TNO Onderzoek 2022 - Overzicht Vraaggestuurde programma’s volgens het MTIB

Unit	Roadmaps	Vraaggestuurde Programma's (VPs)	MTIB
EMT	System Transition	P325 System Transition	
	Sustainable Subsurface	P307 Geo-energy	
		P310 Karakterisering Grondwater	
	Renewable Electricity	P321 Renewable Energy	
	CO2 Neutral Transition	P323 Co2 Neutral Industry	
	Environment & Sustainability	P510 Luchtkwaliteit	
		P515 Circulaire Economie	
	Sustainable Chemical Industry	P603 Sustainable Chemical Industry	
		P616 Industriële elektrificatie en CCUS	
MBE	Sustainable T&T	P408 Sustainable Traffic & Transport	
	Smart T&T	P407 Smart Traffic and Transport	
	Buildings & Infrastructures	P502 Duurzaam bouwen	
HLW	Prevention & Productivity	P204 Future of Work	
		P211 Jeugd	
		P511 Human Health RM Nano	
		P207 Sociale Innovatie	
	Biomedical & Digital Health	P203 Biomedical Health	
		P210 Digital Health Technologies	
DSS	Information & Sensor Systems	P104 Radar & Sensorsystemen	
	National Security	P102 Veilige maatschappij	
		P106 Kennisopbouw politie	
ISP	Digital Innovations	P103 Cyber Risk & Resilience	
		P706 ICT	
		P707 ESI	
	Transitions and Transformations	P901 Transitions & Transformations	
HTI	Space & Scientific Instrument.	P607 Space & Scientific instrument.	
	Semiconductor Equipment	P612 Semicon & Quantum	
	Flexible & Free-form Products	P615 Flexible and Freeform Products	
	Smart Industry	P617 Smart Industry	

MTIB Thema's	
Klimaat & Energie	Gezondheid en Zorg
Circulaire Economie	Veiligheid
Mobiliteit	Sleutel-technologie
Landbouw & Water	

Titel	**VP System Transition (P325)**
MTIB-thema	Klimaat en Energie
Contactpersonen TNO (DM en VPM)	VP-manager: Ruud van den Brink Directeur Markt: Harm Jeeninga
Contactpersonen Overheid	Marianne Zandstra (EZK), Mart van Bracht, Maarten de Vries (Missies)

Programma jaar 2022 - Samenvatting

In het onderzoeksprogramma System Transition ontwikkelen we in de praktijk toepasbare kennis en inzichten voor beleidsmakers en andere professionals in de energietransitie zodat zij grip krijgen op de maatschappelijke, economische, operationele en gedragsmatige vraagstukken van de energietransitie. Hieronder worden enkele in het oog springende resultaten uit 2022 gepresenteerd; alle resultaten van de projecten zijn te vinden op onze webportal energy.nl.

In 2022 zijn de energiescenario's ADAPT en TRANSFORM opnieuw doorgerekend (PMC-cluster Energietransitiepaden). Hieruit blijkt dat een ambitieus, duurzaam scenario (TRANSFORM) goedkoper is dan een scenario waarin we nog fossiele energie gebruiken (ADAPT). De scenariostudie is uitgevoerd nog voor de grote prijsstijgingen als gevolg van de oorlog in Oekraïne; hogere prijzen voor aardgas en olie vergroten het kostenverschil. In opdracht van de Tweede Kamer heeft TNO alternatieven voor Russisch gas voor de korte en middellange termijn in kaart gebracht. De hoge gasprijzen hebben het probleem van energiearmoede nog meer op de voorgrond gebracht. TNO heeft als onderdeel van het Landelijk programma Energiearmoede onderzoek gedaan naar mogelijkheden om de gevolgen van de prijsstijgingen te beperken (PMC-cluster Sociale Innovatie). Met name het bij het verduurzamen van huizen prioriteit geven aan de huizen met de slechtste energiekwaliteit biedt een oplossing die zowel wat betreft kosten als wat CO_2-reductie betreft goed uitpakt.

In 2022 was naast de hoge energieprijzen ook het klimaat centraal in het maatschappelijk debat. Uit onderzoek van TNO onder een representatieve groep Nederlanders blijkt dat een grote meerderheid zich zorgen maakt over klimaatverandering (PMC-cluster Sociale Innovatie). Over een aantal maatregelen om klimaatverandering te voorkomen leven er echter zorgen bij mensen. Veel mensen maken zich ook zorgen over de gevolgen van verschillende. Genoemde zorgen zijn: zijn ze wel effectief, wat zijn de gevolgen voor de werkgelegenheid, en zijn de kosten niet te hoog?

Het warmer wordende klimaat verhoogt ook de vraag naar koeling (PMC-cluster Energietransitie in de wijk). TNO heeft berekend dat er in de toekomst serieus rekening moet worden gehouden met een toenemende energievraag van onder andere koeling met airconditioners in de zomer. De elektriciteitsvraag in de gebouwde omgeving en op bedrijventerreinen groeit sowieso, onder andere door de elektrificatie van personen- en distributieverkeer (PMC-cluster Regionale Energietransitie). TNO ontwikkelt oplossingen voor het flexibeler maken van de energievraag, waardoor er binnen de beperkingen van de huidige netcapaciteit meer mogelijk is.

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)	Maurice Hanegraaf
Contactpersoon Regie-voerder	TKI UE: Robert Jan van Egmond, TKI Geo Energie: Jorg Gigler, EZK: Ronald Schillemans, Pieter Jongerius

Programma jaar 2022 - Samenvatting

De noodzaak tot versnelde ontwikkeling van warmtenetten en de inzet van geothermie en Hoge Temperatuur Opslag (HTO) is opgenomen in het coalitieakkoord van het kabinet Rutte IV[1]. Een tweede belangrijk speerpunt in het regeerakkoord zijn de veiligheidsrisico's van de energietransitie en het bijbehorende risicobeleid. In de lopende regeerperiode wordt gewerkt aan het ontwikkelen van een ruimtelijk programmatische aanpak waarbinnen alle verwachte activiteiten in de ondergrond worden vastgelegd: gas-, warmte- en zoutwinning alsmede opslag van warmte, gas, waterstof, CO_2 (CCS) en compressed air. De opschaling van duurzame warmtenetten en de veiligheid van mijnbouwactiviteiten zijn prioriteiten in het regeerakkoord en sluiten naadloos aan op doelstellingen van dit vraaggestuurd programma:

1. Reduceren van pre-drill geologische *Exploratie- en realisatierisico'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 programma's samen met industriepartners (bijvoorbeeld Huisman Geo, Eavor, WEP, warmtebedrijven), Nederlandse kennisinstellingen (Deltares, KWR, academia). De missies worden onder andere gedreven door kennisagenda's die samen met de industriepartners en kennisinstellingen worden gedefinieerd. De benodigde innovaties worden vervolgens grotendeels gerealiseerd in nationale en internationale onderzoeksprogramma's zoals WarmingUP (budget 18 mln euro, loopt door in 2023), en door TKI of EU gefinancierde projecten, zoals DEPLOI, DGE-ROLLOUT, DRAGLOW, ELFO, PERFORM, REFLECT, RESULT etc. Circa 80% van het SMO-budget wordt ingezet voor de onderzoeksprogramma's. In 2023 begint een viertal projecten die worden gefinancieerd door RVO onder de regeling Missiegedreven Onderzoek, Ontwikkeling en Innovatie (MOOI[2]): MOOI GOO Geothermal (PMC Exploration), MOOI ComToHeat (Well Technology), MOOI HT ATES (Heat Networks & storage) en MOOI WGOBES (Groundwater).

De belangrijkste resultaten in 2022 waren:

Ad 1. Betrouwbaardere inschatting van de pre-drill aquiferkwaliteit wat zal leiden tot een grotere succes ratio bij het boren van geothermische putten; betere resultaten in de exploratiefase zullen leiden tot betere putontwerpen, beter producerende putten en kostenreductie; machine learning (ML) algoritmes voor automatische herkenning van breuken op seismiek; snelle en efficiënte scanning van seismiek op potentiële ondergrondrisico zoals gaslekkage; oplossingen om efficiënter grote hoeveelheden data op te slaan die het resultaat zijn van hoog-frequente monitoring zoals DAS- en DTS-metingen; verbeterde toegang tot grote hoeveelheden semi-gestructureerde data door ML.

[1] "Op wijkniveau zetten we, waar dat kosteneffectief kan, in op de realisatie van duurzame warmtenetten. De onrendabele top van collectieve warmteprojecten zal deels worden gefinancierd uit een nationale subsidieregeling, zodat dit voor huishoudens betaalbaar blijft."

[2] https://www.rvo.nl/subsidies-financiering/mooi

Ad 2. Snellere processing en interpretatie van monitoring-gegevens en karakterisatie van well test data maakt doorrekenen meer ontwerp-opties mogelijk wat leidt tot betere beslissingen; tooling voor Life Cycle Assessment kan de efficiency en duurzaamheid van geothermie quantificeren en optimaliseren; onderzoek naar closed loop systemen verbetert het inzicht in geothermische potentie en de duurzaamheid van dit soort systemen. Met de MOLE-simulator kunnen snel cyclische (opslag-productie)-scenario's voor waterstof en perslucht doorgerekend worden

Ad 3. Verbeterde bepaling van seismische events en karakterisatie door gebruikmaking van S-golven. Nieuwe modelleer-opties van materialen om putten af te sluiten zoals klei en zout. Studie aan actuele data van het Kwintsheul-doublet laten zien dat verhoogde stress op de breuk niet heeft geleid tot voelbare seismische events. Beter begrip van ondiepe vs. diepe bodem-daling.

Ad 4. History matching van de Middenmeer HTO geven meer inzicht in het thermisch gedrag van de ondergrond, wat gebruikt kan worden voor toekomstige systemen. Een ontwikkelde life cycle assessment (LCA)-module kan gebruikt worden voor optimalisatie van de HTO.

Ad 5. Ontwikkeling van een volledig geïntegreerde modelketen die in staat is het volledige systeem van CO_2-injectie en opslag met alle onzekerheden te adresseren. Het is de bedoeling in 2023 de bestaande tools EVEReST, ERT en MACRIS verder te integreren in een modelketen zodat die gebruikt kunnen worden door CCS operators waardoor CO_2 opslag veiliger zal worden.

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

Programma jaar 2022 - 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. De kwaliteit van het grondwater bepaalt in grote mate de waarde van dit natuurlijk kapitaal. Verder is grondwater een efficiënte drager van thermische energie en kan gebruikt worden voor warmte- en koude-opslag in de energietransitie.

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' (een programma van de gezamenlijk Geologische Diensten in Europa).

Hiertoe wordt samengewerkt met universiteiten, met name de Universiteit Utrecht en Technische Universiteit Delft, onder meer via gezamenlijk onderzoek en begeleiden van stagiaires en studenten die BSc of MSc-thesis onderzoek doen.

De hoogtepunten voor 2022 vormden de succesvolle afronding met Nederlandse partners van de grondwaterprojecten binnen het ERANET-programma GeoERA van de gezamenlijke Europese geologische diensten (https://www.geoera.eu), de start van een vervolg in de vorm van een CSA voor een 'Geological Service for Europe' (GSEU), de inbreng van de expertise op het gebied van vergrijzing van het grondwater in de Kennisinpuls Grondwaterkwaliteit, de vernieuwing van grondwaterstanden-in-beeld met historische trends van de grondwaterstijghoogten en de start van FreshEM-NL en onderbouwing voor Nationale Grondwaterreserves samen met Deltares.

Titel	**VP Renewable Electricity (P321)**
MTIB Thema	Klimaat en Energie / MMIP2, MMIP3
Contactpersonen TNO (DM en VPM)	Harm Jeeninga (Director Market), Arthur Weeber (VP manager Solar Energy), Jan Willem Wagenaar (VP manager Wind Energy)
Contactpersoon Regie-voerder	Ministry of Economic Affairs and Climate. Directorate General Climate & Energy • Debby Joosen (Kendall Esmeijer tot 2022) • Eva de Leede: “Clusterleider windenergie op zee” • Laura Jansen: “Beleidsmedewerker windenergie op zee” • Florentine van der Wind: “Beleidsmedewerker windenergie op zee/ecologie” • Ruben Prins: “Senior beleidsmedewerker energie-innovatie" • Erik ten Elshof: “Senior beleidsmedewerker energie-politiek" • Micha Rots: “Senior beleidsmedewerker energie-innovatie" TKI Wind op Zee • Bob Meijer: Director “TKI Wind op Zee” • Bram van der Wees: Program manager “TKI Wind op Zee” TKI Urban Energy • Robin Quax: Program Manager Renewable Electricity • Ümit Duman: Innovation Analyst Renwable Electricity Missie Team Electricity • Frans van den Heuvel

Programma jaar 2022 - Samenvatting

The overall ambition of the Roadmap Renewable Electricity is to gain knowledge and to develop technologies that enable large-scale deployment of wind energy and photovoltaic solar energy. Our research program is carried out together with partners from industry and science. We focus on reducing generation cost of renewable electricity, and on developing technological solutions to resolve barriers with respect to implementation. These technological solutions should also increase the economical, societal, and ecological value of renewable electricity systems, and should result in an improved performance. Furthermore, it should result in a better market position for our public and private partners and contribute to manufacturing leadership in Europe, enabling a significant market share.

For Wind Energy, this VP supports the implementation of the required wind power in the Netherlands at the lowest cost to society. Current outlooks, updated in 2022, foresee an installed capacity of 21GW in 2030 (‘Aanvullende Routekaart Windenergie op zee 2030’) and up to 72GW in 2050 (‘Noordzee Energie Outlook’) of offshore wind. Recent developments in the energy markets and in the geopolitical arena provide an additional incentive to accelerate the achievement of these goals.

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. Also onshore wind is addressed; these activities address in particular the environmental, societal, and regulatory aspects.

The VPSolar Energy supports large scale deployment of PV in the Netherlands at low cost and high value. Current outlooks foresee an installed capacity of 250 GWp in 2050 ('Ruimtelijk potentieel van zonnestroom in Nederland’, TKI Urban Energy 2021). This VP also strengthens the Dutch and European PV industry, aiming to bringing back manufacturing to Europe. Our R&D covers a large part of the value chain, focusing on increasing the energy generation per surface area (which is related to the conversion efficiency but includes more factors), on spatial and/or physical integration of PV in remote areas and in the built environment (making PV ‘invisible'), and finally on making solar energy fully sustainable and circular. All these aspects are key in realising the climate goals in which PV plays a significant role.

Goals for the next 3 years

The R&D programme on Wind Energy is part of the TKI Wind op Zee and is seamlessly aligned with the MMIP1 of Mission A. The programme for Solar Energy is fully aligned with MMIP 1 and 2. The MMIPs are being updated. This reflected in the VP. For the next three years the main goals are to:

1. Support the accelerated offshore wind energy development;
2. Improve the integration of wind power in the energy system;

3. Reduce the costs of wind power even further;
4. Ensure safe, efficient and reliable operation of offshore wind farms;
5. Increase circularity of wind energy;
6. Expand ecological (e.g. birds and bats) research and move towards inclusive wind farm design;
7. Develop a framework for the profitability of solar parks on land and driven by societal value;
8. Ensure successful pilots of floating PV on the IJsselmeer and North Sea;
9. Create technology solutions for high-volume manufacturing of customized PV products that can be integrated in elements for buildings, infra and mobility while maintaining the primary function of these elements with proven reliability and safety;
10. Realize cost competitiveness for recycling of PV modules and resulting in easy access to high-value materials;
11. Be one of the key partners in establishing novel PV manufacturing in the EU;
12. Increase the efficiency of large area so-called tandem PV devices beyond the limits of the current silicon PV technology.

PMC Clusters

In order to achieve the goals of this VP we have structured our R&D program and are aiming for innovations in offshore wind energy and in solar energy. The implemented innovations should support the competitiveness of the Dutch industry, should remove barriers for the accelerated implementation of renewably generated power and should create many green jobs. The main pillars (PMC clusters) of the programme are

- Offshore wind farms: Supporting fast implementation and reliable operation of offshore wind farms towards 2030 and further reduction in cost of energy for offshore wind power.
- Wind Energy System Integration: Improving the implementation of wind energy in its surrounding system in terms of power, ecology and society. Increasing the flexibility, conversion, storage and markets are important themes in power system integration.
- New Technologies: Developing new wind energy system concepts for the period after 2030 and for which a viable business case does not exist yet. Experimental validation is explicitly part of this pillar.
- Sustainable Solar Parks on Land and Water: Developing solutions for profitable solar parks on land and driven by societal value.
- Integrated Solar and Safety: Realizing technologies for safe and integrated PV at competitive cost and for multiple use of available area.
- Circular modules and mass customization: Developing technologies for customized PV and recycling of PV products, and supporting local manufacturing in this field,
- Advanced solar technologies: increasing the conversion efficiency beyond the limits of current silicon and thin-film PV by developing tandem and on the long-term multijunction PV.

Highlights and Results 2022

- To support the ambitious Dutch goals of having an installed offshore wind capacity of 21GW by 2030, TNO provides long term wind measurements across the North Sea such that developers can make solid business plans.
- TNO demonstrated that glass fibers from old wind turbine blades can be recovered properly and through thermolysis processed such that they can be re-used for new materials. Particularly, TNO demonstrated that new car dashboards could be made from this recycled materials.
- TNO is developing the SWITCH scaled, hybrid power plant as an open innovation research facility together with Wageningen University and Research. The wind turbines and solar panels are already there and the teams are now making all the operational preparations to welcome the battery and electrolyser, arriving in due 2023.
- TNO made a whitepaper on the profitability of offshore wind in 2030 based on scenarios of offshore wind development and industrial electrification together with the colleagues from Energy Transition studies. This whitepaper was well received by various national media.
- In 2022, TNO develop an improved version for bird impact detection and installed it in at full-scale wind turbine in the US. Currently, measurements are being taken, studying the impact of birds at this machine.
- New and innovative blade tips are being installed and tested at the TIADE research wind turbine with the aim to increase yield at minimal costs. In 2022, dedicated tests have been performed at the TIADE turbine. These including

mounting blade add-ons (vortex generators) in order to demonstrate improved yield and mounting torsion sensor to tip to measure blade twist.

- At the fieldlab Zephyros facility, it was demonstrated that a robotic arm can execute tasks in the nacelle. With such relatively small scale demonstrations we aim to facilitate the introduction of robotics in wind energy and initiate larger innovations in automized inspection and maintenance.
- Sustainable Solar Parks on Land and Water: Based on field tests we improved our digital twin for so-called bifacial PV systems and the simulation could predict the energy output within 3-4%. For floating PV reports on reliability risks and norms, on LCoE, and LCA were finalized.
- Integrated Solar and Safety: For 2022 safety was a main topic of research and several overviews with respect to for example norms and regulations were published. A prototype of a car hood in which PV is integrated was realized and displayed at the InterSolar (a huge Trade Fare in Munich) and several other occasions.
- Circular modules and mass customization: Recycling is becoming more important and technologies to separate individual layers in a module were tested. A novel encapsulant with a factor 10 improved release rate was successfully tested. An inline pilot line for developing low-cost technologies for a variety customized products with a single tool was installed and made operational in our facilities in Eindhoven. Solar half-fabricates enabling integration of PV in all kind of surfaces and up to prototyping level can be carried out with this novel tool.
- Advanced solar technologies: In 2022 and together with TUD, TU/e and imec a record efficiency for a so-called 4-terminal tandem was realised. The combination of a semi-transparent perovskite top cell and a silicon bottom cell resulted in an efficiency of over 30%, and higher than the maximum theoretical efficiency of a single junction silicon cell. Furthermore, the efficiency of the top cell used for this record tandem was certified.

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), TKI-BBE, Peter Besseling, Paul Verbraak, Tom Mikunda (EZK) & Ed Buddenbaum (up to September 2022)

Programma jaar 2022 - Samenvatting

The demand driven program "CO_2 neutral industry" responds to the societal need for a carbon neutral industry as formulated in the Climate Agreement. The government's central goal with the National Climate Agreement is to reduce greenhouse gas emissions in the Netherlands by 55% by 2030 compared to 1990 levels. An integral knowledge and innovation agenda (IKIA) was established, following the Dutch climate agreement. Five "missions" were defined containing 13 MMIPs (multi-year mission driven innovation programs). Following the missions and MMIP the VP CO_2 neutral Industry is structured in 8 clusters of product market combinations. Below a concise description is presented.

Short overview of relevant research topics in the various PMC-Cluster in the VP CO_2 neutral industry.

The key focus of each of the PMC Clusters is as follows:

Industrial CO_2 capture: focusses on cost reduction, process stability, energy efficiency, CO_2 purity, overall emissions of industrial CO_2 capture units. Key words include, blue hydrogen, capture from flue gases and in-process capture. New directions include negative emissions. Key results in 2022 were:

- *Productivity SEWGS improved at least doubled*
  TNO has shown that using the SEWGS kinetic interaction model a the productivity can be at least improvement by a factor 2 can be reached. Experimental validation will be the next step and is planned in 2023.
- *Pilot demonstration of new application and concepts for SEWGS in the steel industry.*
  The first demonstration of reheating steel products with STEPWISE carbon-free hydrogen at the TRL6 pilot site in Sweden has been successfully completed. This shows the internal usability of the hydrogen as a combustion fuel.
- *First proof of principle AI for degradation profiles amines*
  The in-depth knowledge of degradation of CO_2 capture solvents has been translated into a classification protocol so that the industry can make informed decisions on the solvent to use.

Sustainable Industrial Heat System: technology development to reduce, reuse, store and supply industrial heat. Specific topics include, energy efficient molecular separations; industrial heat pump and storage technology, high temperature heat supply through combustion and electrical heating solutions. Highlights in 2022 were:

- *Liquid sorption technology for drying process can increase energy efficiency largely.*
  Tests have demonstrated the technical feasibility of liquid sorption technology for recovery and re-use of waste heat in drying processes. The techno-economic analysis indicate energy savings of 20-85% and payback times between 4-6 years, depending on the specific application.
- *Multipurpose electric, hydrogen and methane heating concept proven*
  The HyFlexFlOx burner consists of a flexible H_2/CH_4 flameless combustor with electrical preheating. This allows for fast, load-following utilization of renewable electricity. The combustion system can indeed be operated in a flameless oxidation regime in the whole H_2/CH_4 blend ratio, while fulfilling the NO_x emission criteria.
- *European whitepaper 'Industrial Thermal Energy Storage' published*
  As part of TNO activities as a Thought Leader, TNO chairs the EERA joint program Energy Efficiency in Industrial Processes. Within this JP the whitepaper 'Industrial Thermal Energy Storage has been published along with a successful webinar with over 150 attendants.

Energy Infrastructure: focusses on (trans)national on-shore infrastructure development, for new value chains (H_2, CO_2) coupled to offshore production of green hydrogen or CO_2 storage. Key aspect include supply and demand balancing including storage needs, cost efficiency, quality sensing, safety of operation, public acceptance and minimum negative ecological and societal impact. Highlights in 2022 were:

- *Unique testing environment*

  TNO has realized a test infrastructure for materials testing in a high pressure hydrogen atmosphere. The materials testing including fatigue analyses under various high pressure gas conditions.
- *Repurposing mining locations for gas storage leads to lower costs*
  The potential of the re-use of current mining locations for the production or storage of renewable gases (green gas or hydrogen) has been assessed. There can be a significant saving of public investment in new infrastructure when existing infrastructure can be repurposed.

Clean Hydrogen Production: This PMC Cluster focusses on next generation electrolyser technology development for the low temperature (PEM and AEM) and high temperature (SOE) electrolysers. In this development we focus on : cost reduction, performance improvements, circularity, reduced iridium usage and high precision manufacturing. This includes validation of potential (technical and commercial) of (Dutch) electrolyser components innovations and support electrolyser integration. Highlights in 2022 were:

- *200 fold reduction in iridium for electrocatalysis*
  The main highlight of 2022, was the breakthrough reduction iridium content by 200 times, while maintaining 40% of the activity of the PEM electrolyser. This is the corner stone of our 3rd generation PEM electrolyser development.
- *Major new projects*
  In 2022 we further strengthen the Dutch High-tech (start-up) companies in their journey developing next generation electrolyser solutions via the Electrolyser makersplatform, the large Hyscaling consortium and via bilateral research projects. The launch of our first Shared Research Program where we collaborate with the leading industry on next generation PEM electrolyser.

Biobased Fuels & Chemicals: the research focusses on maximizing the molecular capital from biogenic sources like demolition wood, seaweed and all sorts of agricultural residues. The aim is to develop sustainable bio-fuels for e.g.

aviation and shipping. The maximum climate impact is reached when the excess carbon is sequestrated either as CO_2 or bio-char. Highlights in 2022 were:

- *EZK investment for biobased fuels fully operative*
  TNO has successfully operated the whole production process from feedstock to end product using woody biomass and bagasse as test materials, demonstrating the functionality of all unit operations. The included operations include a gasifier a steam reformer, a CO_2 scrubber, and a Fischer-Tropsch pilot reactor.
- *Cow manure can be treated with Torwash*
  A five day continuous pilot was run on a farm using untreated cow manure, proving the concept of the Torwash technology as a potential solution to the nitrogen problem in The Netherlands. Scale up of this application can be rapid as the construction of a Torwash demo for treating sewage sludge has commenced.
- *ENERCHAR project demonstrated at TRL5*
  The TNO process to produce high quality, sustainable, stable biochar has been proven at 2 ton scale. This material can be used as a soil enhancer and acts as a negative CO_2 emission sink.
- *Patent highlights*
  In 2022, three patents were granted on biomass- and seaweed pre-treatments and the isolation of valuable chemicals via gasification, as well as two new patents were filed on bio-char production and a combination of steam explosion in combination with Torwash to extract valuable chemicals from biobased feedstocks (called SWIAT).

Synthetic Fuels & Chemicals: The processes to synthetically produce and convert carbon and nitrogen based value added compounds , like ammonia, formaldehyde, methanol, DME, ethylene, propylene, and kerosene are hindered by a low conversion and a poor selectivity. Improving this process is the main topic of research in this program line. Highlights in 2022 were:

- *Ammonia chemistry as new topic*
  In 2022 we started to intensify our work around ammonia, specifically focusing on smart cracking, conversion and therewith connecting the industry with imported ammonia. The first novel concepts have been identified and resulted in patent applications.
- *Containerized SEDMES installation commissioned*
  The realization of a containerized SEDMES pilot installation (sorption enhanced DME synthesis) has resulted in several project opportunities and market interest, which is promising, as this technology will be making the step to industry in the coming years.

Radical New Industrial Processes: within this PMC-Cluster we develop new technological approaches and options, for the longer term with a more embryonic character leading to portfolio rejuvenation. Highlights in 2022 were:

- *Aminoacid salt solvents first candidate for direct air capture*
  Aminoacid salt solvents show promising properties for direct air capture application. As the experiments have pointed out that relatively good loadings of the solvent at 400 ppm CO_2 in air can be achieved, at relatively high solvent concentration (3M), without any sign of precipitation
- *Proof-of-principle on carbonates removal from water was achieved*.
  The carbonate removal from water using Membrane Capacitive Deionization (MCDI) was successfully demonstrated with current densities, comparable to reported in literature. Maximising current density leads to the lowest cost of removal as it leads the lowest catalyst loadings and electrode area per kg of bicarbonate removed thus minimising the equipment cost.
- *Pulsation of electrolyte flow doubles current density in TNO Redox Flow Battery*
  The current density in TNO Redox Flow Battery concept with environmental benign charge carriers can be doubled when a pulsating electrolyte flow is applied without a need to modify the electrochemical

cell. This enables a tunable power output of the battery. A patent application regarding the use of pulsating electrolyte flow in redox flow batteries has been filed.

Industrial Transformation: governments and industrial cluster in North Western Europe will be taking far reaching decisions with respect regional development and interregional connectivity in the coming years. To do so, the relevant stakeholders need to balance the societal, ecological and economic costs and benefits, while fast decision making is needed. Within this PMC Cluster, we develop tools to support this decision making process. Highlights in 2022 were:

- *"Green print" approach launched*
  Under the banner of "Green Print" TNO has launched Industrial Transformation proposition and knowledge position. By combining the tooling capabilities and in depth knowledge, TNO is capable of proving concrete advice for governments, industrial clusters and individual companies.
- *Delivery of first version Circular value chain model*:
  A big steps was made concerning the modelling of circular options and the impact on the supplying industry, focusing on mass flows of materials in the Automotive industry. The model is flexible in nature and can be transferred to any other sectors.
- *Launch of the academic collaboration program*:
  Five PhD lines have successfully been started. Combined, these studies cover the full spectrum of modelling industrial transformation at factory, cluster and national level, as well as calculating structural economy changes taking into account learning curves of disruptive technologies.

Titel	**VP Luchtkwaliteit (P510)**
MTIB Thema	
Contactpersonen TNO (SD en VPM)	Paula Bronsveld (VPM), Martijn Schaap (depSD)
Contactpersoon Regie-voerder	Paul Rijkse (MinIenW)

Programma jaar 2022 - Samenvatting

The Netherlands is facing pressing environmental challenges, predominantly related to anthropogenic emissions. Approximately 11.000 yearly premature deaths can be attributed to poor air quality. Global warming may lead to catastrophic sea level rise, droughts, and more frequent extreme weather within a few decades. If critical loads for atmospheric nitrogen deposition keep being exceeded in Dutch nature areas, significant biodiversity loss is expected.

To curb these impacts and to comply with European legislation, the Dutch government has committed itself to a strict set of agreements within the "Schone Lucht Akkoord (SLA)" in 2020, the "Klimaatwet" in 2016 and the "wet stikstofreductie en natuurverbetering (WSN)" in 2021. These agreements focus on significantly reducing the emissions of particulate matter (PM), greenhouse gases and reactive nitrogen species. The targets set within these agreements are ambitious. Reaching these policy goals will require the development of cost-effective mitigation strategies, which in turn will rely on technology that provides in-depth knowledge of the current situation as well as insight into the relationship between source, exposure, and effect.

Therefore, within the VP Air Quality, TNO focusses on the development of innovative technological methods and solutions for state-of-the-art verification and monitoring of atmospheric emissions. These technologies allow progress tracking and support the designing of strong policies for reducing emissions that harm air quality, climate and biodiversity. The combination of a wide range of competences, both on measuring and modelling atmospheric emissions, makes TNO a unique partner in the Netherlands and abroad for the development of such technology.

In the development and implementation process for these technological solutions, TNO seeks synergy with other Dutch scientific partners like RIVM, KNMI, SRON, TUD, RUG, WUR, VU, UU and GGD. The VP is also well embedded in the European scientific community for air quality and greenhouse gas monitoring and supports related activities.

In the coming years the program will focus on methods to determine:

- the fraction of PM that is most relevant for health, and its distribution from source to humans
- the impact of (individual) nitrogen emitting sources on the Dutch Natura 2000 areas
- locations and intensities of sources and sinks of, mostly non-CO_2, greenhouse gases

The program takes advantage of the strong overlap in the technological expertise required to achieve these goals, shifting between the development of tooling that serves all 3 goals and tooling that is more specific.

For 2022 there were the following highlights:

- In June, the **position paper "Particulate Matter: standard achieved, problem unsolved"** was launched, in which a new approach for health relevant monitoring and regulation of particulate matter emissions was proposed. Some first actions towards achieving the goals set out in this paper, consisting of a toolset for monitoring UFP and preparations for the oxidative potential measurement campaign, were performed and will be continued in 2023.
- New tooling was developed and tested for the **automated analysis of SEM-EDX measurements**, with which the chemical composition of PM can be determined faster and less ambiguously.
- TNO has gained experience in using the **Positive Matrix Factorization (PMF) method** for source attribution based on a wide range of chemical species. With this method, local atmospheric emission "fingerprints" of different types of sources can be discriminated.
- A new, more compact and portable **instrument for measuring near real-time NH_3 dry deposition fluxes** was tested successfully. Future deployment of comparable measurement set-ups in the Dutch nature reserves can play a crucial role in the ongoing nitrogen debate.
- A **methane dedicated LOTOS-EUROS model** was developed and used to create a dedicated version of TOPAS for methane. LOTOS-EUROS (LE) is an open-source chemical transport model (CTM) that is used for a wide range of

applications supporting scientific research, regulatory programmes and air quality forecasts[3]. The new model for methane was validated against CH_4 observations of the Cabauw tower and other ICOS-stations and demonstrated at the hand of the methane leak of the Nord Stream pipelines end of September 2022. TOPAS[4] is a routine based on LE, which shows the calculated contributions of different sources to the measured/modeled concentration at a specific location.

Several valuable **extensions and adaptations of the LOTOS-EUROS model** were made, related to its UFP and ozone modelling capacities, implementation of land use variations, simultaneous nitrogen emission and deposition, emission mitigation strategy tooling and a more accessible TOPAS interface for the website.

[3] https://lotos-euros.tno.nl/

[4] https://lotos-euros.tno.nl/applications/source-apportionment/

Titel	**VP Circulaire Economie (P515)**
MTIB Thema	Circulaire Economie
Contactpersonen TNO (DM/SD en VPM)	Erlend Deckers (VPM), Peter Wolfs, Ardi Dortmans (SD)
Contactpersoon Regie-voerder	Bas Warmenhoven (IenW)

Programma jaar 2022 - Samenvatting

The Circular Economy (CE) is a critical means to achieve the sustainable development goals and the Paris agreement on climate change. A circular economy aims for using fewer raw materials, substituting limited raw materials with renewable raw materials, and optimising the re-use of materials, components, and products. In doing so, the circular economy contributes to the prevention of climate change and environmental pollution, reduction of loss in biodiversity, improvement of socio-economic effects, and to a reduction of criticality/ depletion of raw materials (see "Mogelijke doelen voor een circulaire economie", Policy Brief, PBL, July 2021).

Over the past few years, several documents and reports have been published by (amongst others) the EU, the Dutch government and/or Dutch ministries, and PBL that describe - at high level - the (Dutch) policy and priorities concerning a more circular economy (KIA CE 2019, policy brief PBL 2021, Coalitieakkoord 2021, brief Grondstoffenvoorzieningszekerheid 2022, etc). The activities in this VP aim to contribute to the acceleration of the transition to a more circular economy in the Netherlands. This VP relates to the high-level policy and goals in the following ways:

(1) Committing to Circular Economy goals 2050 & 2030, respectively a 100% circular economy and 50% reduction of use of abiotic raw materials.
(2) Supporting the maximalisation of raw material efficiency, Design for Recycling, Circular materials & processes (KIA CE).
(3) Supporting ambition towards circular industry and circular built environment (Coalitie akkoord).
(4) Supporting priority value chains (plastics, build environment, manufacturing industry, batteries / electronic devices (kamerbrief 2022, coming National Program CE).
(5) Intensifying research concerning criticality and strategic autonomy (kamerbrief 2022, coming National Program CE).

The VP Circular Economy focuses on 3 topics: Circular Value Creation (CVC), Circular Plastics and Circular Electronics.

Circular Value Creation (CVC)

The overarching ambition of the CVC program is to accelerate the transition towards a circular economy by providing fact-based consulting services to support decision making for public authorities (policy development), and industry (technology- and product development as well as investment strategies). Our uniqueness is based on the combination of insights into value chains, deep understanding of current and future technologies, and the latest knowledge in impact assessment (environmental, economical, & social). Our work area typically lies within the triangle of impact assessment, business models, and technology development. In the Circular Value Creation program, we quantify and model the impact of CE, focusing on a number of product groups from the Dutch National Program CE like built environment & infrastructure, manufacturing industry, and energy transition. The priorities in this program are (1) methodological development of the LCA methodology, being defined by the EU as the reference methodology for determining environmental impact, including backcasting tools; (2) business models and the influence of new technologies on business models in particular for the creation of circular hubs and (3) strategic materials autonomy for NL and EU in view of current geopolitical developments.

Circular economy / circularity as such is not sufficiently or satisfactorily covered by current standard LCA methodology. The research developed in 2022 provides valuable insight on the current shortcomings of calculation rules and existing methods when it comes to circularity in LCA.

Until 2022, prospective LCA knowledge development had mainly occurred within the realm of academic research. The work on developing a prospective LCA model for perovskite solar panels, and the work on modelling and calculating the current and future environmental impacts of CIGS solar panels, puts TNO at the front of developments considering future policy and technologies. This work on future developments in renewable energy technology is also an important basis for the link to criticality of materials and materials independency for the energy transition.

Finally, In the work on material passports done in 2022, TNO is also one of the front runners in the Netherlands and EU. With respect to criticality of materials needed for the energy transition, material passports are a crucial element in better estimating the potential of the urban mine. Also regarding material passports and urban mine modelling, TNO is at the front of the developments in the Netherlands.

Circular Plastics Program

The overarching ambition of the Circular Plastics program is that stakeholders adopt our solutions (technologies, product designs, policy advice, etc.), resulting in the reduced use of naphtha as source for plastics. Dutch targets are 750 kta plastics through mechanical recycling and 555 kta via chemical recycling by 2030. For this purpose, in the period 2023-2026, the program will develop:

1) Improved methods for the environmental and techno-economic impact analysis of new technologies and products.

2) An integral impact-based systemic model as a basis for decision support and guidance of stakeholders in the transition towards a circular economy.

3) Intrinsically safe & circular design principles and products (e.g. packaging).

4) Sustainable pre-treatment and recycling technologies for plastics and composites.

5) A greater understanding of health effects of microplastics and strategies to mitigate formation of- and exposure to- microplastics.

Highlights for 2022 were:

- The publication of TNO's whitepaper "Microplastics are everywhere: 70% reduction achievable"
- The use of systemic models (e.g. PRISM, which allows the modelling of future plastic circularity scenarios) in large collaborative projects (e.g. InReP and Syschemiq).
- The broadening of the toolset for impact assessments (e.g. incorporation of social LCA)
- The publication of TNO's work on modelling the quality of recycled plastics
- The development of prototypes for enhanced characterization of polymer quality (Raman-tool)
- The deepening of our knowledge on polymer degradation during use and recycling.
- The (basic) design of a TRL5 pilot plant for TNO's solvent-based dissolution process (funding secured as well).

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.

Circular Electronics

In 2022, a new program on Circular Electronics and the criticality of materials for the energy transition was initiated. The 2025 goal of the Circular Electronics program is of a technological nature: the development of a sustainable and versatile, yet robust, recycling process to treat urban and industrial waste streams in the Netherlands. The goal of this treatment is to extract and recover those critical and strategic materials that are essential for current and future technologies within the energy transition. Material criticality has long been identified as one of the goals of the circular economy (see various TNO reports on this subject and PBL policy brief). Recent geopolitical developments such as the war in Ukraine has only increased the urgency of this development (see "Towards a circular energy transition" Metabolic, June 2021). The activities of the Circular Electronics program have been of explorative character:

- A review of current and future battery technologies and the impact on the recycling industry.
- A landscape scan of best available technologies for battery recycling at high TLR
- A patent scan for best available low TLR technologies for battery recycling.
- A network in the Dutch recycling sector and heavy duty and battery sector has been initiated, yielding participation in the Growth Fund proposal 'Material Independence & Circular Battery Technology'.

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

Programma jaar 2022 - Samenvatting

Driven by the needs of society in general, and the value chain of the chemical industry in particular, the program Sustainable Chemical Industry is in line with the ambitions of the Topsector Chemie. The program focuses on developing technology within demand-driven Public Private Partnerships (PPPs) that are embedded in specific regional and national ecosystems with international collaborations. This program collaborates closely with other programs and Early Research Programs and provides a complete proposition for the chemical value chain. The PPPs Biorizon and Brightlands Materials Center form a key part of the program.

Biorizon

Aromatic building blocks are crucial in providing functionality in our day-to-day applications, but are today almost exclusively fossil based. Biorizon's mission is to enable commercial production of bio-aromatics by 2025, providing increased revenues for biorefineries, economic and sustainable building blocks for the chemical industry, and enhanced applications for a circular society. Biorizon has established a strong global IP position, unique know-how and TRL4-5 research facilities in support of their Diels-Alder technology platform, providing multiple opportunities to access a plethora of bio-aromatic products. In 2020, TNO spin-off Relement was launched, which is commercializing the Biorizon-established production technology for 1st gen. bio-aromatic MPA. Since this initiation, further technology and IP developments, collaborations and organizational plans for Biorizon have shifted focus towards the development of furanic and next gen. bio-aromatic building blocks, to afford a wider range of novel and existing, high-impact, sustainable building blocks for the chemical industry. Biorizon's goal is to bring production technologies for these building blocks to TRL5/6 towards 2026.

In 2022, Biorizon progressed the next gen. bio-aromatics and furanic building blocks with the following achievements: alignment of regional hemicellulose feedstock with TNO's furfural production and upgrading technology, development and characterization of novel biobased surfactants, technical support for scale-up of 1st gen. aromatics by Relement, advancement of the next gen. bio-aromatic technology platform, leading to a competitive cost price for bio-phenol, and delivery of proof-of-concept for bio-aromatic based materials with improved recyclability.

In 2023, Biorizon will focus on bringing the next gen. bio-aromatics and furanic building blocks to TRL4. This will include the production and first validation of first-of-its-kind building blocks in applications. In support of these goals, further expansion of TNO's TRL4/5 facilities at the Green Chemistry Campus and establishment of the Biorizon Application Center are foreseen in 2023.

Brightlands Materials Center

This VP focuses on two program lines within the PPP Brightlands Materials Center: Sustainable Buildings and Sustainable Mobility.

Sustainable Buildings

The Sustainable Buildings program line focuses on the development of pigments and nanocomposite functional coatings and polymer films to create new solutions for optimized use of sunlight and solar heat in the built environment. Within Brightlands Materials Center's Sustainable Buildings program, we develop building envelope materials that contribute to a reduction in energy consumption and/or building-integrated generation of renewable electricity. These building envelope materials are functional coatings and polymer films that are chemically synthesized, and which are optimized with respect to chemical composition and functional component performance to achieve optimum functionality in the application of choice. Currently, we focus on three major applications: (i) reducing the energy consumption for heating and cooling of buildings through application of solar control coatings and films for insulating glass units; (ii) improving the efficiency and lifetime of photovoltaic panels through application of optically functional encapsulants that avoid heating up of PV panels through blocking of sub-bandgap solar radiation; (iii) improving the aesthetics/freedom-of-design of building-integrated photovoltaic panels

through use of structural colour coatings on the glass cover. Examples of such materials developed in 2022 are thermochromic coatings and films for energy efficient smart glazing, heat blocking encapsulants to enhance performance and lifetime of building-integrated photovoltaics (BIPV) and colored glass coatings to improve aesthetics/freedom-of-design of BIPV. In 2023, we will establish a pilot scale process to assess the techno-economics of the thermochromic coatings and produce 1m² sized demonstrators for validation in test buildings. Furthermore, we will optimize the performance of thermochromic pigments and polymer films, and demonstrate the colored coatings for BIPV in the built environment. Furthermore, we will start a study on smart re-use of glass from old windows, incl. potential removal of coatings or polymer films, and chemical treatments required to prepare the old glass surface for new functionalization.

Sustainable Mobility

The program line Sustainable Mobility focuses on the development of technologies for processing and recycling of thermoplastic composites, to accelerate the implementation of lightweight, structural thermoplastic composites (TPCs) in the mobility sector and thus support the energy and materials transition in this sector. In 2022, the previously developed upscaling technology for the production of Long Fiber reinforced Thermoplastics from composite scrap ("reLFT") has been further optimized and demonstrated in a number of successful example applications, together with a network of industrial partners. Furthermore, we have developed and validated multi-physics and multi-scale based material models predicting performance of thermoplastic composites for lightweight structural applications, in collaboration with universities and other knowledge institutes. In the upcoming years, we aim to further develop a flexible pilot scale facility for reLFT production, suitable for a wide range of waste sources. Secondly, the program line develops technology for the production of thermoplastic composite products by additive manufacturing. We have shown good mechanical performance of the produced parts in a number of demonstrator products, and will develop and validate this further together with industrial partners.

Photons-2-chemicals

Within Photons-2-chemicals, we focus on sunlight-powered conversion of CO_2 to chemicals and fuels. Targets of choice are CH_4, CO/syngas and methanol. In 2022, we developed and validated multiple plasmonic catalysts for the sunlight-powered Sabatier and reverse water gas shift process, studied the integration and performance of those catalysts in tailored transparent flow reactors, and made a first assessment of the process economics. In 2023, we will optimize the catalysts, transparent flow reactors and overall processes based on the lessons learned from the technical and economic assessments, and add two further reactions to our portfolio: sunlight-powered dry methane reforming and direct reduction of CO_2 to methanol.

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

Programma jaar 2022 - Samenvatting

The VP Industrial Electrification & Carbon Capture and Utilisation (CCU) contributes to the future implementation of affordable industrial electrification and CCU technologies. This will help to mitigate CO_2 from industrial production of platform molecules towards fuels, materials and food ingredients. 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 focussing on process-integrated electrosynthesis of platform molecules using biomass and CO_2 as feedstock.
- Co-development of next-generation highly efficient and low-cost electrolyser technology reducing total system and production costs tapping into the high-tech sector.
- Co-development of plasma synthesis technology for production of platform molecules.

The program delivered the following concrete technical results in 2022:

- Detailed techno-economic comparison of electrochemical conversion routes based on experimental results and open literature.
- Delivery of the ZEUS CO_2-to-Formic Acid conversion pilot, to be commissioned and tested in 2023.
- Delivery of a proof-of concept and associated business-case for paired electrolysis of biobased furfural and levulinic acid and a proof-of-concept for electrochemical oxidation of sucrose to monomers for bioplastics.
- Infrastructure and tools for Solid Oxide Cell lifetime assessment, development and validation of a new Solid Oxide Electrolysis stack and techno-economic analysis of a showcase for production of kerosene using renewable CO_2.
- Delivery of a small arc plasma system to continue plasma synthesis research at Brightsite.

Apart from technology developments, we also worked on the further development of the industrial electrification business community, and on extension of the Power-2-X Supply Chain Model with FT-fuels import, last-mile distribution, sensitivity analysis capabilities and integration of renewable carbon feedstock origins. Furthermore, we delivered multiple tools for assessing renewable carbon flows and CCU value chains in the framework of Power-2-X. Last but not least, in the context of our Fieldlab Industrial Electrification, we supported multiple large companies and SME's and further procured the central hub infrastructure together with partners to be delivered to the FLIE location.

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, Jannete de Bes (VPMs)
Contactpersoon Regie-voerder	Topsector HTSM: Leo Warmerdam Topsector Logistiek: Niels Agatz Topsector Water & Maritiem: Bas Buchner Ministry of IenW: Michel Duinmayer (IenW-DGMO/Unit Strategie) Ministry of BZK: Kees de Jong (DGBRW/Directie RenL, cluster E/account kennis) en Arie Versluis (PDGRO/Geobeleid Kennis en Data)

Programma jaar 2022 - Samenvatting

The roadmap Sustainable Traffic &Transport (T&T) focuses on technology and policy for making the mobility sector more sustainable with a focus on air quality and climate. The research within the roadmap Sustainable T&T focuses on the development of technology, tools and policy advice for reducing the environmental impact of mobility with a focus on air pollutant emissions ("clean") and greenhouse gases ("economical/sustainable"). The VP[5] 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 impact 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 2022:

- In the TNO Powertrains Test Centre we run projects aiming at breakthrough developments in sustainable powertrains. TNO has designed its own single cylinder test set up. The single cylinder is a perfect research platform to study innovative combustion concepts. In 2022 we have demonstrated that BMEP 20 (Brake Mean Effective Pressure) can be reached in a H_2 driven combustion engine. The significance of this achievement is that we have demonstrated that we can achieve a sufficiently high power density in a combustion engine running on hydrogen. With this we continue to be a worthy partner for Dutch industry.
- TNO was awarded second prize during the EARTO innovations award ceremony in Brussels, on 13 oct 2022, for the development of an innovative hydrogen combustion engine (e.g. for maritime applications).
- The EU project ASSURED has successfully come to an end in March 2022. The project produced recommendations for an interoperability standard between charging infrastructure equipment and electric vehicles.
- The measurement set-ups for measuring brake-wear and plume chasing were successfully used, among others in tests where trips without and with feedback about driving style were made and a measurement campaign in Prague with a ‘sniffer bus’ with which vehicles that were broken or tampered with were automatically detected by driving around on the road with TNO’s ‘sniffer bus’ and matching expected emissions with real-time emissions of surrounding vehicles.
- Behaviour maps were added to the Augmented Emission maps (AEM) and the use of them was presented in the Taakgroep Verkeer and Vervoer. The Augmented Emission Map (AEM) is a standardised data set on the pollutant emissions of a specific vehicle or group of vehicles, and with that the ideal data format for personalized recommendations for drivers.
- An ‘uptake model’ was developed to determine how fast the uptake of Zero Emission vehicles, in particular hydrogen and battery electric trucks, can occur. This model was used for the Klimaat- en Energieverkenning (KEV – ‘Climate and Energy Exploration’).

[5] VP = Vraaggestuurd Programma – *demand driven (research) program*

- Real-world GHG emissions and energy efficiency of both conventional vehicles and those with alternative drivetrains were measured (including losses at charging / refuelling). It was found that charging losses of battery electric vehicles could be as high as 30%. This knowledge insight helps us bring across that it is important to take these losses into account.
- A policy paper was written summarizing current knowledge on methanol and other options that are currently in consideration in the maritime energy transition ("Green Maritime Methanol – A Call To Action"). It discusses impacts on climate change, air quality, operations, supply side availability and the role for Dutch maritime sector, resulting in eight actions. For example *Re-invest 'carbon tax' revenues to support early adopters.*
- In the Green Deal project MAGPIE a State of the Art report on electric heavy duty trucks was delivered. In this report, the focus is on the use of green connected trucking to demonstrate the feasibility of using electric driving with heavy duty trucks (mostly battery-electric). The innovation consists of replacing the current fleet of diesel heavy duty trucks with a fully electric fleet, to carry out the transport operations to and from the Port of Rotterdam. This report presents the plan of approach to set up the demonstration of deploying electric heavy duty vehicles in real logistic operation. It also develops further on the first steps of this approach, by providing a state of the art analysis of heavy duty electric trucks and the availability and developments of special charging infrastructure for these types of vehicles. Additionally, the review contains a list of available trucks on the market, updated to April 2022
- The DKTI Proeftuin Verzet project resulted in a report outlining the lessons and experiences from the real-world deployment of heavy zero-emission trucks in construction. The project yielded a final report with the main conclusions that ZE vehicles are already well suited for logistics concepts with multiple short trips in a day with minimal planning adjustments. And that the use of ZE heavy vehicles in the construction industry, despite the still limited range, is possible by thinking out the logistical concept in advance and applying smart loading strategies.In the CATALYST project, several aspects regarding autonomous yard vehicles and yard operations were investigated. The project delivered reports about the link between connected and automated transport and electric driving, the operational use and emission monitoring of terminal tractors and trucks at yards and the contribution of connected and automated transport at yards to reduction of emissions (CO2 and pollutants). One of the conclusions was that there are no technical reasons why autonomous yard vehicles cannot be electric, and based on legal and operational conditions, it is expected that most (but not all) autonomous yard vehicles will also be electric vehicles, in view of (soon to be) available vehicles and climate targets.
- In the DUET project a *RESTful API* was developed with which a coupling of specific software to a common system can be realized. TNO developed software that can connect to Urban Strategy (TNO's computational model for interactive planning) and the open standard. This makes it easier to get the data, modelling and visualisation for a digital twin of a specific city or region in order and makes Urban Strategy accessible for any party to apply and contribute.
- In the NetZeroCities project, a database of expertise and technological solutions was set up, to be used in upcoming city pilots and to support action planning. TNO contributed to the factsheets on digital twinning and predictive modelling, explaining what digital twinning and predictive modelling is and how cities can use it in their planning process.

In the MOVE21 project, digital twins of three living lab cities (Gothenburg, Hamburg and Oslo) were built. A hub module has been prepared and tested in the first set of sessions with the cities. TNO also has a central role as lead partner in developing the Living Lab methodology, preparing cities for innovation projects (innovation capacity and policy coherence) and to develop governance approaches to support cities to keep collaborations going after the project ends.

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, Jannette de Bes (VP-managers)
Contactpersoon Regie-voerder	Topsector HTSM: Leo Warmerdam Topsector Logistiek: Niels Agatz Ministry of IenW: Michel Duinmayer (IenW-DGMO/Unit Strategie) and Karen de Ruijter (IenW-DGMO/Unit Strategie) Ministry of BZK: Kees de Jong (DGBRW/Directie RenL, cluster E/account kennis) and Arie Versluis (PDGRO/Geobeleid Kennis en Data)

Programma jaar 2022 - Samenvatting

The roadmap Smart & Safe Traffic &Transport focuses on technology and policy for digitization in passenger mobility and logistics. The research within the roadmap Smart & Safe T&T focuses on knowledge and innovation of smart mobility and logistic solutions (digitalization and automation) for increased road safety, accessibility, inclusivity, efficiency and comfort. The VP[6] Smart and Safe Traffic & Transport focuses on:

- Development and optimization of smart mobility systems and smart logistics systems (digitalized, connected and automated)
- Assessment of impact of smart mobility systems and smart logistics systems
- Development of modelling and simulation tools to be used in the assessment of 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 digitalization and automation of mobility and logistics to support future proof, well informed decision making on mobility impacts
- Concepts that optimise traffic safety ('zero casualties') and the efficiency of the mobility and logistics systems ('zero loss')

Highlights of 2022:

- The multi-year research program Quantification of Safe Driving started together with IenW, RDW and CBR. In the first year we successfully mapped gaze tracking of drivers to the world model of the car, while real CBR examiners assessed the official driver safety.
- TNO's continuous work on filling and further developing the Streetwise scenario-based safety assessment method resulted in TNO and Torc Robotics announcing their collaboration to use real-world data for autonomous truck validation. https://www.tno.nl/en/newsroom/2022/11/tno-torc-autonomous-truck-validation/
- TNO has further improved their localization (host vehicle state estimation) algorithms using in-vehicle sensors that replace current grid-based solutions (NextPerception). Part of this was the development of novel ultra-wideband radio beacon-based localisation.
- Successful first demo in the MAGPIE project of the electric truck driving autonomously to a charging station for refuelling. The work in realising this truck has been performed by TNO together with DAF and Frauenhofer. TNO realised the Route Planner and the Mission Control.
- A detailed and very realistic Adaptive Cruise Control (ACC) controller was implemented into the Large Scale Micro Simulator (LSMS). This controller is identical to the ACC controller in the test vehicles of the car labs of TNO (with only minor simplifications) and is therefore much more accurate than earlier implementations in microsimulation and much more suitable for safety analyses. With the high performance capabilities of the LSMS, this controller can be upscaled to a large number of agents, such as a percentage of all vehicles in a large networks.
- In SUMMALab, a method was developed to estimate transport mode-independent parameters based on revealed preference data using the following attributes describing the transport mode: cost (€), travel time (min), driving task (-), skills (-) (i.e. driving license), weather protection (-), luggage (-), shared vehicle (-), availability (-), need to

[6] VP = Vraaggestuurd Programma – *demand driven (research) program*

reserve (-), active transport mode (-) and accessibility (-). New transport modes can be described as a new combination of the same attributes, which enables determining the effect of a new transport mode on the modal split without having to perform new parameter estimations or expert estimates of the parameters of this new transport mode. The model was used to calculate the future modal split of shared autonomous vehicles and electric scooters under various conditions and different parameters. In addition to using it in the New Mobility Modeller, it can be explored whether similar approaches can be used in the LMS/NRM and regional and urban models.

- The project Smart & Attractive Travel Alternatives looked into what would be needed to find a new balance in our travels, i.e. reducing the car kilometres travelled while being able to fulfil the desired activities, by examining which (car) trips that we currently make can be avoided (e.g. done on-line), shortened or replaced by more sustainable transport modes. Together with ANWB, a survey was carried out to collect information from 1965 respondents on current travel patterns and factors influencing the preference towards specific alternatives for car trips. Motives and barriers for proposed alternatives to car trips were investigated, such as the usual aspects like travel time and travel costs, but also familiarity with the proposed alternative.
- Research and development was carried out to make the New Mobility Modeller more flexible, e.g. introduce the possibility to add new modes without altering the code itself, as well as define population groups using data tables instead of the 80 population groups currently hard-coded, and to introduce mode-specific parameters per population group. This makes the New Mobility Modeller suitable for handling results for target groups, and for advanced mode choice models.
- In the HEU project MOVE21 (see https://move21.eu/), digital twins of the three living lab cities (Gothenburg, Hamburg and Oslo) were built. A hub module has been prepared and tested in the first set of sessions with the cities. Also, the theoretical part of the logistics module is ready. In the project TNO also has a central role as lead partner in developing the Living Lab methodology, preparing cities for innovation projects (innovation capacity and policy coherence) and to develop governance approaches to support cities to keep collaborations going after the project ends.

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), Huub Keizer, Richard Mulder, Anita Baas (allen TKI Bouw & Techniek), David van der Woude (BZK), Joram Snijders (BZK), Sabine Jansen (BZK), Johan Slobbe (BZK), Debby Joosen (EZK), Erik ten Elshof (EZK), Peter Jongerius (EZK), Ronald Schillemans (EZK), Hester Dijkstra (EZK), Hans van der Weijde a.i. (TKI HTSM, M2i), Guus Mulder en Robert Jan van Egmond (TKI Urban Energy), Bas Buchner (TKI Maritiem), Bob Meijer (TKI Wind op Zee) en Ruud Oerlemans (TKI Hernieuwbare Energie)

Programma jaar 2022 - Samenvatting

VP Duurzaam Bouwen richt zich op het optimaal verduurzamen van de gebouwde omgeving en van maritieme en offshore constructies. Dit betreft met name bruggen, viaducten, gebouwen, windmolens op zee en schepen. Maatschappelijk thema's zijn daarbij CO_2-reductie, verminderen van de gasafhankelijkheid, circulariteit, veiligheid, (voorspelbaarheid van) onderhoud en vervanging en digitalisering. VP Duurzaam Bouwen bestaat uit zes deelprogramma's: Infrastructuur, Bouwkwaliteit, Digitalisering, Energie in de gebouwde omgeving, Bouwmaterialen en Maritieme constructies. Doel van deelprogramma Infrastructuur is het optimaliseren van het beheer van de verouderende infrastructuur door reductie van risico's, hogere beschikbaarheid en beperking van stijging in kosten. Doel van deelprogramma Bouwkwaliteit is het garanderen van de veiligheid van de voorraad gebouwen in de veranderende omgeving en het verduurzamen van het bestaande zorgvastgoed. Doel van deelprogramma Digitalisering is het ontwikkelen en toepassen van digitale methodes, data-uitwisseling en -deling en software tools voor besluitvorming over de gehele levenscyclus van bouwwerken. Doel van deelprogramma Energie in de gebouwde omgeving is het versnellen van de transitie naar een daadwerkelijk energiepositieve, comfortabele gebouwde omgeving en het verlagen van de maatschappelijke kosten van die transitie. Doel van deelprogramma Bouwmaterialen is verlenging van de levensduur van bestaande constructies, reductie van primair materiaalgebruik, en terugdringing van emissies zoals CO_2 en NO_X. Doel van deelprogramma Maritieme constructies tenslotte is om nieuwe en bestaande maritieme en offshore constructies, opererend onder de meest extreme omstandigheden, veiliger en betrouwbaarder te maken. In 2022 is besloten om de VP's Duurzaam Bouwen (P502) en Maritiem en Offshore (P311) te integreren tot één VP Duurzaam Bouwen (P502). De verslaglegging over 2022 vindt plaats volgens deze nieuwe opzet.

Infrastructuur

Een steeds groter deel van de Nederlandse civiele constructies ('kunstwerken') is toe aan vervanging of renovatie om de veiligheid, beschikbaarheid en het functioneren ervan te waarborgen. Om deze enorme vervangings- en renovatieopgave efficiënt en effectief uit te kunnen voeren, rekening houdend met de uitdagingen op het gebied van klimaatverandering en circulariteit, spelen er verschillende kennisvragen. Hoofdvragen zijn of en wanneer kunstwerken moeten worden vervangen voordat de veiligheid in het geding komt. Het onderzoek in het deelprogramma richt zich daarom op het nauwkeuriger voorspellen van de restlevensduur van constructies. Zo kunnen kosten voor de vervangings- en renovatieopgave worden verminderd. De kennisontwikkeling heeft met name betrekking op de beoordeling van de constructieve veiligheid ten behoeve van het assetmanagement van individuele kunstwerken. Voor waterbouwkundige constructies ('natte kunstwerken') in het bijzonder geldt dat deze onderdeel uitmaken van een systeem dat in zijn geheel dient te worden beoordeeld. Om die reden is het voor dergelijke constructies van belang om kennis te ontwikkelen voor de integratie van de constructieve veiligheid in relatie tot systeemveiligheid met behulp van risico-gebaseerde (probabilistische) technieken en modellen.

Het onderzoek heeft in 2022 onder andere geleid tot diverse methoden, algoritmes en modellen waarmee TNO in staat is om de veiligheid van constructies nauwkeuriger te bepalen. Zo is onder andere een verbeterd algoritme ontwikkeld voor de bepaling van de ontwerpwaarde van de verkeersbelasting op basis van rekstrookmetingen (Bridge-WIM).

Daarnaast zijn grote stappen gemaakt in de ontwikkeling van slimme data-verwerkingstechnieken voor rekstrookmetingen aan de hand van een Timeseries Database. Deze is gedemonstreerd voor metingen die in de laatste twee jaar aan de Moerdijkbrug zijn verricht, onder andere tijdens een trial van nieuwe type voertuigen (Super Ecocombi). Deze informatie kan worden gebruikt voor de Load Map waarin modellen worden ontwikkeld waarmee de verkeersbelasting kan worden bepaald

voor plaatsen waar geen (directe) metingen zijn uitgevoerd. Met deze aanpak is het mogelijk om ook op plaatsen waar geen gedetailleerde verkeersbelastinginformatie aanwezig is, de restlevensduur van kunstwerken nauwkeuriger te bepalen.

Verder zijn numerieke modellen ontwikkeld waarmee het effect van gecorrodeerde wapening op de ductiliteit (vervormbaarheid) van wapening in beton inzichtelijk kan worden gemaakt. Ook is het effect van temperatuurswisselingen voor complexe, gedrongen kokerbruggen onderzocht. Gebleken is dat dit effect groter is dan altijd werd verondersteld.

Bouwkwaliteit

Deelprogramma Bouwkwaliteit bestaat uit twee onderdelen: veiligheid en zorgbouw. Het onderdeel veiligheid richt zich op het borgen van de veiligheid van gebouwen onder invloeden vanuit klimaatverandering, bodemdaling alsook materiaalgebruik. Het in voorgaande jaren ontwikkelde voorspellingsmodel voor schade aan metselwerk ten gevolge van aardbevingen of bodemdaling is gekalibreerd en gevalideerd voor een metselwerk woning. In het breed opgezette ERP (TNO *Early Research Programme*) Bodemdaling en Gebouwschade is dit voorspellingsmodel een van de nieuwe aanpakken om de effecten van bodemdaling op de gebouwde omgeving (metselwerk woningen) te kunnen beoordelen. In het kader van het hergebruik van bestaande gebouwen wordt de beoordeling van de constructieve veiligheid steeds belangrijker. In 2022 is een eerste opzet gemaakt van een beoordelingssystematiek op basis van meet- en monitoringmethoden.

In het onderdeel zorgbouw gaat TNO na hoe de bouwkundige en installatietechnische infrastructuur van complexe zorggebouwen zoals ziekenhuizen effectief verduurzaamd kan worden en hoe de instellingen van de installaties geoptimaliseerd kunnen worden. TNO ontwikkelt scenario-instrumenten en voorspellende modellen om te onderzoeken hoe optimalisatie en verduurzaming in bestaande zorggebouwen technisch en kosten-optimaal kan plaatsvinden met behoud van comfort en veiligheid voor patiënt en personeel, en van de bedrijfscontinuïteit. Hierbij wordt tevens de noodzaak van verduurzaming van de sector betrokken. Deze activiteiten hebben in 2022 mede plaatsgevonden binnen het Expertisecentrum Verduurzaming Zorg (EVZ) dat als één van de pijlers van het Kennis- en Innovatieplatform Maatschappelijk Vastgoed (KIPmv) bijdraagt aan de CO_2-emissiereductie in de zorg. Extra aandacht gaat daarbij uit naar de luchtkwaliteit met het oog op infectiepreventie en pandemiebestendigheid als belangrijk onderzoeksonderwerp.

Digitalisering

Dit deelprogramma richt zich op de ontwikkeling en toepassing van digitale methodes, open standaarden voor data-uitwisseling en -deling en software tools ten bate van beoordeling van huidige en verwachte prestaties van fysieke bouwwerken ('assets') in de gebouwde omgeving. Om datagedreven besluitvorming mogelijk te maken bij de grote maatschappelijke opgaven in de bouw- en infrasector is digitalisering cruciaal. TNO richt zich daarbij op het ontwikkelen en implementeren van een uniforme aanpak voor het modelleren en verbinden van informatieverzamelingen, informatiemodellen en prestatiegericht beoordelen. Voor domeinspecifieke vraagstukken werkt TNO binnen de andere deelprogramma's van dit VP aan de ontwikkeling van *predictive twins*: digitale replica's van bestaande assets waarin data uit statische bronnen, voorspellende modellen en monitoringsystemen worden gecombineerd en geanalyseerd. Binnen het deelprogramma digitalisering ligt de nadruk op schaalbare data-architectuur en dataplatforms voor het modelleren en verbinden van informatie. In 2022 is een digitale checklist ontwikkeld om de kwaliteit van data te kunnen beoordelen. Hierbij vindt onder andere kruisbestuiving plaats met de ontwikkeling van een predictive twin voor de glastuinbouw. Daarbij wordt gebruik gemaakt van een nieuwe gemeenschappelijke taal (Common Greenhouse Ontologie) met architectuur waarmee meetdata van verschillende bronnen opgehaald en gekoppeld kunnen worden. Voor een veilige en eenvoudige data-uitwisseling wordt de Hortivation Hub ontwikkeld. Bij het bewerken en beoordelen van de (sensor)data wordt Artificial Intelligence toegepast en gebruikt voor ontwerp en controle modellen van kasconstructies en installaties. Daarnaast is in 2022 ten behoeve van het TKI LAM-project (asfalt-levensduur model) de data van onderhoudsprojecten van 20 wegen via een ontwikkelde applicatie geschikt gemaakt als uniforme input van het asfalt-levensduur model. Verder geïnventariseerd hoe data uit BIM modellen kan worden gekoppeld aan predictive twins, waarbij de concrete vraagstukken die daarbij leven zijn uitgewerkt. Het RWS-TNO fieldlab voor de Moerdijkzone is als casus gebruikt om aan te tonen hoe een Common Data Environment (CDE) kan worden ingezet om data te koppelen aan een predictive twin. Aangaande informatie- en kennismodellering is een samenwerking aangegaan met de TU Eindhoven om gezamenlijk tot een verdere invulling van de kennisontwikkeling op dit gebied te komen

Energie in de gebouwde omgeving

In dit deelprogramma richt TNO zich op het ontwikkelen van technologieën, oplossingen en tools voor met name verduurzaming van woningen en utiliteitsgebouwen, en de opschaling daarvan. Dit met als doel de transitie naar een daadwerkelijk energiepositieve gebouwde omgeving te versnellen. Hierbij werkt TNO aan vier speerpunten.

Het eerste speerpunt betreft de ontwikkeling van datagedreven gebouwmodellen (predictive twins), waarmee de daadwerkelijke prestaties van verduurzamingsconcepten (energie, comfort en binnenluchtkwaliteit) kunnen worden voorspeld. Dat helpt bij het maken van afwegingen tussen verschillende verduurzamingsconcepten, het afgeven van prestatiegaranties, energieflexibilisering en foutdetectie en -diagnose. In 2022 zijn de datagedreven gebouwmodellen doorontwikkeld voor zowel woningen als kantoren, waarbij de focus lag op energieflexibilisering en het beter modelleren van gebruikersgedrag. Daarnaast zijn gesprekken gevoerd met verschillende stakeholders om te kijken hoe TNO samen met de sector stappen kan zetten om in de praktijk meer te sturen op werkelijke prestaties, iets wat nu nog niet goed kan.

Het tweede speerpunt richt zich op de ontwikkeling van tools voor gebouwclustering (contingenten) om de opschaling van bestaande en nieuwe verduurzamingsoplossingen voor woningen en utiliteitsbouw te verbeteren. Deze 'contingenten-aanpak' leidt door slimme matching en vraagbundeling tot een meer uniforme renovatieaanpak die het mogelijk maakt om verduurzamingsrenovaties efficiënter (goedkoper en sneller) uit te voeren. In 2022 is de tool voor gebouwclustering verder doorontwikkeld. Er is een modulaire, opschaalbare architectuur en een interface ontworpen en voor twee verduurzamingsoplossingen is aangetoond dat de gevormde contingenten in ongeveer 75% van de gevallen een goede voorspelling geven van de toepasbaarheid van de verduurzamingsoplossing.

Het derde speerpunt betreft de ontwikkeling van duurzame warmte-, koude- en ventilatiesystemen, waarbij het onderzoek zich richt op de integratie van klimaatsystemen (onder andere warmtepompen) in het gebouw en op de interactie met het energiesysteem (met name het elektriciteitsnet). In 2022 is uitgebreid onderzoek gedaan naar de werkelijke dynamische prestaties van hybride warmtepompen als onderdeel van een woninginstallatie, wat veel inzicht heeft gegeven in het gedrag van de verschillende typen warmtepompen en in de mogelijkheden om de prestaties te verbeteren. Daarnaast zijn de thermoakoestische warmtepomp en de 'warmtepomp–warmteschil-warmtebatterij' renovatieoplossing verder doorontwikkeld.

Het laatste speerpunt is de ontwikkeling van compacte warmteopslag met een opslagtermijn van één week tot enkele maanden, gericht op drie verschillende technologieën: voelbare compacte opslag, thermochemische opslag door middel van zouten en compacte opslag door middel van redoxreacties. Voor thermochemische opslag is in 2022 het gesloten loop reactorconcept verder doorontwikkeld en toegepast in een demo. Ook is een economische analyse gemaakt van verschillende usecases voor compacte thermochemische warmteopslag, waaruit is gebleken dat de business case voor toepassing in individuele woningen niet altijd evident is. Daarom is besloten de scope te verbreden naar andere usecases, en het onderzoek te richten op de maatschappelijke meerwaarde van compacte warmteopslag voor het totale energiesysteem om focus aan te brengen in verdere technologieontwikkelingen.

<u>Bouwmaterialen</u>

Dit deelprogramma richt zich op innovaties met betrekking tot steenachtige materialen, asfalt en houtbouw. Belangrijk daarbij zijn het verlengen van de levensduur, hoogwaardig hergebruik van materialen, alternatieve bindmiddelen en het reduceren van emissies van schadelijke stoffen. Centraal punt bij steenachtige materialen is de ontwikkeling van nieuwe duurzame betonsoorten door hergebruik van reststromen en toepassing van alternatieve bindmiddelen. In 2022 is het in voorgaande jaren ontwikkelde testprogramma voor de beoordeling van prestaties van nieuwe betonsoorten gevalideerd voor een drietal bindmiddelen. Het testprogramma blijkt adequaat, echter de prestaties van de onderzochte bindmiddelen bleven achter bij de verwachtingen. Aanvullend zijn de gevormde reactieproducten voor deze en aanverwante systemen gekarakteriseerd. Tevens is het model om de levensduur van gewapend beton te beoordelen aangescherpt op basis van de beoordeling van de corrosie van meer dan 20 jaar oude monsters. Daarnaast staat het beoordelen van de prestaties van bestaande betonnen elementen bij hergebruik in nieuwbouwprojecten centraal. Daartoe heeft TNO in 2021-2022 de *Materiaalgedreven Multi-criteria Ontwerpoptimalisatie* (kortweg MIMO) ontwikkeld.

Voor asfalt is de kennisontwikkeling gericht op duurzame materiaalinnovaties van biobased materialen en het ontwikkelen van betere meetmethoden om de levensduur van wegenbouwmaterialen nauwkeuriger in te schatten. In 2022 is in het kader van onderzoek naar bio-based materialen gewerkt aan een optimale mengprocedure om alle componenten in het bindmiddelmengsel op te nemen om een homogeen en stabiel product te verkrijgen. Daarnaast is vorm gegeven aan de aanpak van

databewerking van de DOS-LCMS (Detectie Oppervlakte Schaden met het Laser Crack Measurement System) ten behoeve van de levensduuranalyse. Op basis hiervan is een algoritme voor de databewerking geformuleerd, wat het mogelijk maakt om data uit opeenvolgende jaren met elkaar te vergelijken.

Vanwege de klimaatdoelen en de grote bouwopgave kiezen partijen steeds vaker voor houtbouw waarbij massieve wanden en vloeren of een houten skelet als constructie worden toegepast. Om succesvol en competitief te zijn, wordt deze vorm van bouw geïndustrialiseerd. TNO ontwikkelt kennis voor deze nieuwe bouwwijze ten aanzien van optimalisatie van materiaalgebruik, ontwerp en productie ten behoeve van vereiste bouwkundige prestaties én duurzaamheid. In 2022 zijn internationale inventarisaties gemaakt naar constructieve veiligheid, brandveiligheid en levensduur van houtconstructies. Constructieve rekenregels voor massieve houtbouw komen in de nabije toekomst in de nieuwe generaties Eurocodes. Tevens zijn voor de sterkteclassificering van hout verschillende methoden vergeleken, waarbij ultrasound en röntgen methoden goede alternatieven blijken voor de huidige visuele methode. Vanwege de hogere vuurlast zullen verschillende eisen uit het Besluit bouwwerken leefomgeving en bijbehorende NEN normen moeten worden herzien; daarvoor worden stappen gezet met het ministerie van BZK en NEN. Factoren die de levensduur van houtbouw bepalen en mogelijke voorspellingsmodellen zijn geïdentificeerd. Daarnaast is onderzoek gedaan aan de mogelijkheden van hergebruik van hout waarmee de in het hout aanwezige CO_2 langer wordt opgeslagen. TNO heeft voor diverse materiaalsoorten en toepassingen verouderingsonderzoek en levenscyclus analyses uitgevoerd waarop opschaling en industrialisatie kan volgen.

Maritieme constructies

Binnen het maritieme domein richt dit VP zich op veilige en betrouwbare constructies ten behoeve van offshore hernieuwbare energie (wind, zon) en de scheepvaart (bijvoorbeeld op het gebied van alternatieve brandstoffen). Voor ontwikkeling, ontwerp en onderhoud van grootschalige constructies vraagt dit om begrip van het constructieve gedrag van detail- tot systeemniveau en inzicht in het effect van de belasting- en omgevingscondities in zee op de levensduur. Dit deelprogramma richt zich op het (faal)gedrag van materialen, het (dynamisch) gedrag van constructies en het uitvoeren van veiligheidsanalyses. Hiervoor ontwikkelt TNO modellen die gecombineerd worden met metingen en experimenten, zowel in het lab als in het veld. Kijkend naar 2026 is een drietal speerpunten gedefinieerd voor het onderzoek.

Het eerste speerpunt richt zich op de ontwikkeling van gegeneraliseerde en gevalideerde modellen voor het voorspellen van de levensduur en het monitoren van het gedrag van maritieme en offshore constructies, gemaakt van staal (funderingsconstructies, pijpleidingen, opslagtanks) dan wel composiet (bijvoorbeeld windturbine bladen of opslagtanks). Hier speelt de combinatie van deterministische en probabilistische modellen met monitoringsdata een belangrijke rol. In 2022 zijn langdurige vermoeiingstesten gestart met verschillende staalsoorten onder diverse corrosie condities. Omdat het fenomeen corrosievermoeiing zich niet laat versnellen, zijn hiervoor langdurige testen nodig. De duur van deze testen ligt tussen de 6000 en 9000 uur, wat neerkomt op 250 tot 375 dagen non-stop testen. De resultaten van deze testen worden medio 2023 verwacht en worden gebruikt voor de kalibratie van de ontwikkelde vermoeiingsmodellen, zodat deze gebruikt kunnen worden om de scheurgroei te schatten en deze langdurige testen in de toekomst minder noodzakelijk te maken.

Het tweede speerpunt betreft het ontwikkelen en demonstreren van een veiligheidsmethodiek voor de introductie van alternatieve brandstoffen voor schepen (zoals waterstof en methanol) op basis van equivalente veiligheid. Hiervoor zijn in 2022 testplannen opgezet om te onderzoeken hoe brandstofcellen zich gedragen als ze blootgesteld worden aan scheepsbewegingen en scheepstrillingen. Deze testen zullen begin 2023 worden uitgevoerd, met een operationele brandstofcel op waterstof. Daarnaast is een de veiligheidsmethodiek ontwikkeld voor het ontwerpen van schepen op waterstof. Hierbij is een aantal kritische scenario's geïdentificeerd, zoals het mogelijk vallen van een waterstof container uit een kraan. Voor deze scenario's zullen in 2023 de bijbehorende risicoanalyses en numerieke simulaties uitgevoerd worden.

Bij het derde speerpunt wordt ingezet op het analyseren van het dynamisch gedrag van grote drijvende constructies (zonne- en windturbinefunderingen). Hierbij lag in 2022 de focus op het bepalen van de (mechanische) belastingen op grote, gekoppelde, constructies, waarvoor een simulatiecode is ontwikkeld.

Titel	VP Future of Work (P204)
MTIB Thema	Gezondheid en Zorg
Contactpersonen TNO (DM en VPM)	Seth van den Bossche
Contactpersoon Regie-voerder	Eef Voogd, Hanneke van den Bout (beiden waarnemend, Ministerie van Sociale Zaken & Werkgelegenheid)

Programma jaar 2022 - Samenvatting

Het onderzoeksprogramma Future of Work maakt deel uit van de Roadmap Prevention & Productivity van de TNO Unit Healthy Living. Het programma richt zich op innovaties voor een gezonde werkomgeving en een toekomstbestendige arbeidsmarkt. Daarmee dragen we bij aan een 'Gezonde samenleving', één van de vier centrale maatschappelijke uitdagingen in de TNO strategie 2022-2025. Ook versterken we hiermee de innovatiekracht en het verdienvermogen van Nederland. Een toekomstbestendige, adaptieve en inclusieve arbeidsmarkt met een hoge kwaliteit van werk zorgt niet alleen voor meer welvaart in brede zin, maar is noodzakelijk om grote maatschappelijke transities (energie, klimaat, digitalisering, gezondheid etc.) te faciliteren.

Het programma omvat de volgende kennislijnen en hoofddoelen:

Kennislijnen 2022	Doelstelling 2022-2025
Inclusive organizations	Nederlandse arbeidsmarkt inclusiever maken, door middel van innovaties die inclusief ondernemerschap vergroten.
Labour activation	Nederlandse arbeidsmarkt inclusiever maken, door versterking en innovatie van de uitvoeringspraktijk.
Skills/Life Long Learning	Adaptiviteit van de Nederlandse arbeidsmarkt en leven lang ontwikkelen (upskilling/reskilling) bevorderen, door ontwikkeling van skills-gebaseerde strategieën.
Stress & sensing	Verminderen van werkgerelateerde mentale gezondheidsproblemen door vergroten van inzicht in oorzakelijke factoren en het ontwikkelen van effectieve interventies.
Occupational Exposome	Ontwikkeling effectieve preventieve maatregelen voor werkgerelateerde aandoeningen, in het bijzonder aandoeningen als gevolg van blootstelling aan gevaarlijke stoffen.
Occupational Safety Innovation	Vermindering arbeidsongevallen en incidenten bij bedrijven door ontwikkeling van innovatieve digitale veiligheidsmanagement systemen.
Monitoring & foresight	Structurele monitoring van ontwikkelingen in de Nederlandse arbeidssituatie via verschillende datastromen en structurele verkenningen naar de (potentiële) impact van technologische en maatschappelijke veranderingen op werk en arbeidsmarkt.

Highlights 2022

- **Inclusive organizations:** 3 succesvolle inclusieve technologie pilots afgerond (onder meer *Groen-app)*, gericht op de duurzame inzet van mensen met een cognitieve beperking in het arbeidsproces. Naast versterking duurzame inzet is performance van bedrijven aantoobaar verbeterd.
- **Skills/Life Long Learning**: Realisatie 1e demoversie CompetentNL, dynamische skills-ontologie om matching op arbeidsmarkt te verbeteren.

- **Stress & sensing**: succesvolle afronding pilot "Memrec voor Veteranen": zeer effectieve kortdurende behandeling werkgerelateerde PTSS.
- **Occupational exposome**: lancering European Partnership for the Assessment of Risks from Chemicals (PARC). Hiernaast relaisatie EPHOR working life exposome toolbox WE-EXPOSE en Proof-of-Concept Virtual Occupational Hygiene Assistant.
- **Occupational Safety Innovation**: Ontwikkeling Digital Safety Enterprise Architecture-platform (Azure) voor digitale safety tools, resp. algoritme ontwikkeld en succesvol getest voor automatische detectie van persoonlijke beschermingsmiddelen op het werk.
- **Monitor & foresight**: Publicatie en symposium Dynamiek Nederlandse Arbeidsmarkt (DNA) VI met aanbieding aan de ministers van Gennip (SZW) en Wiersma (OC&W), door TNO & CBS (redactie). Hiernaast toepassing van ontwikkelde methodologische foresight-kennis in verschillende andere projecten (SZW, NLA, GINI/EU).

Titel	VP Jeugd: Gezond, Veilig en Kansrijk opgroeien (P211)
MTIB Thema	Gezondheid en Zorg
Contactpersonen TNO (DM en VPM)	Sandra Eikhout, Simone Detmar
Contactpersoon Regie-voerder	Kallista de Graaf (VWS), Liliane de Ruiter-Nanninga (MEVA)

Programma jaar 2022 - 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 : “In 2040 leven alle Nederlanders tenminste vijf jaar langer in goede gezondheid, en zijn de gezondheidsverschillen tussen de laagste en hoogste sociaaleconomische groepen met 30% afgenomen”

We ontwikkelen kennis en innovaties via de volgende lijnen:

1. Integrale aanpak eerste 1000 dagen: De eerste 1000 dagen, van preconceptie tot minimaal 2 jaar, zijn cruciaal voor de ontwikkeling van het kind, en daarmee voor een gezonde en kansrijke toekomst. Wij richten ons op het ondersteunen van (aanstaande) ouders, met een focus op ouders met lage gezondheidsvaardigheden, door doorontwikkeling van preventie en zorgmodellen waarbij zelfmanagement, interactief leren en peer support centraal staan (bijvoorbeeld Centeringpregnancy en Centeringparenting). Komende jaren richten we ons op implementatieonderzoek voor landelijke en internationale toepassingen. In 2022 zijn online modules ontwikkeld voor moeilijk bereikbare groepen, is een module ontwikkeld “community aanpak” voor betere aansluiting medisch en sociaal domein. Beide modules zijn in gebruik door de zorgverleners. Ook is een internationaal congres georganiseerd. Tevens richten we ons op de doorontwikkeling van de D-score (een nieuwe maat om ontwikkeling van kinderen te kunnen monitoren). In 2022 hebben we een eerste succesvolle verkenning uitgevoerd tot het oprichten van een internationaal consortium om de D-score uit te breiden naar 6-jarige leeftijd.

2. Preventie en Jeugdhulp op maat. Hierbij richten we ons op het ondersteunen en versterken van kinderen en ouders en professionals in het (preventieve) veld voor jeugd. We richten ons op hoe om te gaan met uitdagingen en ingrijpende levensgebeurtenissen en op de persoon toegesneden instrumenten en interventies tbv een gezonde leefstijl en mentale weerbaarheid. In 2022 is de beslisondersteuning voor de HPV vaccinatie doorontwikkeld voor nieuwe doelgroepen en landelijk ingezet door het RIVM. Binnen deze lijn richten we ons ook op het integreren van digitale innovaties voor de zorg voor jeugd middels het doorontwikkelen van het I-JGZ platform. In 2022 is het aantal gebruikers sterk toegenomen (van 5 naar 15 JGZ-organisaties), en het aantal TNO digitale innovaties, dat via het I-JGZ platform wordt ontsluiten, toegenomen. Tenslotte wordt I-JGZ nu ook ingezet in het onderwijs, door aansluiting van een robot-platform.

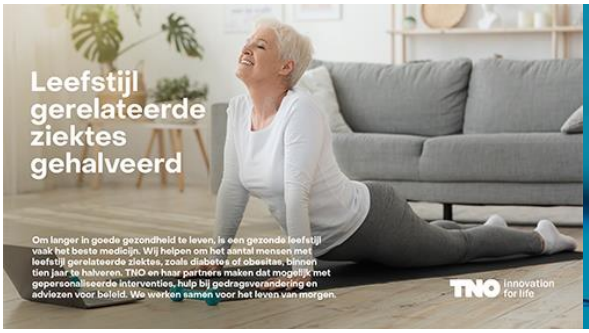
Samenwerking en implementatie: Met kennis van samenwerkings- en implementatievraagstukken richten we ons op het ondersteunen van organisaties om de transitie en transformatie van het jeugdstelsel goed vorm te geven. Op het gebied van scheiding en pesten werken we aan het landelijk implementeren van effectieve interventies. Onze focus ligt op het opzetten van duurzame leernetwerken en ontwikkelen van strategieën om innovaties te implementeren. In 2022 is het LISO framework ontwikkeld: “Systematische aanpak voor leren en implementeren binnen samenwerkingsverbanden in de zorg voor jeugd” en hebben we zowel het landelijk leernetwerk jongerenparticipatie als het leernetwerk complexe ouderkind relaties gestart.

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

Programma jaar 2022 - Samenvatting

VP Biomedical Health (BMH) supports the Mission driven Innovation approach of the Dutch Ministry of Health, Wellbeing and Sports ('VWS'), Topsector Life Sciences & Health ('LSH') and **the central mission aiming for all Dutch citizens to live five years longer in good health and decreasing the health inequalities between the lowest and highest socioeconomic groups by 30% (+5; -30).** More specifically we will mainly contribute to: **reducing the burden of disease resulting from an unhealthy lifestyle or living environment (Mission I)**, and we will also **help to increase societal participation of chronically ill individuals (Mission III).** We do this by reducing the risk for disease development and help manage disease by contributing with ground-breaking technologies and approaches to more efficient drug and lifestyle intervention development.

Research program Biomedical Health will contribute to two moonshots of TNO:



To help achieve these, new technologies and knowledge that we develop will be implemented in the context of the quadruple helix that includes collaborations with other research programs, academic and industrial partners, health professionals in field labs, healthcare insurance companies, governmental and local policy makers, citizens, in order to provide systemic solutions. The instruments are public private projects and projects for industry. For drug development, breakthrough technology is developed by TNO and applied in services for industry and in public-private consortia (e.g. in growth fund ('*Groeifonds*') projects).

By 2026 we want to have achieved the following:

Support reducing societal and economic burden of diseases by developing preventive and curative interventions:

1. Demonstrate metabolic and immune health improvement through (combination of) personalized dietary, lifestyle or medication support in stratified groups of patients; right drug and intervention for the right patient (CM, M1 and M3).
2. Prove that tailored interventions contribute to vitality, societal participation and productivity of citizens, improving the quality of health care and cost management (CM, M3).
3. Develop tailored and personalized interventions for and with at risk individuals (incl. lower SES), understanding their socio-demographic context, thus being more effective in improving a healthy lifestyle than with current, rather generalized interventions (CM, M1).

Enable lower attrition rates and more efficient development of innovative drugs that will lead to lower pricing:

1. Demonstrate in practice that current pre-clinical trajectories can be improved (reducing costs, time and animal use) when new approaches and technologies are employed (M3).
2. Demonstrate that smaller clinical trials for a novel therapy can be achieved by targeting the right patient population through novel tools for stratification (M3).
3. Demonstrate that a lower cost price of innovative medicine is possible by applying the right technology and integrated discussions with pharmaceutical industry and public stakeholders (CM).

To progress towards these above goals some of the achievements in 2022 are:

- Active participation in national Groeifonds consortia OncodePact and NXTGen HighTech Organ-on a chip to improve drug development technologies **(CM, M3).**
- Evaluation and test of different strategies to improve metabolic and immune health in at risk groups, **(CM, M1, M3).**
- Identification new composite biomarkers and new targets for systems interventions for prevention of dementia **(CM, M1, M3, M4).**
- Clinical validation of new fibrosis blood biomarkers for less invasive and more accurate diagnosis of different stages of liver fibrosis **(M3)**
- Demonstrator of a combined in-vitro and in-silico method for mechanism-based drug target selection for fibrosis, a better and faster choice in drug development **(M3).**
- Translational pre-clinical model for testing of drugs for chronic disease diabetic nephropathy **(M3)**
- Demonstration of pathway probing with advanced microtracer techniques, by measuring newly synthesised fatty acid fluxes for testing of drug efficacy of compounds developed for inhibition of fatty acid synthesis, a target for treatment of Non-alcoholic fatty liver disease **(M3).**

CM: *central mission, Everyone linger in good health;* ***M1:*** *mission 1, Lifestyle and living environment;* ***M3:*** *Mission 3, Chronically ill;* ***M4:*** *quality of life with Dement*

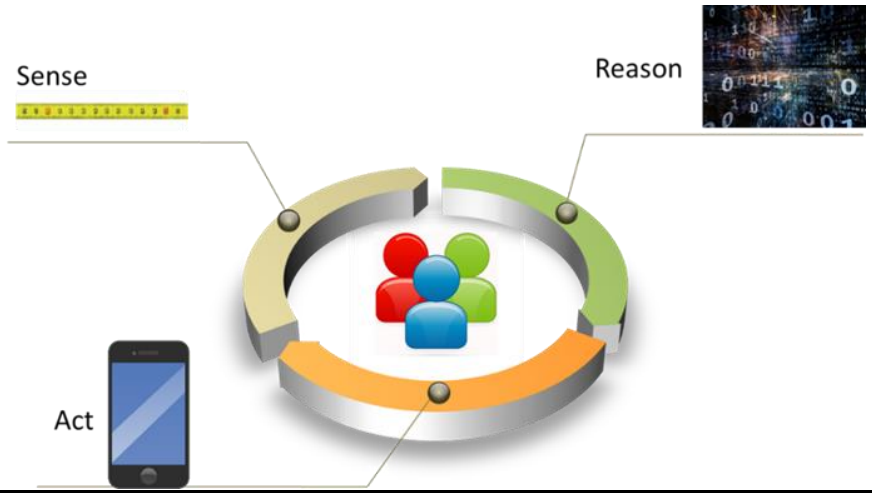
Titel	VP Digital Health Technologies (P210)
MTIB Thema	Gezondheid en Zorg
Contactpersonen TNO (DM en VPM)	Sandra Eikhout (DM), Jennifer McCormack (VPM)
Contactpersoon Regie-voerder	Nico van Meeteren (LSH)

Programma jaar 2022 - Samenvatting

The Digital Health and Technologies (DHT) program supports the mission driven Innovation approach of the Dutch Ministry of Health, Wellbeing and Sports ('VWS'). It supports the central mission: **aiming for Dutch citizens living 5 year longer in good health and reducing the health differences between the higher and lower social classes.** More specifically, the program contributes to the 1) **reduction of health issues that are a consequence of an unhealthy lifestyle or exposure to an unhealthy environment (mission I)**; and 2) **helping 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 world around us is becoming more and more digital. Although the implementation of digital technologies is also visible in health care, its advancement here occurs at a much lower pace compared to other disciplines or areas. This is despite the fact that it is common practice for individuals to gather huge amounts of health data by using apps. Such data entails, for example, recording a person's pulse rate, daily activity, and diet. Apart from using an app, each person is also able to electronically gain access to their own medical data. This Real-World Evidence (RWE) data — combined with standardized health data — has the potential to generate or improve models and software applications that provide personalized health, lifestyle and medical advice. By offering such guidance, the occurrence and progression of disease and its burden can potentially be prevented, reversed, cured, or relieved. As such, these digital technologies can transform healthcare to a provide more personalized, efficient, and cost-effective care. However, to realize the promise of digital technologies, personal health data needs to be unlocked to the scientific community while respecting the individual's privacy.

DHT brings together knowledge and data from the biomedical, lifestyle and behavioural domains. By applying AI and data science, digital services and solutions are created both at TNO and in various collaborations with partners outside TNO (including several SMEs). Given its huge impact on the ability to create and implement digital technologies, the program focuses on secure, privacy-by-design and transparent (to the eco-system) systems for data re-use. Embedded in these systems are personal advice systems which make use of predictive models and are connected to new wearables solutions. As this global system is directly connected to individuals by design, citizens are empowered to specify their needs and preferences (person centred health). The technology developed in this program is relevant for MedTech, HealthTech, Pharma and ICT companies.



In 2022, the aim of the DHT program was to contribute to the implementation and operation of 1) innovative digital health interventions that measure health at a higher quality while being less intrusive; 2) improved insights in how lifestyle factors impact disease; 3) deeper understanding on how to best use behavioural change techniques in various populations; and 4) innovative ways to conduct clinicals trials, for example remote or virtual clinical trials.

In 2022 the program has contributed to the development of various public private partnerships (PPPs). This includes PPPs regarding the development of improved health measurements as well as at home solutions to treat patients (groeifonds Prevention Promotor, Urdan Diagnostics and Edison-RPM). The project 'C4yourself' was continued this year and explored the feasible of health data reuse by using the PGO (Persoonlijke Gezondheids Omgeving) as personal data locker. In several projects, including some projects for VWS, TNO has worked on data governance issues thereby extending our ELSI (Ethical Legal Societal Implications) capabilities on the reuse of health data. In addition, the PPS 2DIAREM was started. This project extents the TNO diabetyping algorithms with minimally invasive methodology. Another focus area of the DHT program is to create AI solutions for which the outcomes are explainable based on the used knowledge/data, rather than using black box algorithms. Finally, various results have been disseminated. A publication regarding the validation of the Nutri-plus module, quantifying food intake, was written. Five strategic papers were published including the 'Gezond Akkoord' paper on cooperative management of personal health data and peer-reviewed references 4-6 (see also the highlight section).

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 2022 - 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 risk 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 and guidance 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 2022 consisted of collaborative work in various H2020 EU projects (Gov4Nano, SbD4Nano, PeroCUBE, HARMLESS, RISKHUNT3R). Further results in 2022 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 project on pragmatic implementation of Safe-by-Design principles in industry. 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 2022 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	Joren Schep (Ministry of Economic Affairs)

Programma jaar 2022 - Samenvatting

Smart Working is a key driver of changes in companies to achieve higher productivity. As a Healthy Living & Work programme, it is connected to the (HTSM) Smart Industry initiative. To achieve this goal, Smart Working delivers improvements to make work physically less 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 ever. In the programme, robotics and digital technologies are deployed in the workplace. The separate projects are focused 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 Factory of the Future Experience Center 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: AI and Human centricity in production (HE HumAInUP) and exoskeletons (HE Fibrethink).

Titel	VP Veilige Maatschappij (P102)
MTIB Thema	Veiligheid
Contactpersonen TNO (DM en VPM)	DM: drs. R. Pellemans, MSc 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 2022 - Samenvatting

Veiligheid en rechtvaardigheid zijn 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.

Veiligheid is één van de vijf centrale maatschappelijke thema's binnen het missiegedreven topsectoren en innovatiebeleid van het kabinet. Een veilige samenleving is ook één van de vier beloften uit de TNO-strategie 2022 – 2025.

TNO draagt bij aan een veilige 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. Het onderzoek heeft een precompetitief karakter waarin ideeën worden uitgewerkt tot prototypen. Waar relevant wordt voor de doorontwikkeling van prototypen naar producten gekeken naar het bedrijfsleven en dit valt buiten de scope van het Vraaggestuurd Programma. TNO zet middels het VPVM in op een meerjarige onderzoeksprogrammering voor justitie- en veiligheidsorganisaties. Het doel van deze meerjarige programmering is innoveren door toepassingsgerichte wetenschappelijke kennis op te bouwen en technologie te ontwikkelen op díe onderwerpen die voor het justitie- en veiligheidsdomein het belangrijkst zijn.

In 2022 stonden vijf inhoudelijke thema's en een programma rond verkenningen en innovatiemanagement centraal. De vijf inhoudelijke thema's zijn: Cyber en Kritieke Digitale Infrastructuur; Rechtstaat en Opsporing; Data en Intelligence; Security en Surveillance; en Weerbaarheid Veiligheidsprofessionals.

Enkele highlights uit de resultaten van het onderzoek in 2022:

- In het kennisopbouwprogramma Openbaar Ministerie (OM) heeft TNO in het project Argument Mining een demonstrator ontwikkeld om te onderzoeken of beoordelaars van klachtenbrieven of verzoekschriften ondersteund kunnen worden met deze AI technologie.
- In het Ondermijningslab is, samen met de Regionale Informatie en Expertise Centra, gewerkt aan een model en instrument t.b.v. kwetsbaarheidsanalyse van het fenomeen jonge aanwas in drugscriminaliteit.
- In het onderzoeksprogramma met Dienst Justitiële Inrichtingen (DJI) is een proof-of-principle implementatie ontwikkeld dat kan ondersteunen bij het proces van verzoek, bezwaar en beroep rond het (her)plaatsen van gedetineerden en het toekennen van vrijheden. Hiermee is de Divisie Individuele Zaken eenvoudiger en beter in staat om bij een verzoek (of bezwaar en beroep) vergelijkbare casuïstiek te vinden. Vergelijkbare technologie is ontwikkeld in samenwerking met het Openbaar Ministerie rond beroep en bezwaar tegen verkeersboetes. Hiernaast is met de DJI ook een prototype monitoringsmethode getest voor de professionele fitheid van DJI medewerkers. De methode bestaat o.a. uit een app waarmee de medewerker zichzelf dagelijks kan monitoren, doelen kan stellen en evalueren. De methode moet in de toekomst bijdragen aan een effectievere inzet door het vergroten van zelfregie en het versterken van de professionele fitheid van DJI medewerkers.
- In het Europese project D4FLY heeft TNO, samen met de Immigratie en Naturalisatie Dienst (IND) en de Koninklijke Marechaussee (KMAR) technologie ontwikkelt voor de authenticatie van brondocumenten en reisdocumenten. De technieken zijn op een kort-cyclische manier ontwikkeld, meer regelmatig nieuwe software versies van TNO en feedback van de eindgebruikers om de resultaten te verbeteren. Er is uitgebreid getest in Zwolle (door IND) en in Ter Apel (door KMAR) en er is een internationale einddemonstratie geweest bij de Koningin Maxima Kazerne bij Schiphol.
- Met Interpol is een *demonstrator* ontwikkeld van een *darkweb simulator* (TOR netwerk) waarmee rechercheurs en analisten wereldwijd kunnen worden getraind voor onderzoek op het *darkweb*.

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 2022 - Samenvatting

Veiligheid is een essentiële voorwaarde voor het welzijn van de samenleving. Maatschappelijke en technologische ontwikkelingen zorgen voor een continu veranderende omgeving waarbinnen de politie als grootste veiligheidsorganisatie opereert om de veiligheid van de Nederlandse samenleving te beschermen en te versterken. 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 om de veiligheid in Nederland te waarborgen. 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 topsectoren- en innovatiebeleid.[7]

Voor de politie is het van belang om in te spelen op technologische en maatschappelijke 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 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.
Op basis van de prioriteitsgebieden uit de Strategische agenda politie 2021-2025, de Science & Technology agenda van de politie en voortbouwend op de kennis en ervaringen uit de eerdere kennisopbouw programmering richt de programmering zich op vier kernprogramma's en een doorsnijdend technologie-ontwikkelprogramma. Hierbij werken politie en TNO eveneens samen met (inter)nationale partners zoals veiligheidsorganisaties en kennisinstellingen. De kernprogramma's 2022-2025 zijn: politiewerk van de toekomst, politiemedewerker van de toekomst, politiedata en intelligence en techniek in de operatie. Hiernaast wordt ingezet op technologieontwikkeling voor o.a. robotica en privacy enhancing technologies.

Binnen bovenstaande programmalijnen wordt kennis opgebouwd hoe technologieën kunnen worden ingezet om de operationele slagkracht van de politie te vergroten. Hiertoe wordt zowel onderzoek gedaan naar de uitdagingen waar de politie nu tegen aan loopt als naar de uitdagingen van overmorgen. Centraal binnen het hele programma staat een multidisciplinaire aanpak waarbij mens, proces en techniek als integraal geheel worden benaderd.

Enkele highlights uit de resultaten van het onderzoek in 2022:

- In het programma *politiedata en intel* is o.a. een overzicht van relevante AI-modules gemaakt (de OSINT capaciteiten catalogus) voor b.v. ontdubbelen, het automatisch herkennen van informatie in tekst en beeld en ook voor combineren van data en het analyseren van risico's. Inzicht is gegeven in toekomstgerichte analysemethoden en -technieken en hoe een indicator gebaseerde techniek toegepast kan worden voor anticiperen op potentieel groot en gewelddadig protest. Kennis is opgebouwd over de informatiestructuur voor het dynamisch veiligheidsbeeld. Ten behoeve van competentieontwikkeling is inzicht gegeven in de vereiste competenties voor toekomstig intelligencewerk, en de bijbehorende innovatieve leerinterventie, meetmethode en inzicht in effectiviteit.
- In het programma *techniek in de operatie* is technologie ontwikkeld waarmee de politie effectiever verdachten kan observeren en voortvluchtigen kan vinden. Een grotere meerwaarde is gehaald uit bestaande databronnen. Daarnaast is het toevoegen van nieuwe bronnen, zowel ontsluitings- als verwerkingstechnieken onderzocht om te komen tot een versterkt operationeel beeld.
- Voor *counter drones* ligt de focus van het onderzoek op het bestrijden van drones met soft kill methodieken. Dit betreft detectie van de radioverbinding tussen drone en operator en het storen ervan of de mogelijkheid om de besturing over te nemen. Hiervoor worden verschillende methodieken onderzocht en uitgeprobeerd, zodanig dat het op termijn ook veilig en wettelijk gebruikt kan worden.

[7] KIA Veiligheid | Holland High Tech

- Voor *politiewerk in het digitale domein* zijn verschillende tools en platformen ontwikkeld: *Magneto*: tool om criminele profielen in kaart te brengen en inzicht creëren in misdaadmarkten op berichtendienst Telegram; *Rattenval*: tool waarmee RATs (Remote Access Trojans) kunnen worden geanalyseerd; *Lancering van BEC-off*: platform waar bedrijven hun BEC-mails naartoe kunnen sturen om data te verzamelen en inzichten te creëren over het fenomeen BEC (business email compromise, zoals een 'CEO hack').
- Voor de *weerbare professional* is o.a. weerbaarheidsmonitor voor aspiranten ontwikkeld; en is een start gemaakt met een experiment naar de effecten van het gebruik van wearables en app op de bewustwording, gedragsverandering en inzetbaarheid van politiemedewerkers.
- In het programma *bewaken & beveiligen uitkijkcentrale* wordt onderzocht hoe de ontwikkeling van technologie kan leiden tot een slimme uitkijkcentrale die bijdraagt aan een nieuw innovatief bewakings- en beveiligingsconcept.
- Tot slot heeft in 2022 een verkenning plaatsgevonden van toepassingsmogelijkheden van (semi-)autonome *robotica* in de politie operatie.

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

Programma jaar 2022 - Samenvatting

Observe without being seen. Be able to exert force and deploy weapons based on a correct and timely situational awareness. Get situational awareness faster than our opponents and increase the quality and accuracy of our (networked) sensor information. Be prepared for future threats, guarantee access to tomorrow's sensors and sensor information and optimize its manning.

We aim to strengthen the global leadership and competitiveness of our national defence and security ecosystem by industrially relevant R&D that excels in speed of innovation. The challenge is to translate operational needs into relevant R&D of crucial high-tech components, subsystems and complex sensors and associated C2 systems to carry out successful defence and security operations. This is a combined effort in the Triple Helix where TNO and industry work together with government as launching customer. Thereto, technological breakthroughs are built in only those areas that are strategically crucial to the Netherlands and when the knowledge cannot be obtained anywhere else, contributing to Europe's strategic autonomy.

The activities are undertaken within their national and international context. In the national context, the activities match and implement the roadmaps *Security* and *Electronics* of the Topsector High Tech Systemen en Materialen (HTSM); the Topsector Water & Maritiem; the five missions within the *KIA Veiligheid*; and the *KIA Sleuteltechnologieën*. In the international context, the activities are predominantly performed within EDA/EDF and NATO partnering, with an increasing role of the EU. Finally, an important and immediate contextual factor is the planned replacement of the Air Defence and Command Frigates (ADCF) with Above Water Warfare Frigates by the Dutch Ministry of Defense in 2032.

In 2022, research was carried out in projects within the following constitutive program lines:

Radar and integrated sensor suites, the largest theme in the program, focuses on the integrated sensor suite for future frigates of the Royal Netherlands Navy (RNLN), with a current timeline established up to 2030. Around 2024, a multi-million prototype of an X/S-band one-radar, functionally integrated with an ESM system, will be demonstrated; all activities below contribute to that. In 2022, the SiGe supply chain was assessed; robust machine learning methods for radar classification have been investigated; radar waveforms to detect and classify objects at very large distances were developed, in view of threats such as ballistic missiles; high power, high efficiency GaN amplifier technologies and robust receivers for contested and congested electromagnetic spectrum were designed; activities for an RF chiplet approach for future sensors have started; a radar Resource Manager that is able to optimize multi-mode radar transmissions was initiated, research on the feasibility of a Arbitrary Beam and Waveform Antenna was continued; the test environment for RF fuze sensors has been realized; existing optical turbulence compensation algorithms were analysed and benchmarked; a data collection campaign in Meppen for their evaluation was organized and executed.

Smart manning & automation focusses on the design and development of the next generation combat management and platform management systems for managing the internal and external battle in networks of highly autonomous sensors and effectors. Highly autonomous naval and land operations resulting from reduced crew size and increased system complexity, are enabled through a joint architecture, mission management functionalities and a standardized methodology for verification and validation of the behavior of autonomous system designs. In 2022, we have demonstrated improved situational awareness of armed forces in an urban environment with a network of low-cost heterogeneous sensors by autonomous run-time reconfiguration; contributed to a standardized test methodology for verification and validation of run-time adaptive Countering-UAS systems through three trials; demonstrated enhanced situation understanding using machine learning and artificial intelligence.

Agile design of collaborative autonomous UAVs and UGVs targets agile, quick and easy design and development of runtime adaptive systems with strong focus on collaborative small/medium military UAVs and UGVs. As such, this theme provides the naval and land platforms considered in the Smart manning & automation program line with stand-off capacity to sense and effect. In 2022, we contributed to defining an interoperability standard for military unmanned vehicles; contributed to a Combat Unmanned Ground Systems simulation environment and contributed to a simulation environment with distributed agent autonomy for robust tactical swarm behaviour.

Imaging systems for defence and security focusses on image capture systems for high-end security, targeting improved image quality over longer periods, longer distances and against lower cost. Simulation, modelling, design, demonstration and validation of innovative combinations of sensors, processors and algorithms should lead to systems that make the difference to the user in critical missions, without adding additional complexity. In 2022, we advanced on the development of an EO systems performance simulation tool and developed algorithms for small object detection and monocular depth estimation; we have developed focus assist algorithms that were implemented on a 4K HD prototype sensor, employing a 65Mp 35 fps camera. With a final hardware upgrade and tuning of the image processing this is shown to be a feasible solution for a compact UAV.

Space Situational Awareness (SSA) is a prerequisite to guarantee, e.g., the security of (military) satellites. This requires, amongst others, that The Netherlands takes part along with its European partners in the development of an independent Space Situational Awareness (SSA) capability by upgrading and expanding the current infrastructure. We explore the different ways in which industry together with the Dutch government can be helped to establish these. In 2022, multistatic detection of space objects was achieved through our partnership with ASTRON and MIT; TNO participated in the inventory and assessment of relevant non-space based radar systems as input for the derivation of Space Based Missile Early Warning System requirements.

Ground Situational Awareness (GSA) focuses on heterogeneous fusion of observations from satellites and other relevant platforms such as aircrafts, drones, aerostats and ground sensors to detect anomalies and events of interest for the MinJ&V and the MinDef operational end users. In 2022 we investigated the combined use of earth observation data (wide area monitoring) and autonomous unmanned systems (high resolution data, flexible use), where the unmanned systems are used to enrich situational awareness for adaptive mission planning and execution.

Quantum sensing explores various quantum sensing techniques in the context of military-relevant applications as they may transform the military battlefield in the future or even disrupt the balance of power. To anticipate on this future, we develop understanding of the potential added value in military use cases in parallel to the process of improving technical understanding of this fast-changing field. In 2022 we have updated the quantum sensing catalogue and explored Position, Navigation and Timing applications as well as the potential of quantum enhanced radar and electronic countermeasures; we have developed the first magnetic map matching algorithms; we implemented a quantum-Boltzmann machine on the D-Wave quantum annealer to investigate the use case 'model based acoustic localization'.

Ocean Resilience and Transparency (ORT) seeks to minimize the impact of maritime operations on the ecosystem in a cost-effective manner and without compromising physical safety. We seek to understand and mitigate the negative effects of underwater sound and bring international standards closer. In 2022, we contributed to underwater radiated noise standardization, we created an acoustic measurement plan for near shore tests, we created a 3D world model for the robotic container handling system; we tested and integrated a dynamic scheduler and a short-term vessel voyage plan predictor for an optimal vessel voyage; we contributed to North Sea shipping and wind sound maps; we created an acoustic bubble modelling approach and validation method.

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	L. Roffel (HTSM/Security)

Programma jaar 2022 - Samenvatting

Digital security is an essential 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, monetizing the economic opportunities that cybersecurity brings'. This VP enablesTNO, together with other knowledge institutions, governmental agencies and (cybersecurity) companies, to create an environment to experiment with cybersecurity technologies and methodologies in order to develop and transfer innovationsto the market. A focussed and effective approach with respect to cybersecurity and the emerging threats of quantumcomputing to contemporary cryptography is crucial to safeguard the reliability and confidentiality of data and ICT networksand systems. Our main stakeholders are national security organisations and administrators of vital services and corporations that are vital for the Dutch economy. These organisations must be equipped to recognize and interpret cyber threats and besupplied with both preventive fortifications and possibilities for repressive actions to ensure – in the case of disruptive cyberincidents or phenomena – the continuity of their vital services.

Our main stakeholders recognize the need for external applicable research to complement their own expertise. In close collaboration and continuous communication with our stakeholders we stimulate interaction and communication between our stakeholders in joint projects, such as ASOP (***Automated Security oplossingen***) and Hapkido (*HAPKIDO**: for quantumsafe Public Key Infrastructures***). This gives us an insight in their cybersecurity challenges and provides valuable feedback thatwe use to further finetune our cyber knowledge development and our development of creation of models and tools. The evolution of quantum computing and the impact of this technology on cybersecurity is of particular interest for ourstakeholders.

In the past few years we have developed cybersecurity technologies that fit very well in the Security Operation Centers(SOC's) of office IT environments. In 2022 we have finalized the SOCCRATES EU project that resulted in expansion of ourexpertise on automated response and detection of anomalies in networks including some concrete deliverables such as theDomain Generation Algorithm detector. As it is also expected that quantum computing technology will come into the handsof groups of people or state actors with malicious intent we developed and will continue to develop a zero-knowledge latticebasedprotocol that can withstand attacks on today's encryption tools based on quantum computing.

In 2021 we started to explore the cybersecurity challenges of the companies that make use of operational environments (OT). In 2022 we actively worked with companies and organisations with OT cybersecurity challenges, with a special focus on the water sector in order to determine the focus for technology development in OT cybersecurity. Besides the growing concern about security in OT environments, the industry also faces the challenges created by being part of a network of suppliers. We therefore focussed also on cybersecurity in the supply chain. This is a relatively new field of expertise for us.

In 2022 we expanded our unique position within the vital, financial and government sector through a new joint cybersecurity research program with the Dutch Tax Office (Belastingdienst). This shared research program is focussed on improving security monitoring and detection within the security operating centers of the Tax Office and has started in the beginning of 2022.

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 2022 we continued our work with the cybersecurity cooperation platform dcypher; specifically within the dcypher roadmaps cryptography and automated vulnerability research. 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, the departments of Security and Justice, Defence and with the police.

Titel	VP ICT (P706)
MTIB Thema	Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Berry Vetjens (DM) / Björn Håkansson (VPM)
Contactpersoon Regie-voerder	Frits Grotenhuis, Directeur Topsector ICT

Programma jaar 2022 - Samenvatting

TNO aims to guide industrial and societal stakeholders in the 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, and require fast open infrastructures and trusted ICT solutions to overcome their challenges in operating in digital ecosystems. To guide these developments, the VP ICT in 2022 focused on three common needs of our stakeholders and aimed to reach the results as described below:

The use of Artificial Intelligence (AI) is fuelled by data. **Data sharing** is a key enabler for new business opportunities by combining data sources, but access to data is hindered by lack of trust between data owners, insufficiency in data interoperability and limited business models. Our ambition is to resolve barriers for data sharing and trustworthy usage of AI, by enabling data spaces in and across domains, ensuring interoperability of data sharing systems, avoiding vendor lock-in, achieving national data-hub(s) ecosystems, and developing methods to ensure trustworthy AI. In our efforts to contribute to these ambitions, in 2022, we achieved the following:

i) TNO aided more than 15 public and private organizations in their quest to understand and adopt SSI principles paving the way to set up a Dutch public-private SSI ecosystem in 2023;
ii) we successfully used Privacy Enhanced technologies (MPC) for poverty reduction with the SVB using operational data;
iii) we set up a Dutch and European Data Space Support Center, delivering the first data space blueprint building blocks including an open source International Data Spaces (IDS) implementation, demonstrator, and toolkit: TNO Secure Gateway;
iv) we were first in piloting interconnecting of data spaces between The Netherlands and Japan; and
v) we improved food safety by enabling tracking & tracing of agri-food in a distributed context and reduced energy consumption in household context by extending our TNO knowledge engine.

In **fast and open infrastructures**, we design the future digital connectivity, storage and processing as the foundation for the further digitalisation of society that citizens, businesses and public sectors have already rapidly become to depend on. We provide technology and architecture blueprints for extremely powerful and efficient future digital infrastructures, around our targeted contributions that improve the performance, efficiency and economical and geopolitical sovereignty. In 2022, our key contributions were:

i) performing the first combined cloud-edge and slicing interoperability tests between two 5G networks in our automotive field lab;
ii) making the Cloud Federation Testbed a cornerstone of the first national multi-provider developments in context of the Gaia-X hub; and
iii) realizing first time integration of social XR building blocks in a commercial platform
iv) developing with key parties and stakeholders a National Growth Fund program for Future Network Services for submission in 2023.

Our ambition with a **trusted ICT approach** is to deliver practicable implementations of relevant applications on current and near-future quantum hardware. With a focus on practicable algorithms for quantum optimization, in 2022 we delivered:

i) a quantum optimization pipeline framework;
ii) various new implementations of experimental use cases using quantum hardware; and
iii) a multi-vendor ecosystem for quantum algorithms and application development.

Titel	**VP Embedded Systems Innovation (ESI) (P707)**
MTIB Thema	Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Berry Vetjes (DM), Jacco Wesselius (VPM)
Contactpersoon Regie-voerder	Ronald Fabel, TKI HTSM, Roadmap Systems Engineering

Programma jaar 2022 - Samenvatting

The Netherlands has a world-leading Dutch high-tech systems industry generating a consistent and increasingly positive economic impact and societal value by constantly improving the effectiveness of their way of working. It is the mission of ESI[8] to strengthen the Dutch high-tech industry by embedding cutting-edge methodologies into the industry to cope with the ever-increasing complexity of their products.

To fulfil this mission, ESI:

- participates in national and international agenda setting;
- executes a research program on engineering methodologies, in close collaboration with the Dutch high-tech industry; based on industry roadmaps; tightly linked to academic research; leveraging the value of cooperation in international research consortia;
- consolidates and publicly disseminates the results from this research;
- prepares industrial deployment of the engineering methodologies by:
  - human capital development: defining and executing a competence development program for industry;
  - preparing for scaling-up: bringing results (e.g., software tools) into open source and seeking partnerships with professional tool suppliers, service providers and industry.

The ESI research agenda addresses system-level multidisciplinary engineering/architecting challenges that are key to the high-tech industry. In 2022, the ESI research program consisted of five key program lines addressing challenges that are tightly coupled to the 2020 HTSM Systems Engineering roadmap[9].

- System Performance (meet and balance key system performance indicators);
- System Dependability (meet quality and reliability requirements);
- System Evolvability (be ready for upgrades and updates);
- Exploiting System Context (analyse and optimize systems in their operating context);
- System Architecting (translate market, product, technology choices into system concepts).

The research is done in long-term programs with a yearly go/no-go management-level review, based on results and impact.

In 2022, a full research program has been executed, delivering new methodologies (incl. software tools) and extensions to existing methodologies. In collaboration with industry partners, these were directly inspired by and validated with industrial use cases (TNO-ESI's Industry-as-a-Lab approach).

[8] The ESI department of TNO (inside the unit IS&P) is fully focussed on realizing VP ESI. This report therefore describes the activities and achievements of TNO-ESI (the department, working in close collaboration with its industry and academic partners) as well as those of VP ESI. Separating these would be very artificial (if possible at all). For clarity, at several places in the report "VP ESI" or "TNO-ESI" has been used to emphasize that some activities are part of the TNO-ESI department.

[9] https://hollandhightech.nl/_asset/_public/Innovatie/Technologieen/z_pdf_roadmaps/Roadmap-Systems-Engineering-update-2020-final-v20200724.pdf

On September 27, 2022, TNO-ESI organized its ESI Symposium in which results from our research were presented in cooperation with our industry and academic partners[10]. Two of TNO-ESI's international partners (SERC and DLR) co-organized a track at the symposium and several industry partners presented their industry cases and the results from our collaborations. During the symposium TNO-ESI proudly presented its 20th Anniversary Book[11], describing its history, mission, research results and ambitions.

The day after the symposium, TNO-ESI and three of its international peer institutes (SERC from the USA, DLR from Germany and KTH/-TECoSA from Sweden) founded the ARCHIMEDES INITIATIVE to strengthen their collaboration on research on systems engineering methodologies. In 2022, these parties jointly created a special issue of the INCOSE INSIGHT magazine[12] to publish their roadmaps on systems engineering methodology research and to bundle the results from their research programs.

In 2022, TNO-ESI performed an in-depth analysis of the challenges and opportunities in the high-tech equipment industry together with their industry and academic partners. Based on the outcomes of this process, the ESI research agenda has been reviewed and refreshed (description of this process and of its results can be found in an article in the above-mentioned special issue of the INCOSE INSIGHT magazine). The main conclusions from this process can be summarized as follows:

- the current research program lines are still highly relevant;
- in all program lines, additional emphasis is needed for systems-of-systems aspects, the opportunities of using AI (AI4Engineering) and for new challenges introduced by the introduction of AI in high-tech equipment (Engineering4AI);
- the topic of Democratization deserves attention: this involves (i) making it easier to use high-tech equipment (expanding market opportunities) and (ii) making it easier to develop high-tech equipment in view of the shortage of engineering experts (human capital agenda);
- the topic of Systems Engineering for Sustainability will be added to the agenda for 2023.

TNO-ESI has executed a series of competence development programs in the industry in a wide variety of formats. Examples are system architect training programs (e.g., a system architect training program for multiple companies) and a training on mastering systems integration. Both attract a lot of attention and receive a maximum customer-satisfaction rating.

In 2022, TNO-ESI initiated a multi-company training program, giving smaller companies access to the available programs. Another successful initiative has been a systems architecting program executed with an industry partner and one of their key suppliers. Both initiatives are steppingstones for further enhancement of impact through the competence development program.

Finally, ESI continued making its methodologies and tools available via open-source platforms (like Eclipse). With implementation partners (in the ESI Implementors Council) and professional tool providers, TNO-ESI has organized professional support scaling up the embedding of the ESI methodologies in the high-tech industry.

[10] https://esi.nl/symposium-2022/symposium-2022

[11] https://publications.tno.nl/publication/34640058/iS48dL/roos-2022-managing.pdf

[12] This special issue is expected to be available in the first month of 2023

Titel	VP Sleutelmethodologieën voor Transities en Transformaties (P901)
MTIB Thema	KIA Maatschappelijk Verdienvermogen / Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Mirjam Groote Schaarsberg (VPM), Wimar Bolhuis (DM)
Contactpersoon Regie-voerder	Paul Vetter (EZK)

Programma jaar 2022 - Samenvatting

De samenleving wordt geconfronteerd met grote uitdagingen, zoals klimaatverandering, grondstoffen schaarste, en het waarborgen van mensenrechten, veiligheid & privacy in digitalisering. Hiertoe zijn verschillende maatschappelijke transities in gang gezet. Het is belangrijk om op systeemniveau te begrijpen hoe deze transities op elkaar ingrijpen en welke mogelijkheden tot sturing er zijn. Anders kunnen pogingen om problemen op te lossen ineffectief zijn of zelfs leiden tot onbedoelde en onvoorziene gevolgen. Voorbeelden hiervan zijn de beschikbaarheid van kritische grondstoffen voor de energietransitie, de ruimtelijke impact van transities of het vergroten van de maatschappelijke ongelijkheid.
Het nieuwe Vraaggestuurde Programma (VP) *Sleutelmethodologieën voor versnellen van transities en transformaties (Key Enabling Methodologies, KEM's)* ontwikkelt methodologieën (KEM's) voor de versnelling van transities naar een duurzame en digitale economie en samenleving met een hogere brede welvaart. KEM's zijn de niet-technologische aanpakken, gebaseerd op sociaalwetenschappelijke, bestuurskundige, economische en bedrijfskundige inzichten. De strategische inzet van deze vormen van maatschappelijke innovatie verhogen de impact en het rendement van technologische investeringen.

Het programma richt zich op drie complexe socio-technische systemen: stedelijke systemen, industriële systemen en innovatie systemen. Van deze systemen wordt gevraagd om meerdere transities tegelijk te maken. Het doel van het VP is om met nieuwe methodologieën het handelingsperspectief van beslissers te vergroten, met als impact de publieke en private besluitvorming te verbeteren en de brede welvaart te verhogen. De maatschappelijke uitdagingen zijn urgent en complex en vragen om een snelle maar ook lerende aanpak. De kennisontwikkeling in het VP vindt daarom vooral plaats door middel van actiegericht onderzoek en nauwe interactie met marktpartijen en relevante stakeholders.

In het VP worden drie methodeclusters van KEM's ontwikkeld:
1) het **analyseren en begrijpen van complexe systemen** en het identificeren van interventies die bijdragen aan de transities naar de economische en maatschappelijke doelen;
2) het **ontwerpen van adaptieve besturing:** structuren, besluitvorming en beslisondersteuning voor bedrijven en overheden in complexe transitieprojecten met onzekerheden en onbedoelde gevolgen;
3) het **organiseren van werkende ecosystemen** voor economische en maatschappelijke waardecreatie en nieuwe **collaboratieve business modellen**.

Highlights 2022

- Data gedreven impact & monitoring van het Nederlandse AI-ecosysteem. De start van een meerjarige samenwerking met het groeifondsprogramma AiNed en CBS om de impact van innovatieprogramma's beter kwantitatief te meten. Door het nieuwe impactmodel dat databronnen als vacatureteksten en subsidies benut, krijgen bedrijven en publieke partijen meer kennis en inzicht om transities te versnellen en richting te geven, zodat de potentiële positieve economische en sociale impact van AI wordt behaald.
- Publiek-private besluitvorming in schaarse ruimte. Door middel van de Urban Assessment onderzoekslens bracht TNO de gewenste samenwerkingsvormen, agenda en activiteiten voor het Nederlands support platform voor NetZeroCities, gekoppeld aan de EU Steden missie "100 Climate Neutral and Smart Cities by 2030", in kaart. Dit platform ondersteunt, vanuit publieke en private partijen, Nederlandse missiesteden in het halen van klimaatneutraliteit in 2030 en verspreidt lessen naar andere gemeenten. De methodologie geeft steden onderbouwde opties om sneller klimaatneutraal te worden en om beter van elkaar te leren.
- Collaboratieve transitie- en business modellen voor de transformatie van de chemische industrie. TNO stelde de actieagenda Groene Chemie Nieuwe Economie op en voerde deze mede uit. Het betreft een meerjarige samenwerking met de chemische industrie, start-ups, financiers, kennisinstellingen en overheid van opstart naar opschaling en tot de eindgebruiker. Nieuwe innovatieve bedrijven en ketens op het gebied van biobased en circulaire grondstoffen sneller toegang tot private financiering, waardoor nieuwe duurzame industriële waardeketens ontstaan.

Het VP KEM's sluit aan bij de KIA Maatschappelijk Verdienvermogen (MV) en de onderzoeksagenda voor sleutelmethodologieën (KEM's). Het VP KEM's is gestart op 1 januari 2022. Het richt zich specifiek op kennisontwikkeling voor complexe

systeemveranderingen en bouwt voort op de huidige kennis(ontwikkeling) gericht op de versnelling van individuele transities. De overkoepelende en interdisciplinaire inzichten uit deze roadmap kunnen ook ingezet worden voor andere transities, zoals de overgang naar een CO2-neutrale industrie, naar circulaire plastics of naar een digitaal inclusieve samenleving.

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

Programma jaar 2022 - Samenvatting

Our multi-annual R&D program 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 organize the VP along program lines directly connected to this ambition; Instruments for **Earth Observation** and related **Space Data Utilization,** technologies for **Satellite Communication**, and **Scientific Instrumentation** focusing on instruments for **Ground Based Astronomy** and **Space Based Astronomy** including instruments for **Big Science and Diagnostics for Fusion Energy**. A new development in the space domain is the increased priority at ESA and the EU for **Space Situational Awareness**, including space weather, Near Earth Objects, and Space Surveillance and Tracking including Space Traffic Management. It is seen that TNO can contribute with its strong heritage in optical systems, in the field of observation and diagnosis. This theme will be further investigated in 2023 to define positioning and ambition of TNO, in close collaboration between the TNO Units High Tech Industry and Defence, Safety & Security.

The main parts of the VP Space & Scientific Instrumentation 2022 are summarized below.

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

The program 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 program, in close contact with industrial partners.

The program 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 2022 are the creation of the 'Clear Air' Consortium in which the KNMI, TNO, SRON and Delft University of Technology will collaborate on research and technology development in the field of earth observation. The creation of the 'Clear Air' consortium is intended to strengthen the prominent knowledge position of the Netherlands in using satellites to measure emissions and the composition of the atmosphere. Public authorities and companies will be able to use this knowledge to limit climate change, and improve both air quality and biodiversity. During a feasibility study completed in early 2022, the HIGS consortium proved that the HIGS instrument enables measurement of atmospheric composition with higher spatial resolution and accuracy. HIGS has high sensitivity to relative differences in gas concentrations on small spatial scales. HIGS is the latest development, and has the potential to be a major breakthrough technology for earth observation, atmospheric monitoring and climate change reversal. Following an extensive performance and environmental testing program, the SmallCAT (Small Communication Active Terminal) laser communication system has been delivered in September 2022 by TNO to UTIAS SFL (University of Toronto Institute for Aerospace Studies Space Flight Laboratory), for integration into the Norwegian NORSAT-TD spacecraft. The launch of the spacecraft will be in early 2023 after which an in orbit demonstration of SmallCAT will ensue to increase data transmission capabilities of small satellites via direct to earth laser communication. In September 2022 TNO and partners have successfully completed a field test establishing an optical laser communication link over 10 km between the KNMI test site in Lopik and the Gerbrandy tower in IJsselstein. This is a big step in developing a commercial

optical ground station product and further advance in faster and more secure broadband connectivity in the Netherlands and Europe. In July 2022 TNO was awarded conceptual design of the Gemini North Telescope's Adaptive Optics Bench. The Gemini North Observatory is one of the largest and most advanced optical and infrared telescopes in the world. It is located on Mauna Kea in Hawaii, one of the world's premier astronomy locations.

Titel	**VP Semiconductor Equipment (P612)**
MTIB Thema	Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Rogier Verberk, Jasper Flipse
Contactpersoon Regie-voerder	Frans List (leader HTSM Roadmap Semiconductor Equipment; ASML), Toon Evers (leader HTSM Roadmap Healthcare; Philips Healthcare), Ronny van 't Oever (leader HTSM Roadmap Nanotechnology; Micronit)

Programma jaar 2022 - Samenvatting

TNO's Roadmap on Semicon & Quantum and Medical Photonics provides critical enabling technologies to the Dutch and international high-tech industry to enable manufacturing of integrated circuits (chips). Consumer electronics, mobile devices, industrial processes, communication equipment, the car industry, artificial intelligence and nearly all potential solutions to societal challenges rely on these chips to generate, process, and store data. By industrializing such technologies this Dutch high-tech industry enables many other industries and development goals, and at the same time became a strategic asset for The Netherlands and Europe, in order to balance our dependency on other (chip manufacturing) countries.

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. We aim to have the Dutch semiconductor industry by 2026 have strengthened this position by world record performance in lithography systems, have expanded this position to other critical manufacturing equipment (e.g., metrology, processing, and pick-and-place), and having taken pole position in the emerging market of quantum technologies. TNO supports this ambition by pushing the limits in thermal management, contamination control, material sciences, metrology, optics and optomechatronics, quantum technologies, and systems engineering. Developing and utilizing unique technological infrastructure like EUV beam lines, and optical and vacuum test rigs are an integral part of this strategy.

In 2023 the unique EUV testing infrastructure will be further upgraded and expanded to study induced plasma effects and material sciences for EUV lithography mirrors as well as reticles, enabling higher productivities and higher resolution ('NA') systems. Young research topics like computational optics will continue. The R&D program integrated photonics (PIC) will be continued with a stronger focus on applications (LIDAR, Medical, and Quantum). The program on micro-fluidics and cooling techniques remains focused on immersion lithography and 5G/6G communication chip cooling, but is expanded to cooling for data centers. Relatively new is the development of metrology equipment for large scale PIC manufacturing, which started in 2022 by a consortium of Dutch SME's plus TNO, supported by European funding.

TNO's innovations in scanning probe based (SPM) and acoustics based metrology concepts have gained attention by world leading chip manufacturers. Starting in 2022 and expected to be expanding in 2023, TNO will execute research in cooperation with those IDM's to gain insight in their state-of-the-art and even future challenges in chips manufacturing. The metrology concepts itself will be further developed in European projects starting in 2023.

Within the mission of QuTech, the development of a quantum computer that is accessible for end users via the web, and establishing a quantum communication channel for entanglement distribution between Delft and Den Haag will continue in 2023. During 2022 and 2023 TNO sets up test and development facilities for quantum sensing. This will all further propel the Netherlands as a vivid hotspot for quantum technologies in the coming decade. Our activities are part of the next phase of the national program led by QDNL, Started at the end of 2022, as well as support by new European projects kicking-off in 2023.

TNO's research on Medical Technologies focusses on accelerating photonics-based innovations that can help people to stay healthy, diagnose diseases earlier, and facilitate remote patient management, supporting affordable and easily accessible healthcare for the ageing population. To achieve this we develop diagnostic optical and opto-acoustic devices for use in home, primary and secondary care, including multispectral fundus camera's for early diagnosis of eye diseases as well as systemic diseases, wearable diagnostic photonic devices for remote patient management, and optoacoustic sensors based on PIC to boost the performance of photoacoustic and ultrasound devices. In 2023 we will learn to add AI and machine learning expertise in order to fully exploit the large and complex data sets generated by simulations and measurements.

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

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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 recognized as a potentially market-changing advancement in health and nutrition. TNO has been developing Additive Manufacturing expertise for more than 30 years.

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. To enable this personalized medicine vision we want to demonstrate and validate personalized medication in a clinical setting using newly developed printing systems. Key milestones in the roadmap include in line 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. In the past years proof-of-concept cases have been demonstrated. For the near future, the focus will be on scaling up the printing technology to create viable business cases. Key milestones in the roadmap are include increasing throughput, ability to combine different food ingredients in one product with varying composition, and in line quality control.
In 2022, a setup was realized with an in-line Raman monitoring system able to measure active pharmaceutical ingredients (API) non-destructively.

Also, together with 6 industrial partners a concept for a production machine was developed to produce personalized food snacks for professionals and medical patients. We develop the process and equipment for these ambitions and this is in line with the KIA sleuteltechnologie *Smart personalized food and medicine*.

Hybrid Printed Electronics

Hybrid printed electronics is an enabling technology for next generation of electronics, being a hybrid combination of additive manufacturing and 'conventional' silicon-based electronics. These technologies enable future electronic products with unprecedented form factor and functionality. Specifically, we focus on these 3 domains:

- Health care monitoring, key technology for enabling the emerging trends for value-based care and bringing the hospital to the home. A platform patch able to monitor ECG and breathing rate is being tested in several clinical environments. Concepts for measuring core body temperature and blood oxygenation were shown in 2022.
- Advanced chip packaging for new generation of chips such as high power electronics and RF electronics. First concepts for both dealing with thermal stresses in high power chips and integration of 6G antennas in package were shown in 2022.
- New printing technologies aimed at enabling 3D printed electronics and ultrahigh resolution high speed printing of electronics. In 2022, impulse printing was shown to print at resolution below 10 microns, of which the technology will be spun out in the company PhononTech BV. In addition, existing printing and assembly technology was spun out to a foundry, Tracxon BV, to enable end-users scale-up of flexible electronics based products, such as the health patch.

In the coming 2-3 years the health patch will be extended with sPO2 and core body temperature. Besides this, we continue developing novel enabling printed electronics technologies that further increase the possibilities of deploying printed electronics and showcasing 5 micron printing technology.

Thin Film Electronics

Using our thin film infrastructure (e.g. the technology used for making flat panel displays) and expanding our capabilities towards thick film technology, new applications are explored primarily in the health care domain such as organ-on-chip, advanced X-ray, ultrasound imaging, and vital sign monitoring.

We accelerate our activities on next generations of batteries for electric driving and wearables, making use of our core capabilities in deposition technologies (and in line with KIA 'Batteries of the future'), in collaboration with the newly established start-up LionVolt, that aims to commercialize solid-state batteries with high-aspect ratio 3D geometry. In 2022 we finalize a battery pre-pilot line infrastructure in support of this work.

Integrated Photonics

In 2022 the Photonic Integration Technology Centre (PITC) was established, a collaboration between TUE, UT, TNO/Holst Centre and Photondelta. The PITC aims to accelerate the uptake of integrated photonics by bridging the divide between research and application. The application of photonic chips will help to solve some of society's biggest challenges, ranging from road safety and health monitoring to energy-efficient data handling and communication to data security. The main role of TNO/Holst Centre will be to develop a heterogeneous integration platform enabling integration of different integrated photonics and electronic platforms (eg, InP, SiN and Si) in one package.

Titel	VP Smart Industry (P617)
MTIB Thema	Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Mark Courage MSc MBA, Dr. Adam Schmidt
Contactpersoon Regie-voerder	Jan Post (leader HTSM Roadmap Smart Industry & Philips Consumer Electronics), Joren Schep (EZK)

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The vision for smart industry is to create in the Netherlands the most circular, interconnected, automated, and intelligent industrial ecosystem that is capable of responding to changing market conditions and customer needs in real-time. This will enable businesses to increase efficiency, reduce costs, increate quality and improve customer satisfaction. Smart industry enables businesses to leverage data and analytics to gain insights into their operations and make better decisions. The digitalization of the industry will increase the agility to cope with the challenges of tomorrow like becoming circular, resilient supply chains, ageing populations, sovereignty, etc

The roadmap Smart Industry invests and lines-up for significant growth and development since its official launch in 2021 within TNO. The main theme of this roadmap is Industry 4.0 or, as it is commonly known in the Netherlands, Smart Industry. The long term TNO objective for the VP 'Intensivering Smart Industry' 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 & Manufacturing technologies:

"The Netherlands has the most circular flexible and best digitally connected circular 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."

Smart Industry stands for digitalization; connecting products, machines and people, and the use of new manufacturing technologies. The optimization of production through the application of ICT and new production technologies makes manufacturing more efficient, flexible, cheaper and boosts quality. This leads to higher labor productivity and contributes to waste reduction. Smarter machines, robots and other components of the production process communicate with each other, optimizing their cooperation, not only within a company but even between different companies across the value chain.

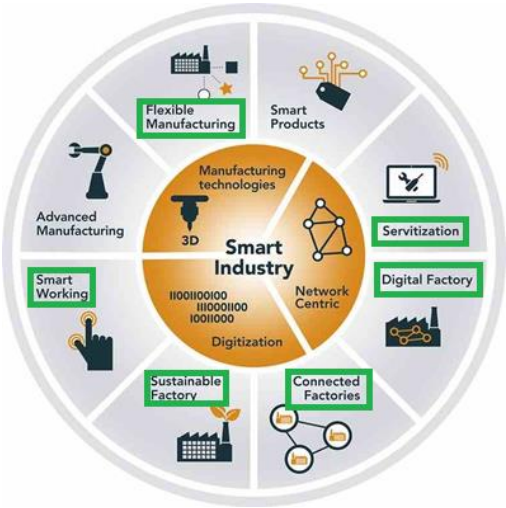
Smart Industry enables new business to be created from large and diverse information streams on the basis of new, affective technologies like big data processing, Artificial Intelligence, Augmented Reality, the Internet of Things, new generation-adaptive robots, 3D printing, opto-mechatronics, microelectronics, nanotechnology and miniaturization as well as new sensor technology.

The Netherlands has everything at its disposal to make Smart Industry a success. We have a powerful industrial base of large companies and SMEs. We have an excellent ICT infrastructure, good logistics, a well-educated workforce and collaboration is part of our DNA. The development of new initiatives is encouraged by the creation of regional fieldlabs in which companies, educational and knowledge institutions collaborate. To this end we are working on connecting to the European Digital Innovation Hubs (EDIHs) and Testing and Experimentation Facilities (TEFs).

Although TNO works with companies from small to large, a special emphasis is put here onto SMEs as these are collectively seen as the key lever to boost the earning power of the Dutch economy.

In the national implementation agenda Smart Industry, 8 transformations are defined to enable manufacturing companies in the Netherlands to achieve the national objective (see picture table 1 for the 8 transformations). To support manufacturing companies and integrators TNO focusses the 6 most important transformations covered in 5 Product Market Combinations (PMCs) aligned with the transitions, plus one PMC focused on policy and ecosystem development as further described in table 1.

Table 1: PMC's VP617 Smart Industry & Smart Industry transitions

#	PMC TNO	Description PMC	Relation Smart industry transformations
1	Flexible Manufacturing	Enabling single-piece production at a cost price of mass production by developing state-of-the-art "robot-sensor-software" solutions	
2	Smart Work	Keeping scarce human resources at manufacturing companies sustainably employable in times of rapidly changing technologies	
3	Connected Factories	Enabling the most competitive supply network for high-tech, high-complexity, low volume manufacturing by sharing data in and across supply chains	
4	Digital Factory	Enable increasingly autonomous manufacturing by utilizing the power of data via interoperable digital connectors, digital twins and artificial intelligence.	
5	Sustainable Factory	Address the increasingly important need to reduce the environmental footprint of manufacturing as well as the shift to Servitization business models and development towards a Circular Economy	
6	Smart Response	Responding to the acceleration of the digitization process while realizing the desired economic and social impact	

One of the trends observed in 2022 is the strong need for industry 4.0 (I4.0) solutions to increase productivity to cope with the current labour shortage in an ageing population. In addition, increased awareness by the manufacturing industry is observed for I4.0-technology solutions which contributes to a more circular and sustainable economy. For this reason TNO established in 2022 next to the PMC sustainable factory (also called circular economy smart industry, CESI) for the development of new technology to enable and accelerate towards a circular economy.

Due to the delayed start of the NXTGEN High-Tech Growth Fund not all research goals as set could be achieved. However, with the limited available national funding in NL for smart industry (compared to the Belgium and Germany) and the scattered NL SI landscape, TNO and its partners excel in bottom-up innovation with wide industry acceptation and implementation. This is supported by TNO's strong backbone in the knowledge development related to dataspaces, artificial intelligence, robotics, optics and opto-acoustics. With the focus of TNO on 6 of the 8 transition in combination with its niche expertise on advanced manufacturing, TNO is able to orchestrate and develop the Dutch innovation ecosystem for industry 4.0 on all the key aspects.

The main highlights for 2022 are:

- **Strategic planning:** Development and launch of the national scale growth agenda 2022-2026 **(**Smart Industry Schaalsprong Agenda 2022 - 2026 | Kamerstuk | Rijksoverheid.nl). De scale agenda focusses on the increase of the impact national SI program. Intention is to support more than 1.000 firms in their digitalization journey. To enable this TNO has developed "10xklaar" (Homepage - 10xKlaar) program and has launched the "Smart Connected Suppler Network" (Home (smart-connected.nl)) concepts to enable SME's easy access in digitalization towards I4.0. In addition
- **Orchestrating SI innovation landscape**: TNO orchestrated and support the setup of the 5 Innovation hubs (EDIH's), Test Experience Facility (TEF), the NXT GEN High Tech growth fund and "luchtvaart in transition" growth fund to accelerate the development and implementation of I4.0 technology in the Dutch industry landscape.

- **Market trend sustainability, new PMC**: To meet the growing demand for circular and sustainable solutions within the industry TNO has established a new PMC sustainable factory. In this PMC the "9R strategies" for a circular economy are connected to I4.0 technology. In addition, as part of future "true pricing" TNO conducted research for the development of a digital product passport Productpaspoort: Basisvoorwaarde voor een duurzame economie (tno.nl). This new PMC is also the step up toward the development of new high tech equipment for sustainable processes for hydrogen production and transformation of CO_2 in new green chemical building blocks planned for 2023 and beyond.
- **Technology development**: With regard to technology development 2 new patents have been granted: **1)** ultrasone direct velocity mapping non destructive testing (DVM NDT) and **2)** adaptive operator workstation. These new technologies play an important role in the development towards autonomous production process and increasing the productivity
- **Knowledge dissemination I4.0**: TNO strengthened the cooperation with EFFRA, EU RTO's and Universities (Tue, TuD, UT) and has started new cooperations with the Open Industry 4.0 Alliance (OI4), euRobotics and International Digital Twin Association (IDTA) to accelerate national and international standardization of I4.0 technology.
- **Highlighted executed projects: 1)** Successful completion of **FOKUS project** with more than 200 companies involved in project activities in the last 4 years. 16 knowledge sessions organized in 6 different learning communities the topics human-robot collaboration, operator guidance and remote assistance. Furthermore 13 pilot projects were facilitated in manufacturing SME's and 6 demonstrator setups at the Factory of the Future Experience Center at BIC Eindhoven. **2)** Completion of the **SMITZH program** in which several operator support technologies were tested and a demonstrator of a Digital Twin was realized for Rheavita's high tech pharmaceutical vial continuous aseptic freeze drying equipment. **3)** the **MAS4AI** is an final stage and providing great results. The project aims at developing and testing a distributed and interoperable AI architecture based on multi-agents technology in such a way that it contributes to hyper-agility of European factories though modular and flexible production while at the same time keeps the humans in control of the AI technology and creating impact by spreading the technology over large groups of European manufacturing companies. One of the items developed by TNO is the factory planner in which easily for different types of equipment the Asset Administration Shell (AAS) can be setup. AAS is the digital representation of an asset. The AAS consists of a number of submodels in which all the information and functionalities of a given asset – including its features, characteristics, properties, statuses, parameters, measurement data and capabilities – can be described. It allows for the use of different communication channels and applications and serves as the link between objects and the connected, digital and distributed world.