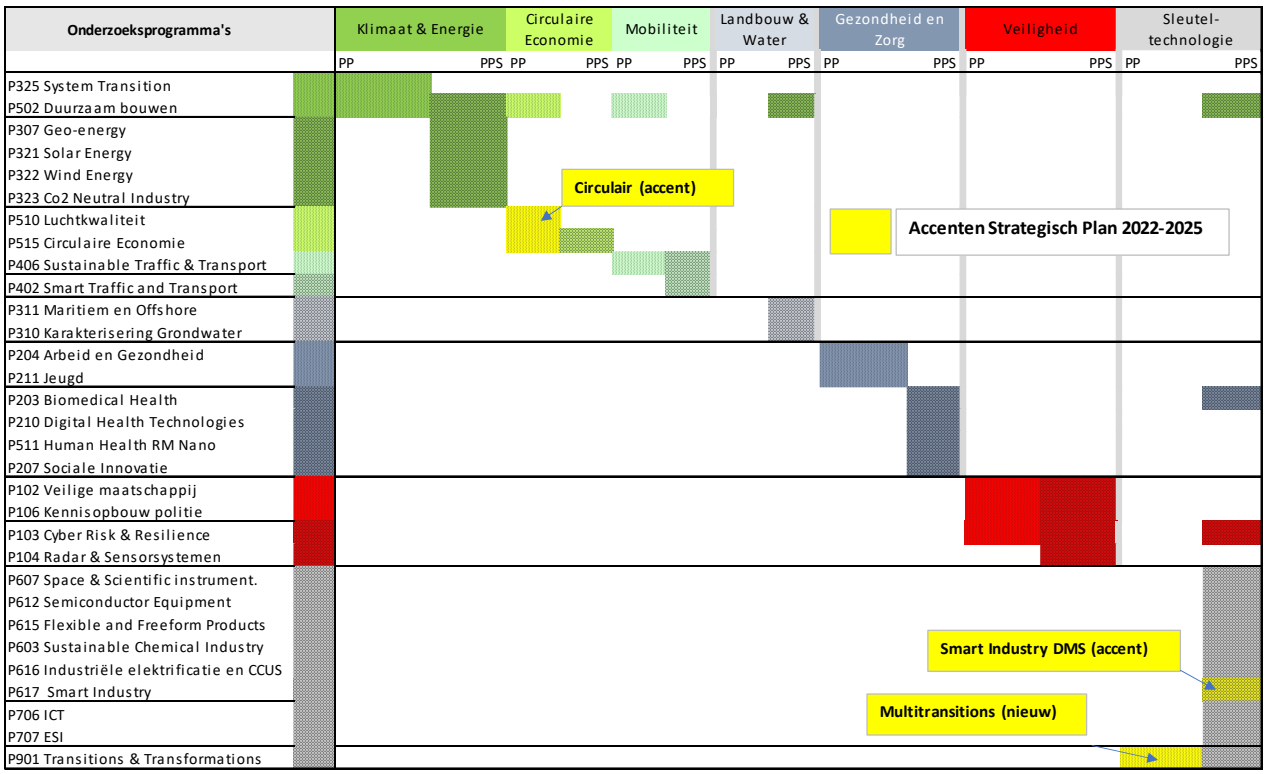
## TNO Onderzoek 2021 - Overzicht Vraaggestuurde programma's volgens het MTIB



| Titel | VP System Transition (P325) |
|---|---|
| MTIB-thema | Klimaat en Energie |
| Contactpersonen TNO (DM en VPM) | VP-manager: Ruud van den Brink<br>Directeur Markt: Harm Jeeninga |
| Contactpersonen Overheid/Topsector | Marianne Zandstra, ministerie EZK; Mart van Bracht, Missie Systeem-integratie; Michiel Kirch; Maarten de Vries, Missie gebouwde omgeving |

**Programma jaar 2021 - Samenvatting**

The research programme System Transition develops actionable knowledge for policy makers and other professionals in the energy transition on the societal, economic, operational and behavioral issues of the energy transition. In 2021, TNO conducted research projects for energy policy makers, as part of a new research programme for the ministry of Economic Affairs & Climate Policy. The highlights of this programme are presented below. The complete results can be found on the web portal energy.nl.

In one of the new studies, public support for proposed climate policy measures was assessed. It was found that *perceived justness* and *effectivity of the measures* are the main factors determining public support. We also studied the possible role of electricity generation from water (e.g., wave and tidal) in the Dutch energy supply. Here the disadvantages, such as relatively high cost and low technical maturity, outweigh the advantages, such as predictable or baseload production. In another study we developed a method to *compare rates for heat from heat networks across different countries* and found that in the Netherlands consumer prices for heat are higher than in neighboring countries.

Important resulted from new research that combined insights from qualitative research with innovative big data analysis. Here TNO identified the number, type and location of energy poor households up to the neighborhood level. In doing so, we measured - for the first time in the Netherlands - energy poverty not only in terms of the affordability of the energy bill, but also in terms of the energetic quality of homes and the extent to which residents can participate in the energy transition. It was found, for example, that 7% of households in the Netherlands currently face an acute form of energy poverty, while almost 50% of households depend on others to participate in the energy transition. The study was discussed with parliament, and attracted a lot of media attention.

Another key finding comes from a study on the import of solar energy from North Africa, directly or in the form of hydrogen, into the EU. Because of the significantly higher solar irradiation in North Africa, the import of solar energy into the EU is beneficial for both parties, despite the costs of energy transport.

| Titel | VP Duurzaam Bouwen (P502) |
|---|---|
| MTIB Thema | Klimaat en Energie |
| Contactpersonen TNO (DS en VPM) | Arjen Adriaanse en IJsbrand van Straalen |
| Contactpersoon Regie-voerder | Rob Hofman (RWS), programmacommissie Deltatechnologie (PCDT), Hans Weijers (BZK), David van der Woude (BZK), Joram Snijders (BZK), Sabine Jansen (BZK), Johan Slobbe (BZK), Kendall Esmeijer (EZK), Erik ten Elshof (EZK), Peter Jongerius (EZK), Ronald Schillemans (EZK), Hans van der Weijde a.i. (M2i) en TKI Urban Energy. |

**Programma jaar 2021 - Samenvatting**

VP Duurzaam Bouwen richt zich op het optimaal verduurzamen van de gebouwde omgeving. Dit betreft met name bruggen, viaducten en gebouwen. Maatschappelijk relevante thema's zijn daarbij digitalisering, energiezuinigheid, circulariteit, veiligheid, onderhoud en renovatie. Vanaf 2021 worden binnen dit VP ook projecten uitgevoerd binnen het BTIC programma Emissieloos bouwen. VP Duurzaam Bouwen bestaat uit vijf deelprogramma's: Infrastructuur, Bouwkwaliteit, Digitalisering, Energie in de gebouwde omgeving en Bouwmaterialen. In 2021 is besloten om de VP's Duurzaam Bouwen (P502), Urban Energy – EnerGO (P505), Delta Technologie (P508), HTSM Bouw Innovaties (P513) te integreren tot een VP Duurzaam Bouwen (P502). De verslaglegging over 2021 vindt plaats volgens deze nieuwe opzet.

***Infrastructuur*** - TNO onderscheidt de onderzoekslijnen droge kunstwerken (staal- en betonconstructies) en natte kunstwerken. Technieken worden ontwikkeld voor de beoordeling van de constructieve veiligheid, die bijdragen aan het nauwkeuriger bepalen van de restlevensduur en veiligheid zoals vastgelegd in normen en richtlijnen. Het onderzoek heeft in 2021 onder andere geleid tot geavanceerde probabilistische modellen voor dwarskrachtbezwijken bij betonnen constructies en het bezwijken onder invloed van vermoeiing van stalen constructies. Hierdoor kan de constructieve veiligheid nauwkeuriger worden bepaald. Ook zijn methoden voor het monitoren van constructies ontwikkeld waarmee beter inzicht wordt verkregen in de staat van onder andere lasverbindingen. In het kennisprogramma Natte Kunstwerken is een meetprotocol gevalideerd voor het betrouwbaar bepalen van de dikte van stalen damwanden. Daarnaast is uitwerking gegeven aan het zogenaamde jaargebonden veiligheidsniveau van constructies waarin rekening kan worden gehouden met de resultaten van inspecties en metingen.

***Bouwkwaliteit*** - Bodemdaling wordt meer en meer als een groot probleem ervaren, ook wat betreft de impact op de gebouwde omgeving. Tezamen met Deltares heeft TNO een eerste stap gezet naar een onderzoeksagenda funderingsproblematiek. In 2021 zijn simulaties uitgevoerd om het gedrag van metselwerkwoningen onder ongelijkmatige zettingen te voorspellen. Hoogbouw wordt steeds vaker toegepast in binnenstedelijk gebied. Het dynamisch gedrag bij wind speelt een belangrijke rol in het ontwerp. Om tot een bruikbaar voorspellingsmodel te komen, zijn in 2021 voorbereidingen gedaan voor meerjarige metingen aan nieuwe hoogbouwprojecten. Het Expertisecentrum Verduurzaming Zorg (EVZ) draagt als één van de pijlers van het Kennis- en Innovatieplatform Maatschappelijk Vastgoed (KIPmv) bij aan de CO2-emissiereductie in de zorg. Evenals in voorgaande jaren richt de bijdrage van TNO zich op het verzamelen, het valideren, het specifiek toepasbaar maken en het ontsluiten van voor CO2-reductie relevante kennis. In 2021 zijn er naar aanleiding van de coronaproblematiek onderzoeken uitgevoerd naar de effecten van maatregelen op blootstellingsrisico's in relatie tot de ventilatie en het gebruik van specifieke gebouwen en ruimten. Dit heeft geleid tot een aantal rapportages die als Kamerstuk publiek zijn gemaakt.

***Digitalisering*** - In 2021 is het concept van predictive digital twins toepasbaar gemaakt voor civiele infrastructuur, gebouwen en glastuinbouw. Een opzet van een architectuur voor een Common Data Environment (CDE) voor predictive twins, waarin BIM-modellen, (meet)data, rekenmodellen en softwaretools kunnen worden samengebracht, is uitgewerkt. En er is een aanpak beschreven om de door TNO ontwikkelde algoritmes (artificial intelligence/machine learning) te koppelen aan expertmodellen en geschikt te maken voor toepassingen in predictive twins. Deze aanpak is toegepast voor defect/schadedetectie en diagnose in civiele constructies, predictive maintenance van luchtbehandelingskasten in ziekenhuizen, en binnenklimaat optimalisatie in kassen.

In predictive twins moeten verschillende databronnen samenwerken. Daarvoor ontwikkelt TNO de zogenaamde ALIM-aanpak (Asset Lifecycle Information Management) op basis van linked data open standaarden en semantic web technologie. In 2021

is een rapport opgeleverd waarin wordt geïnventariseerd hoe de ALIM-aanpak kan worden toegepast in predictive twins bij eigenaren en beheerders van assets, rekening houdend met hun bestaande IT-systemen. De focus lag op specifieke use cases zoals onderhoud van assets van Rijkswaterstaat. Resultaat daaruit is een aanpak en strategie die nodig is om predictive twins op te schalen van individuele assets naar een asset portfolio. Tenslotte is vervolgonderzoek gedaan naar de toepassing van op BIM gebaseerde technologie voor automatische toetsing van eisen in het Bouwbesluit ('BIM Bots'). In het onderzoek is onder meer aandacht besteed aan de business-case voor het gebruik van BIM Bots.

***Energie in de gebouwde omgeving*** - TNO richt zich op het ontwikkelen van technologieën, oplossingen en tools voor met name renovatie van woningen en utiliteitsgebouwen, en de opschaling daarvan. In 2021 zijn de modulaire datagedreven gebouwmodellen (predictive twins) doorontwikkeld voor het vaststellen, voorspellen, verbeteren en sturen van de werkelijke prestaties op het gebied van energie, comfort en binnenluchtkwaliteit. Dat gebeurde voor woningen én kantoren, waarbij de nadruk lag op de ontwikkeling van modellen voor gebruikersgedrag en de verbetering van de modelarchitectuur. Ook is de tool voor gebouwclustering, die de basis vormt voor de contingentenaanpak , verder doorontwikkeld. Daarbij zijn gebruikersaspecten toegevoegd, is er een blauwdruk ontwikkeld voor een schaalbare data- en ICT-infrastructuur, en is de tool ingezet voor twee verduurzamingsconcepten. Daarbij zijn contingenten gevormd die zijn opgeschaald naar toepassing in heel Nederland. Op het gebied van duurzame warmte- en koudesystemen is onderzoek gedaan naar de werkelijke prestaties van hybride warmtepompen, is een systeemmodel ontwikkeld voor de combinatie van een warmtepomp met een warm water buffer, is de thermoakoestische warmtepomp verder doorontwikkeld en is de warmtewingevel (inclusief regeling) toegepast bij de renovatie van 6 rijwoningen. Voor compacte warmteopslag is een opslagvat voor voelbare warmteopslag in water ontwikkeld en gepatenteerd en is het werkingsprincipe van een opslagbatterij voor hoge temperatuur voelbare warmteopslag in metalen aangetoond. Verder is voor thermochemische warmteopslag met natriumsulfide (Na2S) een opslagdichtheid van 0,75 GJ/m3 op materiaalniveau en 0,4 GJ/m3 op systeemniveau aangetoond en is het vacuüm reactorconcept gedemonstreerd in een bewoonde woning. Voor het naar de markt brengen van het gesloten loop reactorconcept is de joint venture Cellcius opgericht.

**Bouwmaterialen** - Om nieuwe duurzame betonsoorten te kunnen ontwikkelen wordt een voorspellingsmodel uitgewerkt. In 2021 zijn in dat kader nieuwe meetinstrumenten gebouwd voor het beoordelen van betonmengsels en is de manier van ontwerpen en produceren van de mengsels gestandaardiseerd. Verlenging van levensduur is van groot belang, ook voor bestaande betonconstructies. Een karakterisatie van corrosieproducten van wapeningsstaal is uitgevoerd op basis van 23 jaar oude monsters met behulp van SEM-EDS en Raman spectroscopie. De resultaten zullen vanaf 2022 in voorspellende modellen worden ondergebracht. Vanaf 2020 ondersteunt TNO bouwpartijen bij de ontwikkeling van innovatieve constructieve houtproducten. In 2021 is nagegaan welke kennis internationaal beschikbaar is over toepassingen en innovaties, aangaande de bouwkundige prestaties en over de productie. Het onderzoek naar asfalt richt zich op het beter kunnen voorspellen van de levensduur en specifieke materiaaleigenschappen. Dit is van belang bij ontwikkelen van nieuwe asfaltsoorten op basis van hergebruik en bio-based asfalt. In 2021 is onderzoek gedaan naar veroudering van open deklagen in de wegpraktijk en zijn stappen gezet in het ontwikkelen van een methode voor de karakterisering van bindmiddeleigenschappen.

| Titel | VP Geo Energie (P307) |
|---|---|
| MTIB Thema | Klimaat en Energie / MMIP4: Duurzame warmte en koude in de gebouwde omgeving (individueel en collectief), MMIP 6,7 (Verduurzaming warmtevraag Industrie, CO2 opslag, grootschalige energieopslag) |
| Contactpersonen TNO (DM en VPM) | Richard Braal (DM TNO), Maurice Hanegraaf |
| Contactpersoon Regie-voerder | Ronald Schillemans, Pieter Jongerius (EZK), Jorg Gigler (TKI Geo Energie), Robert Jan van Egmond (TKI Urban Energie) |

**Programma jaar 2021 - Samenvatting**

De noodzaak tot versnelde ontwikkeling van warmtenetten en de inzet van geothermie en Hoge temperatuuropslag (HTO) is opgenomen in het regeerakkoord van het aantredende kabinet. Een tweede belangrijk speerpunt in het regeerakkoord zijn de veiligheidsrisico's van de energietransitie en bijbehorend risicobeleid. De komende regeerperiode wordt gewerkt aan het ontwikkelen van een ruimtelijk programmatische aanpak waarbinnen alle verwachte activiteiten in de ondergrond (Geothermie, opslag waterstof, gaswinning, warmte en zoutwinning ) vast worden gelegd. Deze prioriteiten in het regeerakkoord sluiten (opschaling duurzame warmtenetten en veiligheid van mijnbouwactiviteiten) sluiten naadloos aan op doelstellingen van dit VP programma :

1. Reduceren van pre-drill geologische Exploratie en Realisatie risico's voor geothermie en HTO door betere data-analyse, acquisitie, publieke informatiesystemen en modellen
2. Verhogen productie geothermie en HTO door betere resource ontwikkeling en beheer
3. Vergroten van veiligheid en verlagen van mogelijke negatieve (milieu)impact bij ondergrondse activiteiten (geothermie en HTO, CCS, abandonneren putten):
4. Verlagen kostprijs voor aanleg en aansturing van warmtenetten en optimalisatie van warmtevraag en aanbod door ontwikkeling van de publieke design toolkit
5. Veilige en kosteneffectieve Ontwikkeling van CCS en Energie-opslag

Voor deze doelstellingen werkt TNO in missiegedreven ecosystemen samen met industrie, Nederlandse kennisinstellingen (i.e. Deltares, KWR, academia). De missies worden o.a. gedreven door kennisagenda's die samen met industrie en kennis instellingen worden gedefinieerd. De benodigde innovaties worden vervolgens grotendeels (ca 80% van het SMO-budget) gerealiseerd in nationale en internationale onderzoeksprogramma's zoals het lopende WarmingUP (budget 18 mln euro, looptijd 2020-2022) en SCAN project, en door TKI of EU gefinancierde projecten, zoals HEATSTORE, PERFORM, RESULT, ELFO, etc.

***Highlights in 2021***

Ad 1. Integrale geologische, structurele en geochemische karakterisatie van marginale en ondiepe geothermische reservoirs; succesvolle test van DAS-VSP data acquisitie technieken voor HTO; AI gerelateerde workflows voor 2D en 3D seismiek (OpendTect AI-omgeving) voor betere geothermische reservoir karakterisatie; oplevering beta-versie gratis gebruiksvriendelijke 3D geothermische reservoir simulator;

Ad 2. techno-economische fast-model voor de evaluatie van de trade-offs tussen verhoogd debiet voor complexe well designs en hogere kosten voor aanleg, en technische risico's; Een Doublet Digital Twin (DDT) is ontwikkeld voor de analyse van LCA, emissies en corrosie en scaling, op basis van TNO's REACT software inclusief: TNO's state of the art optimalisatie-tooling (EVEReST), oorspronkelijk ontwikkeld voor olie en gas toepassingen is in 2021, verbreed voor toepasbaarheid en bruikbaarheid naar alle (geo)energiesystemen, met toepassingen in meerdere door de geothermische industrie gecofinancierde projecten waaronder optimalisatie van well designs in WarmingUP en RESULT samen met industriële partners EBN, HVC, WEP, Shell, Engie.

Ad 3. Afdichtende en mechanische eigenschappen van bentoniet, zout en Sorel-cement zijn onderzocht voor toepassingen in geothermische; een grootschalige laboratorium opstelling is gerealiseerd voor de opbouw van kennis over cementhechtingskwaliteit en leksnelheid tussen cement en een zachte formatie; Uitgebreide tooling is ontwikkeld om breukreactivatie

en seismiciteit door afkoeling bij doubletten in zandsteen reservoirs te analyseren en thermo-mechanische experimenten zijn ontworpen en uitgevoerd in het iM4RockLab (TNO-Utrecht).

Ad 4. De ontwikkeling en het gebruik van de WarmingUP design toolkit voor het ontwerp van warmtenetten en case studies voor RES ontwikkeling door verschillende industriële partners in WarmingUP; de design toolkit is uitgebreid met multi commodity capabilities voor een flexibel optimalisatiekader voor hybride systemen.

Ad 5. Voor CCS is voorbereidend werk gedaan voor de verwachtte opschaling van CCS in 2022 in projecten samen met industriële partners (e.g. Porthos); Een prototype Energie-storage atlas is ontwikkeld voor zowel warmte, waterstof als andere energiedragers. Deze zal verder zal worden uitgewerkt in 202; Robuuste simulatoren zijn ontwikkeld voor energieopslag (technisch-economische MOLE simulator is opgeleverd, die gebruikt kan worden voor CAES, UGS en UHS), en waterstof gekoppelde reacties zijn ontwikkeld in de TNO's REACT simulator.

| Titel | VP Renewable Electricity (P321 Solar – P322 Wind) |
|---|---|
| MTIB Thema | Klimaat en Energie / MMIP2, MMIP3 |
| Contactpersonen TNO (DM en VPM) | Harm Jeeninga (DM), Arthur Weeber, Peter Eecen (VPM) |
| Contactpersoon Regie-voerder | Kendall Esmeijer, Ruben Prins, and Erik ten Elshof (EZK);<br>Robin Quax, Wijnand van Hooff, and Ümit Duman (TKI Urban Energy) and Bob Meijer (TKI Off-shore Wind Energy);<br>Frans van den Heuvel (Mission Team Electricity) |

**Programma jaar 2021 - Samenvatting**

The Renewable Electricity program contributes to reaching climate goals described in the Paris Agreement, the European Green Deal and the 'FIT for 55' package, and the Netherlands Climate Agreement (particularly through its Missions Electricity and Built Environment, MMIP1, 2 and 3), by enabling rapid and large-scale deployment of wind energy and photovoltaic solar energy, and developing technological solutions to overcome barriers with respect to integration, societal acceptance, circularity, etc. This Renewable Electricity program consists of programs on solar and wind energy with significant collaboration and synergies.

***The program on Solar Energy*** provides innovative technological solutions enabling large-scale deployment of photovoltaic solar energy and overcoming barriers as described above. The program also supports strengthening and rebuilding the European solar energy industry to seize economic opportunities, reduce dependence on imports and avoid supply disruptions, maximize sustainability and accelerate the energy transition, by joining forces with industry along the value chain from developing innovative manufacturing up to and including applications.

Together with partners in research and industry, the program on solar energy set the following selected goals for 2025:

- Sustainable solar energy on land and water: (1) a framework for the assessment of solar parks available (2) a first pilot of solar PV on the North Sea operational;
- Integrated solar energy and safety: (1) integrated and safe solar energy elements demonstrated to be a preferred option for energy neutral buildings, and on the longer term for energy positive buildings, (2) a framework for integration of solar in infrastructure available and (3) the mass customization approach for Vehicle Integrated PV application proven;
- Circular solar modules and mass customization: (1) an ecosystem with partners along the value chain for mass customization of cost-competitive integrated solar products established, (2) the potential for recycling of solar modules demonstrated, especially for high-value materials;
- Advanced solar technologies: (1) large-area hybrid perovskite-silicon tandem solar cells with 27% efficiency potential and proven stability, (2) demonstration of a flexible all-perovskite thin-film tandem with efficiency potential of 24% for roll-to-roll processing and proven stability.

***Highlights Solar in 2021***

- First steps in modelling where we look for a compromise between LCoE of a solar park versus carbon fixation;
- Several reports with learning on safety aspects for solar parks besides roads and on infra (with RWS);
- Measurement setup specified for dynamic shading measurements on PV modules in a combined wind-solar field;
- The TNO VIPV Energy Flow Model was updated this year in order to include more complex energy systems like a reefer truck;
- World record energy yield established with ZigZag Solar with an esthetic façade product on the TNO BIPV test facility SolarBeat;
- High-performance tri-angular PV module made from back-contacted pixel cells demonstrating the flexibility in design;

- High-performance tandem PV devices made (with partners): 29.6% for a hybrid perovskite-silicon tandem, and 27.2% for an all thin-film tandem;
- Snap cure conductive adhesives have been shown as a possible market acceptable interconnection solution for high throughput manufacturing using roll lamination compatible with the TNO mass customization line.

***The program on wind energy*** provides the TNO innovations, knowledge and technology required to implement the required wind power in the Netherlands against lowest societal costs. The upscaling of offshore wind encounters barriers such as costs, speed of implementation, use of offshore space, safety, ecology, human factor and the integration in the energy system. These are addressed in the TNO research program. The activities on onshore wind is starting again after the focus has been mainly on offshore and focuses primarily on environmental and societal aspects as well as regulation. By including the companies in an early stage of development, the innovations are expeditiously implemented by the companies and therefore have their impact in building the offshore sector before 2030. An example is the Dutch offshore industry, enabling the Dutch energy transition and creating activities all around the world by installing and maintaining offshore wind farms.

The R&D programme of TNO wind energy is part of TKI Wind op Zee and seamlessly aligns with the MMIP1 of Mission A. For the next three years the main goals are to contribute to the implementation of offshore wind by removing barriers:

- Reduction of cost of energy of offshore wind power
    - By improving the business case of large wind turbines
    - By improving installation, operation and maintenance of wind turbines
- Integration in the energy system by increased flexibility, storage and market
    - Development of conversion and storage technologies relevant for large-scale wind
    - Integration concepts to include floating solar in offshore wind farms
    - Development of scenarios for 2030 and 2050 considering hybrid systems
    - Support the infrastructure development to secure energy sector-coupling.
- Development of new concepts for the development of a CO2-free energy system in 2050
    - Innovative accelerated test methods for rapid validation and thus fast time-to-market
    - Robotisation and digitalisation to support cost-effective and reliable operation
    - Off-grid wind concepts to exploit the full potential of offshore wind energy

***Highlights Wind in 2021***

*Knowledge production with the TIADE research wind turbine*. Success has been achieved in 2021 with innovative pressure monitoring on the surface of large scale blades with hundreds of small pressure sensors integrated into the blade installed by our specialists. The data have been analysed by TNO and incorporated into fluid dynamics models for performance analysis. A coating developed by TNO has been tested to remotely detect erosion damage to the leading edge of the blade as a result of raindrop impact, using UV light mounted on a drone.

*Towards recyclable next generation wind turbine blades* - The success achieved is the TNO optimized pyrolysis process for reclamation of glass fibers. This solution resulted in good recycled material and production properties that have been demonstrated with the fabrication of a component for the automotive application.

*Assisting industry on global wind farm effects using dedicated TNO machine learning techniques* - TNO Wind Energy is engaged with a large consortium to apply dedicated machine learning to address so-called global blockage problems. The TNO machine learning technique was successfully applied in an onshore demonstration case at the Fraunhofer test site, proofing that it works.

*VR/AR and drone techniques for wind turbine inspections at Zephyros fieldlab* - TNO Wind Energy is developing virtual reality technology and drone technology to improve inspection and maintenance of offshore wind farms. Successful tests demonstrate that modern techniques as drones and AR/VR aid offshore work, significantly. Videos are available at https://youtu.be/kw9L3o5YLZ4.

| Titel | VP CO2-neutral industry (P323) |
|---|---|
| MTIB Thema | Klimaat en Energie |
| Contactpersonen TNO (DM en VPM) | Richard Braal, Jaap Vente |
| Contactpersonen Regie-voerder | Rob Kreiter (TKI-E&I), Jörg Gigler (TKI-Gas), Kees de Gooijer (TKI-BBE) |

**Programma jaar 2021 - Samenvatting**

The demand driven program “CO2 neutral industry” responds to the societal need for a carbon neutral industry as formulated in the Climate Agreement. TNO supports the (inter)national industrial sector by developing suitable technologies and making them widely available to the market through, such as through licensing, to maximize use of these approaches and to generate impact. Key objectives for the period up to 2025 include:

- Technology contribution to at least 5 major CO2 capture plants
- Heat pump technology demonstrated up to 150°C in three sectors
- Joint cross- border vision on energy infrastructure for H2 and CO2 in collaboration with German partners.
- Realisation of a first integration project for offshore hydrogen production from offshore wind and admixing of hydrogen to natural gas stream (PosHYdon).
- Biofuel production demonstrated at industrial scale
- 30% cost reduction and 50 times lower use of scarce materials in electrolyser systems
- Three novel synthetic fuel production routes proven up to TRL 5

Some highlights achieved in 2021 include:

- Solvent degradation in post combustion CO2 capture determined using the TNO mini plant, is the same as in large scale installations. This can lead to low cost experimental validation of the suitability of a certain solvent in a specific application
- A conceptual study has shown that a novel freeze concentration concept can increase the energy efficiency with >80% for selected processes in the food industry
- Real time H2 sensor has proven to be suitable for gas stream analyses.
- A porous electrode structure was proven to enable an over 10 fold reduction of iridium in water electrolysis applications
- The first 100 hour test for the production of biochar and energy using TNO Enerchar technology has been completed successfully
- The newly designed mobile pilot plant for the sorption enhanced DME synthesis has been delivered to TNO. After commissioning and first optimization test rounds, this facility can be used on-site of an industrial party with industrial gas streams as a feed

| **Titel** | **VP Luchtkwaliteit (P510)** |
|---|---|
| MTIB Thema | |
| Contactpersonen TNO (SD en VPM) | Erlend Deckers (VPM), Ardi Dortmans (SD), Martijn Schaap (depSD) |
| Contactpersoon Regie-voerder | Bas Warmenhoven, Paul Rijkse (MinIenW) |

**Programma jaar 2021 - Samenvatting**

The demand driven program “Environment and Sustainability” has two focal areas, **Environment** and **Circular Economy**.

The **Environment** part focuses on the atmospheric emissions “ABC” of Air quality, Biodiversity and Climate change.

Every year around 7 million people die prematurely from exposure to polluted air. Critical loads for atmospheric nitrogen deposition are exceeded in 72% of the Dutch nature areas, leading to significant biodiversity loss. Global warming may lead to catastrophic sea level rise, droughts, and more frequent extreme weather. All these pressing environmental challenges relate to anthropogenic emissions into the atmosphere and their negative impact on the environment and health.

TNO details the sources and impact of health relevant particulate matter (combustion particles, non-exhaust, microplastics), reactive nitrogen species and greenhouse gases. Emission monitoring strategies are developed based on novel experimental facilities and satellite data.

In 2021 we continued installing the Ruisdael observatory, greenhouse gas emission quantification and reactive nitrogen deposition , . In this activity area we have continued our cooperation with Copernicus, Ruisdael, Eindhoven City (fieldlab emission monitoring) a.o. and established new partnerships with ZONMW, topsector LSH and the Momentum consortium on microplastics.

The knowledge and technology within TNO for atmospheric composition modelling was strengthened through improvements in nitrogen deposition calculations, particulate matter modelling and source apportionment and validation of modelling results with data.

**Circular Economy** works to the benefit of our living environment and economy by reducing the use of virgin feedstock. Our priorities in 2021 were on plastics, building and infrastructure and impact assessment.

For circular plastics, the main activity in this VP consists of the H2020 project PLAST2bCLEANED which targets a human and environmentally safe recycling process for Waste Electrical and Electronic Equipment (WEEE) plastics in a technically feasible and economically viable manner. The main result for 2021 was the completion of the final Process Flow Diagram (PFD) of the dissolution process based on the experience gained by TNO and Fraunhofer ICT based on over 300 experiments.

For the former circular building and infrastructure – and the impact assessment domain (from 2022 on named Circular Value Creation) the activities in this VP focussed on sustainable and circular material use in the construction industry, including the potential of biobased materials, and the H2020 project Panorama. The publication of a TNO exploratory study on the potential of CO2 sequestration in timber frame constructions led to an intensive public debate and wide attention. This initiated further research on how to incorporate CO2 sequestration of biobased materials in the Milieu Prestatie Gebouwen (MPG) https://milieudatabase.nl/start-onderzoek-bepaling-waardering-van-de-milieueffecten-van-co2-opslag-en-emissie-in-bouwmaterialen/

| Titel | VP Circulaire Economie (P515, P512 and P504)) |
|---|---|
| MTIB Thema | Circulaire Economie |
| Contactpersonen TNO (DM/SD en VPM) | Erlend Deckers (VPM), Ardi Dortmans (SD) |
| Contactpersoon Regie-voerder | Bas Warmenhoven, Dirk-Jan Sloot (IenW), Marc Hendrikse, Hans van der Weijde (HTSM) |

**Programma jaar 2021 - Samenvatting**

The Netherlands has the ambition to achieve a circular economy by 2050: sustainable circular chains in which raw materials are fully reused, no waste is produced, and all used energy is sustainably generated. Earlier TNO research showed that promoting circular product chains can lead to an additional added value of 7 billion euros in 2025 and 54,000 extra jobs in the next 5 years. This VP contributes to this ambition and is in line with the Mission-driven Topsectors and Innovation Policy (MTIB, Mission C and CE), the Dutch National Science (NWA) agenda and key enabling technologies (measurement and detection).

TNO aims to accelerate the Dutch transition towards a circular economy and contributes to the KIA-CE by providing guidance in design and development of the circular economy (eco-system, policy, incentives, business models, impact assessment, technology, infrastructure, products) and by co-development of concrete solutions (products, technologies).

The VP Circular Economy focusses on 2 topics: Circular Value Creation and Circular Plastics. In the Circular Value Creation program we quantify and model the impact – environmental, economic and social - of circular and sustainable technologies, strategies & policies. We focus on impact analyses and value creation, and accelerating transition to a circular economy. The Circular Plastics program focusses on development of innovative recycling technologies for plastics, as well as on impact assessment specifically for plastics. Methodologically there is a strong link between the Circular Value Creation Program and the impact analyses part of the Plastics program. The same modelling framework is used as a starting point and innovation in models is aligned.

In the circular plastics domain a mass flow analysis model of macro and microplastic releases of different polymers from different sectors and applications in all countries of the world was developed. Furthermore, TNO developed a web-based sustainability assessment tool on Battery Electric Vehicle Sustainability. In the field of circular packaging, TNO redesigned non-recyclable multilayer packages to recyclable monomaterial packages. In addition, TNO built a model on sealing properties that calculates the temperature of the polymeric foil at the sealing interface during thermal sealing processes. To protect our IP on dissolution technology 2 patents were filed: one on polycarbonate recycling and one on post-consumer waste foils recycling. Furthermore dissolution route was developed for the chemical recycling of polylactic acid (PLA) and the ways to separate the enantiomers

In the building and infrastructure domain distance to target assessment on climate and circularity for the Dutch asphalt sector was assessed. It can be concluded that with the large scale implementation of existing innovations, large reductions can be achieved in the field of both climate as well as circularity goals. However when all innovations are implemented to their maximal potential, the absolute targets (50% reduction by 2030 and 100% reduction by 2050) are still not within reach. This means that more rigorous measures are necessary.

In the impact assessment domain the development of a social LCA methodology for material use of large cities was started. A first methodological concept has been developed based on the “social hotspot database”. This social LCA method has successfully been piloted for 25 priority material flows for a large Dutch city.

***2021 Programme on Environmental Technology (P512 – from 2022 included in VP Circular Economy)***

The TNO demand driven program P512 ‘Environmental Technology’ supports the transition to a sustainable society by developing technology, methods and tools to support and quantify sustainability impacts, thereby orchestrating innovation. The overarching goals are (1) to reduce the use of primary raw materials and (2) to develop sustainable recycling technologies. The program is complementary to the research done in P504 Water technology, P510 Environment and Sustainability, and P515 Circular Economy, and aligns with Mission-driven Topsectors and Innovation Policy (MTIB) Missions C andCE. Finally,

this research in contributes to key topics ofthe Dutch National Science (NWA) agenda and key enabling technologies (materials, measurement and detection).

*Circular Economy* **-** An important focus area for TNO in the transition towards a circular economy is plastic recycling, where we aim to largely reduce the use of virgin feedstock. In 2021 we also initiated new research on the recycling of e-waste. For the topic of circular electronics, the state of the art of current recycling technologies including their pro's and con's is being mapped. Before a new technology is being developed, it is important to think about the sustainability of the technology beforehand (circular and sustainable by design). To support the sustainability-quantification of a technology, it is studied whether thermodynamic principles could be used as circularity indicators to compare different recycling technologies. These thermodynamic based circularity indicators are indeed expected to be of added value in selecting the most sustainable technology. In addition to recycling, reuse and repair strategies, which are preferred options in the waste hierarchy (R-ladder), were adressed by studying ways to measure the state-of-health of batteries. On this topic, we collaborated with the UPCM (Uitvoeringsprogramma Circulaire Maakindustrie), M2i (materials 2 innovate), the TU Delft, and Utrecht University of applied sciences.

*Environment* **-** In To reduce environmental and health risk, our goal is to develop and validate methods for the determination of pollution in the environment. To this end TNO works on the development of new sensors. In 2021 the focus was on the design of sensing layers for man-made, persistent PFAS (per- and polyfluoroalkyl substances) compounds. The impact of PFAS in our environment is large: human exposure to PFAS type compounds is continuously increasing, the PFAS concentrations in nature (including animals) is building up, and these increasing concentrations now contribute to social problems such as major delays in construction of new houses. A promising synthetic route towards an imprinted polymer (MIP) as sensing layer for PFAS compounds is designed. This research is ongoing.

***Programme on Watertechnology' (P504 – from 2022 included in VP Circular Economy)***

The demand driven program "Watertechnology" focuses on microplastics, as one of the key environmental concerns in Dutch society and as a priority in the roadmap of the TNO unit Circular Economy and Environment. Microplastics are increasingly found in food, water, air and the human body. Very little is known about their formation, the potential (human health) risks and suitable mitigation approaches. The activities in this VP are in alignment with the policy objectives of our primary stakeholders, the Ministry of Infrastructure and Water (IenW) and the Circular Economy Mission (CE Mission).

The aim of the TNO Microplastic research program is to mitigate the risk of microplastics. We do this by:

- Understanding the whole chain involved in microplastic-pollution: from source to effect via the different human exposure routes (air, water, food)
- Providing solution strategies that minimize and reduce the risk of microplastics, where possible at the source.

Microplastics is a challenging multidisciplinary area where materials science, measurement & detection, and human health sciences come together with system thinking and in-depth domain knowledge as key elements. This is an excellent fit with the core capabilities of TNO.

TNO unit Circular Economy and Environment combines all required internal expertise and knowledge on this subject, from material science via analysis, detection and dispersion modelling to health expertise. We are connected to other initiatives in the Netherlands and Europe such as the Growthfund proposal Duurzame MaterialenNl, the Microplastics and Health initiatives of ZonMw and Health Holland (MOMENTUM), EC projects (LEON-T) and initiatives of ministry of IenW. TNO cooperates with fundamental research partners (UU, UM, RUG e.g.), knowledge partners like RIVM, scientific networks like Ti Coast and industrial partners. Our research initiatives fit within the Mission-driven Top Sector and Innovation Policy (MTIB). Finally, the microplastics research programme aligns with the Dutch National Science (NWA) agenda, as well as with core elements of "The European Strategy for Plastics in a Circular Economy" and "The European Green Deal".

| Titel | Sustainable Traffic and Transport (P408) |
|---|---|
| MTIB Thema | Mobiliteit / Missie D+ (MMIP 9 & 10; deel-KIA Toekomstbestendige Mobiliteitssystemen) |
| Contactpersonen TNO (DS en VPM) | Marieke Martens (DS), Marika Hoedemaeker, Isabel Wilmink, Geiske Bouma (VPMs) |
| Contactpersoon Regie-voerder | Topsector HTSM: Leo Warmerdam<br>Topsector Logistiek: Albert Veenstra<br>Ministerie IenW: Michel Duinmayer (IenW-DGMO/Unit Strategie) en Karen de Ruijter (IenW-DGMO/Unit Strategie)<br>Ministerie BZK: Kees de Jong (DGBRW/Directie RenL, cluster E/account kennis) en Rosemarie Bastianen (DGBRW/Directeur Ruimte en Leefomgeving) |

**Programma jaar 2021 - Samenvatting**

The roadmap Sustainable T&T is concerned with technology and policy research to advance the sustainable goals of the the mobility sector with special enphasis on air quality and climate. The research within the roadmap Sustainable T&T centres on the development of technology, tools and policy that aid in reducing the environmental impact of mobility in particular air pollutant emissions ("clean") and greenhouse gases ("economical/sustainable"). The VP Sustainable T&T focuses on:

- Development and optimization of sustainable logistics systems and zero emission mobility systems (with links to the research on digitalized, connected and automated vehicles and mobility)
- Assessment of impacts of sustainable logistics systems and zero emission mobility systems
- Modelling and simulation tools to estimate impacts of sustainable logistics systems and zero emission mobility systems, at the vehicle, system (traffic) and societal level
- Model and governance concepts regarding the effectiveness of sustainable logistics and mobility.
- Concepts that optimise the efficiency of the mobility and logistics systems (“zero emissions’).

***Highlights of 2021***

- Official launch of Battery Competence Centre in Oct 2021 with VDL, DAF, DAMEN, TU/e, RAI). Win of REACT EU for phase 1 BCC, Successful win of Green Transport Delta.
- Hydrogen Dual Fuel first experiment, enabled by Technotrans.
- DAF multicylinder project finished and built in a DAF truck.
- Finalisation and successful end-event of the AEROFLEX project on longer-heavier electrified vehicles, where TNO has developed assessment methods as well as novel testing for Vehicle-in-the-Loop within the ICSP facilities (Innovation Center Sustainable Powertrains).
- Publication of the white paper ‘Clean car fleet requires more than 'plug-in subsidy' - Environment and climate will benefit from more targeted car taxes for the entire fleet’.
- New techniques for emission measurements on non-road mobile machinery. First measurements regarding the use and associated emissions of mobile machinery and development of a database for the ‘Measurement programme and pilot Emission Monitoring and Periodic Inspection’ (EMPK).
- A measurement procedure for robustness testing in real-world emission tests – with special attention for city driving with a cold engine, simulating a traffic jam, driving very sporty and dynamic, idling for a long time, driving with all kinds of consumers on or off (air conditioning, seat heating, etc.). The TNO proposals all became part of the final test procedure which means that they became part of the GVI (GreenNCAP) vehicle assessments procedure.
- Set of three models (increasingly more specific) that can predict fuel consumption and CO2 on the basis of a vehicle's year of manufacture and weight. Model 3, delivered in 2021, is for journey-specific estimates of fuel consumption. It is suitable for determining fuel consumption very accurately based on very specific driving behaviour and environmental conditions, on the basis of monitoring data collected.
- Measurements with remote sensing instruments which can be used to find out whether it can be detected if a vehicle in front of the measurement vehicle has a removed or not functioning particulate filter.

- The CATALYST living lab about Connected Automated Transport of heavy road transport investigated the link between automated transport and sustainable transport, resulting in a paper titled “Verduurzamen met Connected Automated Transport”.
- The DKTI project Flex-EV delivered a monitoring report and journal paper regarding the use of electric vehicles and how to increase their range by (fast) charging while en-route. The paper also discusses a methodology for modelling different charging strategies.
- The linking of two TNO models (Urban Strategy and ESSIM) that makes it possible to map the effects of the increasing use of electric vehicles on the energy system (or electricity grid), showing that are limitations to the implementation of certain plans (in time) due to limited capacity on the electricity grid.
- Toolbox for evaluating the efficiency of e-mobility, which was tested and released to the public domain (see ): e-Mobility Toolbox (emobility.tools).
- Contribution to the development of a European Standard for Digital City Twins via the EU-project DUET.
- Setting up digital twins and living lab methodology to research the impacts of micro-hubs, in the context of cities as climate-resilient, connected multimodal nodes for smart and clean mobility (EU-project MOVE21).

| **Titel** | **VP Smart & Safe Traffic & Transport (P407)** |
|---|---|
| MTIB Thema | Mobiliteit / Missie D+ (MMIP 9 & 10; deel-KIA Toekomstbestendige Mobiliteitssystemen) |
| Contactpersonen TNO (DS en VPM) | Marieke Martens (DS), Marika Hoedemaeker, Isabel Wilmink, Geiske Bouma (VP-managers) |
| Contactpersoon Regie-voerder | Topsector HTSM: Leo Warmerdam, Topsector Logistiek: Albert Veenstra<br>Ministerie IenW: Michel Duinmayer (IenW-DGMO/Unit Strategie) en Karen de Ruijter (IenW-DGMO/Unit Strategie)<br>Ministerie BZK: Kees de Jong (DGBRW/Directie RenL, cluster E/account kennis) en Rosemarie Bastianen (DGBRW/Directeur Ruimte en Leefomgeving) |

**Programma jaar 2021 - Samenvatting**

The roadmap Smart & Safe T&T develops technology and policy for digitization in passenger mobility and logistics, to increase traffic safety and accessibility and to improve the efficiency of mobility and logistics. The research within the roadmap Smart & Safe T&T focuses on knowledge and innovation for smart mobility solutions (digitalization and automation) that increase road safety while improving efficiency and comfort. The VP Smart and Safe T&T focuses on:

- Development and optimization of smart mobility systems and smart logistics systems (digitized, connected and automated)
- Assessment of the impact of smart mobility systems and smart logistics systems
- Modelling and simulation tools to estimate the impact of smart mobility systems and smart logistics systems, at the vehicle, system (traffic) and societal level
- Modelling and policy/governance concepts regarding the effectiveness of the digitization and automation of mobility and logistics to support future proof, well informed decision making on mobility impacts
- Concepts that optimise the efficiency of the mobility and logistics systems (‘zero loss’) and traffic safety (‘zero casualties’)

***Highlights of 2021***

- Public demonstration in real traffic of multi-brand truck platooning in the ENSEMBLE project.
- Together with DAF, DAIMLER, IVECO, MAN, SCANIA and VOLVO Group, TNO defined the specifications for platooning as an automated function, which makes the transition from Platooning as a support function to higher automation levels. These specifications are inputs for standardisation in ETSI.
- TNO developed a new AI-based model for situational awareness for Automated Driving where the boundaries of the learned-ODD (Operational Design Domain) are automatically identified. The self-awareness of the algorithm was increased, allowing for a prediction model to know when it can rely on its prediction and when not. (Fabulos APPL.AI).
- A collaborative article on European NCAP Program Developments to Address Driver Distraction, Drowsiness and Sudden Sickness was written together with experts from other institutions under the EuroNCAP working groups (VTI, Sweden, Monash University, Australia, Thatcham Research, UK).
- An autonomous algorithm for self-organising truck trip planning that results in 10-20 minutes in a planning that would take a human planner hours to make, and which needs fewer trucks.
- In 2021 the Flex-rail project was finished. Results include recommendations for the European rail sector on how to transition from the current state to a user centric ‘Railway 4.0’ by the year 2050. One of the topics was the modelling of key decision variables that users apply to choose a mode of transport (which can be done for passenger and freight transport). The project also delivered a rail/road innovation model with which the impact of packages of specific rail and road innovations were examined.
- Development of a Multilevel Safety Assessment Framework, e.g. for the assessment of safety impacts of advanced driver assistance systems.
- Exploration of a new approach for Large Scale Micro-Simulation (LSMS) (proof of concept). LSMS uses the cores on the graphical card of a computer which enables simulation of much larger networks, simulation of conflict situations

and accidents which have a very low frequency, and the use of the improved driver and vehicle models.

- Method for automated conflict and accident analysis based on video data, which also provides input for a new way of modelling traffic safety.
- Methodologies for analysis of potentially disruptive mobility concepts (such as Hyperloop): 1) framework for impact analysis of disruptive mobility concepts and evaluation and 2) safety framework for testing with a detailed safety work plan.
- Model development for assessing impact of automated mobility concepts, going from real-world measurements via very detailed vehicle & traffic models to models for impact assessment at the system level (city or region).
- Vehicle Dispatcher module for assessing mode choice in mobility systems with demand responsive transport.
- Close cooperation on national and international level with universities –TU Delft, University of Oregon/ Urbanism Next, the University of Amsterdam and TU Eindhoven– to build up fundamental knowledge that is needed to model the effect of new mobility concepts, to design future mobility systems in the urban area and to work on the impact of automated driving (technical side and human-vehicle interaction).

| **Titel** | **VP Maritiem & Offshore (P311)** |
|---|---|
| MTIB Thema | Water |
| Contactpersonen TNO (DM en VPM) | Arjen Adriaanse (SD), Sander Dragt (VPM) |
| Contactpersoon Regie-voerder | Dr. Bas Buchner (TKI Maritiem) |

**Programma jaar 2021 - Samenvatting**

Nederland is een knooppunt voor ontwerp, bouw, beheer en onderhoud van maritieme en offshore systemen. Grote maatschappelijke ontwikkelingen zoals de energietransitie en toenemende digitalisering zijn uitermate belangrijk voor de sector. Als kennisinstituut draagt TNO bij aan het versterken en duurzaam ontwikkelen van de sector. Door het uitvoeren van toegepast onderzoek, in samenwerking met overheid, industrie en kennispartners, en als onafhankelijk instituut voor advies en beleidsontwikkeling voor de overheid.

Samenwerking in de sector is onmisbaar, daarom sluit het onderzoek van TNO aan bij de doelen en thema's van Topsector Water (Winnen op Zee, Schone Schepen, Slim en Veilig Varen en Effectieve Infrastructuur), Topsector Energie (Offshore Wind) en de Meerjarige Missie gedreven Innovatie Programma's (MMIP). Daarnaast levert TNO een bijdrage aan het opstellen en uitvoeren van de voor de sector relevante Kennis en Innovatie Agenda. Ten slotte hecht TNO veel waarde aan de samenwerking binnen onder andere GROW, JIC iBotics en het DOTC.

Ons maritieme onderzoek richt zich op vier thema's, samenvattend:

**Smart Megastructures**. TNO heeft als doel om nieuwe en bestaande Maritieme & Offshore (M&O) systemen, opererend onder de meest extreme omstandigheden, veiliger en betrouwbaarder te maken. Hiervoor zijn afgelopen jaar corrosiemodellen ontwikkeld, defecten in composieten bladen onderzocht en veiligheidsvraagstukken rondom alternatieve brandstoffen in kaart gebracht.

**Green Maritime Performance.** TNO zet in op het versnellen van de energietransitie en het behalen van de doelstellingen rondom verduurzaming uit de Green Deal Zeevaart, Binnenvaart en Havens (C-230) en doelen van de IMO en de Europese Commissie. Dit wordt onder andere gedaan door samenwerkingen zoals Green Maritime Methanol 2.0 met betrekking tot de introductie van methanol als scheepsbrandstof, EVERLONG met betrekking tot carbon capture aan boord van schepen en SCIPPER als het gaat om het uitvoeren van emissiemetingen aan boord of aan de wal.

**Underwater Acoustics**. TNO is een internationale speler op het gebied van meten, analyseren, modelleren, valideren en reduceren van onderwatergeluid. TNO ondersteunt overheden bij het ontwikkelen van beleid, en de industrie bij (kosten-) effectieve inzet van mitigerende maatregelen. In 2021 zijn kaarten van het onderwatergeluid van de scheepvaart op de Noordzee ontwikkeld, ten behoeve van de implementatie van de Europese Kaderrichtlijn Mariene Strategie. Het ontwikkelde bronmodel voor scheepsgeluid is gepubliceerd in de Journal of Marine Science and Engineering.

**Operations at Sea**. Samen met partners werkt TNO aan de ontwikkeling en validatie van onbemande, op afstand bestuurde en autonome systemen. Deze systemen vergroten de veiligheid en effectiviteit van logistiek, inspectie, onderhoudsoperaties en monitoring van het ecosysteem. Dit doen wij door het fuseren van sensordata, wat leidt tot efficiëntere en meer nauwkeuriger beeldopbouw. Afgelopen jaar is, onder andere, in het IJmuiden fieldlab de onderwateromgeving met verschillende akoestische en optische sensoren in kaart gebracht en is in Scheveningen velddata verzameld om het zoeken naar drenkelingen met drones te optimaliseren.

| **Titel** | **VP Karakterisering en Dynamiek Samenstelling Grondwater (P310)** |
|---|---|
| MTIB Thema | Water |
| Contactpersonen TNO (DM en VPM) | DM: Tirza van Daalen<br>VMP: Willem Jan Zaadnoordijk |
| Contactpersoon Regie-voerder | Wilbert van Zeventer (I&W), Roeland Allewijn (RWS); programmaraden TKI Watertechnologie, TKI Deltatechnologie |

**Programma jaar 2021 - Samenvatting**

De beschikbaarheid van voldoende grondwater van goede kwaliteit is een belangrijke randvoorwaarde voor de Nederlandse samenleving. De grondwaterstand is van groot belang voor bijvoorbeeld natuur, landbouw, bebouwing en infrastructuur en heeft een directe relatie met bodemdaling.

In dit VP richt TNO Geologische Dienst Nederland (TNO-GDN) zich op informatie rond de processen in de ondergrond die bepalend zijn voor de kwantiteit en kwaliteit van het grondwater. Bedreigingen zijn o.a. veranderingen in het landgebruik, klimaatverandering en intensiever gebruik van de ondergrond. Hierdoor dreigen dalende grondwaterstanden, verzilting en conflicten, bijv. tussen seizoensopslag van warmte en koude (WKO) en drinkwaterwinning. Voor grondwaterkwaliteit spelen de risico's vanaf het oppervlak een rol (uitspoeling gekoppeld aan landbouw en stedelijk gebied) en door activiteiten in de diepere ondergrond (bijvoorbeeld hoge-temperatuuropslag (HTO) en diepe boringen). De energietransitie doet de noodzaak voor energie gerelateerde activiteiten in de ondergrond sterk toenemen. Ook voor het veiligstellen van de zoetwatervoorziening is een grotere rol van de ondergrond voorzien, bijv. in het Deltaplan Zoetwater met het mitigeren van frequentere zoetwatertekorten en de structuurvisie ondergrond (STRONG, noemt strategische grondwaterreserves). Informatie en kennis ten aanzien van de dynamiek en de samenstelling van het grondwater alsook ten aanzien van de opbouw van de ondergrond is noodzakelijk voor het voorspellen van effecten, afwegen van risico's en het toetsen van beleidsbeslissingen.

Het doel van dit VP is methoden en informatieproducten te ontwikkelen om de effecten op en risico's voor het grondwater te voorspellen van klimaatverandering, ontwikkelingen in de landbouw, verstedelijking en verduurzaming van de energievoorziening. De kennisontwikkelingsactiviteiten in dit VP leiden tot:

- Data-analyse en nieuwe informatieproducten betreffende de ondergrond;
- Specifieke advisering van stakeholders aangaande het grondwater;
- Bijdrage aan nationale ontwikkelingen, zoals het innovatiecontract Watertechnologie, specifiek met kennis ten aanzien van grondwater en ondergrond;
- Bijdrage aan internationale ontwikkelingen, onder andere via de CSA voor een 'European Geological Service' (het programma van de gezamenlijk Geologische Diensten in Europa als vervolg op GeoERA, het EU-ERANET-programma, dat begin 2022 afgerond wordt).

Belangrijke resultaten in 2021 waren:

- Kennis van grensoverschrijdende grondwater kwaliteit en kwantiteit in de Roerdalslenk (NL, BE, GE) en visualisatie daarvan in de GeoERA RESOURCE groundwater quality viewer en - quantity viewers en voor Nederland ook in http://www.grondwaterkwaliteitinbeeld.nl en http://www.grondwaterkwantiteitinbeeld.nl.
- Pan-Europese inzichten in grondwaterkwaliteit en -kwantiteit in de GeoERA-grondwaterprojecten HOVER en TACTIC samen met Deltares en Europese partners.
- Binnen grondwaterkwaliteit nog speciaal nieuwe inzichten in nieuwe stoffen (o.a. PFAS), gassen en isotopen in grondwater.

| Titel | VP Arbeid & Gezondheid (P204) |
|---|---|
| MTIB Thema | Gezondheid en Zorg |
| Contactpersonen TNO (DM en VPM) | Seth van den Bossche |
| Contactpersoon Regie-voerder | Drs. Olinde Andringa (SZW), Dr. Anne van Putten (SZW) |

**Programma jaar 2021 - Samenvatting**

Doel van het Vraaggestuurde Programma Arbeid is om kennis en innovaties te ontwikkelen voor een toekomstbestendige arbeidsmarkt met een hoge kwaliteit van werk. Het programma omvat drie hoofdlijnen: 1. Sustainable work, 2. Future of work en 3. Inclusive work. Deze hoofdlijnen zijn tot stand gekomen in samenspraak met het ministerie van SZW, mede op basis van raadpleging van diverse kennispartners, stakeholders en kennisagenda's.

Het ministerie van SZW heeft evenals in voorgaande jaren een aanvullende Rijksbijdrage ter beschikking gesteld. Deze omvat drie onderdelen:

1. Maatschappelijk Programma Arbeidsomstandigheden (MAPA, gestart in 2018)
2. Kennisprogramma Inspectie SZW (KIS, gestart in 2018)
3. Kennisprogramma Werkgeversinterventies Arbeidsmarktdiscriminatie (KWA, gestart in 2019)


In de interactieve brochure '[Innovaties voor toekomstbestendig werken]' worden verschillende highlights geschetst van het Vraaggestuurde Programma Arbeid (in januari 2022 aangeboden aan ministerie van SZW, centrale regievoerder VP Arbeid).

| Titel | VP Jeugd: Gezond, Veilig en Kansrijk opgroeien (P211) |
|---|---|
| MTIB Thema | Gezondheid en Zorg |
| Contactpersonen TNO (DM en VPM) | Simone Detmar |
| Contactpersoon Regie-voerder | Alice van Gent (VWS), Liliane de Ruiter-Nanninga (VWS) |

**Programma jaar 2021 - Samenvatting**

Het programma Jeugd: Gezond, Veilig en Kansrijk opgroeien richt zich op kinderen en jongeren vanaf preconceptieperiode tot jong volwassene met als doel dat ieder kind zo goed mogelijk kan participeren in de maatschappij. Specifieke aandacht gaat uit naar het bereiken van kwetsbare gezinnen, in lijn met de missie van VWS, zoals verwoord in de kamerbrief van 27 april 2019: ''*In 2040 leven alle Nederlanders tenminste vijf jaar langer in goede gezondheid, en zijn de gezondheidsverschillen tussen de laagste en hoogste sociaal-economische groepen met 30% afgenomen*" [1] . Onze aanpak richt zich derhalve op het op maat ondersteunen van (aanstaande) ouders in de opvoeding en het begeleiden van kinderen en jongeren waar nodig en het bieden van een systematische en integrale aanpak met richtlijnen, signaleringsmethodieken en onderbouwde vroege interventies in het hele netwerk van preventie en zorg voor jeugd. Hierbij is veel aandacht voor het ontwikkelen van methodieken mbt het versterken van kwetsbare groepen, zoals voor mensen met lage gezondheidsvaardigheden.

In 2021 is, vanwege COVID, veel aandacht gegaan naar het ontwikkelen van digitale en gepersonaliseerde zorg en preventie. We werken met en voor vele (landelijke) organisaties. Onze belangrijkste partners zijn: ZonMw, NCJ, RIVM, KNOV, NJI, Bernard van Leer Foundation, BMGF en diverse gemeenten, universiteiten en Hoge Scholen. Voor de komende jaren streven we naar een 10% afname van ongezonde opvoedsituaties door het (door-)ontwikkelen en implementeren van persoonsgerichte interventies op gezondheid en weerbaarheid voor kinderen en jongeren van preconceptieperiode tot jong volwassenheid.

Ons programma wordt uitgevoerd binnen drie kennislijnen: Versterken 1e 1000 dagen; Advisering en vroeghulp op maat en Versterken (regionale) samenwerking op terrein van jeugd.

***Highlights 2021:***

*Versterken 1e 1000 dagen*

1a) groepszorg doorontwikkeld, momenteel geïmplementeerd bij 30% van verloskundigen praktijken. Implementatiestudies lopen in 5 landen (ondanks COVID)

1b) Zes Jeugdgezondheidszorgorganisaties hebben do it yourself ontwikkelingsonderzoek versneld geïmplementeerd (ouders meten zelf de ontwikkeling van hun kind).

*Advisering en vroeghulp op maat*

2a) Vijf JGZ organisaties werken met slimme richtlijnmodule en gepersonaliseerd advies binnen PPS

2b) er is een beslisondersteuning voor vaccinatie COVID ontwikkeld en landelijk ingezet.

2c) De ScheidingsATLAS (interventie voor ouders in scheiding) heeft de ZonMw parel prijs ontvangen.

*Versterken (regionale) samenwerking op terrein van jeugd*

3a) Leernetwerken succesvol geimplementeerd binnen regionale kenniswerkplaats SAMEN; digitale factsheet leernetwerken ontwikkeld die organisaties kan ondersteunen bij het opzetten hiervan.

3b) Digitale factsheet ontwikkeld voor doelgroepparticipatie.

[1] https://www.rijksoverheid.nl/documenten/kamerstukken/2019/04/26/kamerbrief-over-missiegedreven-top-sectoren-en-innovatiebeleid

| Titel | VP Biomedical Health (P203) |
|---|---|
| MTIB Thema | Gezondheid en Zorg |
| Contactpersonen TNO (DM en VPM) | Sandra Eikhout (DM), Ivana Bobeldijk (VPM), Ric van Tol |
| Contactpersoon Regie-voerder | LSH: Nico van Meeteren |

**Programma jaar 2021 - Samenvatting**

The goal of this program is to support professionals and industry to develop (personalized) critical support and effective treatment strategies to maintain health and prevent or cure diseases. Thus, supporting the mission of the Top Sector Life Sciences and Health (LSH), *Vitally functioning citizens in a healthy economy*, and effectively contributing to solving one of the main societal challenges, Health & Care, as identified by Ministry of Health, Wellbeing and Sports (VWS). The goals of the program were aligned with LSH and VWS.


We developed advanced analytical methods, pharmacokinetics knowledge, detection of viruses/pathogens, measurement of (digital)biomarkers, knowledge of mechanisms driving metabolic disorders, stratifications of patients, and strategies to influence lifestyle/behavior. This to allow the early identification of (chronic) disease development, and more effective and personalized strategies for prevention and/or treatment. Thus, contributing to reduced healthcare costs and a more vital and productive society.

More specifically we implemented a fast method for COVID-19 and Legionella detection, and added models to evaluate and interfere with viral replication and infection. A biomarker panel was established (patent pending) to detect non-alcoholic fatty liver disease (NALFD/NASH) in plasma; significantly less invasive than taking liver biopsies. Together with industry a first version of a skin model was developed to study different interventions on skin microbiota. New methods to evaluate bacterial composition/function help us to better understand their role in disease, unveiling new targets for intervention. Our pre-clinical models have been characterized  more in depth to reflect human disease processes, making these valuable test systems for new drugs. Our BMH program also addressed metabolic/immune health through the identification of biomarkers and extrinsic factors (e.g. diet, pollution, stress) that affect health or disease, in conjunction with personalized lifestyle intervention strategies. The latter was proven quite successful in reducing T2 Diabetes in a couple of field studies. Furthermore, an obesity (risk) screener for children has been developed. The in-silico modelling platform now provides valuable propositions to identify immune benefits of compounds. Moreover, non-invasive vital function monitoring has progressed from technology development into clinical study evaluations (COPD/asthma/IBD).

We joined new consortia, e.g. 4 have submitted proposals in the ‘Groeifonds’ call. Proposals NextGen, MedNext, Biotech-Booster and Pandemic Preparedness  haveadvanced to the next step. We received quite some media attention for the LifeStyle4Health initiative that started in 2018 and is rapidly growing. Lifestyle interventions may support metabolic/immune

health, an aspect shown to be of utmost importance in this COVID pandemic. TNO scientists were interviewed for several radio and TV programs, and for popular publications with respect to Lifestyle4Health and Food Allergies. We published 28 scientific papers, and our leading scientists were invited to speak at various (digital) conferences. They also contributed to the education and training of young scientists, with several master theses supervised within Biomedical Health projects. As in previous years, Early Research Programs Organ-Function on a Chip, Personalized Health and Body&Brain were important contributors to our Biomedical Health (BMH) program.

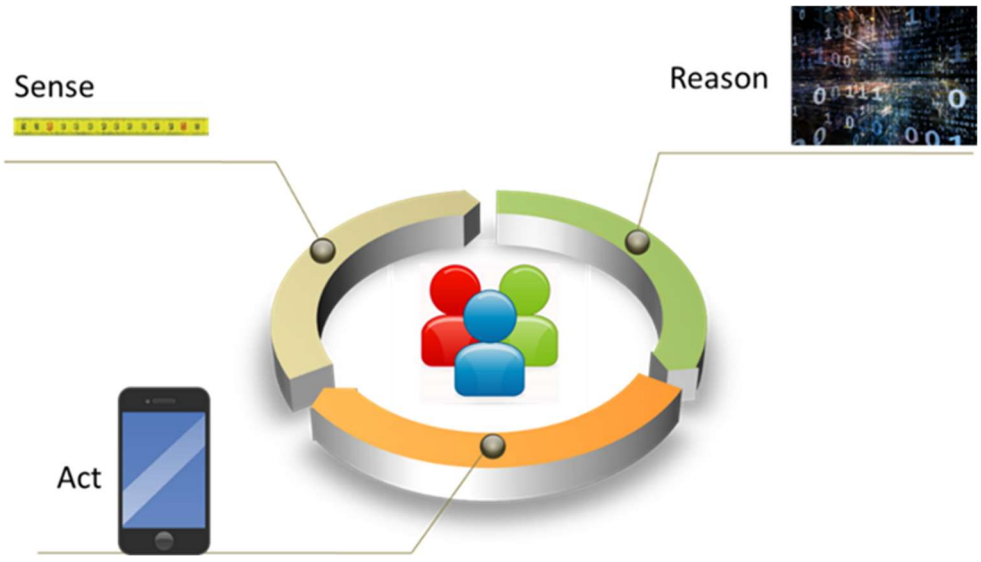
We conclude that 2021 was quite a successful final year of the 2018-2021 strategy period. Moreover, the Program Biomedical Health will continue to focus on technologies for efficient drug development and developing intervention strategies to prevent or treat disease. This will be further accelerated through facilitating an interdisciplinary way of working, facilitating synergies between expertise groups, and continue with a comprehensive and integrated portfolio review.

| Titel | VP Digital Health Technologies (P210) |
|---|---|
| MTIB Thema | Gezondheid en Zorg |
| Contactpersonen TNO (DM en VPM) | Sandra Eikhout (DM), Jildau Bouwman (VPM) |
| Contactpersoon Regie-voerder | Nico van Meeteren (LSH) |

**Programma jaar 2021 - Samenvatting**

The world around us is digitizing, also in health care, although in a slower pace compared to other disciplines/areas. Individuals gather masses of health data using apps that record their pulse rate, daily activity, diet, etc, but they also gain access to their medical data. It is not only members of the public who are interested in this data, it is also valuable to scientists and the common good. Such Real World Evidence data combined with standardized health data has the ability to create and improve models and software applications that provide personalized health and medical advice. Based on these models, personalized health advice tools can assist both patients and healthy individuals, by offering guidance about their health and lifestyle and prevent, reverse, cure or relieve disease/progression of disease. These models and applications enable a more efficient healthcare. This research programme supports the Mission driven Innovation approach of the Dutch Ministry of Health, Well-being and Sports ('VWS'). The central mission is for Dutch citizens living 5 year longer in good health and reducing the health differences between the higher and lower social classes. More specifically, we will contribute to: *reducing health issues that are a consequence of unhealthy lifestyle or exposure to unhealthy environment* (Mission I), and we will also help to *prevent chronic diseases and increase the proportion of people with a chronic illness or lifelong disability who can participate in society as desired* (Mission III).

The research program Digital Health Technologies ("DHT") brings together new bio-medical, lifestyle change and behavior knowledge and data. For this, AI and data science is used, resulting in digital services and solutions. In this program we work together with partners outside TNO (including several SMEs). We focus on secure, privacy-by-design and transparent (to the eco-system) systems for data re-use. As part of these systems, personal advice systems are embedded that include predictive models and connects to new wearables solutions. As the whole system is directly connected to individuals by design, citizens can also specify their needs and preferences (person centered health). The technology developed in this program is relevant for MedTech, HealthTech, Pharma and ICT companies.



The goal of this 2021 program was to contribute to the implementation and operation of innovative digital health interventions to better measurements of health, deeper insights in the importance of lifestyle factors in disease and innovative ways to perform clinicals trials. The program has developed knowledge, (ICT-) solutions, facilities and services that are applied in several projects. In 2021 the project 'C4yourself' was started this project is testing whether it is feasible to reuse individual health data (COVID test and vaccination data) for the public good, without leaking and showing any privacy sensitive data. In addition, in 2021 several resilience biomarkers for inflammatory health were developed that are published din a peer reviewed article. Together with (commercial) partners we started developing programs on hybrid intelligence within the NL-AIC consortium focused on Preventive health. The projects in these programs should build AI solutions that make use of the current knowledge and data and result in explainable outcomes. Moreover, health advice systems were developed with partners for COPD and psychological stress and currently they are being implemented in practice.

| Titel | VP Human Health RM Nano (P511) |
|---|---|
| MTIB Thema | Gezondheid en Zorg |
| Contactpersonen TNO (DM en VPM) | Sander Eikhout (DM), Wouter Fransman (VPM) |
| Contactpersoon Regie-voerder | HTSM: Frank de Jong (FEI), Nico van Meeteren (Topsector LSH) |

**Programma jaar 2021 - Samenvatting**

As one of the Key Enabling Technologies, nanotechnology has emerged in a broad area of industries and applications. The lack of timely alignment between material innovation and human health assessment has formed a crucial hurdle to appropriately govern the risks of nanotechnology.

TNO develops knowledge to assist industries in taking into account the safety of their (nano)product during the innovation of new materials and products. TNO invests in this VP Human Health Nano in the development of innovative tools, guidance and training to support safe-by-design, safe innovation and risk governance for innovative SME, sector organizations and industry in the absence of clear guidance and regulations.

The activities of VP Human Health Nano in 2021 consisted of collaborative work in various H2020 EU projects (Gov4Nano, SbD4Nano, PeroCUBE, HARMLESS, RISKHUNT3R). Further results in 2021 were the development of Safe-by-Design (SbD) and Safe Innovation principles / methodology and connection to the regulatory process as well as support to the recently launched NWA call on Safe-by-Design. For future and emerging substances and materials (such as nanomaterials), clear communication about the state of the art knowledge, concepts about risk perception, and transparency about dealing with uncertainties is of utmost importance. These help to influence the risk perception of the public regarding nanomaterials, increase their market value and help companies in anticipating potentially conservative regulations.

TNO's work in 2021 contributed to clear conclusions and communication on chemical/nanomaterial health risks for the commercial success of chemical innovative research and implementation in Europe.

| Titel | VP Sociale Innovatie (P207) |
|---|---|
| MTIB Thema | Gezondheid en Zorg |
| Contactpersonen TNO (DM en VPM) | Sandra Eikhout (DM), Steven Dhondt (VPM), Tim Bosch |
| Contactpersoon Regie-voerder | Henk Gritter (EZK), Joren J. Schep (EZK) |

**Programma jaar 2021 - Samenvatting**

Smart Working is a key driver of change in companies to achieve higher productivity. As a programme of Healthy Living, it is connected to the (HTSM) Smart Industry initiative. To achieve this goal, Smart Working delivers improvements to make work less physically demanding, to support operators in their cognitive tasks and to create working environments that are motivating and stimulating. Better performing operators are crucial to support critical processes in companies. In the programme, robotics and digital technologies are deployed in the workplace.

The separate projects focus on exoskeletons, cobotics, cognitive support systems, smart incentives, and digital information in work settings. The main idea is that operators need to have maximum autonomy to use these tools in their work settings. More autonomy is a precondition for generating the required knowledge and skills to deal with the necessary changes. Therefore, the projects create solutions that take account of physical and psycho-social demands on operators at the workplace level (exoskeletons support; augmented reality guidance for operators; models to adapt systems) and at the organisational level (workplace innovation; incentives in smart contracts).

Scientifically, the programme connects different social-scientific and engineering perspectives to support operators in the knowledge intensive environments. It delivers tools for assessing the impacts of technology changes and includes designing work settings and organisational designs. For the programme's success, the disciplines human factors, information technology, organisational sciences and technical sciences need to work in concert on solutions. Next to a new set of projects, the programme invested into three Fieldlab environments (RoboHouse (Smitzhe), BIC Flexible Manufacturing and Sharehouse) with possibilities to develop, demonstrate and test operator support systems, exoskeletons and hybrid cobotic workplaces.

Smart Working has had a successful year developing the projects and acquiring a new set of long-term projects and collaborations. Two major EU-initiatives have been undertaken which helps move the programme into new domains: Industry 5.0 (HE Bridges5.0) and AI-knowledge (HE SupervAIsor).

| Titel | VP Veilige Maatschappij (P102) |
|---|---|
| MTIB Thema | Veiligheid |
| Contactpersonen TNO (DM en VPM) | DM: drs. R. Pellemans, MSc<br>SD: dr. H.J. van Veen<br>VPM: dr. T.W.J. van Ruijven |
| Contactpersoon Regie-voerder | Mr. H. Hanoeman en drs. B. ter Luun (Ministerie van Justitie en Veiligheid) |

**Programma jaar 2021 - Samenvatting**

Veiligheid is een voorwaarde voor welzijn en economische ontwikkeling. Veiligheid is niet vanzelfsprekend. De kansen en bedreigingen voor recht en veiligheid zijn divers en veranderen voortdurend. De snelheid van ontwikkelingen is dusdanig dat het justitie- en veiligheidsdomein in hoog tempo moet innoveren om de dreigingen het hoofd te kunnen bieden en om kansen te benutten om Nederland veilig en rechtvaardig te houden.

TNO draagt bij aan een veilige en rechtvaardige samenleving door met het Vraaggestuurd Programma Veilige Maatschappij (VPVM) relevante nieuwe kennis, technologie en sociale innovaties te ontwikkelen en deze te vertalen naar innovatieve toepassingen voor de praktijk. VPVM is onderdeel van de TNO roadmap Nationale Veiligheid. Binnen VPVM wordt toegepast wetenschappelijk onderzoek uitgevoerd op vijf inhoudelijke thema's, vier focustechnologieën en een programma rond technologieverkenningen en innovatiemanagement:

**Thematisch onderzoek**

*Weerbaarheid Veiligheidsprofessionals*

- Rechtstaat en Opsporing
- Data en Intelligence
- Security en Surveillance
- Kritieke Digitale Infrastructuur

*Focustechnologieën*

- Augmented en Virtual Reality
- Privacy Enhancing Technologies
- Artificial Intelligence
- Robotica

*Technologieverkenningen en innovatie management*

***Enkele highlights uit de resultaten van het onderzoek in 2021:***

Met Interpol is een demonstrator ontwikkeld van een darkweb simulator (TOR netwerk) waarmee rechercheurs en analisten wereldwijd kunnen worden getraind voorn onderzoek op het darkweb.

In het kennis opbouw programma OM heeft TNO een prototype beproefd (proof-of-concept) voor een zogenaamde JuriRobot 2.0 waarmee officiers van justitie worden geholpen bij het zoeken naar relevante jurisprudentie door automatisch uitspraken te classificeren, samenhangende uitspraken te groeperen en deze groepen te beschrijven.

In het Ondermijningslab is, samen met de Regionale Informatie en Expertise Centra Ondermijning, een model ontwikkeld voor het tegengaan van aanwas van jonge delinquenten in drugscriminaliteit. In het conceptueel model staan psychologische factoren in deze 'jonge aanwas' centraal.

Binnen het technologie ontwikkel programma voor AI-beslisondersteuning is een proof-of-concept implementatie ontwikkeld voor Privacy Preserving Risk Analysis. Hiermee kunnen in de toekomst verschillende soorten risicoprofielen worden opgesteld zonder gegeven te hoeven delen.

En in het Europese project TRESSPASS heeft TNO, samen met de Koninklijke Marechaussee, een Design Basis Threat (DBT), indicatoren voor risico gestuurd grenstoezicht en een risicobeoordeling methodiek voor gebruik bij grensovergangen ontwikkeld. Tevens is een analysetool ontwikkeld voor de ondersteuning van interviews bij grenspassages. De methodieken zijn in een experimentele setting getoetst op Lelystad Airport.

In het onderzoeksprogramma met DJI is een prototype monitoringsmethode getest voor de professionele fitheid van medewerkers van penitentiaire inrichtingen. De monitoring vindt plaats door middel van wearables. De methode moet in de toekomst bijdragen aan een effectievere inzet en betere begeleiding van DJI-personeel.

Door de snelle opkomst van toepassing van deepfake technologie is een verkenning uitgevoerd van de mogelijke inzet van technologie om deepfakes te detecteren. Op basis van de verkenning zijn concrete mogelijkheden van ingrijpen op de impact van deepfakes uitgewerkt. Tevens zijn onderwerpen voor verder onderzoek geïdentificeerd om deepfakedetectie te kunnen verbeteren of beter de accuraatheid van detectiemethodes te kunnen inschatten.

Vanwege het almaar toenemend en steeds urgenter tekort aan veiligheidsprofessionals zijn een analytisch kader en een analysemethode ontwikkeld waarmee inzicht in oorzaken (beeldopbouw) van personeelstekort en effecten van (beleids)maatregelen gericht op het aanpakken van het personeelstekort van taakorganisaties in het justitie- en veiligheidsdomein kan worden verkregen. De methode dient als beslisondersteuning om het probleem van het personeelstekort voor specifieke functiegroepen binnen een organisatie te ontrafelen, beter beheersbaar te maken, en vanuit deze analyse diverse (potentiële) oplossingsrichtingen te kunnen genereren.

| Titel | VP Kennisopbouw Politie (P106) |
|---|---|
| MTIB Thema | Veiligheid |
| Contactpersonen TNO (DM en VPM) | Tjarda Krabbendam (VPM) |
| Contactpersoon Regie-voerder | Drs. S.C. Hamelink |

**Programma jaar 2021 - Samenvatting**

Maatschappelijke en technologische ontwikkelingen zorgen voor een continu veranderende omgeving waarbinnen de politie als grootste veiligheidsorganisatie opereert om 'waakzaam en dienstbaar' te zijn aan de waarden van de rechtstaat . Nieuwe fenomenen zorgen voor grote uitdagingen voor het politiewerk. Om in deze dynamische omgeving effectief te blijven, is het van groot belang dat de politie (digitaal) fit en innovatief is.

Het Vraaggestuurd Programma (VP) Kennisopbouw Politie (KOP) heeft als doel om de politie te versterken in haar vermogen zich aan te passen en voor te bereiden op de toekomst. TNO stelt hiervoor opgebouwde kennis beschikbaar. Door kennis op te bouwen over relevante trends en ontwikkelingen kan de politie proactief gebruik maken van de nieuwste inzichten en (technologische) mogelijkheden. Het VP KOP sluit aan op het maatschappelijk thema Veiligheid uit het missiegedreven top-sectoren- en innovatiebeleid.

Voor de politie is het van belang om in te spelen op technologische en sociale ontwikkelingen. Technologie biedt kansen om het politiewerk of de organisatie te verbeteren, versnellen of vergemakkelijken. De politie houdt eveneens rekening met de impact van technologie en sociale innovaties op de maatschappij en de wijze waarop burgers, criminelen of terroristen gebruik maken van technologie. Het is van groot belang voor de politie om goed voorbereid te zijn op deze ontwikkelingen.

De opgebouwde kennis draagt bij aan het toekomstbestendig maken van zowel de politiemedewerker als het politiewerk. In de periode 2018-2021 hebben gezamenlijke Politie-TNO teams gewerkt aan nieuwe kennis voor het politie informatieproces, techniek voor de opsporing, de samenwerking tussen de politie en de samenleving, het politiewerk in het digitale domein en de weerbaarheid van de politieprofessional.

Voor het politie informatieproces is o.a. een tool voor beeldvorming oordeelsvorming en besluitvorming (zogenaamde BOB-eye) ontwikkeld dat in het reguliere incident response dashboard wordt geïntegreerd. Met behulp van deze tool heeft de officier van dienst alle relevante informatie bij elkaar in het gouden uur na een incident. Voor de opsporing is gewerkt aan technieken die het mogelijk maken bestaande en nieuwe informatie bronnen beter te ontsluiten. Resultaat is onder andere dat rechercheurs grote hoeveelheden video data effectiever kunnen doorzoeken en sneller verdachten kunnen identificeren. Met het handboek 'Eerste Hulp Bij Opsporing' is in kaart gebracht hoe burgers veilig en effectief kunnen bijdragen in de opsporing van verschillende vormen van criminaliteit. Ook is onderzocht op welke wijze gespecialiseerde politievrijwilligers (cyberspecials) betrokken kunnen worden bij de aangifte van cyber gerelateerde delicten. Kennisopbouw voor politiewerk in het digitale domein heeft o.a. geresulteerd in tools die helpen bij het tegengaan van phishing. Onderzoek naar persoonlijke monitoring met apps en wearables heeft inzichtelijk gemaakt hoe deze hulpmiddelen de weerbaarheid en inzetbaarheid van politie professionals kan vergroten.

| Titel | VP Cyber Risk Management and System Resilience (P103) |
|---|---|
| MTIB Thema | Veiligheid |
| Contactpersonen TNO (DM en VPM) | Ir. A.J.A. Vetjens, Director Market ICT; Ir.S. Wiarda, VP manager CRM&SR |
| Contactpersoon Regie-voerder | Johan de Heer (HTSM Security roadmap) |

**Programma jaar 2021 - Samenvatting**

Digital security is a prerequisite for a prosperous society and a strong economy. The goal of the Vraaggestuurd Programma (VP) Cyber Risk Management and System Resilience (CRM&SR) is to 'make the Netherlands digitally more secure and resilient while, at the same time, monetize the economic opportunities that cybersecurity brings'. This VP enables TNO to create an environment to experiment in order to develop and transfer innovations to the market. This is done together with other knowledge institutions, governmental agencies and (cybersecurity) companies. A focussed and effective approach with respect to cybersecurity and quantum computing is crucial to safeguard the reliability and confidentiality of data and ICT networks and systems. Our main stakeholders are national security organisations, administrators of vital services and corporations that are vital for the Dutch economy. These stakeholders have to be equipped to recognize and interpret cyber threats and be supplied with both preventive fortifications and possibilities for repressive actions to ensure – in the case of disruptive cyber incidents or phenomena – the continuity of their vital services. The activities in this VP have been organized along two Product Market Combination (PMC) clusters Trusted ICT and Critical Digital Infrastructure.

**Trusted ICT**: Due to an increasing number of (fully automated) cyber-attacks, a continuously changing ICT landscape and attack surface of organizations, and a shortage of skilled cyber-security personnel, the gap between attackers and defenders is growing, with the attackers having the upper hand. To counter this development automation of cyber-defences is needed, providing the ability to respond to active attacks, but also to proactively improve by automatically assessing the security posture of an organization.

The **PMC Automated Security** wants to develop concepts, standards and technologies to enable and support the automation of security operations and drive the adoption thereof in actual organisations and infrastructures. The highlights of 2021 include:

- Within the SOCCRATES project, the available building blocks of several consortium partners have been combined and integrated with the objective to decrease the mean time to respond (MTTR) and increase the quality of the automated response reaction prior to or during a cyber-attack. The software developed for the integration was released as open source software and the results of the project were shared within the stakeholder group of SOCCRATES and with the outside world with the presentation of multiple webinars.
- During the PPS ASOP project, a demonstrator was developed to demonstrate the capabilities of detecting a cyber-attack, analysing the situational context in which it took place and the available defence options at hand, eventually deploying this mitigation automatically in an IT infrastructure. Based on open standards an open source adapter was created to enforce these automatic response reactions in the (Kubernetes) IT infrastructure.
- The Partnership for Cyber Security Innovation (PCSI) had 10 projects running simultaneously in different phases of the innovation cycle. The software developed for the self-healing subproject was published as open-source software and received positive feedback during conferences.

**Quantum-Safe Technologies** aims to mitigate the threat posed by quantum computers on our digital security and considers the development of and the transition towards quantum-safe cryptography. The highlights for 2021 were:

- Establishment of a new mathematical/cryptographic framework for a modular design of zero-knowledge proofs, with and without post-quantum security (several papers published at CRYPTO and ASIACRYPT).
- Initiated the development of a post-quantum public-key infrastructure (PKI) within the new project Hapkido.
- Created awareness about the imminent threat of quantum computing. In 2021, we have organized two international seminars on post-quantum cryptography, with a third symposium to be organized in April 2022. Further, based on a

TNO position paper published in 2020, we collaborate with MinBZ and CWI to publish a post-quantum migration manual (first version to be expected in Q1 2022).

- Development of key-rate optimization tools for quantum key distribution protocols (software implemented and results published in the Quantum Information Processing journal).
- Implemented an authentication mechanism, using quantum keys generated by QuTech.
- Development of a first version of our computer aided cryptography pipeline. A combination of tools to assist in the security validation of cryptographic primitives.

The **PMC Security Monitoring & Detection** wants to bridge the gap between the state-of-the world monitoring and detection solutions from the research community and the cybersecurity products available on the market. The goal is to strengthen the cyber-defences of Dutch businesses and organizations. To this end, we focus on actionable, better and faster detection of advanced cyber-attacks for IT and OT domains. The highlights for 2021 include:

- A proof-of-concept machine learning model which classifies Emails as malicious based on characteristics of the URL. Since the model is published as open source software it provides organizations, including SMEs, with an extra tool to combat phishing attacks on their employees. The results are communicated by Digital Trust Center and SIDN to their communities.
- New AI-based methods for the detection of malware-generated domains (so called Domain Generation Algorithms). Since the methods are published as open source software, it provides a new tool to security analysts worldwide to better protect their networks.
- To automatically detect policy violations within companies, new methods have been developed to detect illegal VPNs. This enables companies to monitor and enforce policies.
- To enable Security Operations Centers (SOCs) to become more pro-active, a new generic technology is under development to predict upcoming application layer DDOS attacks.
- To improve cyber security in converged IT/OT environments, a digital twin-based demonstrator is developed to promote awareness. It also enables the development of new detection algorithms.

In addition to the Cluster Trusted ICT we have a close collaboration with another PMC cluster within TNO: **Critical Digital Infrastructure**: In our highly digitised society we have become more dependent on ICT (supported) processes and services. Thus, cyber-attacks can potentially lead to more impact on society and our daily lives. We primarily focus on information-sensitive domains, critical infrastructures and the process- and service dependencies of governments and critical sectors. On the crossroad of these PMCs (within the **PMC National Cyber Resilience**) we have the NCSC program where we focus on upcoming trends that potentially can impact digital security. This acts as a maternity room for research developments on current trends as cyber capacity building, cyber workforce development, digital autonomy and quantum migration. In 2021 the highlights have been:

- research on ICT recovery capability in OT infrastructures of critical infrastructure organisations in the Netherlands resulting in the development of online self-assessment tooling (SecureNet). This tooling uses privacy enhancing technologies to ensure privacy, confidentiality and integrity of the data. Organisations can use this tool to identify their maturity and potential shortcomings regarding their ICT recovery capability.
- A new model of different perspectives on ICT supply chain risks has been developed and these new insights form the basis to develop tooling demonstration for NCSC's stakeholders in potential crisis response situations.
- Cyber security risks have been quantified and the results of this research published by the NCSC.

The knowledge roadmap in VP CRM&SR connects to the challenges and topics that have been formulated in the Dutch Digitalization strategy, the Dutch Cybersecurity Agenda (NCSA) and the Mission Cybersecurity of the Knowledge and Investment Agenda (KIA) theme Security as well as with the theme Key Enabling Technologies. In 2021 we connected to the cybersecurity cooperation platform dcypher. In international context TNO participates in the relevant EU working groups, taskforces and events. The development and execution of the knowledge program VP happens in close cooperation with VP Veilige Maatschappij (VM), VP ICT, the program line Cyber Security and TNO research programs with businesses and government organisations.

| Titel | VP Radar and Sensor Systems (P104) |
|---|---|
| MTIB Thema | Veiligheid, |
| Contactpersonen TNO (DM en VPM) | Director Market ISS: K. Agovic<br>VP Manager: F.L.M. van den Bogaart |
| Contactpersoon Regie-voerder | A. Venema – Ministry of Defence HDB<br>KTZ J. Bleijs – Ministry of Defence DMO/AMS<br>KLTZ ir. T. van Heusden – Ministry of Defence DMO/AMS/ Bureau Technologie Integratie<br>B.A.H.M.J. Lussenberg – Ministry of Justice and Security BD/Innovatieteam<br>KLTZ P. Blank, Ministry of Defence CZSK<br>LKol. M. Hädicke, Ministry of Defence CLAS (RAS-unit)<br>LKol. Bernard Buijs – Ministry of Defence / CLSK / Space Security Center<br>Maj. Petra Wijnja – Ministry of Defence / CLSK / Space Security Center<br>Charlotte Rugers – Ministry of Defence / DMO / JIVC / KIXSMaj.<br><br>*KIA Veiligheid:*<br>Mission Space: U. Termote – Airbus<br>Mission Maritime High Tech: M. Krikke – TKI Maritiem<br><br>Topsector HTSM<br>HTSM Roadmap Security: L. Roffel – Thales Nederland B.V.<br>HTSM Roadmap Electronics: H. Naus – NXP |

**Programma jaar 2021 - Samenvatting**

The VP contributed in 2021 to the objectives of the relevant missions and MMIPs of the Societal Theme KIA "*Veiligheid"* and of the KIA *"Sleuteltechnologieën*" with the technical topics *Radar and Integrated Sensor Suites* (including radar, sensor fuzes and space situational awareness (SSA)); *Smart Manning and Automation*; *Imaging Systems for Defence and Security*; and *Quantum Sensing*.

*Radar and Integrated Sensor Suites* targets the development of a sensor suite for the next generations frigates of the Royal Navy; of miniaturized proximity sensors integrated in medium calibre munition; and the classification and recognition of space objects. *Smart manning and Automation* aims to develop intelligent software for autonomous command, control and situation awareness in combat management, platform management, bridge management and unmanned (UXV) systems. *Quantum Sensing* focusses on recognizing upcoming sensors based on quantum mechanics that could be relevant in military applications, further developing insights in the most promising technologies, and developing sensing use cases using quantum computers. *Imaging Systems for Defence and Security* has the objective to develop solutions that automatically deliver intent information using smart sensors and processing algorithms with a focus on image processing and interpretation.

In the MMIP "*Smart kill-chains - Radar en geïntegreerde sensorsuites*" a containerized X/S band one-radar system will be demonstrated in 2023, to this end 2021 was marked by integration tests and subsequent hardware and software improvements. In addition, the following innovations for the next generation frigates of the Royal Navy resulted from 2021: a new class of highly miniaturized high-frequency filters which are shown on high resistivity silicon; a new filtering array antenna has been developed to improve selectivity; a state-of-the-art GaN on SiC 400-Watt MMIC amplifier is demonstrated; AI techniques for the design of very specific and unique MMICs are investigated; AI methods are developed and demonstrated for robust radar signal processing in the military domain; and first steps are made to demonstrate in 2024 new radar waveforms and digital processing techniques to enable detection and classification of multiple, advanced threats at very large distances.

A receive front-end design using modern SiGe technology is demonstrated for future radars; and an architecture for an upgrade to a digital-on-receive concept was finalised.

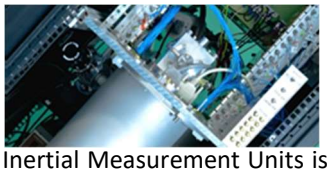
The feasibility of a miniature proximity sensor with all functionality integrated into one single integrated circuit (IC) is proven and completed in 2021 which enables small fuzes for various types of ammunition. A follow-up with the sponsor has been started for further testing of the sensor in realistic environments.

Within the scope of *MJP88* of the *KIA "Sleuteltechnologieën"* new disruptive techniques to enable multiple simultaneous functions at different RF frequencies in Active Electronically Scanned Array (AESA) radar systems are demonstrated; and a novel antenna has been designed that combines multiple amplifier outputs to generate extremely high output power in radar bands.

The contribution to the MMIP *"Real time digitale observatie en ondersteuning*" focused in 2021 on (i) demonstrating an AI enabled high resolution visual observation system for small unmanned flying vehicles using a 65Mp camera; (ii) setting up guidelines and best practises for combining real and synthetic data for training of object detection algorithms, assessed on a real-life use case (proof of concept), the usability of synthetic data for training of Deep Learning detection algorithms, and on the newest Deep Learning algorithms to detect objects with the size of only a few pixels; and (iii) on demonstrating a virtual space around the Johan Cruijff ArenA in Amsterdam with innovative state-of-the-art security measures to provide visitors with a maximally safe and pleasant customer journey.

Within the MMIP *"Smart Manning & Automation"* the flagship project OCEAN2020 integrated military underwater, surface, and aerial unmanned platforms with combat management systems from 10 countries into a unique cross-nation and cross-domain wide-area surveillance demonstration in 2021; and in a H2020 project the added value of equipping coastguard vessels with organic UAVs, enabling greater coverage, better quality of information and shorter response times in maritime surveillance operations has been demonstrated.

Within the mission *"Veiligheid in en vanuit de Ruimte",* (i) radar techniques have been developed to detect, classify and identify space objects; radar imaging has been demonstrated at L-band of space objects at low orbits with a resolution that allows classification; and successful detection of telecom satellites at 36000km distance has been shown by bistatic radar measurements of two satellites; and (ii) a feasibility study has been done on heterogeneous fusion of observations from satellites and other relevant platforms such as aircrafts, drones, aerostats and ground sensors to detect hazardous smoke and gas clouds.



Related to *MJP07 of the KIA "Sleuteltechnologieën", Quantum sensing* technologies relevant for military applications have been identified and explored. Position, Navigation and Timing (PNT) is indicated as a prominent application domain for quantum sensors. Towards this application domain a feasibility study towards the potential of quantum-based, highly accurate Inertial Measurement Units is done. An in depth study of quantum-assisted RF-frontend components has been carried out. Highly precise quantum clocks and their need for sensors relevant for military applications have been researched. A methodology to indicate the potential of quantum computing use-cases in the sensing domain based on expected impact, time to operation and fit to quantum computing has been developed.

| Titel | VP Space & Scientific Instrumentation (P607) |
|---|---|
| MTIB Thema | Sleuteltechnologieën |
| Contactpersonen TNO (DM en VPM) | Kees Buijsrogge, Ton Marée /A.i. Anton Leemhuis |
| Contactpersoon Regie-voerder | Topsector: Rob Postma (Airbus) – Roadmap Space, Marco Beijersbergen (Cosine) Advanced Instrumentation, Eelco van der Eijk, Director Space Policy at Ministry of Economic Affairs |

**Programma jaar 2021 - Samenvatting**

Our multi-annual R&D programme supports our ambition to contribute to **preventing climate change and air pollution,** enable **secure broadband connectivity,** help **understanding the Universe**, and stimulate **economic growth in the Netherlands and Europe.** Therefore, we organise the VP along programme lines directly connected to this ambition; Instruments for **Earth Observation** and related **Space Data Utilisation,** technologies for **Satellite Communication**, and **Scientific Instrumentation** focusing on instruments for **Ground-based Astronomy** and **Space-based Astronomy,** and including instruments for **Big Science and Diagnostics for Fusion Energy**.

The main parts of the VP Space & Scientific Instrumentation 2021 are summarised below.

The programme line Earth Observation focused of the design and development of new instruments, development of technology that supports today's instrument realisation, and space data utilisation. Technologies for both radar-based and optical instruments were developed.

The programme line Satellite Communication has a strong focus on Optical communication. For Optical communication between satellites and from ground to satellite very stable and accurate optical systems are required, and adaptive optics compensates the disturbance of communication by the earth's atmosphere. In off-loading laser satcom to terrestrial users we worked on (among others) connection with multibeam reconfigurable wide-view RF subsystems. These systems were developed in the SMO programme, in close contact with industrial partners.

The programme line Scientific Instrumentation, with the main activities in Space based Astronomy and Ground based Astronomy, focused on opto-mechatronics design & analysis of subsystems for large telescopes and space-based systems, such as adaptive optics, segmented mirrors and pointing technology. For Big Science, the technical evaluation and preparation for the most relevant of the many candidate tenders for instrumentation for the Big Science facilities (ITER and Einstein Telescope) with industrial partners were planned.

Some highlights in 2021 are the delivery February 2021 of the Sentinel-5 Proto Flight Model (PFM) UV1/SWIR telescope to Airbus Defence and Space Germany, completing TNOs contribution to the Sentinel 5 ProtoFlightModel instrument. In April 2021 Airbus and the Netherlands Organisation for Applied Scientific Research (TNO) have launched a programme to develop a laser communication terminal demonstrator for aircraft, known as UltraAir. The project, which is co-financed by Airbus, TNO and the Netherlands Space Office (NSO), is part of the European Space Agency's (ESA) ScyLight (Secure and Laser communication technology) programme. It covers the design, construction and testing of the technology demonstrator. In May 2021 Aircision and TNO successfully completed their field tests establishing the first optical wireless link of 10 Gigabit-per-second (Gbps) over 2.5km in the Netherlands. This will potentially enable 5G and broadband networks to be more accessible, with higher bandwidth and robust connectivity. In April 2021 TNO has been selected to start the design of an essential component for the European Solar Telescope (EST), scheduled for construction in the Canary Islands. The telescope will allow detailed investigations of the Sun. TNO will design the adaptive secondary mirror (ASM) that can rapidly change shape to correct for the distortion of the atmosphere on telescope observations. This innovative contribution will ensure that EST's view of the Sun is as sharp and detailed as it can be. End of 2021 TNO has successfully tested an Elegant Bread-Board (EBB) of the Point Ahead Angle Mechanism (PAAM) to be applied in the European Space Agency (ESA) mission LISA; the Laser Interferometer Space Antenna. This mission aims at detecting gravitational waves in the low frequency range 0.1 mHz and 1 Hz, studying the very nature of gravity itself by exploring the waves that emanate from some of the most massive and extreme phenomena in the Universe.

| Titel | VP Semiconductor Equipment (P612) |
|---|---|
| MTIB Thema | Sleuteltechnologieën |
| Contactpersonen TNO (DM en VPM) | Rogier Verberk, Jasper Flipse |
| Contactpersoon Regie-voerder | Joep Pijnenburg (leader HTSM Roadmap Semiconductor Equipment; ASML)<br>Toon Evers (leader HTSM Roadmap Healthcare; Philips Healthcare)<br>Ronny van 't Oever (leader HTSM Roadmap Nanotechnology (incl. quantum technology |

**Programma jaar 2021 - Samenvatting**

Consumer electronics, mobile devices, industrial processes, communication equipment, the car industry, artificial intelligence and all potential solutions to societal challenges rely on integrated circuits (chips) to generate, process, and store data. A shortage of these chips was causing great concerns when we were coming out of the Corona crisis in 2021, demonstrating this dependency. Most of these chips are manufactured in Asia, with the use of equipment from The Netherlands. This Dutch high-tech industry has become a strategic asset for The Netherlands and Europe, to balance our dependency on chip manufacturing countries. TNO's roadmap on Semiconductor Equipment supports this strategic position of our high-tech industry and provides critical enabling technologies to the information driven society, now (semiconductor industry) and in the future (quantum technologies).

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., metrology and wafer processing equipment. By 2025 the Dutch semiconductor industry aims to have this position enhanced by world record performance in lithography systems, by having new metrology concepts introduced, and by having the next generation of high-NA EUV lithography introduced in the market. TNO supports all these developments, and invests in new technologies and concepts to fuel this industry towards new products. But also by executing supporting research with its unique infrastructure like the EUV beam lines. In 2021 TNO tested multiple reticle absorber materials enabling leading chip manufacturers to make use of EUV lithography. In 2022 TNO will continue research on nearfield optics, integrated photonics, computational optics, and cooling techniques for 5G/6G communication chips.

TNO continues the development of more stable and reliable equipment (flow & thermal management, contamination control), and by introducing new tool concepts (optical-, scanning probe-, and acoustics based metrology, particle detection methods, sensors). In 2021, e.g., Nearfield Instruments shipped its first SPM metrology system based on TNO IP.

EUV induced plasma effects and material sciences for EUV lithography mirrors will be extended to reticle and pellicle developments. New topics include a combination of hardware design and AI (integrated system design based on AI), and metrology systems based on quantum mechanics. Moreover, TNO supports multiple Dutch companies in the development of a national program to develop equipment for the emerging market of heterogeneous integration. In 2021 the consortium was put together and TNO wrote the binding technology overview chapter.

TNO's research line on Medical Photonics focusses on accelerating photonics-based innovations that can help people to stay healthy, prevent diseases, and enhance early diagnosis, with the goal of reducing healthcare costs for the ageing population. Focus in 2022 will be to develop diagnostic optical devices for use in home, primary and secondary care, including multispectral fundus camera's for early diagnosis of eye diseases and systemic diseases, wearable diagnostic photonic devices, and optoacoustic sensors.

Last but not least TNO/QuTech continues the development of a quantum computer accessible via the web, and a quantum network. In 2021 QuTech launched the Quantum Network Explorer (QNE) publicly, and TNO performed first measurements with a quantum sensor. Delft and the Netherlands are evolving into a vivid hotspot for quantum technologies and spin-offs already, creating a new and sustainable ecosystem for additional and high-tech based strategic industrial activities.

| Titel | VP Flexible and Freeform Products (P615) |
|---|---|
| MTIB Thema | Sleuteltechnologieën |
| Contactpersonen TNO (DM en VPM) | Ton van Mol |
| Contactpersoon Regie-voerder | Richard Roemers |

**Programma jaar 2021 - 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:

**Digital Manufacturing Systems**

Additive Manufacturing – or 3D printing – of food and pharmaceuticals has been recognised as a potentially market-changing advancement in health and nutrition.

In digital drug manufacturing, the aim is to help people to get the right dosage of medicine and to combine different medicines in one pill, both for comfort and increase compliance. Key milestones in the roadmap include quality control, accuracy and reproducibility of the API (active pharmaceutical ingredient) dosage to be within 1% , and ability to combine multiple API in one dosage form/pill.

Likewise, in digital food processing, the aim is to help people to get the right nutrition at the right time, especially for people who need to perform high performance tasks (like fighter pilots) and people who need to take special care of their nutrition to remain healthy (like people in rehabilitation). Key milestones in the roadmap are increasing throughput, ability to combine different food ingredients in one product with varying composition, and in line quality control.

In 2021 the following highlights have been achieved:

- Setup for multi-material printing which is flexible and can be scaled to a multi-nozzle system has been demonstrated (technology has been filed and patent is granted).
- In a consortium of 6 industrial partner TNO, together with WUR, is developing a machine concept for personalized nutrition for military personnel and COPD patients.
- Together with WUR a prototype setup printing a tasty meat alternative has been realized and fibrous meat analogous with juiciness haven been made.

**Hybrid Printed Electronics**

In this program we create the technology for next generation of 'internet-of-things' products, being a hybrid combination of additive manufacturing and 'conventional' silicon-based electronics. These technologies enable future electronic products with unprecedented form factor and functionality. The primary focus is on healthcare related applications where we work on body conformable medical patches and non-contact sensing. In 2021, an important success was that one of our key end user customers has launched a product based on our medical patch platform. For our non-contact sensing activities, we made an important step towards improving the sensors and on developing algorithms to derive the key vital signs heart rate and breathing rate.

Besides this, we continue developing novel enabling printed electronics technologies that further increase the possibilities of deploying printed electronics. In particular this concerns 3D printed electronics, high resolution printing, and advanced chip packaging in the framework of CITC Nijmegen activity, which is now in full operation for the second year and first proof-of-concepts for RF chip packaging have been demonstrated. The underlying technological challenges have strong resemblance with the Holst Centre Eindhoven activities. All this is described in the KIAs 'Flexible Electronics'.

**Thin Film Electronics**

Thin film electronics technology, originally developed for (flexible) display applications, is applied and developed towards new application domains to provide a positive contribution to Dutch societal challenges around biomedical technologies and the

energy transition. Applications that are explored are in the biomedical domain revolve around Organ-on-Chip applications for increased drug development and personalized medicine as well as advanced imaging technologies e.g. proton imaging for directed proton therapy and ultrasound imaging for fetal and carotid sonography. In the energy domain, we focus on next-generation battery and electrolyser technology for energy storage, in the form of electricity and hydrogen.

In 2021 the program realized proton imaging with unprecedented accuracy, matured its in-house developed large-area ultra-sound transducer technology and explored into the new domain of Organ-on-Chip applications while solidifying our ambitions in the energy domain by creating the spin-out LionVolt and investing in a Dutch ecosystem of partners to co-develop necessary energy storage technology.

| Titel | VP Sustainable Chemical Industry (P603) |
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| MTIB Thema | Sleuteltechnologieën - Mission C / MMIP 6,7,8 / Mission CE |
| Contactpersonen TNO (DM en VPM) | Ir. Peter Wolfs |
| Contactpersoon Regie-voerder | Topsector Chemie: Jacqueline Vaessen |

**Programma jaar 2021 - 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 focused on developing technology and new business models in three mission-driven Public Private Partnerships (PPP) being Biorizon, VoltaChem and Brightlands Materials Center. In 2021 also investments were realized in photon chemistry that will develop further in a separate program. Within the year 2021 we transferred the activities related to Voltachem towards P616 Industrial Electrification and CCU and is therefore reported in that program.

**Biorizon:** Aromatic building blocks are crucial in providing functionality in our day-to-day applications, but are today almost exclusively fossil based. The mission of shared research program Biorizon is to enable commercial production of bio-aromatics, providing sustainable building blocks for a circular society. Commercialization of a 1$^{st}$ gen. of bio-aromatics is targeted by TNO spin-out Relement by 2025. Biorizon continuous to focus on establishing scalable technology (TRL5) for production of furanic and a next gen. of bio-aromatic building blocks for high volume markets such as surfactants (4 Mta LAS) and phenols by 2025 (> 10 Mta). In 2021, continuous production of platform molecule furfural from seaweed residues was demonstrated at kg-scale (integration with furanic building blocks production (TRL3-4) targeted for 2022) and proof-of-concept was established for novel furanic surfactants (TRL4 targeted for 2023). Also, the Biorizon facilities were expanded with a hydrogenation platform (TRL4) (oxidation platform targeted for 2022). Furthermore, over 50 kg of bio-aromatic samples were produced and the strategy and business plan for a Biorizon Application Center were initiated to aid industry in introducing bio-aromatics in their applications (multi-kg production and validation of furanic and next gen. bio-aromatics targeted for 2025). Additionally, to facilitate Biorizon's cross-sectoral community, the 8$^{th}$ Biorizon Event was held in 2021 with a keynote from Lego's VP Materials (>300 participants). Finally, 2021 was concluded with the launch of the Bright Coatings project to establish pre-commercial production of bio-aromatic MPA (>100 kg) for production of a first-of-its-kind biobased coating and demonstration of produced coating on an electric front loader by 2023.

**Brightlands Material Center:** TNO focused within the Sustainable Buildings programline, on the development of innovative optical coatings and films for glazing to reduce the energy consumption for heating and cooling of buildings and also for building-integrated solar panels to increase their power output. In 2021, we have successfully scaled up the manufacturing process of thermochromic pigments and pigmented PVB films to produce 1 m² laminated glass plates. To scale up the coating manufacturing process, we have designed a pilot plant for the production of 1 m² coated glass sheets.

To produce energy generating facades with a high aesthetic value, we developed colored coatings for glass covers of building integrated photovoltaic panels. The color of these coatings is based on a so-called structural color effect, which yields highly intense metallic colors whilst avoiding a large drop in electricity output. In 2021, we have successfully developed a coating and validated its performance on 40 cm² lab scale PV panels.

Photovoltaic panels yield less electricity if their temperature increases. Therefore, blocking of sub-bandgap wavelengths is of importance. The temperature of solar panels can increase to 80ºC. In addition to reduction in power output, the panel can be permanently damaged. A decrease in operating temperature of 5-10ºC can extend the panel's lifetime by 20-50%.We produced lab scale demonstrator devices comprising our heat blocking encapsulants.

The program line Lightweight Automotive aims to develop and demonstrate multi-physics and multi-scale based material models predicting and optimizing durability and interfaces of thermoplastic composites for lightweight structural applications. Furthermore, technology and infrastructure to recycle these materials for use in structural and semi-structural applications will be established. In 2021, we have expanded our with pilot-scale equipment for recycling to be able to produce materials at a larger scale. We have successfully produced 150 kg of recycled 'reLFT' glass fiber filled polypropylene (PP/GF) granules, with which our partners have produced injection molded products, the first 100% recycled demonstrators made of reLFT. This creates an important step forward in the transition towards circular composite materials for structural applications. In 2022,

we will further validate the performance of reLFT materials in different applications, and scale up this technology towards robust manufacturing of recycled composite materials.

**Photons 2 Chemicals:** Within this program we focus on the development of (plasmonic) photocatalysts and chemical process technology for photochemical reactions. Current focus is on the development of tailored plasmonic nanocatalysts and continuous processes for sunlight-powered conversion of $CO_2$ and green $H_2$ to CO, $CH_4$, $CH_3OH$ and products with more than 1 carbon atom. In addition, we develop lab scale proof(s) of concept of photochemical processes for fine/specialty chemical production involving solution phase chemical synthesis. In 2021, we optimized supported Ru nanocatalysts for the sunlight-powered Sabatier process, and achieved a high activity and complete product selectivity for $CH_4$. Furthermore, we developed an $Au/TiO_2$ catalyst for the sunlight-powered reverse water gas shift reaction. Furthermore, we delivered a first proof of concept for sunlight-powered conversion of $CO_2$ and green $H_2$ to products with more than 1 carbon atom. To distinguish between photothermal and non-thermal contributions to these processes, which is essential for rational further development and scale up, we studied the thermal characteristics of an illuminated $Ru/Al_2O_3$ catalyst bed, viz. temperature profile in x,y-plane and gradient in *z*-direction, both experimentally and via photothermal simulations. Finally, we performed a techno-economic feasibility of the sunlight-powered Sabatier and reverse water gas shift process.

| Titel | VP Industrial Electrification and CCUS (P616) |
|---|---|
| MTIB Thema | Sleuteltechnologieën / Chemie |
| Contactpersonen TNO (DM en VPM) | Ir. Peter Wolfs, Ir. Martijn de Graaff |
| Contactpersoon Regie-voerder | Topsector Chemie: Jacqueline Vaessen |

**Programma jaar 2021 - Samenvatting**

The VP Industrial Electrification & CCU contributes to the future implementation of affordable industrial electrification technologies that will help to mitigate $CO_2$ from industrial production of chemicals and fuels. The main goals for the VP are:

- Maintaining an international business network, working together on international value chain integration, system modelling and regulatory constraints for Power-2-X integration.
- Co-development of industrially applicable low- and high-temperature electrochemical technologies focusing process-integrated electrosynthesis of chemical commodities using biomass and $CO_2$ as feedstock.
- Co-development of next-generation highly efficient and low-cost electrolyzer technology reducing total system and production costs tapping into the high-tech sector.
- Co-development of electric cracking and plasma synthesis technology of production of high-value (intermediates for) olefins.

The program delivered the following concrete technical results in 2021:

- Development of capture-integrated $CO_2$ conversion technology to 100 $cm^2$ scale to be further developed in shared research and design of the ZEUS $CO_2$ conversion-installation at TRL-5 to be delivered in 2022 at the Fieldlab Industrial Electrification in Rotterdam.
- Delivery of a proof-of concept and associated business-case for adipic acid production from butadiene and procurement of an integration conversion-separation unit at 1000 $cm^2$ scale for production of maleic and valeric acid from biobased furfural.
- Demonstration of carbon monoxide production from $CO_2$ at 100 $cm^2$ scale using Solid Oxide Electrolysis in the conversion range of 30-60%. This included the development of test infrastructure, delivery of a stack design suited for a compression force of 7 bar and development of a manufacturing line for 900 $cm^2$ cells, enabling further scale-up in the coming years.
- Delivery of first modelling results in plasma synthesis and a dedicated plasma lab together with partners to accelerate collaborative research in the coming years.

Apart from technology developments, we also worked on the further development of the industrial electrification business community, and developed the Power-2-X Supply Chain Model towards use in assessing dense energy carrier import options. The latter was demonstrated in the CHAIN project in which regional and international production of methanol, ammonia, LOHC and liquid hydrogen were compared and an e-fuels import strategy was developed for the Harbor Industrial Complex of Rotterdam. Last but not least, in the context of our Fieldlab Industrial Electrification, multiple business cases were analyzed and the central hub infrastructure was scoped and designed together with partners and procured to be delivered in 2022.

| Titel | VP Smart Industry (P617) |
|---|---|
| MTIB Thema | Sleuteltechnologieën |
| Contactpersonen TNO (DM en VPM) | Rogier Verberk, Sam Helmer, Peter Laloli |
| Contactpersoon Regie-voerder | Jan Post (leader HTSM Roadmap Smart Industry & Philips Consumer Electronics), Henk Gritter/Joren Schep (EZK) |

**Programma jaar 2021 - 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:
*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.*

To support manufacturing companies to realise these transformations, TNO develops knowledge on 5 expertise area's:

1. Flexible Manufacturing
2. Smart Work
3. Digital Factory
4. Connected Factories
5. Smart Response

Furthermore, this program has been upgraded into a TNO Roadmap per January 1st 2021, with a permanent increase in funding per 2022. This naturally means there will be more manpower and expertise assigned to the topic. Highlights in 2021 include:

**Application of AI for quality**

A new unsupervised anomaly detection algorithm designed by TNO catches twice as many true defects (True Positive Rate is doubled), whilst maintaining the low number of false rejections. This significantly reduces learning time as well as operator time for post-quality checks.

**AR Support in (remote) Maintenance**

TNO has transferred knowledge about various hardware and software systems in the field of step-by-step and remote assistance and visualisation of information in pilots at five SMEs. This is perceived as highly valuable since due to travel restrictions and labour shortages companies experience the need to deploy new technology for (remote) maintenance of machines.

**Assessment of Digitalisation**

Together with EU partners we have developed an assessment that can be used by an SME to understand the current and desired level of digitisation in general and digital twinning in particular. In 2021 it has been adopted by over 30 DIH's and through them used at 80 companies across the EU.

**Submission proposal growth fund Next Gen Hightech**

Various colleagues involved in Smart response have been involved in the writing of the overall Next Gen Hightech proposal and merging all the relevant domains (including Smart Industry). The proposal has been submitted in October this year.

| Titel | VP ICT (P706) |
|---|---|
| MTIB Thema | Sleuteltechnologieën |
| Contactpersonen TNO (DM en VPM) | Berry Vetjens (DM) / Omar Niamut (VPM) |
| Contactpersoon Regie-voerder | Frits Grotenhuis (topsector ICT) |

**Programma jaar 2021 - Samenvatting**

The ambition of TNO is to develop new expertise, insights and innovative solutions in order to guide industrial and societal stakeholders in the innovative digitalisation 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 for example seek to take advantage of new opportunities in data sharing, require fast open infrastructures or look for trusted ICT solutions to overcome their challenges in operating in increasingly complex digital ecosystems. Our goal is to achieve clearly defined milestones in these areas together with clients, partners and other stakeholders. In 2021 the VP ICT has achieved results as described below.

In **data sharing** data is a key enabler for new business opportunities fuelled by combining data sources, but access to data is hindered by lack of trust between data owners, insufficiency in data interoperability and limited business models. Our ambition is to resolve these barriers for data sharing and trustworthy usage of AI, and in 2021 some key achievements have been:

i) Realisation of the first operational data space in manufacturing industry (smart connected supplier network: https://smart-connected.nl/) including to-be open-sourced data space toolkit and first steps in interoperability of data spaces.
ii) Development of key self-sovereign identity (SSI) concepts like guardianship and SSI gateway to enable interoperability of SSI ecosystems, e.g. supporting multiple SSI wallets.
iii) Creation of proof-of-concepts in the energy and greenhouse sector showing data interoperability based on the SAREF standard (which was co-developed by TNO and ETSI).
iv) A setup of an AI Oversight Lab to translate EU and NL guidelines on AI to practical implementation guidelines for data scientists.

A TNO spinout Linksight (https://www.linksight.nl/), based on investments during past years in Multi-Party computation, was launched in 2021 aiming at further operationalizing these technologies.

In **fast and open infrastructures**, we design the future digital connectivity, storage and processing as the foundation for the further digitalisation of society. In 2021, some key contributions have been:

i. Creating an initial 5G stand-alone roaming setup between operator networks in the Netherlands, to be further expanded in 2022 at the Helmond automotive field lab.
ii. Establishment of the Cloud Federation Testbed in which new cluster federation technologies have been validated for the Gaia-X federated data infrastructure.
iii. Realizing reference architecture for an open Metaverse platform, ready for external partners;

We strengthened Dutch and EU ecosystems on digital infrastructure topics. The Future Network Services initiative was formed in collaboration with the Topsector ICT (see FNS paper “Communicatie-netwerken voor en door Nederland”). 5Groningen developed into a further improved testing ground as the new 5G technologies like slicing have been introduced. As partner in Delft DO IoT, we expanded knowledge on 5G stand-alone networks. We became member of 6G-IA to be at the forefront of 6G development. Together with our data sharing colleagues we became even more active in the Gaia-X association enabling data spaces and sovereign EU cloud infrastructures based on cloud federation. We established the Dutch Gaia-X Hub with ECP and facilitated the NL Cloud Infrastructure Coalition.

In the area of **trusted ICT** we developed practicable implementations of relevant applications on current and near-future quantum hardware with a focus on Practical Algorithms of Quantum Optimization. The main results in 2021 were the delivery of a quantum optimization pipeline framework, various new implementations of experimental use cases using quantum hardware and additionally, we contributed to the European standardisation efforts on quantum technologies through TNO's chair position of the CEN-CENELEC Focus Group and the active participation with the NEN working group on quantum standardisation.

| Titel | VP Embedded Systems Innovation (ESI) (P707) |
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| MTIB Thema | Sleuteltechnologieën |
| Contactpersonen TNO (DM en VPM) | Henk-Jan Vink (Managing Director TNO ICT), Frans Beenker (VP manager) |
| Contactpersoon Regie-voerder | HTSM embedded systems / Brit Meier |

**Programma jaar 2021 - Samenvatting**

The overall mission of ESI (TNO) is phrased as "Embedding leading edge methodologies into the Dutch high-tech systems industry to cope with the ever-increasing complexity of their products". The complexity of high-tech systems is increasing and continues to increase as co-innovation and strategic collaborations across supply chains are becoming more and more important. The core business value of many companies is shifting from developing and manufacturing systems towards integrating supplier and platform components into these systems and those systems into the business context of their customers. In addition, the industry engineering scope has expanded from engineering initial systems to engineering systems and system upgrades during an entire product life cycle. More and more focus is on personalized systems. New methodologies are required to cope with this. It is of utmost importance that such methodologies are not only generated for individual companies for their products or applications, but that opportunities for synergy over research projects, knowledge sharing and knowledge exchange over research partners are fostered. Such an approach leads to faster and more efficient build-up of knowledge, sharing of solution strategies, best practices, and education.

Although the 2021 program was in the middle of the COVID-19 pandemic, ESI realized its targets and strengthened its position in the Netherlands and improved its position in its international outreach program. In 2021, most of our research effort was carried out in cooperation with large industrial partners. They consisted of long-lasting partners (ASML, Canon Production Printing, Nexperia/ITEC, Philips, Thales, Thermo Fisher Scientific) and partners that have shown an increasing interest in cooperation with ESI (e.g., Vanderlande and VDL-ETG). We continuously strive to expand our network, both nationally and internationally. Nationally, both Thales and Vanderlande have decided to join the ESI ecosystem and the ESI Partner Board: Thales per January 1st, 2021, Vanderlande per January 1st, 2022. Internationally, ESI continued its collaboration with OFFIS/DLR in Germany and the Systems Engineering Research Center (SERC) in the USA. We are in the process of strengthening our ties with the Software Center in Gothenburg, Sweden. These relationships provide a good opportunity for international collaboration, benchmarking, sharing research agendas and research insights, and exploiting partner networks. Finally, ESI and Capgemini Engineering have signed an "Implementation Partner" agreement which makes Capgemini the first partner to work on the implementation of the ESI methodologies in the high-tech industry. Key examples of successful 2021 ESI research results are:

- A system performance workbench based on models, simulation and visualization;
- Methodologies for SW rejuvenation and change impact analysis based on model extraction;
- A methodology for creating system reference architectures.

ESI pays special attention to further generalization, consolidation and dissemination of the research findings and of the resulting new expertise. The research programs with individual partners take benefit from each other's results and ESI actively manages its expertise and shares and aligns it in its open innovation ecosystem. In 2021, we realized our milestones, of which the following two are key for our impact in the market:

- The set of ESI tools (ComMA, POOSL, TRACE and LSAT) have been brought (or are being brought) to open source via the Eclipse Foundation and in addition open-source distribution and support of the POOSL tooling has been taken over by Obeo;
- A multi-company training program for system architects, bringing together big companies and SMEs, from high-tech and civil engineering has been realized and successfully provided.

Two topics deserve specific mentioning.

- The ESI symposium, physically scheduled for April 2021, was due to the Corona situation, rescheduled into a very successful on-line 6-day webinar drawing an audience of more than 450 participants. The event was co-organized with our international partners OFFIS/DLR and SERC.
- With each of our industrial partners, we started a series of workshops to re-align the ESI research agenda with their long-term innovation challenges. This process will be finalized in 2022.