we aim to have expanded our network and equipment and knowhow base. The program is closely aligned to the Demand Driven program Industrial Electrification and CCUS that has a much broader focus on industrial electrification as a whole. In this field the connection is also made to the new partnership Brightsite.

Brightlands Materials Center

In 2023 the program line Sustainable Buildings will have developed materials that are able to contribute to the reduction of energy usage and the transition towards sustainable energy in buildings. The application of these materials are in adaptive solar control coatings for glass and polymer films/sheets, nanocomposite polymer films/sheets for adaptive infrared light regulation, and nanocomposite polymer foils for light management in solar modules. The developed materials will be integrated in their respective products/modules, and will be demonstrated as a system prototype in an operational environment (TRL7). In 2020, we will further establish pilot infrastructures to study the techno-economic feasibility, and produce pilot scale demonstrator products, and infrastructure for performance validation of the product demonstrators.

In 2023 the program line Lightweight Automotive aims to have developed and demonstrated multi-physics and multi-scale based material models predicting and optimizing durability of thermoplastic composites for lightweight mobility applications. Furthermore, technology and infrastructure to recycle these materials for use in semi-structural applications will be established. In 2020 the Fieldlab Thermoplastic Composites is operational and will show effects of processing and material technologies on properties of over-molded and hybrid parts via inhouse developed demonstrators. Furthermore, research on recycling of TPC's will be expanded to renewable materials.

Photons 2 Chemicals

In 2023, we will be in progress of scaling up the sunlight-fueled reduction of CO_2 to CH_4 and CO from lab (TRL5) to pilot scale (TRL6-7). Furthermore, we will have expanded our process portfolio with the reduction of CO_2 to CH_3OH and the reductive coupling to C2-compounds such as ethylene. In 2020, we will optimize the performance of our catalysts systems, and develop a tailored lab-scale reactor for photoconversion of CO2 to CH4 and CO, resulting in the realization of a complete lab scale mini-factory for this process in 2022 (TRL5). Currently, suited catalysts have been designed, produced and validated for the conversion of CO2 to CH4 and CO.

Korte beschrijving

The long term goal of the total program "Sustainable Chemical Industry" is to establish proven solutions that provides feed-stock flexibility, efficient processing and improved product functionality to the chemical industry. The program is mission driven and organized in Public Private Partnerships that are embedded in regional, national and international ecosystems.

Biorizon

We continue to focus on the long term goal to enable commercial production of renewable, bio-aromatics by 2025. To achieve this, we must first prove the technology at TRL7 in an integrated pilot-plant. We aim to demonstrate this pilot-plant from 2022 onwards. The Diels Alder technology platform provides multiple opportunities to develop applications on the basis of bio-aromatics that are more sustainable, with a lower carbon footprint and often also with extra and improved functionality. This supports the mission Energy and Climate and is one of the selected Key enabling technologies. Process, catalysis and organic chemistry development as well as application development together with industrial users are key for a successful introduction in the marketplace.

VoltaChem

The program line Power-2-Chemicals of the Shared Innovation Program VoltaChem focuses on the electrochemical production of key intermediates for plastics. Within the VP Sustainable Chemical Industry, our knowledge investments specifically target the development of technologies for the production of high-value and specialty products (Power-2-Specialties). The technical focus of this work is on paired electrosynthesis as a platform technology for highly efficient production of chemicals at both electrodes to achieve better business cases. This is enabled by science and expertise that will be further developed together with our partners in the field of electrochemistry, electrocatalysis, electrochemical reactor technology, membrane technology, electrochemical engineering, downstream processing integration and system design. The goal of the work for 2023 is to have demonstrated the technology in at least two pilots at industrial scale in close collaboration with academia and industry labs and in parallel to have realized a set-up of complete screening and piloting testing infrastructure that will accelerate further development towards commercial implementation.

Brightlands Materials Center

The program line Sustainable Buildings contributes to transform current energy consuming buildings into net suppliers of energy. It is focused on developing materials that enable reduction of energy consumption and efficient generation of renewable energy on site. Coatings for application on glass and polymer foils will be developed as well as nanocomposite polymer foils. Functionality of the materials are adaptive solar control coatings for window glazing, IR regulating nanocomposite foils for safety glass, and nanocomposite foils for light management in solar modules (both for improvement of aesthetics and efficiency). Synthesis, surface modification and processing of nanoparticles into solution processed coatings or polymer sheets and foils are required core competences. In 2023, we have tested the application in the pilot infrastructures and are able to produce pilot scale demonstrator products.

The program line Lightweight Automotive contributes to sustainable mobility by developing innovative solutions based on expertise in the field of polymeric materials. An important goal is develop multi-scale, multi-physics based material models that lead to predictable, lighter and durable designs, as well as reduce cost and time needed for testing and validation of parts from continuous fiber reinforced thermoplastic composites and hybrids. Another goal is to develop processing and material technologies for thermo-mechanical recycling of these thermoplastic composites coming from post-industrial and from post-consumer mono-material waste streams as well as integrate these recycled materials in the above mentioned simulation framework.

In 2023 we aim to have validated material models including effects as interface failure, long-term behavior, impact after aging and process induced properties supported by own developed tests. Furthermore, we aim to have developed Long-Fiber-Thermoplastic compounds that can be used as design and construction material for semi-structural applications based on 2 different waste streams (i.e. tapes and sheets).

Photons 2 Chemicals

With plasmon catalysis, we have developed a technological concept to fuel chemical processes with sunlight as energy source. We have demonstrated this concept for the hydrogenation of CO_2 to CH_4 and CO. Until 2025, we aim at realizing a suited reactor for this conversion, and ultimately scaling up to pilot scale (TRL7). Furthermore, we will expand the product portfolio with CH_3OH and C2-compounds such as ethylene.

Resultaten 2020

The challenge of the Dutch Topsector Chemistry is to contribute to the societal transition towards a carbon dioxide neutral circular economy with sustainable energy sources in the coming 30 years, whilst remaining competitive during this transition. The mission Energy Transition and Sustainability is the guiding principle for the innovation tasks. The IKIA Climate and Energy and the Circular Economy KIA are the important drivers for this program. The goals in the KIA and the continuous discussion with our stakeholders and our competences and facilities together determine the focus of the program Sustainable Chemical Industry at TNO. Over the years TNO has set up three mission-driven Public Private Partnerships (Biorizon, Voltachem and Brightlands Materials Center) with public and private stakeholders. In 2020 the program Sustainable Chemical Industry will further strengthen and expand these three existing mission-driven Public Private Partnerships (PPP), further embed them in regional, national and international innovation ecosystems, and at the same time explore new or enabling topics that will add to their strengths.

The program will again contribute in 2020 to:

- Intensified triple-helix collaborations with industry, academia, RTO’s and regions in the Joint Innovation Centres.
- Realization of piloting infrastructure for the key technologies (electrochemistry, Diels-Alder chemistry and nanoparticle synthesis & surface functionalization).
- Delivery of prototypes of sustainable chemical building blocks and smart materials.
- Strengthened knowledge & IP position in the fields of green & sustainable chemistry and smart materials in order to provide industry with competitive solutions.

The PPP’s are leading in the program and therefore individually mentioned below.

Biorizon

For 2020 the focus of the Biorizon program is on the finalization of several proof-of-concepts at TRL5, along with validation of these technologies. The expected results in 2020 will be:

<u>Waste2Furans</u>:

The development of a blueprint for a pilot-plant for the continuous conversion of local residual biomass types such as manure and primary sludge into key renewable raw material furfural (and levulinic acid) will be the goal.

<u>Diels-Alder</u>:

1. Several process installations which are under design and construction in 2019 – ring-opening skid, distillation skid, hydrogenation skid, hydrolysis skid, oxidation skid – will be finalized and delivered in 2020. These will be installed at the Green Chemistry Campus and used to validate each of the associated steps at TRL5. After validation, the skids will be used to generate samples of 5-20 kg which will be subjected to further application testing by industrial partners in various applications, such as resins, lubricants, and polyurethanes. Furthermore, input to the design of the multi-purpose pilot-plant will be generated. This will co-currently generate more information about the technologies generating important input for the design of the TRL7 pilot-plant.

2. The scope of bio-based products available on the kilogram scale will be extended to include key intermediates and close derivatives, further broadening opportunities for implementation.
3. The scope of bio-aromatic targets accessible through Diels-Alder chemistry will be expanded by exploring different starting materials (furans and dienophiles) at TRL1-3.
4. TNO will continue the collaboration with WFBR and Utrecht University on the technology development. In addition, TNO will further expand the number of industrial partners that aim to apply bio-MPA, bio-HMA and related renewable molecules in their products.

VoltaChem

For 2020, the work focuses on three developments:

- Expansion of VoltaChem's industrial community and research network with a dedicated Community-of-Practice on *Power-2-Chemicals*.
- *Electrochemical synthesis*:
  - Continuous flow reactor design for non-aqueous electrosynthesis at TRL4.
  - Testing of paired electrosynthesis in continuous flow at TRL4 and preparing technology validation at TRL5 to be performed in the following year.
- *Enabling technology development*:
  - Expanding our electrochemical toolbox through scouting work.
  - Scaling-up and reactor development towards 2.7 m2 using larger cells.
  - Integrating electrochemical and chemical conversions with downstream processing.
  - Expanding our electrochemical membranes, electrodes and catalysts library.

We expect to have delivered the proof-of-principle of at least 2 new electro-organic selective oxidation/reduction reactions through our scouting work, 1 fully tested electrochemical integrated process including downstream processing at TRL4, and the preparation of technology validation of this technology at TRL5 for the following year.

Brightlands Material Center:

<u>Program line Sustainable Buildings</u>:

- Design and realization of a pilot-sized coater (> 1 m width) for the single-side deposition of solution processed coatings on glass sheets. Dry coating thickness should be between 30 nm and 500 nm, thickness deviation less than 10%, deposition speed min. 6 m/min.
- Design of a pilot-sized thermal curing station for curing of thermochromic solar control coatings under inert gas/reducing gas atmosphere. The curing station should be techno-economically scalable to industrial size.
- Design and preparation of multilayer thermochromic interference coating on lab scale.
- Pilot-scale production of thermochromic VO2 based powders with a switching temperature between 20 and 30°C.
- Successful demonstration of milling of thermochromic VO2 based powders (doped and undoped) to a particle size ≤ 100 nm.
- Design of a strategy for surface modification of VO2 based pigments (doped and undoped) for tuning interfacial tension and protection against degradation (lab scale).
- First thermochromic nanocomposite PVB/polyolefine films realized on lab scale.
- At least 3 concepts developed for demonstration of added value/functionality of nanocomposite films for lamination of PV panels.
- Plan developed for integration of BIPV panels with nanocoated colored cover glass in office/residential buildings for real-life testing, and plan in execution.

- Milestone for monitoring
- Pilot-sized coater and thermal curing station for thermochromic solar control coatings designed, and coater realized and validated for test coating (to be completed end of year 2020).

Program line Lightweight Automotive:

For 2020, the Fieldlab Thermoplastic Composites will be further expanded and used to validate developed technologies, test methods and modeling concepts. The developed demonstrator(s) will be used to evaluate different material concepts, and gained knowledge will be translated and added in design and process rules. The developed recycling technology from Thermoplastic Composites into Long Fiber Thermoplastic compounds will be expanded to more polymer systems, and evaluated on own larger scale equipment. This translates into following milestones:

- The Fieldlab Thermoplastic Composites will show effects of processing and material technologies on interface and structural performance of over-molded parts via inhouse developed demonstrators.
- Identified structural and interface performance of over-molded flexible electronics based on functional and thermo-mechanical reliability tests.
- Establishment of material design, processing and simulation guidelines for adhesively bonded hybrid Steel and fiber reinforced modified thermoplastic composites.
- Realizing an inhouse designed, custom-made recycling infrastructure (extruder) that enables further research to improve BMC's thermo-mechanical recycling technology.
- Demonstrated BMC's mechanical recycling technology for on a commercial waste stream of PP-GF UD-tape.

Photons-2-Chemicals:

- Further development of the reactor for plasmon catalytic conversion of CO2 to methane, including validation.
- Optimized catalyst for plasmonic photoconversion of CO2 to methane with respect to activity/Space Time Yield (STY).
- Development of a library of catalysts for the conversion of CO2 to CO, including:
    - Variation of plasmonic metal
    - Variation in shape/geometry of the metal NP
    - Different carrier materials (setting up cooperation with Sibelco)
- Initial tests on activity/selectivity for the library of catalysts described above under 3.
- First design of complete lab scale mini-factory for the conversion of CO2 to methane and CO.
- Development of strategies of commercial feasible photo(electro)chemical conversion of CO2 to methanol

Collaboration with other VP's

There is a close connection with other VP's that focus on related topics which are of relevance for the work in this VP:

TNO VP ECN Energy System: Energy and feedstock system integration

TNO VP ECN Industry: CCUS, efficiency, heat integration

TNO VP ECN Fuels and Feedstocks: Blue & green hydrogen, hydrogen infrastructure

TNO VP Industrial Electrification and CCUS

TNO VP Circular Economy & Environment

TNO ERP Submicron Composites

TNO ERP Energy Conversion & Storage: Electrons and photons to chemicals

TNO ERP Decarbonization: Brightsite activities related to industrial electrification

External coordination and collaboration with relevant stakeholders

We coordinate and collaborate with many national and international stakeholders to accelerate implementation and to maximize impact:

- The program fits seamlessly in the Integral Knowledge and Innovation Agenda Energy and more specifically in the Multiyear Mission oriented Innovation Programs MMIP 6 and 8 as well as in the Key Enabling Technology programs "Electro Chemical Conversion and Materials" (ST-ECCM), "Biorizon", "Materials Innovations" and "Climate Proof Chemistry.
- We collaborate with relevant academic groups in The Netherlands and abroad. In The Netherlands, connection is made with TU Delft, TU Twente, Leiden University, Utrecht university, TU Eindhoven and Wageningen UR. Futhermore we have connections with Differ, Hogeschool Zuyd, Avans, Hogeschool Rotterdam. Abroad, we focus on collaboration with VITO, University of Hasselt, FZ-Julich, RWTH-Aachen, Fraunhofer.
- During the program period, activities will be continuously aligned in relevant groups, amongst which are ECCM (Topsectors Chemistry, Energy and HTSM), ISPT (Insitute for Sustainable Process Technology), Deltalinqs Climate Program, Biobased Delta, Green Chemistry Campus, Brightlands Chemelot Campus, InSciTe, TKI's (Chemistry, New Gas, Energy and Industry), NWA-routes energy transition, circular economy & materials and directly with the Ministry of Economic Affairs and Climate. Internationally, we will connect with Vanguard, CLIB21, IEA (OECD), Catalisti (Belgium) and DECHEMA (Germany).

Dynamiek

Biorizon

No dynamics concerning technology development, IP position, collaborations or organizational compared to the plan for 2019-2022.

VoltaChem

We continue the work which was started in 2019, bringing one main electrochemical production concept towards higher TRL, whilst working on scouting activities for identifying novel electrochemical routes together with our partners which we expect to be further developed in the successive years. In the meantime, we are starting work on non-aqueous electrosynthesis development which is highly relevant for non-standard application of electrochemistry in chemical production.

Brightlands Materials Center

For program line Sustainable Buildings the technology development is on plan for 2018-2022. IP position needs to be further strengthened and expanded to form a solid base for the Shared Research Program. Strategic collaboration ongoing with Zuyd Hogeschool and Hasselt University on development and performance validation of solar control/adaptive IR regulating products. Collaborations with industrial partners via subsidized projects on plan. Active participation in regional sustainable energy discussions ongoing (e.g. LEKTA, PALET).

For the program line Lightweight Automotive increased market interest for process and material developments related to recycling of Thermoplastic Composites resulted in a new (2nd) Fieldlab project on recycling of TPC starting end of 2019. Consequently, IP position related to this subject gained on importance and is being addressed. Other topics remain constant compared to the previous plan 2019-2022.

Photons 2 Chemicals

The results of the research done in the ERP Energy Conversion & Storage are taken into this VP and will be further expanded. The potential of this platform technology will be further explored also in combination with conversions relevant to the other programs like Biorizon and Voltachem.

Titel	**Industrial Electrification and CCUS (P616)**
Missie/ Topsector	Chemie
Contactpersonen TNO	Ir. Peter Wolfs, Ir. Martijn de Graaff
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Programma jaar 2020 - Samenvatting

In 2018 a new Demand Driven program (VP) Industrial Electrification and CCUS was initiated by TNO, focusing on the unique combination of industrial electrification and carbon capture, utilization and storage. The increasing amounts of renewable wind and solar derived electrical energy offer great opportunities for the industrial production of green hydrogen and the conversion of renewable raw materials (e.g. biomass, CO2) to added value chemicals and fuels. This program aims at the development and piloting of novel Industrial Electrification and CCUS technologies and relevant business models. The focus of the program is on the unique combination of electrification with biomass conversion and the integration of industrial electrification with carbon capture and utilization.

In the previous years first results were generated, mostly on proof-of-principle level, and basic know-how and advanced research infrastructure were established in the field of CO2 (co)electrolysis, Solid Oxide Electrolysis and high temperature electric cracking. Furthermore, the research activities of ECN were integrated in the portfolio and rearranged amongst VP's to aim at dedicated targets. In 2020, we will continue further developing the proof-of-principles towards higher TRL together with regional, national and international stakeholders from industry and government. Focus of the activities in 2020 and the expected results will be:

- High-temperature cracking for decarbonizing ethylene production: development of a proof-of-concept for electric naphta cracking at small scale.
- Solid Oxide Electrolysis technology and its integration in industry: manufacturing capability for 20x20 cm2 SOEC's available and industrially integrated pilot concept developed.
- Paired electrosynthesis of biobased feedstock and CO2: optimization and scale-up of earlier developed (paired) electrochemical CO2 conversion towards integrated system.
- Integrated value chains for CO2 capture and conversion: development of capture integrated CO2 conversion towards TRL4.
- Value chain development for fuels, fertilizers and materials (plastics, steel): assessment of the impact of global energy and carbon prices on strategic relevance.

Furthermore, we will focus on the development of the Fieldlab Industrial Electrification in Rotterdam-Moerdijk and on the support of Hydrohub (Groningen-Eemsdelta) and Brightsite (Geleen-Chemelot). In these Fieldlabs above developments, amongst others, can be further piloted and brought towards demonstration together with industry and public stakeholders. Through this approach we aim to accelerate the development and implementation of results, so that our contribution to the 2030 and 2050 climate targets is maximized.

Korte beschrijving

At the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal. Based on this agreement, the Dutch government has decided in 2017 to cut greenhouse gas emissions by 49% in 2030 and by 80-95% in 2050. This will be a huge challenge for the heavy (chemical) industry and electricity sectors. At the same time this will provide an opportunity for high-tech chemistry and equipment supply companies to develop and market new innovative solutions.

Industrial Electrification and CCUS are important solution directions to achieve a carbon neutral industry, as was also identified by the VNCI in its roadmap 2050 and by the Topsectors Chemistry and Energy and the Ministry of Economic Affairs and Climate. Later this was reaffirmed in the descriptions of the Multiyear Mission Driven Program "Electrification and radical new processes" (MMIP-8) and Key Enabling Technology "Electrochemical Conversion and Materials" (ST-ECCM). The increasing amounts of renewable wind and solar derived electrical energy offer great opportunities for the industrial production of green hydrogen and the conversion of renewable raw materials (e.g. biomass, CO2) to added value chemicals and fuels. Crucial for the energy system of the future is the integration with energy storage and conversion to balance the energy system. This VP aims for the accelerated development and piloting of relevant industrial electrification technologies and associated business models. The focus of the program is on the combination of electrification with biomass conversion and the integration of industrial electrification with carbon capture and utilization. For the latter, the development of cost effective industrial applicable carbon capture technology is of huge importance.

To accelerate development and implementation of Industrial Electrification and CCUS in the Dutch context, parallel tracks are being pursued:

- Co-creation and combination of Industrial Electrification and CCUS knowledge:
  - High temperature heat based on renewable electricity: development of technology for direct use of electricity in high-temperature processes.
  - Renewable hydrogen production and conversion: lowering total system costs, dealing with flexibility and efficient downstream conversion to valuable products.
  - Direct electrochemical conversion: efficient conversion of renewable feedstock (biobased and CO2) towards chemical building blocks and energy carriers.
  - Direct and indirect conversion of CO2: development of technology for efficient CO2 valorization towards useful products using renewable energy.
  - Value chain integration: development of models and scenario's enabling strategic decision making in industry, energy and infrastructure.
- Regulatory aspects: analysis of necessary changes in national and international regulations to enable a cost-effective and balanced roll-out.
- Support of piloting in large Dutch industrial clusters by means of industrial Fieldlabs

Implementation of industrial Fieldlabs in the relevant energy & industry clusters (Rotterdam-Moerdijk, Brightlands-Chemelot, Groningen, Amsterdam-Ijmuiden, Zeeland).

All activities of the program are coordinated and/or co-created with public and private partners from national and international industries, governments and ngo's. A large part of the program is implemented through the Shared Innovation Program VoltaChem, in which approximately 25 companies and institutes from the energy, chemical and equipment sectors work together on acceleration of industrial electrification. Furthermore, the program connects to relevant national and international CCUS platforms. Through these extensive collaborations we aim to accelerate the development and implementation of results, so that our contribution to the 2030 and 2050 climate targets is maximized.

Resultaten 2020

The activities in the VP Industrial Electrification and CCUS are defined using continuous portfolio management. Existing developments are taken further towards piloting and demonstration at industrial partners or in open industrial Fieldlabs and new developments enter the program through continuous scouting activities. Furthermore, there is continuous interaction with projects in other internal and external related programs.

The following activities will be part of the Industrial Electrification and CCUS program in 2020:

<u>1a High temperature heat based on renewable electricity: electric cracking</u>

In 2017 VoltaChem's E-match project identified that electrification of ethylene production could have a huge potential in the energy transition. In this study it was concluded that high temperature Power-to-Heat technologies (> 200 ° C) should be developed and implemented to tap into the CO2 reduction potential that industrial electrification could bring in North Western Europe. Electric cracking is such an option which will make ethylene production more sustainable.

In the preceding year, electric cracking was further investigated within the framework of this VP together with the trilateral strategy workgroup on this topic and with the Chemelot industrial site. These investigations involved determining the patent landscape, formulating key R&D questions, making a first conceptual design of experimental facilities and performing initial research work utilizing existing high-temperature facilities at TNO's location in Petten. Based on the results of this work next steps will by developing a proof of concept as first step in the R&D trajectory.

Specific activities for 2020:

- Determination of the impact of electric cracking on ethylene production.
- Optimization of the cracking product portfolio and decreasing coke formation.
- Development of a proof-of-concept for electric naphtha cracking at small scale.

<u>2b Renewable hydrogen production and conversion: solid Oxide Electrolysis</u>

For green hydrogen production (Power-2-Hydrogen) multiple technologies can be considered. In order of technology maturity these are: Alkaline water electrolysis, PEM (Polymer Electrolyte Membrane) electrolysis, SOE (Solid Oxide Electrolysis) and AEM (Anion Exchange Membrane) electrolysis. Although, we consider all types within the VoltaChem framework, in the VP Industrial Electrification and CCUS we focus specifically on SOE due to its fit with industrial high temperature processes and because of its potential for CO2 utilization.

SOE technology is seen as the best technology for industrial hydrogen production, because of its high efficiency and potential for heat integration with industrial chemical processes like production of ammonia and methanol. Also, the technology can also be used for direct reduction of CO2 towards CO and for tuning the composition of syngas through co-electrolysis towards desired C-H-O ratio's. This has the potential to enhance further reactions towards high-value chemical products like methanol, DME and methane, and is thus a key ingredient for Industrial Electrification and CCUS. In 2018 the first step was made in realizing a SOE cell fabrication line and test infrastructure, which was used for increasing SOE lifetime and scaling-up towards larger capacities and cell dimensions (10x10 cm2). Also, a first assessment was made of the integration opportunities in industrial infrastructure. In 2020 this work will be continued by focusing on further scaling up to 20x20 cm2 cells, on increasing the reproducibility of cell production and on investigating the possibility of an industrially integrated pilot.

Specific activities for 2020:

- Development state-of-the-art cell production for 20x20 cm2 SOE cells.
- Increase reproducibility and decrease cost of cell production.
- Development of an industrially integrated pilot concept.

<u>2c Direct electrochemical conversion: electrosynthesis using biobased and CO2 feedstocks</u>

In this research, electrosynthesis is used for direct conversion of renewable feedstock (biobased and CO2) towards chemical building blocks and energy carriers using renewable electricity. The activities focus on developing chemical showcases together with industry and regional networks related to electrochemical synthesis of specialty chemicals (Power-2-Specialties) and commodity intermediates (Power-to-Commodities). The objective is to transform knowledge from TNO, partner universities and fundamental research institutes from TRL3-4 (lab scale proof-of-principle) to TRL5-6 (benchscale proof of concept). In 2018 first proof of principle research was completed on multiphase paired electrosynthesis and additional lab infrastructure was erected, whilst in 2019 the research was continued towards showing fully continuous paired electrosynthesis of biobased feedstock and CO2. In the new year, the work will be predominantly focused on further expanding our know-how and knowledge network, scaling the technology towards larger cells and on scouting the electrochemical conversion of CO to added-value chemicals.

Specific activities for 2020:

- Expansion of knowledge base on electrochemistry and electrochemical engineering employing selected specialty and commodity showcases together with partners.
- Optimization and scale-up of direct electrochemical CO2 conversion technology.
- Development proof-of-principle electrochemical CO conversion.

2d Direct and indirect conversion of CO2: capture and conversion technologies

In this work, technology and methodologies are developed for efficient CO2 capture and valorization towards useful products to improve the business case of carbon capture. The full value chain of CO2 capture and consecutive direct and indirect conversion towards valuable products should be considered, including integration options. Especially decentral applications, like the use of CO2 capture at waste incinerators, warrant extra attention because this could be considered at Negative Emissions Technology (NET).

In earlier years, the work focused on de-risking CO2 capture at waste incinerators, but since 2019 the focus shifted towards direct integration of CO2 conversion in carbon capture installations, with the aim to drastically improve the business case of Carbon Capture and Utilization. In the new year, the work will be predominantly focused on integrating carbon capture technology with direct electro-conversion of CO2 towards key building blocks and on identifying the sweet spots in industrial clusters for implementation of this technology.

Specific activities for 2020:

- Development of capture integrated electrochemical CO2 conversion towards TRL4.
- Determination of sweet spots in industrial clusters by analyzing the potential CCU value chains in these clusters, the relation with CCS and the associated timeline for implementation.

2e/f Value chain integration and regulatory aspects: system model development

It is important to consider novel technologies in the context of the energy and feedstock transition. For the analysis of the context of industrial electrification, it is essential to take into account the complete supply chain from feedstock to production, distribution and application of the chemicals. Besides this, it is important not to limit the scope to Western Europe, but to analyze how global energy supply and production of energy carriers and feedstocks influence the Western European market. Both energy sector and the chemical industry are rather (more and more) global markets.

In 2019 the earlier top-down system model and business case calculation tools for electrification technologies were further developed to be able to analyze worldwide value chains towards fuels, fertilizers and materials (plastics, metals). This work will be continued in 2020, further expanding the toolbox enabling us to help public and private partners better in their assessment of the opportunities. Furthermore, attention will be put on assessing the impact of transnational infrastructure, (hybrid) financing and regulatory hurdles and sweet spots.

Specific activities for 2020:

- Complement existing toolbox with additional technical, economic and LCA parameters.
- Assessment of the impact of global energy and carbon prices on strategic relevance of industrial electrification and CCUS and on adoption of technologies in specific regions.
- Assessment of drivers and barriers for adoption in the following areas: Infrastructure, (Hybrid) Financing, Regulatory hurdles and sweet spots.

3 Support of piloting in large Dutch industrial clusters by means of industrial Fieldlabs

To accelerate the development and implementation of Industrial Electrification and CCUS processes, and thereby realize large scale CO2 reduction in industry, a cost effective and efficient means for scaling up and testing new technologies is needed. Validation of technologies must happen at an industrially relevant scale in a practical environment. This allows for continuous development towards commercialization while verifying business cases and bringing together input from various stakeholders: end users, technology providers, equipment manufacturers, and knowledge institutes.

In 2019, several Fieldlabs were initiated with the involvement of TNO. The Brightsite and Hydrohub initiatives were launched in Geleen-Chemelot and Groningen-Eemsdelta respectively and a first step was made in the development of an Fieldlab industrial electrification in Rotterdam-Moerdijk. In 2020 these initiatives will be further supported by the VP Industrial Electrification and CCUS and associated VP's to enable them to facilitate industrial pilot and demonstration activities.

Specific activities for 2020:

- Support R&D and piloting activities in the existing Fieldlabs Brightsite and Hydrohub based on the needs of these Fieldlabs and the fit with the focus of the VP.
- Support the development of Fieldlab Industrial Electrification in Rotterdam-Moerdijk.

<u>Scouting activities</u>

Next to the RD&I work that has already been programmed in multi-year activities, we keep looking externally for novel technologies and methodologies that help accelerating Industrial Electrification and CCUS. To be able to assess the value of such novel external developments, we employ a continuous technology scouting activity and start new scouting projects together with our partners on a regular basis. When assessed positively, these activities can be taken further in the next

year as larger projects.

<u>Collaboration with other VP's</u>

There is a close connection with other VP's that focus on related topics which are of relevance for the work in this VP:

- TNO VP ECN Energy System: Energy and feedstock system integration
- TNO VP ECN Industry: CCUS, efficiency, heat integration
- TNO VP ECN Fuels and Feedstocks: Blue & green hydrogen, hydrogen infrastructure
- TNO VP Sustainable Chemical Industry: Biobased chemistry, selective electrochemistr
- TNO ERP Energy Conversion & Storage: Electrons and photons to chemical
- TNO ERP Decarbonization: Brightsite activities related to industrial electrification

External coordination and collaboration with relevant stakeholders

We coordinate and collaborate with many national and international stakeholders to accelerate implementation and to maximize impact:

- The program fits seamlessly in the Integral Knowledge and Innovation Agenda Energy and more specifically in the Multiyear Mission oriented Innovation Program on "Electrification and radically new processes" (MMIP-8) as well as in the Key Enabling Technology "Electro Chemical Conversion and Materials" (ST-ECCM).
- A large part of the activities is performed within the Shared Innovation Program VoltaChem, in which approximately 30 companies from the energy, chemical and equipment sectors work together on acceleration of industrial electrification. Furthermore, we connect to national and international CCUS platforms. Aim is to develop the technologies towards pilots in industrial Fieldlabs in the most important industrial energy & industry clusters (Rotterdam-Moerdijk, Brightlands-Chemelot, Groningen, Amsterdam-Ijmuiden, Zeeland).
- We collaborate with relevant academic groups in The Netherlands and abroad. In The Netherlands, focus will be on TU Delft, TU Twente, Leiden University, Utrecht university (CO2 electrolysis, CCUS), TU Eindhoven (intensified electrolysers) and Wageningen UR (bio based conversions). Abroad, we focus on collaboration with VITO, FZ-Julich, RWTH-Aachen and Fraunhofer.
- During the program period, activities will be continuously aligned in relevant groups, amongst which are ECCM (Topsectors Chemistry, Energy and HTSM), ISPT (Insitute for Sustainable Process Technology), Deltalinqs Climate Program, TKI's (Chemistry, New Gas, Energy and Industry), NWA-routes energy transition, circular economy & materials and directly with the Ministry of Economic Affairs and Climate. Internationally, we will connect with IEA (OECD), Catalisti (Belgium) and DECHEMA (Germany).
- Externally, we have a close collaboration with multiple EU projects (e.g. E2C, PERFORM, H2FUTURE) and RVO projects (e.g. PheCam, AMPERE, NextGenP2H2). Also, we align extensively with regional activities in which we are directly involved: Port-of-Rotterdam electrification program, Brightsite and Hydrohub.

Dynamiek

In the previous 2 years a start was made with this new VP Industrial Electrification and CCUS, focusing on the unique combination of industrial electrification and carbon capture, utilization and storage. In the same period ECN was integrated in the TNO organization and the associated research programs were internally aligned and consolidated. In 2019, the activities dedicated solely to CCUS and to industrial heat have been integrated in the VP ECN Industry, while the activities on Alkaline and PEM electrolysis have been integrated in the VP ECN Fuels and Feedstocks. This alignment has enabled the VP Industrial Electrification and CCUS to focus more on its core activities and formulate better targets and research activities in alignment with the other VP's.

In 2019 large investments have been made in the so-called Faraday Lab facilities in Petten, which enables the VP Industrial Electrification and CCUS and earlier mentioned associated VP's to perform more advanced research and therefore accelerate the research. Furthermore, a new ERP Decarbonization has been started that specifically focuses on decarbonizing the Chemelot industrial site. In this ERP electric cracking, methane decarbonization and site electrification development will form an important part of the activities, thereby directly linking to part of this VP for its long-term development. All these new activities will contribute to the VP and vice-versa helping to achieve the collaborative targets of society and industry together faster.

Titel	**Space & Scientific Instrumentation (P607)**
Missie/ Topsector	HTSM
Contactpersonen TNO	Kees Buijsrogge, Hans Klaufus
Contact extern	Arnaud de Jong (ADS NL) Space, Marco Beijersbergen

Programma jaar 2020 - Samenvatting

Our multi-annual R&D program 2019 – 2022 supports our ambition to:

- contribute to preventing air pollution and climate change;
- help to understand the Universe;
- enable secure broadband connectivity,and;
- stimulate economic growth in the Netherlands and the European Union.

Therefore, we organise the VP along the following program lines:

- instruments for Earth Observation and related Space Data Utilisation;
- technologies for Satellite Communication;
- instruments for Ground-based Astronomy and Space-based Astronomy;Scientific Instrumentation, including instruments for Big Science, and Diagnostics for Fusion Energy.

<u>Instruments for Earth Observation, Space Data Utilisation</u>

Our main objective in this area is to maintain and strengthen the Dutch position with regard to monitoring the composition of the Earth's atmosphere. We want to contribute to help monitor the Paris agreement and give detailed insight in emissions and spread of air pollutants and greenhouse gases. We have two long term goals: Dutch involvement in the institutional Copernicus CO2M mission and the in-orbit-demonstration of a small and very accurate instrument with related downstream models. In the commercial EO market the emphasis is on information products, rather than on instruments. We will work on the development of data processing methods that can enable global information services that provide actionable information to decision makers in governments to help address these issues.

For 2020 the focus will be on the development of instruments that measure CH4, NO2, SO2, CO2, CO and aerosols. We will work on improving our LOTOS-EUROS and TOPAS models by including more air quality trace gases and CH4.

<u>Technologies for Satellite Communication</u>

Our aim is to develop state-of-the-art optical terminals for ground, air and space usage for the value chain of global satcom providers. We follow four main use cases: Secure & Robust Comms for worldwide Mobile Security Operations; Cyber Proof/Quantum Resilient Comms over Ground Networks for Secure Connectivity; Ultra-High-Speed Global Secure Connectivity Network (constellations); Data Relay for Earth & Space Sciences from (deep) Space.

We will work on our four main drivers:

- Fast: ultra-high data throughput with a long-term target of a 10 Tbit/s feeder link to a GEO-satellite.
- Secure: communication links with ultimate protection, suitable for the quantum era with a long-term target of a Quantum Key Distribution service with satellite nodes, which is resilient to hacking attacks.
- Multi-point: simultaneous communication with multiple senders and receivers with a long-term target of a multi-beam optical space terminal in GEO-orbit, receiving data from various nodes (space, aerial, naval) and transmitting towards multiple users.
- Far: data links over very long distances with a long-term target of a link to a deep space science mission, such as a planetary or asteroid mission.

These emerging markets provide a very promising opportunity for Dutch industry to extend its space-related activities into a commercial market: in this development we will position Dutch high-tech companies as potential suppliers for the terminals and their subsystems based on user requirements from this market.

<u>Ground & Space Based Astronomy and Scientific Instrumentation</u>

We intend to strengthen our position with regard to developing high-grade instruments to perform world-class science, both in space and on ground.

Our long-term goal for Earth-based astronomy is to contribute to the development of the Thirty Meter Telescope (TMT) optics with a 3m diameter deformable mirror. Steps towards that goal are deformable mirrors of increasing size, better support structures and laser guide stars for the big telescopes in the world (UH88, EST, ELT, GMT, MAORY, GEMINI, KECK). For 2020 the goal will be to develop a larger deformable mirror of 60cm diameter (UH-88) to create our first on-sky-heritage.

In the space-based astronomy domain we use ESA's long-term planning for space science missions, ‘Cosmic Vision 2015–2025’, as a guideline. The coming years we will work on pointing mechanisms for the LISA (detection of gravitational waves) mission. We intend to position ourselves for the metrology system for the PLATO (detection of terrestrial exoplanets) mission.

In big science we want to prepare for the future by making sure that the Einstein Telescope (detection of gravitational waves) will be built partly in the Netherlands and aim for a technical role in developing mirrors and metrology systems. In addition, we want to contribute to nuclear fusion technology by applying our optical systems design expertise to develop technologies for diagnostic instrumentation in the extremely challenging environment of the nuclear fusion chamber.

Korte beschrijving

Our programs are aligned with the Sleuteltechnologieen (Photonics and Light Technologies, Engineering and Fabrication Technologies, Quantum Technologies, Nanotechnologies), the MJP ruimtevaart and the missies Veiligheid, Energietransitie en Duurzaamheid and Landbouw, Water en Voedsel.

Instruments for Earth Observation, Space Data Utilisation

Institutional Instruments and Subsystems (optical/radar) and Optical Calibration

Air pollution and climate change is a global problem, it does not stop at borders of countries. Our aim is to remain world class in the development of EO instruments to measure the worldwide background of these gasses and the local hotspots that are responsible for major emissions. We have been doing this together within the Dutch ecosystem (Airbus NL, SRON, KMNI) and want to continue this.

TNO works on space-based monitoring solutions that will enable independent verification of emissions in a matter of years, not decades. We have three Earth Observation technology goals: Measurement instruments & systems, Data assimilation (merge data from all sources) and the Lotus Euros model (incl. TOPAS, to visualise and predict). The three related visions are: to provide monitoring instruments or subsystems for relevant greenhouse gases and air pollution; the ability to assimilate any relevant satellite data to better monitor emissions; and use of LOTOS EUROS for daily updated global information source about pollution and used to realise emission reduction.

Technology development is needed to more accurately measure emissions of more relevant species (NO_2, CH_4, CO, SO_2, NH_3, N_2O, VOCs, aerosols), include them in our models and increase the accuracy and predictability of the models.

Satellite Communication

Global IP Traffic has been growing exponentially (8-fold over 2015 - 2020, and beyond). Secure broadband connectivity is a top priority for Governments, Industries, and Banks, whereas it is a daily need of consumers worldwide to have a reliable internet connection 24/7. We follow four main use cases: (1) Secure & Robust Comms for worldwide Mobile Security Operations; (2) Cyber Proof/Quantum Resilient Comms over Ground Networks for Secure Connectivity; (3) Ultra-High-Speed Global Secure Connectivity Network (constellations); (4) Data Relay for Earth & Space Sciences from (deep) Space.

It is our objective in this field to develop technologies supporting manufacturers and service providers to meet those needs by focussing on two expertise areas: Laser SatCom and RF SatCom.

<u>Laser SatCom</u>

The introduction of Laser Communication technology in satellite communication systems, including Quantum Key Distribution (QKD), enables orders of magnitude larger bandwidth, absolute security, resilience to jamming and provides an alternative for the overloaded RF spectrum. This technology shift towards photonics in the satellite telecoms market presents a huge new opportunity for the Netherlands. We will enable laser satellite communication by developing optical terminals for usage on ground, in the air and in space. Due to our heritage in optical systems design for EO instruments and adaptive optics for astronomy purposes, we have rapidly built a position in this more commercial market. We have defined 4 key long-term performance objectives:

1. *Fast*: ultra-high data throughput

   Long-term target: a 10 Tbit/s feeder link to a GEO-satellite

   Application: broadband communication by governments (defence), businesses and citizens

2. *Secure*: communication links with ultimate protection, suitable for the post-quantum era

   Long-term target: a Quantum Key Distribution service with satellite nodes, which is resilient to hacking attacks

   Application: critical infrastructure with vital importance to society (government, defence)

3. *Multi-point*: simultaneous communication with multiple senders and receivers

   Long-term target: a multi-beam optical space terminal in GEO-orbit, receiving data from various nodes (space, aerial, naval) and transmitting towards multiple users

   Application: defence and commercial

4. *Far*: data links over very long distances

   Long-term target: a link to a deep space science mission, such as a planetary or asteroid mission

   Application: science

A range of novel laser communication systems (including QKD systems) are desired by OEMs, satellite integrators, service providers and governments for the next generation secure & broadband information networks and services. Our goal is not only to develop state-of-the-art terminals for the world leading companies in this field, but also to position the strong Dutch high-tech supply chain for series production, making this an economic growth opportunity for the Netherlands.

<u>RF SatCom</u>

High throughput satellites (HTS) are communications satellites that provide at least twice, though usually by a factor of 20 or more, the total throughput of a classic Fixed Satellite Services (FSS) satellite for the same amount of allocated orbital spectrum, thus significantly reducing cost-per-bit. The implementation of HTS communication downlink at radio frequencies require wide absolute bandwidths. Currently, the Ka-band is considered for this link, but to further enlarge the bandwidth an increase in the operating frequency is foreseen (Q-, V-, W- bands). This, together with the need of generating multiple beams, will require the support of significant RF front-end and antenna technology advancements.

Furthermore, the trend in SATCOM user terminal antennas for the professional (mobile) market is toward low-profile high-end solutions, based on phased array antennas. In particular, inter-continental flights need large beam-steering capabilities in order to keep the connection with the satellite while travelling over different sectors of the globe. At present, bulky mechanical beam-steering is the preferred technique. We focus on the development of a low-profile dome antenna solution to enlarge the field-of-view of phased arrays from 60º to 80º. A further height reduction is crucial for this concept to be considered as a candidate in new generation aeronautical terminal antennas.

Satcom goals

Goals for 2020 relate to the four long-term performance goals (although Far is not covered in the VP plan, but in the longer term TNO ERP plan). Focus for Fast will be on continuation of a Terabit Optical Ground Terminal, Coarse Point Assembly (CPA) for Space Terminals, Photonic Integrated Circuits for development of waveguide technology and a Phase Lock Loop Demonstrator. For Secure the focus will be on QKD ground station breadboarding activities, and for Multipoint on highly compact freeform telescope design.

Ground & Space Based Astronomy and Scientific Instrumentation

Ground-based Astronomy

TNO's program in Astronomy is focused on delivering cutting-edge precision opto-mechatronic components and subsystems to enable world class scientific discovery. In close collaboration with scientific partners and involving industry, we support them to address basic scientific questions that for instance, relate to the origin of the universe, the true nature of gravity or finding exoplanets.

Our long-term goal (2028) for Earth-based astronomy is to enable the realisation of the Thirty Meter Telescope (TMT) with a 3m deformable mirror. In addition, we want to position Dutch companies for the series of instruments derived from our technology developments. Steps towards these goals are the development of technologies for the biggest telescopes in the world (UH88, EST, ELT, GMT, MAORY, GEMINI, KECK): the key path on this roadmap is the advancement of active and adaptive optics systems, including large-mirror corrective support structures (M1 thru M5 active whiffle trees), deformable mirrors (DMs) increasing in size and actuator count (M2 thru Instruments), laser guide stars (LGS), related control systems and complementary technologies (sensors and actuators).

Space-based Astronomy

The aim for this activity is to ensure the participation of TNO technology in the European missions LISA and PLATO. In addition, we have the ambition of joining non-European missions, e.g. NASA, JAXA, CNSA (BISME). This goal is defined for the period 2018 – 2034.

The knowledge needed to achieve the goal of the Space Scientific Instrumentation area is related to:

- Development of picometer accuracy pointing mechanisms
- Optical design of low straylight minimum components optical systems
- Metrology in highly dimensional space (100 dimensions for PLATO)
- Development of small sat instruments for scientific purposes, e.g. exoplanets detection in constellation missions as opposed to large institutional instruments.

Scientific Instrumentation

In Scientific Instrumentation we focus on two topics: the realisation of the Einstein Telescope in the Netherlands and diagnostics for nuclear fusion.

We want to prepare for the future by making sure that the Einstein Telescope (detection of gravitational waves) will be built in the Netherlands and aim for a technical role in developing mirrors and metrology systems.

By the year 2023, we target being in the implementation phase of the research program for ITER, putting together the VSRS diagnostic system with our research partners, which will include 4 separate sensor systems to monitor the safety and products of the ITER fusion reactor system. The knowledge for this work includes plasma cleaning, shutters, overall diagnostic system design of a system with multiple (4) sensor types, which all must work in the challenging ITER environment, with radiation, contamination, thermal loads, crossing a vacuum barrier. The goal for 2020 is technology development needed for the ITER VSRS system.

Resultaten 2020

<u>Instruments for Earth Observation, Space data utilisation</u>

Our goals for the coming year(s) are twofold: a contribution to the Copernicus program with emphasis on CO2M (global background monitoring of CO2 and related gasses) and a Dutch small satellite instrument that will measure emissions (like NO2, CH4, CO, SO2, NH3, aerosols) with a very high accuracy. To be able to calibrate these instruments we will accordingly further develop our expertise in that field. Main technology drivers are a higher spatial resolution (on the ground) and increased spectral range (new types of gases) and wavelength resolution, reduction of straylight and lower size, weight and cost.

We will work on compact spectrometer concepts that make 1-D images of gases in UV-VIS (NO2, SO2), relevant for CO2M and small instruments.

We will expand to Short Wave Infrared (SWIR) (CH4, CO2, CO) and the next step are 2-D imaging interferometers that can track plumes and have better SWIR performance for small instruments. We will work on both developments in 2020. Long term development will focus on the measurement in Thermal Infrared (TIR) (CH4, N20) and on Volatile Organic Component (VOCs).

The above will include design activities, (additive) manufacturing and coating techniques of (optical) components, testing and breadboarding.

For the CHIME instrument (Hyperspectral land imaging) we will work with industry to study the calibration requirements for instrument concepts to establish the process and equipment needed to successfully characterise and calibrate the instrument to meet challenging requirements.

Related to the above is the further development of our air quality and greenhouse gas downstream models: we need to include more data on air quality and greenhouse gases to make these models more accurate. Such models are needed to provide actionable data for policy makers, other institutions and companies so that they can act and fight air pollution and global warming. Development is needed to include more species (CO2, VOCs) in our models and enable source apportionment for those species (currently only for PM). We will work on parts of that in 2020.

<u>Technologies for Satellite Communication</u>

The goals for the satcom program in 2020 are derived from our long-term goals (Fast, secure, multi-point, far):

- Fast -> enabling fast communication:
    - Terabit class ground station (TOmCAT) - high power breadboard to demonstrate that the optical systems can survive the extreme laser powers required for the future feeder link grounds stations. This includes building a breadboard of a high-power multiplexer where multiple optical channels will be merged into a single beam with an aggregated power of >600W.
    - Coarse Point Assembly (CPA) for Space Terminals – We will be building an elegant breadboard demonstrating new high performance (low jitter) and disruptive combined encoder/actuator technology at SWaPC (size weight power cost).

- Photonic Integrated Circuits (PIC) – We will be developing novel bulk optics<-> PIC waveguide to enable future detection systems that are cost effective.
- Phase Lock Loop Demonstrator – We will be breadboarding a phase lock loop for a coherent detection system which could be used in multiple projects and technology applications such as a wavefront sensor and ultra-high rate data detection system.

- Secure -> enabling security communication
  - QKD ground stations – we will be breadboarding complex adaptive optics system designed to couple extreme low photon counts into fibres.
- Multipoint -> enabling the development of future multipoint communication terminals.
  - Telescope – We will design a highly compact freeform telescope with a large optical aperture 400mm for future GEO space terminals. The study will include design for manufacture, with a large field of view in combination with a low WFE.

Note: 'Far' man on the moon is considered a low TRL market, therefore activities are mainly being performed in the ERP.

<u>Ground & Space Based Astronomy and Scientific Instrumentation</u>

Instruments for Ground-based Astronomy

The goals in this program will prepare us for technologies suited for the increasingly bigger telescopes.

We need to create sky heritage with our deformable mirror technology, therefore we will work on a working prototype (to the testing phase) of the 60cm DM for UH2.2, in a team-wise approach with Dutch industry (VDL, Hyperion, S&T) and a mirror supplier/partner. This may include DM component lifetime and other testing reports. For the bigger mirrors we will start with technology development for more actuators in a mirror: better dynamic performance (looking into SiC), better electronics (speed, dissipation) and higher temperature stability.

In addition, Laser Guide Stars are projected to be needed for the European Extremely Large Telescope (ELT), as well as some complementary smaller telescope systems. This R&D roadmap includes working with industry partners to improve relevant diagnostics, controls and electronic systems in the LGS (FSM, BCDS, Electronics and Controls). By 2022, we target development to near-completion of the ELT LGS (dependent on ESO scheduling). The star will be a joint design study of the ELT LGS, leading to potential contract award with Dutch industry.

Finally, based on customer planning, this roadmap targets initiation of the challenging 3-meter active whiffle tree support structure of the Thirty Meter Telescope (TMT) telescope by 2022. This development sets the stage for future development of the second generation fully active TMT M2 (DM), by a merger of these technology lines (projected late 2020s). We will work on better figure control, lower weight, higher stiffness (SiC) and faster tip/tilt correction technologies.

Instruments for Space-based Astronomy

In 2020 TNO will demonstrate the feasibility of its technology for the LISA and PLATO missions. Those activities fit very well with our priorities as described in the National Space Roadmap (Optical Instrumentation Roadmap). In addition, they support the NWO Strategy 2015-2018 to strengthen the science system in the Netherlands and increase the science contribution to society. For LISA we will continue our work on very precise pointing mechanisms for the alignment of the three satellites. For PLATO we will prepare ourselves with the first concepts of a metrology system for the telescopes, if geo-return regulations allow us.

Scientific Instrumentation

For 2020 we are targeting participation in the development of the Einstein Telescope Pathfinder, a scaled-down engineering model for the Einstein Telescope: a third-generation gravitational wave telescope. Technological developments will be in silicon mirror development and metrology systems.

In diagnostic instruments for nuclear fusion, we target being in the implementation phase of the research program for ITER, putting together the VSRS diagnostic system with our research partners, which will include 4 separate sensor systems to monitor the safety and fusion products of the ITER fusion reactor system. The knowledge for this work includes plasma cleaning, shutters, overall diagnostic system design of a system with multiple (4) sensor types, which all must work in the challenging ITER environment, with radiation, contamination, thermal loads, crossing a vacuum barrier. Goal for 2020 is technology development needed for this VSRS system.

Dynamiek

Given our limited budget and resources and the opportunities we see in our other programs, we decided to stop our investments in our igniters and propulsion activities. We are open to questions from the market in this field, but we will not invest in them and we will not pursue them actively.

Instruments for Earth Observation, Space Data Utilisation

Our long-term goal for a new TROPOMI-like Dutch instrument will not materialise: as the Netherlands we want to contribute to the Copernicus CO2M mission. In addition, we are aiming for a Dutch small instrument. The emphasis of our VP program for 2019 was on knowledge development for state-of-the-art CO_2, NO_2 and aerosol instruments in the coming years. This was relevant for the above-mentioned goals.

The developments we did on space data utilisation, amongst others, resulted in the LOTOS EUROS- TOPAS model: real time source apportionment of PM (aerosols) and enabled us in finding CH_4 hotspots. We see that developments on information (actionable space data) go hand in hand with the need for the development of new instruments. This connection will be increasingly important and gives TNO a meaningful and rare proposition.

Satellite Communication

In 2019 big service providers explicitly stated their ambition for optical satcom networks. TNO have developed critical technologies in support of these ambitions and are in discussion or collaboration with an increasing number of those service providers. Two Dutch companies have sent RFI responses of appr 80mlnE to a German company, TNO is part of that for only 10%. Without TNO, those companies could not have sent those responses out. Another major step was a TKI contract with ABN AMRO and QuTech on free space QKD: a first project in this field. We will continue work on technologies that will position us and the Netherlands globally in this emerging market. We have a very clear focus: with our continuous improving technological building blocks and our systems and domain knowledge, we will work on the development of state-of-the-art optical terminals

Ground & Space Based Astronomy and Scientific Instrumentation

In Ground-Based Astronomy we have built further on our position from our M1 ELT success. Dynamics in this market are slow: programs evolved at a slower pace than we anticipated and some of our intended research was delayed and will be done next year.

With our technology development for Space-Based Astronomy in the past years for the LISA instrument we have positioned ourselves very well. In 2019 we have started an activity funded by the NSO parallel to the ESA phase A study that prepares us for the next phase of the mission. Due to geo-return restrictions, it is still to be determined whether we are able to join the PLATO consortium.

With the limited national funding available TNO faces a difficult challenge to contribute to the Einstein Telescope. If this situation remains, we will have a limited role in this very exciting project.

Titel	**Semiconductor Equipment (P612)**
Missie/ Topsector	HTSM
Contactpersonen TNO	Rogier Verberk, Jochem Janssen

Contact extern	Joep Pijnenburg (leader HTSM Roadmap Semiconductor Equipment; ASML), Ton Flaman (leader HTSM Roadmap Healthcare; Philips Healthcare), Frank de Jong (leader HTSM Roadmap Nano-tech-nology (incl. quantum technology); Thermo Fisher Scientific)

Programma jaar 2020 - Samenvatting

TNO's roadmap on Semiconductor Equipment aims to position the Dutch high-tech industry to provide critical enabling technologies to the information driven, ageing society and digitization challenges, leading to sustainable jobs and growth of the national GDP now (semiconductor industry) and in the future (quantum industry), while addressing the sustainability of the healthcare system.

The Dutch semiconductor industry is leading in lithography, the most critical process step in chip manufacturing, and has dominating positions in equipment & modules for, e.g., electron beam microscopy and wafer processing equipment.

By 2023 we aim to have this position enhanced by world record performance in productivity and overlay (immersion lithography), by full industrialization of EUV lithography, by having new metrology concepts introduced by Dutch vendors, and by having the next generation of high-NA EUV lithography under way.

TNO supports this by continuously pushing the limits of flow & thermal management to enable cleaner and more stable lithography equipment, contamination control (including equipment for cost-effective detection of particles of 1 micron on surfaces, based on TNO IP, to be commercialized in 2020), material science (including understanding of EUV induced plasma effects, and qualification of materials for EUVL mirrors, reticles and pellicles with the EBL2 facilities in 2020), by developing new sensors for alignment down to 1 nm, and by developing scanning probe-, acoustics-, X-ray-, and nearfield optics based metrology towards semiconductor applications.

TNO's Medical Photonics program aims to improve health while reducing health care costs for the ageing population by accelerating photonics-based innovations and their implementation in health care. Focus in 2020 is to develop diagnostic optical devices for use in primary care, including multispectral hand held fundus camera's for primary care based screening of eye diseases and systemic diseases.

TNO will support the ambitions by the PhotonDelta PPP to develop a sustainable industrial ecosystem on integrated photonics by 2026, by investing in photonic integrated chips for quantum technologies, medical applications, and laser satellite communication.

A spin qubit based quantum computer accessible via the web, and a quantum communication channel between Delft and The Hague are two of the 2020 milestones for QuTech/TNO, towards the Netherlands as a vivid hotspot for quantum technologies in the coming decade.

Korte beschrijving

<u>Semiconductor Equipment – System Lifetime and productivity</u>

Optics lifetime for EUV lithography has advanced into a domain where plasma effects, e.g., material-plasma interactions, and plasma formation are dominant over the conventional photon-based contamination growth. To enhance understanding of EUV processes in lithography systems and on critical parts, such as EUV reticles, TNO commissioned its new EUV beamline EBL2. In 2020 EBL2 will be key infrastructure for research to understand EUV scaling effects with the aim to perform detailed accelerated lifetime tests on critical parts.

Production with EUV is sensitive for particle contamination, since a single particle at the wrong place could be a "yield killer". To screen critical parts on particle contamination, TNO is developing a cost effective inspection system, Fast Micro to be commercialized in with a Dutch SME. Another development is TNO's mass filtered ion gauge (MFIG), a fast molecular contamination detection system, which is also planned to be commercialized with a partner.

<u>Semiconductor Equipment - Metrology</u>

At TNO the Semiconductor Equipment Metrology developments are aimed at the metrology technology needed to enable research and high volume manufacturing of the future's semiconductor devices. Moving further on Moore's law to shrink device dimensions and going to 3D device integration can only be done by making use of new materials and new manufacturing technologies, which needs continuously improved resolutions as well as materials characterizing metrology at sufficient speed. To that end we combine our leading positions in probe microscopy, optics, optical spectroscopy, metrology platforms and newly developed quantum technology to push for new, multimodal, solutions.

The TNO roadmap for developing these tools is fully aligned with the International Roadmap for Design and System (IRDS), attuned with the leading industry partners and anchored in the PMC semiconductor metrology roadmap of TNO.

Optical instrumentation for the (bio) medical market

Medical technology development related to the HTSM Healthcare Roadmap is embedded in the “Medical Photonics” research program. The Medical Photonics program aims to accelerate medical and technological innovations and their implementation in health care.

Within the program we develop biophotonics technologies to enable better and faster diagnosis and monitoring of diseases in (a)symptomatic stages; better and/or personalized treatment for patients; and less invasive surgical procedures leading to improved health outcomes, reduced healthcare costs and a sustainable health care system. Four different technology platforms are used as underlying technologies for our developments:

- An ophthalmic imaging platform
- A nano-photonic sensing platform
- Tissue characterization platform
- A fluid characterization platform

Integrated Photonics

The 2020 Integrated Photonics program will focus on the topics that have been identified in the 2019 program will focus on topics where TNO can add value to the Dutch photonics community, work directly with industry and which fit within the national agenda. The program focus on:

- Photonic integrated circuits for medical applications: development of opto-acoustic source- and detector arrays for proton therapy, partly funded by ATTRACT and NWA-ORC 2018. The opto-acoustic devices are expected to provide improved performance. For label-free biosensing, a TKI project with TNO spin-off Delta Diagnostics is aimed for.
- Photonic integrated circuits for quantum technology: the development of an integrated nitrogen vacancy (NV)-based entanglement source has started in 2019, and will continue in 2020.
- Light Detection and Ranging (LIDAR) & Satellite communication applications: Optical Phased Arrays (OPAs) can enable the solid state beam steering functionality that is demanded for in these two domains. Initial work on OPAs in 2019 will be continued.

Quantum Technology

The plan for quantum technology is reported in the Early Research Program plan for QuTech - Quantum computing and quantum internet.

Resultaten 2020

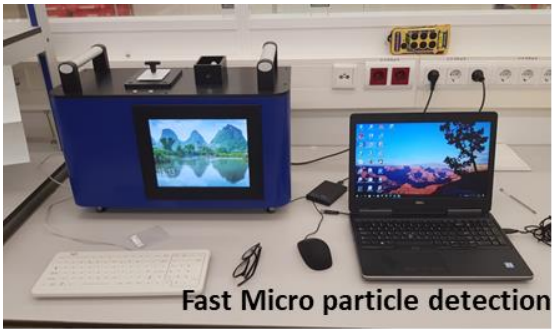
Semiconductor Equipment – System Lifetime and productivity

The recently developed EBL2 is currently being used for EUV exposures in research projects and customer projects. In 2020 new insights are expected to be gained on the behavior of EUV induced plasma, surface degradation mechanisms, and scaling parameters for lifetime prediction. Also concepts for EUV reflectometry and contactless thermal measurements are expected (ECSEL project TAPES3).

First results are expected to be gained on understanding the effects of spectral distribution of EUV light to sensitive surfaces with respect to contamination and surface degradation effects.

TNO's developed mass filtered ion gauge (MFIG) will be tested with consortium partners in the ECSEL project MADEin4. The use cases will be used as input for possible commercialization of this sensor with and transfer to a development partner.

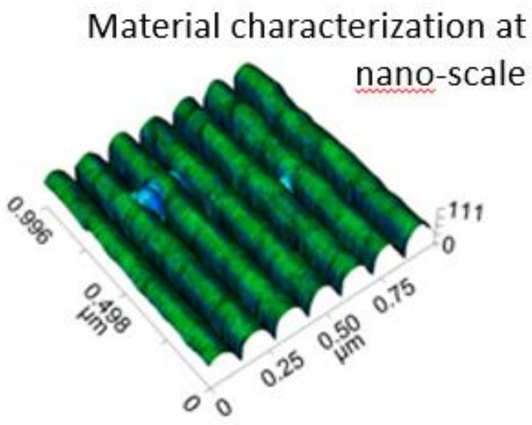
In 2019 TNO's new particle detection system, the Fast Micro was developed and demonstrated on a/o pellicles. In 2020 TNO plans to commercialize the Fast Micro, in cooperation with the Dutch SME Lans Engineering, aiming to have all "particle critical" parts for EUV lithography screened or qualified with the Fast Micro.



Semiconductor Equipment - Metrology

For the 2020-2023 timeframe, we focus on developing the building blocks for a multi-modal imaging metrology platform, as we will need to rely on the inputs from multiple sensors, making use of different technologies, integrated to provide the most relevant process steering information. Building blocks are:

- Subsurface scanning probe microscopy (SSPM): focus will be on photo thermal acoustic actuation and the high GHz acoustic scattering region to combine few nm's scale resolutions at large penetration depths. A first proof of concept set up is due for 2020.
- Material characterization at the nano-scale: combining leading probe microscopy technology and spectroscopy for materials characterization at higher resolution purposes. Set up and first results to become available in 2020.



- Quantum sensing: first steps towards making use of newly developed quantum technologies in combination with probe microscopy to characterize material properties and critical process steps at the needed (few nm's) resolutions.
- Optical (soft)XR: exploring and, where possible extending the limits of (fast) photon based metrology.
- Development of suitable magnetic levitation based metrology platform: to enable multi-sensor head agile movement and precise positioning.

- AI-based data analyses: smart combination of multi sensor based data into effective control and steering the manufacturing processes.

Applications targeted are in alignment, overlay, critical dimensions, tomography and materials and defects characterization for the semicon equipment industry. Spin-off applications are in e.g. biomedical characterization and diagnostics.

The above activities will be conducted in multiple TNO, academia and leading semiconductor industry based cooperation.

Optical instrumentation for the (bio) medical market

TNO continues, within a EU-funded project ("MOON"), with the clinical validation of a fluorescent fundus camera for curcumin imaging, which binds to protein (senile) plaques in the retina and can be visualized using fluorescence imaging. This is an important development aiming at earlier detection of Alzheimer's disease using an eye-scan.

Efforts will continue to develop a novel ophthalmic imaging platform that involves looking in to the eye with a camera and quantifying light scattering, absorption and fluorescence from the retinal images thus made. These measurements enable earlier detection of eye diseases such as diabetic retinopathy, age-related macular degeneration and glaucoma, as well as of systemic diseases such as cardiovascular and neurodegenerative diseases.

In 2020 we will set up a TKI project with Sanquin and retinascope to develop and clinically test a medical device that can measure systemic Hb concentration fast and non-invasive in the eye.

TNO will continue to explore the use of Photonic integrated circuits (PICs) and waveguides for medical applications. An EU and a NWO project will start in 2020 regarding the development of a PICs-based optoacoustic sensor for dosimetry in proton therapy.

Integrated Photonics

TNO aims for a first iteration of opto-acoustic detector arrays, partly funded by ATTRACT, thereby a follow-up proposal for ATTRACT submitted & granted. Also a prototype PIC-based opto-acoustic emitter is foreseen.

Regarding quantum technology TNO aims for a prototype integrated NV-based entanglement source, and for LIDAR applications an OPA design based on sparse arrays.

Quantum Technology

The plan for quantum technology is reported in the Early Research Program plan for QuTech - Quantum computing and quantum internet.

Dynamiek

Semiconductor Equipment – System Lifetime and productivity

The new EUV beamline (EBL2) is ramping up and starting to be used for multiple EUV research exposures for customers and mixed-funding research projects. TNO aims to enhance our position and visibility by positioning our extensive knowledge base in combination with experimental systems, such as EBL2 to an extended community of semiconductor equipment, e.g. mask industry.

With the aim for commercialization of the Fast Micro and MFIG, TNO will introduce new knowledge and/or combinations of knowledge transfer supported by proven prototypes to commercial parties in the field.

Semiconductor Equipment - Metrology

TNO has established a signification knowledge base and leverage during the last years to be a technology partner in the field of SPM (Surface Probe Microscopy) and platform solutions. This leading edge of TNO shall be kept, exploited, and increased where possible during the coming years. But the new device design developments necessitate the need to go into new directions, making use of TNO's established positions in complementary areas. As (composed) materials, dopants, chemical and electrical properties are getting more key for enabling the future nodes, we will need to develop the technology to characterize them at sufficient resolutions and with sufficient speeds. Multi-modal imaging platform and AI technologies are deemed crucial elements as well, as the future can only be made visible combining the strengths of multiple sources information into truly hybrid metrology

Optical instrumentation for the (bio) medical market

The launch of the Photonics Technology for Health Center in Amsterdam is expected for 2020 is expected to be ambitious.

Investigations on potential fusion of acoustics and integrated photonics technologies resulted in a granted NWA project of acousto-optical sensing for proton therapy dosimetry starting in 2019.

Integrated photonics

After signing the PhotonDelta Convenant in December 2018, TNO started in 2019 with a program on photonic integrated chips (PIC) developments aiming for applications in the medical-, quantum-, and satellite communications areas.

The Chip Integration Technology Center, initiated in Nijmegen in 2019, will be the place to research packaging of PIC's, but will focus on starting up the programs on electronic chips packaging first.

In 2019 TNO celebrated the start of two spin-off companies: Delta Diagnostics (medical instrumentation based on integrated photonics) and Valley Optics (developing software tools for opto-mechanical designs).

Quantum Technology

After a very positive external evaluation of the knowledge position of QuTech, QuTech and TNO took the initiative to develop the National Agenda Quantum Technologies together with all relevant parties in the Netherlands. This agenda will be presented in November 2019.

Development of qubits for the Quantum Inspire platform as well as the technologies for the quantum communication link between Delft and The Hague turned out to take more time than originally scheduled. 2019 Milestones shift to 2020.

More detailed plan is described in the Early Research Program plan for QuTech - Quantum computing and quantum internet.

Titel	**Flexible and Freeform Products (P615)**
Missie/ Topsector	HTSM
Contactpersonen TNO	Ton van Mol
Contact extern	

Programma jaar 2020 - Samenvatting

In VP 'Flexible and Freeform Products' we develop technology for next generations of smart products, made by digital manufacturing processes. Applications are in multiple domains such as healthcare devices, automotive and home products. The program consists of the following program lines:

<u>Digital Manufacturing Systems</u>

We develop new technologies for digital manufacturing processes such as 3D printing. With digital manufacturing, the shape of the product is not defined physically (e.g. by a mould or mask) but by the software that controls the manufacturing system, allowing for customization of products and cost-effective small series manufacturing. In 2020 we further develop this technology for use in the food and pharma industries towards.

- Personalization by control and being able to vary the composition throughout the product (e.g. more or less sugar/fat/salt in food and dosage control in pills).
- Improved texture, to create better taste perception of food products.
- Release profile control.

This will be implemented in our flexible R&D setups for faster development and innovation. This is in line with the KIA Smart personalized food and medicine which has been selected.

<u>Materials for Additive Manufacturing</u>

One obstacle to Additive Manufacturing becoming a mature manufacturing technology is the limited performance of available materials. We therefore aim to gain more insight into the relations between material composition, processing conditions and product performance, and to develop new materials with improved mechanical performance to enlarge the application possibilities for polymer materials in Additive Manufacturing. In 2020 our focus is on developing material-process combination to 3D-print parts with continuous fibers in it, for (1) improving the mechanical performance of these parts, and (2) allowing integration of new functions, such as thermal conductivity, electromagnetic shielding and sensing of mechanical and thermal stresses.

<u>Hybrid Printed Electronics</u>

In this program (also described in KIA Flexible Electronics) we create the technology for next generation of 'internet-of-things' products, being a hybrid combination of printed electronics and 'conventional' silicon-based electronics. In 2020 we continue developing the underlying technologies. We will develop sensors and arrays of sensors that can measure human vital signs over large area, enabling innovations in e.g. healthcare like automotive driver monitoring, wearable health patches etc. We will also continue developing the enabling technologies for 3D electronics, which we believe will be the next application space for printed electronics with applications in the field of 5G (printed antenna's) and radar systems. And finally, in 2020 we will work on advanced chip packaging in the framework of CITC Nijmegen activity.

Large-Area Technologies

We continue to develop capabilities and applications in 'Spatial Atomic Layer Deposition' (S-ALD), a key technology to cost-effectively make nm thin layers of high quality. Our prime focus will be to facilitate uptake by multiple industries, incl. our spin-off SALDtech and other local equipment manufacturers, and with partners to demonstrate new applications in electronics and energy domains.

We accelerate our activities on next generations of batteries for electric driving and wearables, making use of our core capabilities in deposition technologies (and in line with KIA 'Batteries of the future'). In 2020 we proceed with an advanced concept (3D Li-ion batteries) making a second-generation demonstrator, establish a pre-pilot line to scale up to pouch cell size with dedicated equipment, and develop shorter-term improvements for existing battery concepts using our S-ALD capabilities.

We have finalized establishment of a pilot line for Organic Light Emitting Diodes (OLEDs) for lighting and signage purposes to enable companies to step into this technology without having to commit to mass manufacturing.

Thin-Film Transistors

Our metal-oxide transistor circuits are directly deposited on large-area substrates. This enables cost-effective distribution of intelligence (simple electronic circuits) over large areas such as in imagers and sensor arrays. In 2020 we develop alternative, simplified manufacturing process flows for lower cost. We develop advanced X-ray imaging modalities for medical applications, we transfer to industry ways to manufacture and integrate biometric security based on fingerprint or palm sensing. We develop new propositions based on NIR sensors and large-area ultrasound transducers for next generations of imagers and sensor devices in the healthcare domain. All this is described in the KIAs 'Flexible Electronics'.

Korte beschrijving

Digital Manufacturing Systems

Within the food domain TU/e, WUR and TNO are teaming up on under Digital Food Processing Initiative (DFPI). Digitally controlled manufacturing processes such as 3D printing/additive manufacturing provide opportunities for personalization and customization of products and in the design of texture and release profiles. These processes however still have limitations in materials, productivity and quality. Goal for 2022 is to enable application of digital manufacturing in food and pharma industry, by commercial application of five food industry companies(digital food processing) and two pharma companies (pharma printing).

Materials for Additive Manufacturing

This program line is executed in Brightlands Materials Center (BMC), a joint initiative of TNO and the Province of Limburg with TU/e and UM as academic partners. One of the key obstacles to Additive Manufacturing becoming a mature manufacturing technology concerns the limited mechanical performance of available materials. BMC focuses on polymer materials, in particular fiber reinforced thermoplastic polymers. The 2023 goal is to introduce new fiber reinforced polymer materials suitable for 3D printing of complex products with integrated thermal and sensing functionalities in industry, enabling wider usage of Additive manufacturing, in the production of complex, integrated parts for example in automotive and aerospace applications.

Hybrid Printed Electronics

This program line of Holst Centre combines printing with silicon-based components to realize electronics devices that, unlike standard Printed Circuit Boards, are flexible, stretchable and 3D-shaped (either 3D printed or shaped into 3D). Main application domains are in wearable/medical devices, automotive and human machine interfaces (HMI). The main goals for 2022 are:

- Printing technology innovations: develop novel printing technologies that can print at sub-10 um resolutions; Applications to be found in field of communication (5G, radar).

- Structural electronics (3D electronics made by shaping 2D electronics): establish a mature technology and functionality portfolio for in-mould electronics (IME).
- Sensoric surfaces: develop applications based on printed sensor arrays in combination with advanced algorithms for the field of human vital sign monitoring.
- Wearables: develop health patch and smart clothing applications using printed electronics for monitoring human vital signs like ECG, core body temperature.
- Advanced packaging. Develop innovative chip packaging solutions for high thermal load and RF chips.

<u>Large Area Technologies</u>

This Holst Centre program line develops processes and applications for low-cost, large area thin-layer deposition.

- Contribute to future generations of energy storage based on batteries for electric vehicles and stationary (grid) storage along three axes: demonstrate next generation of 3D Li-ion solid-state battery, apply Spatial Atomic Layer Deposition (S-ALD) to enable Li-metal anodes and battery improvements through interface engineering, and enhance battery system performance by monitoring systems with printed sensors.
- Create and extend applications of S-ALD: deposition equipment for various industries, teaming up with our SALDtech spin-off and other regional companies, develop new S-ALD processes to extend capabilities (lower temperature, patterned layers, new materials, Atomic Layer Processing), demonstrate propositions in additional outlets such as batteries, optical coatings, thin-film photovoltaics, and membranes for fuel cells.
- In partnership with RTOs in EU, exploit a pilot production line for flexible OLEDs for lighting and signage products, making application of OLEDs in products accessible to a large group of companies preceding mass manufacturing.

<u>Thin-Film Transistors</u>

This Holst Centre program line targets applications of thin-film transistor (TFT) technology such as imagers/detectors (image sensor arrays) and electronics.

- Finalize establishment of a TFT manufacturing pilot line for external parties, fabricating prototypes of various large-area electronics applications.
- Develop (im)printing and S-ALD techniques to enable alternative manufacturing process flows with higher simplicity, lower cost, and potentially smaller dimensions.
- Develop new propositions in various health-related application domains, such as ion or gas sensors, lab-on-a-chip, X-ray and NIR sensing that leverage our technology capabilities and pre-pilot line infrastructure.
- Further develop our organic photodetector and X-ray detector technology platforms to NIR -infrared sensitivity and direct-conversion X-ray, respectively, and demonstrate in biomedical applications.
- Transfer our organic photodetector technology for full display-area fingerprint scanner and touch sensor in mobile phones to industry.

Resultaten 2020

<u>Digital Manufacturing Systems</u>

- Food printing: most food items consist of multi-materials and therefore the goal for 2020 is to develop multi-material powderbed printing. For fused deposition moulding (FDM) already initial steps have been made on multi-material printing via coaxial and multi-nozzle printing. The next step in FDM printing is towards personalization and for that purpose inline mixing and dosing is the goal.
- Pharma printing: challenges for the pharma industry are 1) reduction of cost and duration of medicine development, 2) increased effectivity of medicine and 3) improved therapy compliance and patient comfort. Goal is to improve the reproducibility and reliability in order to meet the pharma requirements.

<u>Materials for Additive Manufacturing</u>

- Line of research concerns combining continuous carbon fiber with high performance polymers to enable 3D printing of products able to withstand high mechanical and thermal loads. We will collaborate with industrial partners in One automotive and aerospace applications as well as with material suppliers such as carbon fiber manufacturers, to develop demonstrator products for structural parts.
- The second line concerns integration of additional functionalities such as thermal conductivity, electromagnetic shielding or strain sensing. In 2019, we have shown a proof-of-principle for strain sensing. In 2020, this will be developed further to produce demonstrators for specific application fields.

Hybrid Printed Electronics

Printing process innovations

- Holst Centre has been working for a number of years on printing technologies like LIFT (laser induced forward transfer), PhaTT (photonic ablation transfer technology) and curing technologies like photonic sintering and photonic soldering. For 2020, the goal would be to increase printing resolutions down to 10 um and to demonstrate a printed radar antenna. With regard to 3D printed electronics, in 2020, a first round of process development and demonstrator realization will take place on the newly installed 3D printing equipment, likely also related to antenna printing.

Structural electronics

- We will gradually shift the attention from technology to functionality and application development. The 2020 focus will be on advanced user interaction by creating all-printed pressure sensitive touch buttons.

Sensoric array surfaces

- Printed electronics technologies allow for a relatively easy realization of distributed electronic functionalities on large surfaces. In particular, there has been already for a number of years strong industrial interest to print arrays of sensors on such large surfaces. For example, pressure sensors (shoe inlays, smart bedding) and also temperature sensors (thermal mapping). For 2020, the focus will be on creating sensoric surfaces that can measure human vital signs, in particular driver monitoring.

Wearables

- The capability of our medical patches and smart clothing devices to be highly body conformable (stretchable, thin) will be further increased. New materials will be evaluated with partner companies. Besides this, we will start exploring new patch-based applications like wound dressings.

Large Area Technologies

Advanced Li-ion batteries

- After initial demonstration of 3D solid-state battery (SSB) in 2019, we will work towards a 2nd generation demonstrator with cathode material with higher capacity, as a first step to a Minimum Viable Product (MVP). Secondly, we will continue to develop the key technology building blocks further, especially the Li metal anode deposition step.
- Specification, order and installation of a solid-state battery pre-pilot line, particularly dedicated S-ALD and CVD equipment to enable scale-up to pouch cell size.
- Continue to demonstrate the capability and value of S-ALD for engineering interfaces in Li-ion batteries, such as modification of separator foils, passivation of Li metal anodes, and deposition of solid-state electrolytes. Partners will be in the battery value chain: materials providers, cell manufacturers, OEMs.

Spatial Atomic Layer Deposition equipment and applications

- Facilitate equipment commercialization for various applications through multiple equipment makers: with SALDtech, construct the first S-ALD equipment dedicated to display manufacturing; support other (regional) companies in their equipment development and with application engineering. Demonstrate the applicability and performance of S-ALD layers (TFT channel, dielectric) in TFTs.
- Expand materials and application scope of S-ALD by demonstration of indirect plasma S-ALD, ‘ABC’ S-ALD (with ‘C’-cycle to do in-situ anneal or other additional step), patterned S-ALD (maskless and area-selective growth).

- With partner Solliance, demonstrate performance of S-ALD functional layers in various types of thin-film PV (CIGS, Perovskites).
- Explore potential S-ALD benefits and propositions in adjacent technology domains such as optical coatings, energy conversion applications, and photonics.

Thin-Film Transistors

Imagers

- Building on the existing technology platform for visible light (OPD) and X-ray detection (based on scintillator), we will develop technologies and demonstrators for new functionalities and applications. New photosensitive materials can extend the wavelength region into the (near-)infrared, where a.o. large-area biomedical sensing applications are possible. Direct-conversion X-ray based on thick perovskite material can yield higher-resolution X-ray imaging. Transparent scanners can be used in human-machine interaction. We will also explore high-energy radiation detection for use in scientific and medical instrumentation.
- Technologies for high-resolution fingerprint scanning are relatively mature and in 2020 we focus on transfer to manufacturers of consumer electronics such as smartphones and producers of biometric security devices.

Thin Film electronics

- In partnership with BMC, imec, TU Eindhoven, and KU Leuven, establish a pilot production line for flexible TFTs and a one-stop shop that (local) industry as well as knowledge institutes can approach for support (supported by Dutch-Flemish Interreg office, project ‘Flexlines’).
- Continue to engage with display innovators to develop technologies and prototypes of next-generation displays. Key need is for smaller pixels and transistors that can deliver more electrical current.
- Develop new propositions and new demonstrators, using the TFT technology platform, for new applications. In collaboration with imec-NL, develop ion and gas sensors. Explore potential new applications in the healthcare and pharma domain, such as lab-on-a-chip and machine-brain interfacing, in collaboration with TNO colleagues and academia.

Dynamiek

Compared to our 2019 plans, the main changes are summarized as follows:

- Digital Manufacturing Systems: end of 2018 the focus on food and pharma was chosen. For this purpose on food DFPI has been started to create the right ecosystem with complementary competences on food science and digital manufacturing. For pharma the right partners to team-up with need to be found and synergy needs to be created.
- Materials for Additive Manufacturing: the program line has focused substantially in 2019; no further changed are foreseen for 2020.
- Hybrid Printed Electronics: no changes are foreseen as compared to the 2019 plan.
- Large Area Technologies: no new technology development in the field of flexible OLED will take place in view of technological challenges and low market growth. The pilot line for flexible OLEDs, developed through the EU-funded project PI-SCALE, will continue to be exploited for B2B projects. Key partner will be Fraunhofer FEP as technology co-provider.
- Thin-Film Transistors: no changes are foreseen as compared to the 2019 plan.

Titel	**Intensivering Smart Industry (P617)**
Missie/ Topsector	HTSM
Contactpersonen TNO	Rogier Verberk, Sam Helmer, Peter Laloli
Contact extern	
Programma jaar 2020 - Samenvatting	

The long term TNO objective is the same as the objective of, the HTSM Roadmap Smart Industry, the Routekaart Smart Industry in the NWA and the key enabling technology Engineering & Fabrication technologies.

In 2023, the Netherlands has the most flexible and best digitally connected production network in Europe for the design, production and supply of smart products and associated services. Within this production network the manufacturing companies also achieve substantial energy and material savings in production and the lifespan of the Products. And the employees are continuously able to maintain their (digital) knowledge and skills.

Within this national implementation agenda, 8 transformations are defined as that manufacturing companies in the Netherlands have to make, to achieve the national objective (see picture). Of these 8 transformations, TNO focusses on 4 transformations, i.e.:

1. Flexible Manufacturing
2. Smart Working
3. Digital Factory
4. Connected Factories

And to support manufacturing companies to realize these 4 transformations, TNO develops knowledge on 5 expertise area's:

- Flexible Manufacturing
- Smart Work
- Data Sharing
- Digital Twinning
- Smart Response

Korte beschrijving

The following expertise areas are being developed to contribute to the industrial transformations, the HTSM roadmap and the KIA *Key Enabaling Technologies:*

1. Flexible Manufacturing

How to create Single-piece production at a cost price of mass production with zero-defect, -delay and -waste? Key challenges are the orchestration of smart robotics, sensors, software, work cells and production machines that work together without requiring costly programming that cannot be earned back in low series production. Automatically adapting to changing products without human intervention.

2. Digital Twinning

How to create a digital life cycle next to the physical life cycle. How to create new digital business, adaptable processes and reduce costs on top of regular production. Key challenges: How can data be used as input for models? How can different models work together? How to prove the financial viability of an improvement through a model simulation

3. Data Sharing

How to become the most competitive supply network for high-tech, high-complexity, low volume manufacturing by sharing data? How to combine manufacturing data from the production line with administrative data from financial and logistics systems and do this across company borders? Key challenges: How to enable vendor independent 'plug & play' data sharing within the factory environment and across company borders. How to battle "winner take all" platforms from America and China by giving data sovereignty to companies that provide data?

4. Smart Work

How to keep the very scarce amount of human resources at manufacturing companies sustainably employable in times with rapidly changing technologies? Key challenges are: How to create productive and instructive work environments through human-oriented technology? How to optimally use augmented reality, cobots, machine learning, sensors/feedback, big data, and artificial intelligence.

5. Smart Response

How to respond to the acceleration of the digitization process and how to realize the desired economic and social impact? Key challenges are the research into the social and economic effects of the disruptive changes due to Smart Industry and the disruptive technologies (robotics, AI, embedded sensors and Internet of Things), leading to changes in the labor market, required skills, and new business models etc. and how these changes can be used to the full as a society.

Resultaten 2020

In 2020 the primary focus for this program is the further development of the products, markets and technologies in the previously chosen Product Market Combinations (PMCs) and to do this PMC development in the previously chosen Regional innovation programs. These are the Smart Manufacturing Industriele Toepassing Zuid Holland" SMITZH program in the Province of South Holland, and the "Fabrieken van de Toekomst" program of the Province of North Brabant, located in Eindhoven at the Brainport Industries Campus (BIC).

In both programs TNO will do its work within so-called Fieldlabs. These Fieldlabs are Joint Innovation Centres of Research and Industry, often created by TNO and a local group of companies and provide a "vraaggestuurde omgeving" for making the TNO technology concrete and valuable for industry. In total TNO will work within at least 8 Fieldlabs with at least 40 companies.

Furthermore, TNO will participate in at least 4 EU partnerships on further strengthening the 5 expertise areas.

TNO will run at least 5 "vraaggestuurde projecten" with companies within the Fieldlabs of the BIC and SMITZH.

The following deliverables are defined for the 5 product market combinations:

1. Flexible Manufacturing

- Generation of robot paths using the minimum of manual programming, Method to integrate information and measured data from the surrounding of a robot.
- Strategy to deal with moving or shape shifting products and surroundings
- Strategy to arrange robot paths for manufacturing with multiple robots that work together without collision
- Inventory of machine learning, artificial intelligence, and data analytics, design optimization techniques for flexible manufacturing, especially taking into account small data (small series) and heterogeneous data (mix of signals and information) and multi-disciplinary aspects.
- Concept approach for self-configuration of manufacturing / assembly lines based on theory and tools of manufacturing agents.

2. Digital twinning

- First architecture for a digital life cycle.
- First working flow of machine, data, models & control.
- First coupled set of models (process and production steps).
- First simulations using real-life data.

3. Data sharing

- Architecture for factory automation, using data collection and structuring technologies.
- Create a testbed based on IDS (International Data Spaces) standards.
- Extending the SCSN domain models into a full semantic-web ontology.

4. Smart Work

- Integral approach to task allocation to create an optimal task division between human and robot.
- Developing and demonstrating collaborative robot concepts and operator support concepts.
- AR support in light weight aerospace construction.

This will be a joint effort with P207 Sociale Innovatie.

5. Smart Response

Clear answers on how we respond to the digitization process and how we can anticipate these developments to come to the desired economic and social impact and to avoid negative effects for instance for specific groups. Important elements are smart responses to sustainability and skills development. This will be realized via economic and social impact analysis, scenario's showing unknown future requires, monitoring and insights in the international perspective, in value chains and the platform economy. Orchestrating innovation is also very crucial for a smart response (e.g. via the Fieldlab and digital innovation hub networks via which solutions for a smart response are developed).

External alignment

External alignment and connection of this roadmap is already well established. Although Smart Industry is a relatively new innovation theme, TNO has played a strong role and has involved all relevant stakeholders from the beginning to secure a broad basis for Smart Industry related innovations. Preferably in multiple-partner collaborations and consortia (often denoted as Field labs) as to join forces with these parties as much as possible to leverage the investments made by each.

In particular we strive to maintain a high quality collaboration with or act in alignment with applicable roadmaps and scientific research agendas:

- EU initiatives such as EFFRA (who run the Factories of the Future programs) and I4MS (ICT for manufacturing SME).
- National initiatives such as the Smart Industry action agenda, the implementation agenda and through the HTSM Roadmaps Smart Industry and Advanced Instrumentation.
- Regional initiatives of the Regional Development Agencies such as the Brainport Industries Campus in the South, SMITZH in the West, Smart Industry Boost in the East and Region of Smart Factories in the North.
- NWA route Smart Industry.
- KIA advanced manufacturing systems and processes (knowledge and innovation agenda describing key technologies and societal challenges related to Smart Industry).

Dynamiek

The first 5 years of this program (2014-2019) can be characterized as the “startup phase” where the program has grown from greenfield to an already significant scale within TNO. This has been a great effort by the team, with some opportunism that has led to a good position for TNO in the field. The year 2020 marks the start of the next 5 years of the program where we aim to act more as a “scale-up”: i.e. streamline internal operations, build more mass and make strategic choices on where to direct our efforts.

We trust the product market combination (PMC) choices we made in 2019, and in 2020 we will closely monitor the traction of those PMCs in the outside world and adjust accordingly

Titel	**Bouw Innovatie (P513)**
Missie/ Topsector	HTSM
Contactpersonen TNO	Peter Paul van ‘t Veen, Henk Miedema
Contact extern	Bert van Haastrecht (M2i)

Programma jaar 2020 - Samenvatting

Development of cementitious binders based on secondary materials: Custom-built flow though experimental set-up to determine the dissolution rate of the binder precursors and effects of the activators on dissolution (left) and adapted reverse osmosis experimental set-up to determine the precipitation point (and solution- / precipitationproducts) (right).

Sustainability and cost reduction in construction require reduction of the quantity of building materials used, replacement of raw materials through re-use and use of waste streams and bio-materials, increase of service life through better understanding of degradation at the material level. The main role for TNO in this area is to predict and improve the performance of key materials through analytical techniques and advanced modelling, with a focus on stony materials and asphalt.

For ***stony materials*** we focus on the prediction of the performance (including service life) of existing as well as new materials, with application ranging from monuments to building with secondary materials. By understanding, for instance, the formation of silico-aluminate chain building blocks that make up our future concrete, the (long term) performance of building materials with new aggregates and binders can be better predicted. We develop a methodology (blend tool) with which aluminosilicate side streams can be characterized and blended to alternative binder products for concrete, with similar performance and service life but higher sustainability and lower cost. This requires measurement techniques and models for describing reaction processes in alternative binders, the reaction products and their stability. The latter is crucial for understanding degradation and for the design of accelerated ageing tests. In 2020 our focus will be on thermodynamic modelling of the processes involved and a model for predicting precipitation products and rates. The blend tool developed for dissolution will be extended by including the hardening process. Another topic that will be addressed is degradation of stony materials (masonry, concrete).

For ***asphalt*** we develop models for predicting material performance that take into account material ageing as well as various fatigue loading regimes over time. These models are validated using monitoring data. The models can be used to forecast maintenance needs of existing materials and to predict the performance in pavements of innovative (more sustainable) materials. This requires a better understanding of ageing phenomena in surface layers, taking into account the use of recycled materials and application of rejuvenation techniques as well as mechanical models for translating changes in the behavior of materials to structural performance of pavements. In 2020 we will focus on understanding and predicting of ageing of especially recycled materials and of bitumen quality, and will make a first prototype of a FE-model integrated with a model of important determinants of bitumen quality and other material properties.

Korte beschrijving

Stony materials. Portland cement in stony materials needs to be further replaced to reduce CO2 emissions. By-products from the power plants (fly ash) and steel industry (blast furnace slag) are currently used to partly replace Portland cement. Other types of by-products will have to replace these side streams from non-circular processes. Many other aluminosilicate side streams (e.g. bottom ash from municipal waste incinerators, fly / bottom ashes from biomass power plants, certain types of construction and demolition waste, waste from brick factories and inorganic waste sludges from the paper recycling industry) are available. Our ambition is to make a generic blend tool for (earth-alkali) aluminosilicate side streams with which a binder can be obtained with required performance, but with a higher sustainability and lower cost. This requires measurement techniques and models for describing reaction processes in alternative binders, the reaction products and their stability. The latter is crucial with respect to degradation and the design of accelerated ageing tests. Challenging in all these steps is that both input materials and products are mainly amorphous and chemically consisting of the same elements as well as that dissolution and precipitation simultaneously take place during hardening of the binder. Since both dissolution and precipitation can be the rate-limiting step in the hardening process, both need to be stimulated in a different way to be able to obtain a strong material within 24-48 hours.

Increase of service life of existing masonry and concrete structures requires better understanding of the specific degradation mechanisms of those materials. We will incorporate fracture mechanics in a model for predicting the remaining service life of historical masonry. New analytical techniques, in combination our unique collection of samples with a well-documented history of several decades will be used to improve our understanding of corrosion propagation in reinforcement. This will provide a basis for a revised degradation model for concrete.

Asphalt. Aging of bitumen increases stiffness and reduce flexibility, making the asphalt more prone to damage under fatigue straining due to traffic loading and thermal cycles. On the Dutch highways nearly all (>95%) surface layers are composed of porous asphalt with void content of more than 20%. This high void content is key in reducing noise, but it comes at the cost of a higher propensity to ageing due to the larger surface contact area with air. Factors contributing to aging of asphalt and pavements vary from traffic loads to stresses caused by daily temperature variation and impact of water. The load combinations most critical for the performance of an asphalt material will be determined. Insight in how and when damage develops enables us to develop tools to assist road owners, contractors and raw material suppliers to increase the overall performance of surface layer materials, and reduce maintenance and societal costs. The main subject is the development of a material performance model that takes into account the material ageing, and its validation using monitoring data. The model can be used to forecast maintenance needs of existing materials and for assessing the expected performance of innovative materials which might increase service life or reduce the CO2 footprint. The obtained insights in ageing phenomena will also help to assess the performance of recycled and rejuvenated material. Rijkswaterstaat has the ambition is to significantly reduce its CO2 footprint. High quality recycling of road constructions can help to fulfill this ambition. This means that materials from surface layers that meet relatively high performance criteria are to be reused in new surface layers. This type of recycling will prevent down-cycling. Recycled road materials have a different ageing process than fresh road materials. Therefore the ageing models will be extended with to take these processes into account.

Resultaten 2020

Stony materials. We will address three topics with respect to stony materials: new cementitious binders based on secondary materials, degradation of stony materials (masonry, concrete) and new products. Focus will be on the first one.

In 2018, the focus for new cementitious binders based on secondary materials was on dissolution. Insight was gained on how to steer the composition of the solution of the dissolved precursors. This composition needs to be such that the right products are formed at a specific rate. To this effect, a flow-through experimental set-up was developed and tested for slag, fly ash and metakaolin, and their blends. In addition, also batch tests were run in 2019 in which the effect of increasing concentrations on the dissolution could be studied. Finally, a reverse osmose experimental set-up was developed for precipitation tests. This experimental work has been accompanied by deepening the theoretical understanding of the precipitation processes. A major finding is that for some combinations, precipitation back on the source material delays or inhibits further dissolution and thus prevent hardening. This effect has to be solved, as it is a major influence on the precipitation and hardening. Qualitatively it has been elucidated and on the basis of these results, the role of additives in precipitation and inhibition is being investigated by executing a set of quick scan binding experiments, developed last year, for the most promising additives in the dissolution tests and cancelling out the inhibition effect. On the basis of the results of these quick scan binding experiments, mortar bars have been made to investigate the hardening rate and examine the major reaction products. Results at this stage of the research indicate that we found simple, inexpensive and sustainable activators based on the developed dissolution and precipitation knowledge that help fly ash and metakaolin harden within one day. Currently strength development and reaction product identification tests are executed. In 2020, some dissolution and precipitation tests will be continued but the main focus will be on the combined effect (hardening) and ways to accelerate the process. Accelerating can be brought about in various ways, but most promising is preventing back precipitation and/or establishment of low diffusion boundary layers around the precursors. One way to realize this is by adding small seed crystals to the solution, another way is to stimulate the precipitation of secondary products to manipulate the solution composition. Both will be investigated, among others by determining the zeta-potential under various activator and seeding conditions. In addition, thermodynamic modelling of the system, including the surface effects will be started. Finally, the hardening experiments will be continued, taking advantage of the newly developed insights on dissolution and precipitation rates to develop the blend tool further. Especially the hardening rate in relation to the formed products will be the focus of 2020.

The research on fracture mechanics to describe the degradation behaviour of masonry due to transport phenomena will be started in 2020. After an analysis of geometrical constraints a first model will be developed for the vulnerability of particular kind(s) of natural stone for hygric-mechanic degradation. In the future, this model will be extended to include time and/or other stone types.

Service life for concrete is considered to end when corrosion is initiated. In many existing structures, this stage has evidently been passed and propagation occurs. In order to assess the safety of structures where corrosion has initiated, a better understanding of the propagation is needed and its effect on structural safety. In order to include the effects of propagation in concrete degradation models, information on the composition, distribution and mechanical properties of corrosion products with time is needed (both for carbonation and chloride induced corrosion). Novel techniques such as CT tomography and nanoindentation, combined with optical and electron microscopy will be used. Collaboration is foreseen with TU Delft and the Politecnico di Milano.

Two recent findings are a new process for making masonry bricks which can be applied to make a brick with a significantly higher thermal insulation, and flexible concrete that has attractive features as road surface. At present collaboration with companies has started or is initiated for the development through the higher TRL stages of these applications. In this program we will explore other applications of the same basic findings

Asphalt. We have built a, for the Netherlands unique, database on properties of asphalt mixtures, bituminous binders and road performance in practice. In 2019 this database new data and information was added. It is the basis for a bitumen ageing model which we developed, that can estimate the service life of an asphalt mixture on the basis of binder properties. The combination of this model and the database is a unique benchmark tool for the performance of asphalt mixtures for the highway network. Rijkswaterstaat now stimulates high quality asphalt recycling on their road network so that surface layers meet the high performance standards in Netherlands. This implies high quality requirements for secondary materials. Up until now, there was a restriction on the amount of recycled material in surface layers because of the high performance standards of the surface layers. However, in order to realize the ambitions of the Climate Agreement Rijkswaterstaat and other road owners are now looking for new methods to increase the reuse. Supporting this requires that our benchmark tool is further elaborated. Recycled road materials have a different ageing process than fresh road materials. Therefore in 2020 the ageing model will be extended with additional ageing processes such as physical hardening. For this a literature review will assess the state-of-art with respect to these processes. The possibility to recycle road materials over and over will be a topic of particular interest. Next, methods and test procedures will be designed that simulate and artificially induce aging of recycled materials. In addition, reversing of the ageing process will be investigated, in particular the long term effectiveness of rejuvenators.

Closely related to this is our research motivated by the change in bitumen quality. From January 1st 2020, the limit of sulphur content in fuel oil used for ships will be reduced to 0.50% m/m (mass by mass) worldwide. This will have an impact on process of refining crude oil globally and is anticipated to have an influence on bitumen quality and therefore influence the quality of asphalt. Depending on the strategies adopted by refineries, sulphur separated from the upper streams of the distillation process can be processed into residue products, i.e. bitumen. To understand the consequences for bitumen quality, there is a need to improve our understanding of the influence of the crude oil source and processing on bitumen performance characteristics. It is important to find additional performance indicators that can be used to assess suitability of bitumen for asphalt. We will start the development of our asphalt model so that it can be used to support selection of bitumen suitable for an application.

Within *Asfalt-Impuls*, a public private cooperation with all parties in the asphalt value chain, the project LAM has the objective to develop a methodology for estimating the (remaining) service life of designs of road constructions with available or new asphalt mixtures, of recently built road constructions and of road constructions that are already in use. To accomplish this, a hybrid model will be developed that combines data from performance in the field with fundamental models. In 2020, a proof of concept of such a model will be developed. The aim is to organize these activities in a TKI project in 2020. It is expected that we need to model also, in a next step, the mechanical response of pavements to load. Therefore, an FE model to predict this response will be investigated.

Our research on stony materials and asphalt fits in the HTM roadmap of the Topsector HTSM as well as in the BITC program. The concrete research will be important for realizing the targets of the Betonakkoord.

Dynamiek

Stony materials. In 2017, first steps were made for better understanding reaction processes of new stony materials by evaluating and setting up a complete set of characterization methods. It was found that the state-of-the-art in activation is still on the level of trial-and-error and high dosages of sodium hydroxide were used, a material that is neither sustainable nor cheap and leads to uncertain durability. Therefore, in 2018, it was decided to first gain more fundamental insight in the reaction processes during activation, which involves simultaneous dissolution and precipitation. More specifically, in 2018, the role of the activation on the dissolution rate of the secondary binders has been investigated. A new-flow through experimental set-up was developed to this aim. In addition, thermodynamic modelling of the dissolution combined with quick reaction tests gave a first version of the blend tool and positive results on dissolution. In 2019, the dissolution tests were continued and an experimental set up was built for precipitation. The theoretical understanding of the precipitation progresses according to plan although some results have been unforeseen: a mechanisms leading to back precipitation, and thus retardation or even inhibition of the hardening process was found to be most important and may be the major reason why some combination of precursors and activators do not work. The mechanisms is at the moment further investigated. On the basis of all new information, hardening tests and mortar bar test on new blends of precursors with cheap and sustainable activators are currently run. The results look very promising: some combinations were hard within one day.

New insights regarding degradation can be applied to masonry and concrete. For this reason it is decided to extend the research program with these two items. Because two finding for which applications are being developed may have more potential, this will be explored in the program.

Development of our asphalt model for more accurate prediction of the durability of road surfaces with and without recycled materials is integrated in different projects. The accuracy of the estimated durability strongly depends on the representativeness of artificially ageing protocols in the laboratory. A representative ageing method is developed in the TKI project Molecular structure and stability assessment of bituminous binders under artificial aging conditions. This TKI project will end 2020. Then we aim to form a new consortium for a follow-up TKI project, that focuses on representative ageing (physical hardening) of recycled asphalt. For this TKI project, the results of the VP program focusing on understanding and predicting ageing of especially recycled materials is an important starting point.

In the 2019 VP program an analysis was made to determine the rolling resistance by means of measurable asphalt properties. Two options have been investigated in more detail. The first option is to measure rolling resistance on specimens in the laboratory in a repeatable and representative way using the SR-ITD apparatus. In the laboratory, both the rolling resistance of artificial, 3D printed surfaces and real asphalt surfaces were measured to calibrate existing models and investigate correlations with field measurements. The second approach was to perform a preliminary check, if detailed images as obtained using de LCMS, can be used to assess the rolling resistance of a real pavement. If this is possible, this would mean that there is no separate measurement necessary to assess the rolling resistance and as such it would be much easier to obtain information on actual performances of pavements. The combination of these actions have brought TNO to the point where it is possible to start up new initiatives together with the market. Therefore it has been decided to not undertake further actions on this topic in the VP program in 2020, but start with acquisition of projects.

Titel	**Informatie en Communicatie Technologie (P706)**
Missie/ Topsector	HTSM
Contactpersonen TNO	Ir. A.J.A. Vetjens, Director Market ICT; Dr.Ir. O.A. Niamut, VP manager ICT
Contact extern	topteam ICT / Dutch Digital Delta, o.m. Erik Wijnen en Fred Boekhorst

Programma jaar 2020 - Samenvatting

TNO aims to guide industrial and societal stakeholders in the digitization of their business or domain, by integrating the identified enablers in national and European ICT agendas in first-time engineering solutions. These stakeholders have common needs, where they seek to take advantage of new opportunities in data sharing, and require fast open infrastructures and trusted ICT solutions to overcome their challenges in operating in a digital ecosystem. To guide these developments, the VP ICT focuses on the common needs of our stakeholders and aims to reach the following goals:

The use of Artificial Intelligence (AI) is fuelled by data. **Data sharing** is a key enabler for new business opportunities by combining data sources, but access to data is hindered by lack of trust between data owners, data interoperability and business models. Our ambition is to resolve all barriers for data sharing, by enabling data sharing across domains, ensuring interoperability of data sharing systems, avoiding vendor lock-in and achieving national data-hub(s) eco-systems. In 2020, we create a national open and standardized business ecosystem for secure and controlled data sharing, a secure interoperable IoT smart home/building and smart energy system reference architecture, an operational laboratory for experimenting with our Self Sovereign Identity (SSI) technology tools, tools for automated testing and verification of complex AI model chains for the government sector, and the 2nd generation of our secure multi-party toolbox for federated learning.

To resolve the increasing resource scarcity in our physical infrastructures, we aim to provide our stakeholders with **fast and open infrastructures** with instantly and ubiquitously available ultra-high bandwidth connectivity as well as massive storage and processing, tailored to the specific needs of their applications. We provide technology and architecture blueprints for extremely powerful and efficient future digital infrastructures accelerating economic and societal innovations. Our designs respond to the pressing need for cost and CO2 reduction, as well as to the scarcity challenges regarding human and physical resources, encountered in the infrastructures themselves and in the business and public sectors they serve. In 2020, we deliver an open source ubiquitous digital infrastructure testbed, a controlled network and application environment for PoCs and trials, components in an open source ecosystem for self-assessment and platform and infrastructure adaptivity and a first version of an immersive communication platform.

In a digital society, corporate data is constantly vulnerable to external influences. Our ambition with a **trusted ICT** approach is to make a difference in preventing risks of financial loss, disruption or damage to the assets and reputations of our stakeholders' organizations from failure of their information technology systems and services. In-depth knowledge of the various links in the chain and of the chain as a whole are both essential in a targeted cyber security approach. In 2020, we deliver a platform architecture and interface specification for security decision support to SOC and CSIRT teams, designs and software for quantum(-safe) key distribution, a proof-of-concept for security zones and AI-based anomaly detection agents.

These goals are aligned with national and stakeholder agendas, specifically the *Nederlandse Digitaliseringsstrategie*, the *Visie en bijdrage Team DDD aan missiegedreven innovatiebeleid*, the *Actieplan Digitale Connectiviteit*, the *Nederlandse Cyber Security (Research) Agenda*, and with stakeholder viewpoints. Sectors that have specific attention are agriculture, telecom providers, government, media and financials, but the underlying technology developments allow TNO to contribute to challenges in defence and security, industry, energy, construction, healthcare and mobility and logistics. In relation to the above mentioned goals, the VP ICT actively engages in stakeholder management on both the national and the European level, with academic partners and partners from industry. Until 2023, our objective is to consolidate this role. Furthermore, we aim to maintain our leading position in ICT standardization and within industry fora.

Korte beschrijving

In an increasingly digital world, information and communication technology (ICT) is offering excellent opportunities to solve major societal challenges, ensuring innovation and continuing economic growth . ICT provides key enabling technologies for digital transitions in many sectors and is thus an area of innovation in itself as well as a key enabler for innovation in many sectors. Data and algorithms become increasingly pervasive and data driven innovations are important determinants of economic success and societal impact. For these developments, secure, adaptive and robust sharing and transmission of data is paramount. TNO aims to guide industrial and societal stakeholders in the digitization of their business or domain, by integrating the identified enablers in national and European ICT agendas in first-time engineering solutions. These stakeholders seek to take advantage of new opportunities in data sharing, but require fast open infrastructures and trusted ICT solutions to overcome their challenges in operating in a digital ecosystem. To guide these developments, the VP ICT focuses on three common needs of our stakeholders. These common needs include:

Data sharing is a key enabler for new business opportunities by combining data sources, further process efficiency in value chains, transparency and accountability across the value chain, the digitization of paper processes and the use of Artificial Intelligence (AI). Sectors such as transport and agriculture can benefit from greater efficiency by using joint data efficiently and securely; in sectors such as health, data sharing allows for improved diagnosis and faster detection of diseases. In 2023, we aim to have operational information solutions, in particular for i) smart data agriculture hub, ii) sensitive data analysis (e.g. money laundering detection, effectiveness of health interventions) and iii) digital validation of information. Main research questions are -what technologies allow for sharing of privacy-sensitive and/or confidential data; and -what are the requirements of (partners in) data ecosystems to deploy such technologies.

The Netherlands is among the world's leading countries when it comes to digital infrastructure, but there are still many inefficiencies that need to be resolved. Our stakeholders need **fast and open infrastructures** with instantly and ubiquitously available ultra-high bandwidth connectivity as well as massive storage and processing, tailored to the specific needs of their applications. We provide technology and architecture blueprints for extremely powerful and efficient future digital infrastructures accelerating economic and societal innovations. Our designs respond to the pressing need for cost and CO2 reduction, as well as to the scarcity challenges regarding human and physical resources, encountered in the infrastructures themselves and in the business and public sectors they serve. In 2023, we aim to contribute to the position of our national digital infrastructure by i) realizing first operational 5G implementations that provide slices tailored to AR/VR, mobility/logistics and industry, and ii) enabling the use of very demanding models, applications by runtime adaptivity and orchestration on scalable cloud based processing systems. Main research questions are -what technologies allow for connecting and sharing heterogeneous physical infrastructures; and -what are the requirements of emerging applications, such as immersive communication, for adaptive platforms.

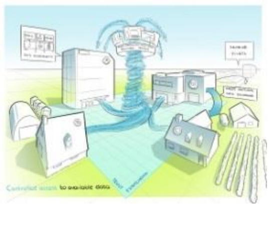
In a digital society, data is constantly vulnerable to external influences. A targeted approach to **trusted ICT** based on the automatic repulsion of incidents and future cyber threats is crucial to ensuring a reliable and secure data chain. In-depth knowledge of the various links in the chain and of the chain as a whole are both essential in a targeted cyber security approach. In 2023, we have made significant contributions to embedding IT security as a strategic prerequisite for their ongoing digital transformations. We will have demonstrated various PoCs and prototypes of secure architectures and technology including automated security and risk-adaptive access control, security monitoring algorithms and tooling, and various quantum-safe technologies. Main research questions are -what technologies allow for automating tasks of cyber security operations; and -what are the requirements of emerging quantum-safe technologies to create a future-proof secure digital intrastructure.

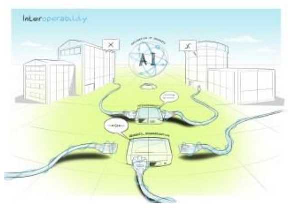
Resultaten 2020

Data Sharing

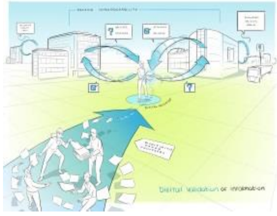
Our ambition is to resolve all barriers for data sharing, by enabling data sharing across domains, ensuring interoperability of 'data sharing systems', avoiding vendor lock-in and achieving national data-hub(s) eco-systems. We expect results for 2020 in the following five focus areas:

Controlled access to available data; we aim to create an national, open and standardized ecosystem where companies of multiple sectors can collaborate effortlessly by sharing data in a secure and controlled way, fully supporting data sovereignty, without centralized control. In 2020, we deliver i) an International Data Spaces (IDS) toolkit exploiting the full possibilities of the IDS architecture; ii) two proof-of-concepts of sovereign data sharing in agriculture, industry, defense and logistics; and iii) a national IDS proposition for organizations to join IDS.





Data interoperability; we aim to support semantic standardization, ontology engineering, linking data, automation of semantics and usage of semantics in blockchain with methodologies and tools. In 2020, we deliver i) a pilot-ready FIT engine for sharing knowledge graphs information according to the ontology based SETU standard; ii) an external evaluation of our SONNET toolset for data-driven ontology engineering and knowledge graph modelling; iii) a proof-of-concept of PLASIDO, our Smart Connector tool to share data with other systems and/or organizations to enable distributed knowledge queries; iv) a proof-of-concept of an IDS connector that is able to share data without a predefined API request; and v) a secure interoperable IoT smart home/building and smart energy system reference architecture based on SAREF/SAREF4ENER.



Digital validation of information; we aim to create the Internet of verified credentials for safe electronic transactions. In 2020, we deliver i) an operational laboratory for experimenting with our Self Sovereign Identity (SSI) technology tools, with at least five Proof-of-Concept running instances; ii) contributions to international standardization towards SSI interoperability; and iii) designs for a high level SSI framework including complex concepts such as mandating.

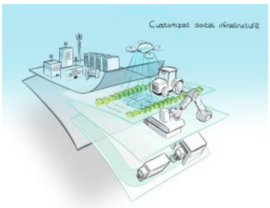
Reliable analysis of data; we aim to increase the trustworthiness of data services over time, by stabilizing and increasing the quality of data products, ensuring accountability and explainability. In 2020, we deliver i) a modelketen platform with built-in accountability and quality assurance, to be used for advice for all mining activities in the Netherlands; and ii) tools for automated testing and verification of complex AI model chains for the government sector.

Sensemaking of sensitive data; we want to enable the analysis of privacy-sensitive and/or commercially confidential data of multiple parties, empowering these parties to create additional value based on improved (AI) models and information without sharing or revealing their data. In 2020 we deliver the 2nd generation of our secure multi-party toolbox (MPC, federated learning), including (PoCs for) hidden set intersection, secure statistics with benchmarking possibilities, advanced learning and/or graph algorithms, as well as concepts of underlying IT platform, and an estimation of scalability and performance (potential improvements thereof).

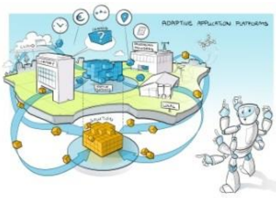
<u>Fast and Open Infrastructures</u>

Our ambition is to amplify the competitive strength of the national ICT infrastructure, driving the future hyper-connected society through cross-domain use of massive Internet of Things and Internet of Skills. We expect results for 2020 in the following four focus areas:

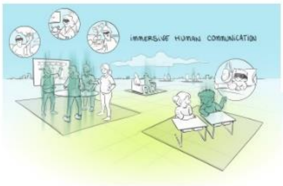
Ubiquitous digital infrastructure; we aim to create a fast and reliable overall digital infrastructure by mixing and matching existing and new heterogeneous infrastructures. Such an infrastructure guarantees that the applications of businesses and citizens everywhere in The Netherlands, indoor and outdoor, cities and rural areas, can always count on high-performance and reliable connectivity, storage and processing. In 2020, we deliver i) an open source testbed based on a blueprint for combining open source and proprietary software and hardware; ii) a blueprint for slice interoperability-based input to GSMA; and iii) a one-touch 5G network deployment demonstrator.



Customized digital infrastructures; we aim to provide infrastructures that live as virtual networks within the ubiquitous digital infrastructure and that provide the specific connectivity, processing and storage that individual businesses and sectors (in particular smart industry, agriculture, health and media) need, as if they were dedicated stand-alone infrastructures. In 2020, we deliver PoCs and trials in a controlled network and application environment that demonstrate the underlying concepts and capabilities of customized digital infrastructures, for three different sectors viz. media, agriculture and smart industry.



Adaptive application platforms; we aim to create autonomous computing platforms which orchestrate integrated processing and control pipelines, that can cope with ever changing user goals, constraints and environmental aspects, where applications can evolve autonomously in order to stay fit for purpose, stay fit for contextual changes and stay healthy during system modifications. In 2020, we deliver i) the fundaments of the platform that is capable of seamlessly shifting computational tasks between the fog, edge and centralized cloud(s) based on application demands; and ii) a unique toolset that uses AI techniques to monitor and detect anomalies during system adaptation based on data quality metrics and system health information.

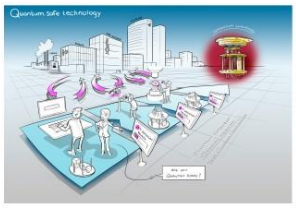


Immersive human communication; we aim to create an AR/VR platform capable of supporting hybrid consumption modes for different users at the same time, who are able to interact fluently with each other and where the video quality is sufficiently high. As we expect these characteristics to impose stringent requirements to the underlying delivery network, we build the platform in a modular and network-aware way, in such a way that different modules can be loaded and used depending on the use cases, can be deployed on different parts of the network and can request the necessary resources as needed. In 2020, we deliver i) a first version of an immersive communication platform, where two forms of immersive consumption are supported (e.g. VR and UWR); and ii) platform modules that exploit edge computing functionalities of a cloud-based 5G infrastructure to deliver lower latencies and higher qualities.

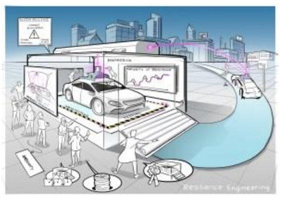
<u>Trusted ICT</u>

Our ambition is to make a difference in preventing risks of financial loss, disruption or damage to the assets and reputations of our stakeholders' organizations from failure of their information technology systems and services. We expect results for 2020 in the following four focus areas:

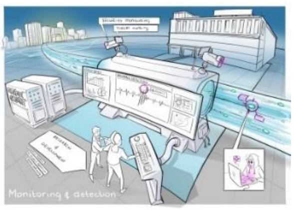
Automated security; we aim to provide technical solutions and concepts for automating cybersecurity that will reduce the Mean Time To Detection and Mean Time To Response, reduce the amount of repetitive tasks of SOC analysts, and contribute to more resilient enterprise ICT infrastructures. These solutions combine techniques for automated security reasoning, risk adaptive decision making and automated response. We will act as coordinator of the H2020 project SOCCRATES, where in 2020 we produce a component of the platform architecture and interface specification, and technology for Attack Defence Graph based analysis. We further establish structural collaborations with TU/e and, define research plans and use cases for effective and efficient response to threats and attacks and automatic vulnerability discovery and patch generation for IoT security in the NWA project INTERSECT (INTERnet of SECure Things).



Quantum-safe technology; we aim to mitigate the threat that quantum computing poses on cryptography currently in use, and to reduce new security risks that arise when adding new quantum technology solutions to the digital infrastructure. In 2020, we deliver i) a first design of a quantum safe key distribution system, including post-quantum and quantum cryptography; and ii) MDI quantum key distribution rate optimization software, including security analysis and parameter estimator.



Resilience engineering; we aim to improve the cyber resilience for ICT systems and digital infrastructures by enabling our customers to build autonomous, zero-down-time networks and ICT systems. In 2020, we deliver i) a white paper on Networked Thinking; ii) a validation of the compositional assurance (COMPASS) methodology; iii) a proof-of-concept for security zones; and iv) a research plan and use cases for security engineering of IoT systems within NWA project INTERSECT.



Security monitoring and detection; we aim to help to protect our stakeholder organizations with actionable, better and faster detection of advanced cyber-attacks. In 2020, we deliver i) innovative detection agents (through (statistical) anomaly detection, AI (e.g. unsupervised deep learning) and smart combinations of multiple (network) data sources; ii) reports on the potential for detection of attacks in encrypted network traffic and of the Smoky Mountains algorithm for security monitoring; iii) a new clustering and anomaly detection technique for lateral movement detection within company networks, integrated into a second version of our ABC tool; iv) a report on the validation of AI-assisted threat hunting tooling with support for analysis of outgoing network traffic; and v) specifications for a prototype of AI based attack detection and threat trend prediction in H2020 project SOCCRATES.

Stakeholder management and standardization

The main objective for 2020 is to consolidate TNO's role in international research communities, standardization groups and business fora. The COST Actions RECODIS on resilient communication systems continues in 2020. Important objectives are to support these developments via contribution to and participation in national multi-year programmes, engage with stakeholders and industry through standardization; and to maintain connections with national and international ecosystems, such as the Dutch Blockchain Coalition, the media klankbordgroep, the initiatives for national AI, Blockchain, Beyond 5G, cyber and quantum programmes, and R&D&I programs (e.g. Horizon2020, ITEA, ECSEL, COMMIT2DATA) and standardization groups and industry fora (e.g. ETIS, ETSI, 3GPP, ISO and IETF). Several part-time professors are associated with the program, to connect to relevant Dutch universities (Rijksuniversiteit Groningen, Universiteit Twente, Universiteit Leiden and Universiteit Maastricht). TNO is also represented on a board level in advisory fora, including 5GPPP, AIOTI, BVDA, PI.lab and VR-IF.

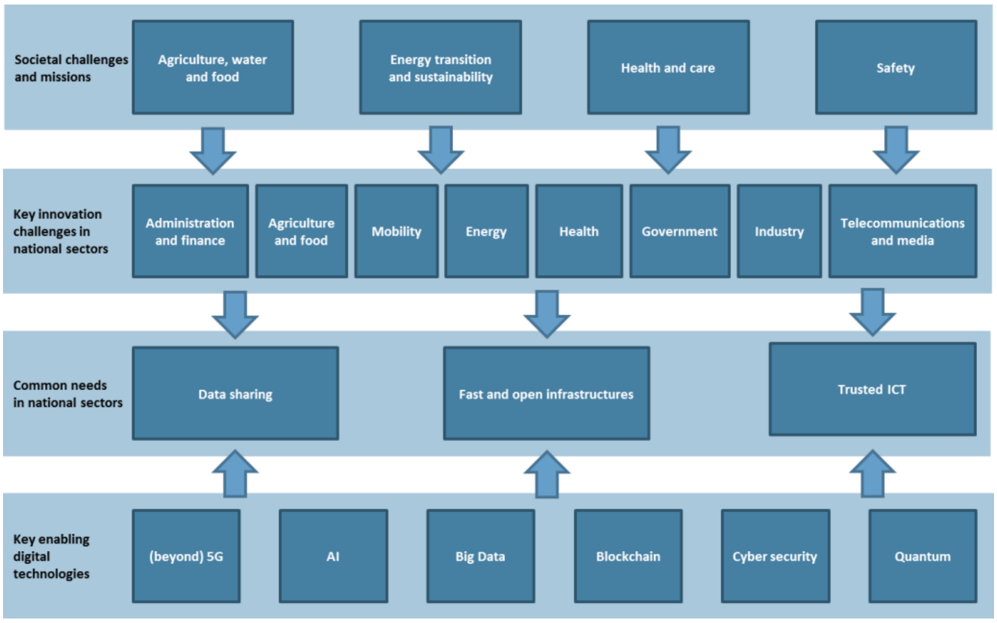
Links to external agendas and roadmaps

In the 2019 update to the Nederlandse Digitaliseringsstrategie , the Dutch government prioritizes research themes for 2020 related to AI, the use of data for addressing societal challenges and economic growth, 5G connectivity and cyber/digital resilience. In the Actieplan Digitale connectiviteit , the Dutch government stresses the importance of innovation in ICT, and experimentation with key enabling digital technologies in the context of policy and public services. The ambitions and concrete milestones of our focus areas are fully in line with these developments. TNO's aim to guide industrial and societal stakeholders in the digitization of their business or domain is well aligned with the mission of team dutch digital delta, which guides industry, government and knowledge institutions in realising ICT innovations and strengthening the international position of The Netherlands with respect to investments in and with ICT innovations. Their report Visie en bijdrage Team DDD aan missiegedreven innovatiebeleid addresses developments and programmatic initiatives on five key enabling digital technologies with cross-sectoral impacts, i.e. artificial intelligence, big data, cybersecurity, blockchain and 5G communication.

Our research programme and topics are aligned with national research agendas and roadmaps. The report AINED: AI voor Nederland confirms the strong position of the Dutch AI knowledgebase, but signals the acceleration of AI developments and applications in other countries. Big Data research is primarily undertaken in the context of the COMMIT2DATA programme , where TNO is active on data sharing technologies. At a national level, the Dutch Blockchain Coalition with over 40 public and private organisations is active on collaborative research and development. The Dutch cybersecurity platform for higher education and research (dcypher) has released its third version of the National Cyber Security Research Agenda . Automated security, security monitoring and detection and cyber resilience engineering are identified as key research topics. Dutch parties in the quantum technology ecosystem are developing a nationale agenda quantum technologie , including topics on secure communication in a quantum internet. Together with universities and knowledge institutes, Agentschap Telecom has initiated work towards a national research agenda for connectivity research, and in the Handvest 5G triple helix parties have agreed on collaboration towards a successful national deployment of 5G. While (inter)national funding programmes provide only few opportunities for media-related research and development, strategic partner KPN explicitly mentions AR and VR experiences in their Technology Book , as a driving force for networks that are capable of massive data transfers, with large bandwidth capacity at low latency.

Dynamiek

In 2019, the VP has seen a major overhaul with respect to its programming process. Work was started to refocus VP ICT more explicitly on common needs within sectors that face significant challenges in the digital transformation of their business, and to redirect our investments in key enabling technologies that are addressed in research agendas and roadmaps both at the national and European levels. The figure below depicts the relation between societal challenges that are identified in our national innovation policies, the smart innovation challenges and opportunities for ICT with respect to digital transitions in specific sectors, the common needs derived from these challenges, and the key enabling digital technologies that can address these needs, opportunities and challenges.



VP ICT focusses on developing and leveraging key enabling technologies to address common needs from national sectors, related to societal challenges.

In the context of cybersecurity, the dynamics are further described in detail in section XX of VP Cyber Risk Management & System Resilience 2020-2023. In 2018, a dedicated programme on AI was started as part of VP ICT. In 2020, this programme will continue, offering new opportunities for strategic collaborations with national and European stakeholders, and providing emphasis on explainability and responsibility of AI algorithms, as well as on data sharing technologies to leverage data pooling for fuelling AI algorithms. TNO will support an initiative for a national AI programme, in collaboration with key national stake-holders. While additional means for AI research in 2020 have been allocated to ERP hybrid AI, the proposed focus of the research is strongly use case focussed and will be undertaken in close collaboration with the AI programme as part of VP ICT.

Additional means for 2020 will be allocated to topics that are central to the research and innovation agenda for public-private partnerships on key enabling digital technologies, with focus on i) beyond 5G, on adaptive and autonomous communication networks (research cluster Fast and Open Infrastructures); ii) cybersecurity, on automated security and quantum-safe tech-nology (research cluster Trusted ICT); and iii) self-sovereign identity management for digital validation of information (research cluster Data Sharing).

Titel	**Embedded Systems Innovation (P707)**
Missie/ Topsector	HTSM
Contactpersonen TNO	Henk-Jan Vink (Managing Director TNO ICT), Frans Beenker (VP manager)
Contact extern	HTSM embedded systems / Brit Meier

Programma jaar 2020 - Samenvatting

The Dutch high-tech industry is responsible for nearly 60% of the Dutch private R&D expenditures and many of them play a world-wide dominant role. Complex industrial products are brought to the market with high speed, enhanced functionality and bet-ter cost performance ratio. These products represent a key element of the competi-tive position of our high-tech industry.

Product innovation is pre-dominantly implemented as a complex multi-disciplinary interplay between software and physical components (i.e. cyber-physical systems, embedded systems). This interplay has a large impact on key system qualities such as safety, reliability and performance. Business models change (from selling boxes to delivering integrated solutions and ser-vices) and there is a continues drive towards efficiency – do more with less people in less time. The complexity of high-tech sys-tems grows steeply. This requires a fundamental basis of systems engineering that improves the efficiency, effectiveness, quality and costs of the architecting and design processes of high-tech systems, and the qualified workforce. This requires special attention to be paid to system engineering methodologies, especially those address-ing the following aspects of system architecting and design:

- **Multidisciplinary architecting and engineering**. The essence of system engi-neering is in addressing the heterogeneity and multi-disciplinary aspects of product architecting and engineering based on fundamentals in computer science, physics, mathematics, mechanical engineering and electrical engineer-ing.
- **Efficient and effective product innovation process**. There is a significant need to improve on the efficiency, effectiveness, quality and costs of the product innovation process. Techniques for product design need to have a strong for-mal basis, involving modelling, analysis, virtualization and simulation to achieve the desired results. There is a major trend towards model-driven system de-sign and engineering in all phases of a product life cycle.
- **Life-cycle context**. There is an increased interaction between the supplier and user of high-tech systems. Requirements changes have to be accommodated quickly and the integration in a, often ill-defined, customer operating environment and workflow is critical. On the other hand, it provides a business opportunity of service and regular product upgrades. This requires new tech-niques for product design that position product design in a life-cycle context.
- **Human capital development**. A systematic investment in a life-long learning program for education and training of embedded system architects.

These aspects support the high-tech industry in achieving their challenges in offering value propositions over the life-cycle of their and address the main trends that are driving the complexity of high-tech systems. Together, they represent the main aspect of the ESI research program for 2020 - 2023.

The target result of ESI is in driving advances in high-tech systems technology by 1) creating impactful and industrially applicable architecting and design methodologies and 2) providing innovation support to high-tech industry with industrially supported tools, knowledge- and experience-sharing activities and a focused competence de-velopment program. A summary of the targeted 2020 results is as follows:

- Building an international cooperation network of excellent research insti-tutes;
- System performance/System-of-systems performance optimization;
- Advanced failure diagnostics;
- System reference architectures, platform approaches, SW architectures;
- SW modularization, interfacing and SW legacy techniques;
- A successful ESI symposium in October 2020;
- Exploiting the added value of the large ESI network for exchanging experi-ences;
- New courses, course offerings, working approach specific for our target groups.

Korte beschrijving

The overall mission of the ESI program is to keep up and improve the competitiveness of the Dutch/European High Tech industry by addressing the challenge of mastering architecting and design of ever increasing complex systems through new and radically improved systems/software design and engineering methods.

It is of utmost importance that new knowledge is not only generated for individual products or applications, but that opportunities for synergy, knowledge sharing and knowledge exchange are fostered in an open-innovation setting.

For successful innovation and value take-up by the ecosystem, it is essential that systematic attention is given to all required elements of the knowledge chain. ESI follows a process, with each step adding value and depth to the previous step:

1. Agenda and programming: Translation of industrial knowledge needs into a re-search agenda and roadmap. The agenda is tightly coupled with "meerjarenplan systeemarchitectuur en systeemintegratie") in the "KIA sleuteltechnologieen" and is closely interlinked with the digital technologies cybersecurity, big data and artificial intelligence.

2. Applied research: Research projects based on strategic research questions from industry with a close cooperation with both industry and academic groups.
3. Consolidation: Development of a sustainable knowledge base for general use.
4. Dissemination: Presenting, sharing, discussing, demonstrating knowledge through network activities, seminars, workshops, publications, etc.
5. Competence Development: training of professional competences.

The 2020-2023 ESI key program lines are as follows:

1. System Performance: Every system has its own, often contradictory, key per-formance indicators (KPIs). For example, in the printer market, pages/minute must be balanced against print quality; in semiconductor manufacturing it is the yield of good dies per wafer and the number of wafers/hour. Every system must meet or exceed, and also balance, these ever more demanding key performance indicators.
2. System dependability: When making significant investment in a new high-tech system, customers want to be assured that it will perform effectively throughout its lifetime, delivering cost benefits in the longer term and reducing the total cost of ownership. This requires a high system quality, including verification and vali-dation tailored to these changing requirement dynamics, to ensure that it will continue to operate without requiring overly frequent mainte-nance.
3. System evolvability: Systems designed to address today's needs need to be able to continue to meet customer's changing future needs. Customer demands, pro-cesses and technologies are changing rapidly, and installed systems need to be ready for upgrades and updates to meet new and changing requirements.
4. Exploiting System Context: Customers no longer want a system, but a solution to their challenge that exploits the context it operates in. This context is increasingly characterized by the combined availability of both relevant and irrelevant data, knowledge and expertise about the system and its context. Being a solution pro-vider means deliv-ering a service, rather than a system – expanding the role of high-tech companies from system developer to solution provider understanding the idiosyncrasies of the context.
5. System Architecting: Getting system design right from the start becomes ever more critical. System Architecting addresses this challenge by helping customers to translate market, product, and technology choices into system con-cepts.

Resultaten 2020

The expected ESI results 2020 are aligned with the ESI knowledge chain:

1. ***Agenda and programming**:*

a) Trends versus program: We continuously align the high-tech industry trends and the ESI knowledge areas and trans-late our roadmap to long-term re-search programs with our industrial partners.

Target 2020:

- Update of the Dutch Embedded Systems Roadmap.
- Involved partners: Dutch high-tech ecosystem

b) Academic research: NWO and ESI have defined an NWO partnership pro-gram (called Mascot) on the topic of "man-aging complexity" with a tight coupling to our research program with our industrial partners.

Target 2020:

- Start of four academic research projects aligned with Dutch high-tech in-dustry.

c) Internationalization: We expand our international horizon with building and exploiting a network of excellent re-search institutes such a Fraunhofer IESE (Kaiserslautern), OFFIS (Oldenburg), the System Engineering Research Cen-ter (SERC, USA). We plan to expand this network.

Targets 2020:

- Joint initiatives in setting up European projects in the context of Itea and Ecsel.

- Two joint IESE/ESI workshops with German/Dutch high-tech industry on selected and industrially relevant topics.

2. Applied research

All ESI research projects are executed as public-private partnerships with a seri-ous investment of the industrial partner. Also, all research projects are executed at industry location in an 'industry-as-lab' setting. This direct collaboration be-tween industry and ESI gives a much better insight, understanding and apprecia-tion of the industrial challenges. It allows the research findings to be directly vali-dated by application to realistic industrial cases. In other words, valorization is pre-built into the process.

a) International research:

Initiate and take the lead in proposals for international research. In particular this holds for Itea and Ecsel calls.

Target 2020:

- Initiate and develop Itea project proposal for contract-based design for system upgrades.
- Depending on the Ecsel review, we start a new project on verification and validation of autonomous and/or AI-based systems.
- Participate in new proposals for the 2020 Ecsel call.

b) National research

Create and execute a research portfolio with Dutch high-tech companies: ASML, Nexperia, TFS, Océ, Philips Healthcare, Thales. We are planning to expand our industrial research network.

Target 2020: Create both results and impact with new methodologies for high-tech industry in all program lines of ESI.

c) Example of targeted results:

a. System performance optimization and system-of-systems performance optimization;
b. System failure diagnostics;
c. Software legacy and SW architecting methods and tools;
d. Verification/validation of system upgrades;
e. System reference architecting and SW architecting.

d) Academic research:

e) Initiate academic NWO-TTW proposals with our academic partners where possible coupled to our industrial research program and the Mascot partner-ship.

3. Consolidation:

Development and consolidation of a knowledge base for general use.

Target 2020:

- A next step in the relationship with "managed open-source" tool provider Obeo – from genuine interest and mutual understanding to contractual agreements and putting tools in the market. This requires a market analysis of the ESI tools, positioning of the tools in industry processes and further professionalization of the tools.

4. Dissemination:

Create access to ESI knowledge and expertise and to share experiences amongst peers.

Target 2020:

- Presenting, sharing, discussing, demonstrating knowledge through network activities, seminars, workshops, publications, and special interest groups. 30 ESI papers and/or conference contributions.

- Exploit the added value of the large ESI network for exchanging experiences and insights for various target groups. Facilitating 6 different peer groups/special interest groups that each meet 2 or 3 times a year.
- ESI symposium on October 6th, 2020. Target number of attendees: 400.
- Transfer ESI knowledge to SW service providers for applying our results in the high-tech industry daily practices.

5. ***Competence Development:***

   Development of required competences at high-tech industry and align ESI re-search program lines with new competence development offering.

   Target 2020:

- Creating a number of new courses and course offerings/ working approach specific for our target groups. Target courses: system performance.
- Execute and manage a competence development program for training of professional competences for Dutch high-tech industry.
- Optimize on learning strategies by combining our research projects, net-working activities, and competence development programs.

Dynamiek

The ESI program has a stable foundation and is characterized by activities and com-mitments that extend over multiple years. The long-term direction is in-line with the HTSM Embedded Systems Roadmap that obtains an update every two to three years. It now also is line with the "meerjarenplan systeemarchitectuur en systeeminte-gratie" in the "KIA sleuteltechnologieen". The short-term (yearly) priorities are dis-cussed and set with the ESI Partner Board, consisting of senior representatives from academia and industry. This board has responsibility for overall strategic direction and value proposition, including supervision of the yearly program objectives, embedding in the academic and industrial network and the general alignment of the ESI program with the Dutch innovation policy.

Each of the ESI research projects is set-up as a yearly commitment with an agreed long-term focus. Yearly, we tune our program towards the current status of results, the observed high-tech industry trends and associated needs, and the Dutch innovation policy. The partnership with our industrial (and academic) partners is therefore stable and focuses on actual industrial needs. Hence, as high-tech industry progress-es, ESI progresses as well. The ESI success rate can be measured in terms of turn-over, academic and research partners, personnel and the actual use of ESI results in indus-try practice. Along each axis, ESI has realized a stable yearly growth of roughly 10% with a year of consolidated stability in 2019. Quality and added value of work is con-sidered of utmost importance. Consequently, we have to build up and manage our own expertise which puts a limit on a too fast growth.

Next to a gradual growth in both research volume and in industrial research partners, an expansion in attention in our program lines is observed. Originally, the interest of our industrial customers was on the design and engineering of their high-tech systems. In 2016 and 2017 we expanded this interest towards the total product life cycle including servicing and condition-based maintenance aspects. This has included the need to integrate data and communication characteristics with embedded systems technology in which we exploited the synergy between the ICT roadmap and the HTSM embedded systems roadmap. A second expansion can be observed in our fo-cus from single product key performance indicator (e.g. performance or quality) to-wards system-level architecting and reasoning for multiple KPIs. An upcoming expan-sion/challenge is the use of AI techniques in systems and services opening up chal-lenges on addressing aspects such as system dependability. We expect these expan-sions to continue.

Next to providing added value to our current industrial partners, we target on new research partners that fit in the observed expansions. We are building up good rela-tionships with new partners. By joining forces between ESI and UT in the Twente re-gion, we create opportunities to multiply the UT and ESI valorization results, while we also aim to define joined goals that go beyond our individual results. This creates the opportunity to open a local ESI office in Twente.

Finally, we continue our efforts to expand on the industrial use of the ESI results. This requires both a professional support of our tools and an expansion of engineers that are trained in our results. The professional support is targeted to be “managed open source” meaning free availability of our tools however with a professional support guaranteed. The selected open-source tool provider is Obeo with whom we have signed an MoU in 2019. The target for 2020 is to make a next step in a market feasibil-ity analysis for some of the ESI tools and making them a success in the market. Next to the professional tool support we will expand on the number of trained engineers that can apply the ESI results. Our strategy is to set up a community of SW service provid-ers that is trained in our results. An MoU with Altran has been signed in 2019. Next to Altran we plan to expand this community.