

**TNO Onderzoek 2023 - Overzicht Vraaggestuurde programma's volgens het MTIB**

Unit	Vraaggestuurde Programma's (VPs)	MTIB Thema's	
<b>EMT</b>	P325 System Transition	Klimaat & Energie	Gezondheid en Zorg
	P307 Geo-energy		
	P310 Karakterisering Grondwater	Circulaire Economie	Veiligheid
	P321 Renewable Energy		
	P323 Co2 Neutral Industry	Mobiliteit	Sleutel-technologie
	P510 Luchtkwaliteit		
	P515 Circulaire Economie		
	P603 Sustainable Chemical Industry		
P616 Industriële elektrificatie en CCUS	Landbouw & Water		
<b>MBE</b>	P408 Sustainable Traffic & Transport		
	P407 Smart Traffic and Transport		
	P502 Duurzaam bouwen		
<b>HLW</b>	P204 Future of Work		
	P211 Jeugd		
	P511 Human Health RM Nano		
	P207 Sociale Innovatie		
	P203 Biomedical Health		
	P210 Digital Health Technologies		
<b>DSS</b>	P104 Radar & Sensorsystemen		
	P102 Veilige maatschappij		
	P106 Kennisopbouw politie		
<b>ISP</b>	P103 Cyber Risk & Resilience		
	P706 ICT		
	P707 ESI		
	P901 Transitions & Transformations		
<b>HTI</b>	P607 Space & Scientific instrument.		
	P612 Semicon & Quantum		
	P615 Flexible and Freeform Products		
	P617 Smart Industry		

Titel	VP System Transition (P325)
MTIB-thema	Klimaat en Energie
Contactpersonen TNO (DM en VPM)	VP-manager: Christiaan van den Berg Divisie Directeur: Patrick Punte
Contactpersonen Overheid	Debbie Joosen, Timon Vervoorn (EZK), Jörg Gigler , Mart van Bracht, Maarten de Vries (Topsector Energie)
<b>Programma jaar 2023 - Samenvatting</b>	
<p>De energietransitie wordt gedreven door de klimaatcrisis: het doel is om de CO<sub>2</sub>-uitstoot in 2050 tot nul of lager terug te brengen. Voor 2030 heeft de Nederlandse regering zich een reductie van 60% ten doel gesteld. Om de doelen te bereiken is een <b>stroomtransitie</b> nodig: naast technologische innovatie voor de opwekking, opslag en gebruik van energie in alle sectoren zijn ook innovaties in beleid, financiering, businessmodellen, energiegemeenschappen en markten nodig. Het zesde beoordelingsrapport van het IPCC benadrukt bovendien het terugdringen van de vraagzijde als een potentiële belangrijke optie om de klimaatdoelstellingen te bereiken. Dit vereist zowel gedrags- als systeemverandering, en vergt inspanningen van mensen in een veelheid aan rollen: als burger, professional, consument, bewoner, etc.</p> <p>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.</p> <p><i>De energietransitie raakt iedereen:</i> de mens – in de rol van burger, bewoner, gebruiker, producent, consument, etc. – wordt steeds belangrijker voor het welslagen van de energietransitie. Ons doel voor de langere termijn is het leveren van nieuwe sociaalwetenschappelijke kennis en in de praktijk toegepaste tools op gebied van gedrag van consumenten en bedrijven, van verdelingseffecten, van draagvlak, van participatie en van duurzame levensstijlen. In dit kader werd in 2023 onder andere veel impact gemaakt met onze publicatie <a href="#">Anders consumeren om klimaatdoelen te halen</a>. En ons onderzoeksprogramma naar <a href="#">energiearmoede</a>, dat gemeenten, provincies en Rijksoverheid handvatten geeft om energiearmoede aan te pakken.</p> <p><i>De energietransitie wordt een stroomtransitie:</i> energiedragers als elektriciteit, warmte en waterstof verbinden sectoren met elkaar die vroeger nauwelijks verbonden waren, nationaal maar ook internationaal. Technologische ontwikkelingen leiden ook tot nieuwe rollen van bestaande sectoren in energiemarkten. Denk aan elektrisch rijden en energieproducerende gebouwen. Ons doel is het bieden van inzicht in de nieuwe afhankelijkheden, het ontwikkelen van marktmodellen en adviseren over nieuwe vormen van regulering. Een voorbeeld van ons werk is de publicatie van onze inschatting van <a href="#">de hoeveelheid flexibel vermogen</a> die nodig is in ons elektriciteitssysteem in de komende jaren. Tevens een is de publieke presentatie van het <a href="#">Hestia model</a> een mooi resultaat. Dit model werd samen met PBL ontwikkeld om beleidsmaatregelen voor de energietransitie in de gebouwde omgeving door te rekenen.</p> <p><i>De rol van overheden wordt steeds belangrijker:</i> er wordt meer regie verwacht van overheden op alle niveaus. Ook de rol van de EU op klimaatgebied is met het Fit for 55 pakket sterk toegenomen. Ons doel is om kennis van en kennis voor energiebeleid te leveren op nationaal en ook op EU-niveau, door de publicatie van toekomstverkenningen zoals <a href="#">ADAPT en TRANSFORM</a>, het uitvoeren van impactvolle studies over onder andere de rol van waterstof en geïmporteerde biograndstoffen voor de energietransitie.</p> <p>Alle resultaten van de projecten zijn te vinden op onze webportal <a href="#">energy.nl</a>.</p>	

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 Regievoerder	TKI UE: Robert Jan van Egmond, TKI Geo Energie: Jorg Gigler, EZK: Ronald Schillemans, Pieter Jongerius

### Programma jaar 2023 - Samenvatting

De noodzaak tot versnelde ontwikkeling van warmtenetten en de inzet van geothermie en warmteopslag is opgenomen in het regeerakkoord en het klimaatakkoord. Een tweede belangrijk speerpunt van het kabinetsbeleid en de aanbevelingen van de Parlementaire enquêtecommissie aardgaswinning zijn de veiligheidsrisico's van mijnbouwactiviteiten en bijbehorend risicobeleid. Er wordt gewerkt aan het ontwikkelen van een ruimtelijk programmatische aanpak waarbinnen alle verwachte activiteiten in de ondergrond (Geothermie, bodemenergie, opslag waterstof & compressed air & warmte, gaswinning en zoutwinning) vast worden gelegd. Deze prioriteiten in het regeerakkoord sluiten (opschaling duurzame warmtenetten en veiligheid van mijnbouwactiviteiten) sluiten naadloos aan op doelstellingen van dit VP programma:

1. Reduceren van pre-drill geologische *Exploratie- en Realisatierisico's voor geothermie en warmteopslag* door betere data-analyse, acquisitie, publieke informatiesystemen en modellen;
2. *Verhogen productie geothermie en warmteopslag* door betere resource ontwikkeling, materialen, beheer en monitoring;
3. Vergroten van *veiligheid* en verlagen van mogelijke *negatieve (milieu)impact* bij ondergrondse activiteiten (geothermie en hoge-temperatuuropslag (HTO), koolstof afvang en opslag (CCS), abandonneren putten);
4. Verlagen kostprijs voor *aanleg en aansturing van warmtenetten* en optimalisatie van warmte- en koudevraag en aanbod door ontwikkeling van de publieke design-toolkit voor operators en overheden;
5. Veilige en kosteneffectieve ontwikkeling van *CCS en Energie-opslag*.

Voor deze doelstellingen werkt TNO in missiegedreven ecosystemen samen met industriepartners, Nederlandse kennisinstellingen (i.e. Deltares, KWR, academia). De missies worden o.a. gedreven door kennisagenda's die samen met industrie en kennisinstellingen worden gedefinieerd. De benodigde innovaties worden vervolgens grotendeels (ca 50% van het SMO-budget) gerealiseerd in nationale en internationale onderzoeksprogramma's zoals de nog lopende of vorig jaar afgesloten projecten WarmingUP GOO, SafeGeo, Diepe Bodemlus (WGO-BES), DRAGLOW, PERFORM, RESULT, ELFO, SafeGeo, Downhole Array Research at Ammerlaan (DHARA) etc. Hieronder worden enkele voorbeelden genoemd van resultaten uit 2022 en 2023, en verwachte impact in 2024:

#### ad 1. Reduceren van pre-drill risico's:

Er is uitgebreide tooling ontwikkeld om breukreactivatie en seismiteit door afkoeling bij doubletten in zandsteen-reservoirs te analyseren. Thermo-mechanische experimenten zijn ontworpen en uitgevoerd in het iM4RockLab van TNO in Utrecht. Dit werk is in 2022 en 2023 uitgebreid en heeft geleid tot nieuwe inzichten wat betreft veiligheid in relatie tot operationele standaarden van geothermie. Deze ontwikkeling wordt in 2024 gecontinueerd. De modellen worden gevalideerd op basis van veldtesten bij het geothermiedoublet Ammerlaan - The Green Innovator (DHARA project). De validatie wordt later mogelijk uitgebreid met meerdere putten.

#### ad 3. Vergroten veiligheid (Well technologie → veiligheid & kostenverlaging):

Er zijn circa 6000 olie- en gasputten in Nederland, en een groeiend aantal geothermieputten. Ook zijn nieuwe putten voorzien voor waterstof- en CO<sub>2</sub>-opslag. Een veilige afdichting is essentieel en kostbaar. Afdichtende en mechanische eigenschappen van bentoniet, zout en Sorel-cement zijn onderzocht. Een grootschalige laboratoriumopstelling is in 2022 gerealiseerd voor de opbouw van kennis over de hechtingskwaliteit van cement, en de leksnelheid tussen cement en zachte gesteenten. Ook zijn er in 2022 en 2023 veldtesten gedaan in een put op diepte van zoutproducent Nobian. De resultaten worden voorgelegd aan het Staatstoezicht op de Mijnen (SODM). Dit proces zal mogelijk leiden tot de acceptatie van bentoniet als afdichtingsmateriaal voor putten. Dit is een kosteneffectieve en veiligere methode voor het abandonneren van putten voor de olie- gasindustrie, geothermie en CO<sub>2</sub>-opslag.

ad 4. Verlagen kostprijs warmtenetten:

De in het WarmingUP<sup>1</sup>-project ontwikkelde 'design toolkit', die gebruikt kan worden voor het ontwerpen van warmtenetten en case-studies voor RES ontwikkeling, is door verschillende industriële partners in WarmingUP gebruikt. De toolkit is uitgebreid met multi commodity mogelijkheden voor een flexibel optimalisatiekader voor hybride systemen. De toolkit is in 2022 en 2023 uitgebreid getest door operators en adviesbureaus. De toolkit zal in 2024, in samenwerking met een software consultant, verder worden ontwikkeld en publiek beschikbaar gemaakt. De toolkit zal worden uitgebreid met nieuwe functionaliteiten zodat ook de koelvraag meegenomen kan worden.

ad 5. Waterstof-opslag:

Robuuste simulatoren zijn ontwikkeld. De technisch-economische MOLE simulator, die gebruikt kan worden voor opslag van perslucht (CAES), gas (UGS) en waterstof (UHS), is opgeleverd. Waterstof-gekoppelde reacties zijn ontwikkeld in de REACT simulator. Deze software wordt verder ontwikkeld in 2024 en gevalideerd aan de hand van praktijkdata van een waterstof-opslagproject in Oostenrijk (grootschalige veldtest waterstofopslag in een aquifer). Opslag van waterstof in aquifers kan ook voor Nederland interessant zijn, naast opslag in zout. Dit is alleen in Noord-Nederland mogelijk. TNO is een van de belangrijkste kennispartners in dit internationale project voor waterstofopslag in aquifers. Dit is de eerste grootschalige veldtest in de wereld. De TNO bijdrage wordt voor de helft gefinancierd door de EU en voor de andere helft uit SMO-middelen.

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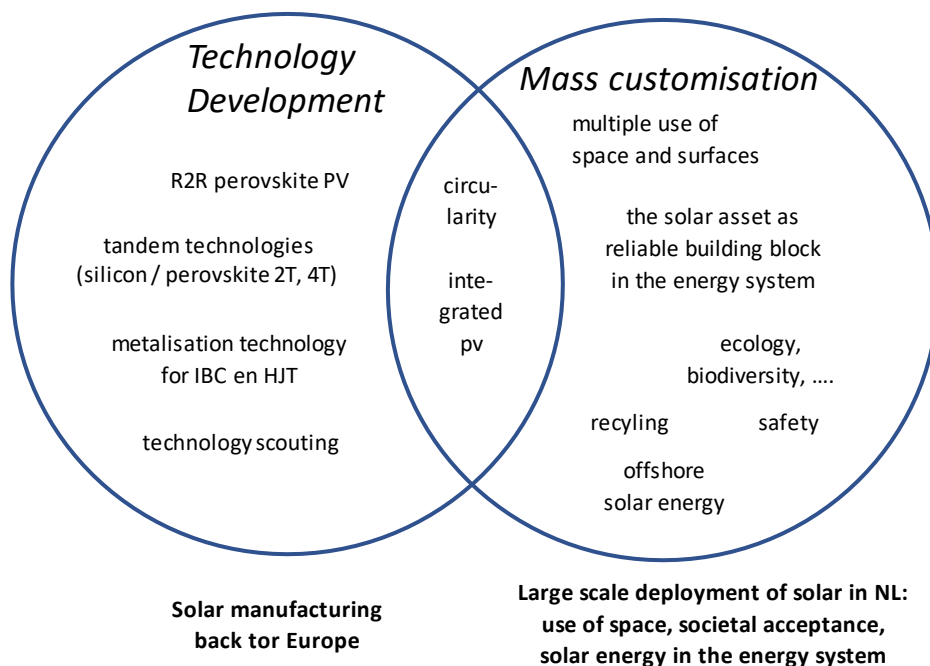
<sup>1</sup> [www.warmingup.info](http://www.warmingup.info)

Titel	VP Karakterisering en Dynamiek Samenstelling Grondwater (P310)
MTIB Thema	Water
Contactpersonen TNO (DM en VPM)	DD: Tirza van Daalen VMP: Willem Jan Zaadnoordijk
Contactpersoon Regie-voerder	Wilbert van Zeventer (I&W), Katja Portegies (RWS); programmaraden TKI Watertechnologie, TKI Deltatechnologie
<b>Programma jaar 2023 - Samenvatting</b>	
<p>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 koudeopslag in de energietransitie.</p> <p>In dit Vraaggestuurd Programma (VP 310) 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 zoet-watertekorten 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.</p> <p>Binnen de instituten die zich met grondwater bezighouden heeft TNO-GDN een unieke positie door de verbinding met geologie inclusief antropogene materialen in de ondergrond, door de affiniteit met data (o.a. DINOloket.nl) en door de aansturing vanuit de gezamenlijke ministeries via de Geo-informatiecommissie (GIC). 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.</p> <p>De kennisontwikkelingsactiviteiten in dit VP 310 KarDySaG leiden tot:</p> <ul style="list-style-type: none"> <li>- Data-analyse en nieuwe informatieproducten betreffende de ondergrond;</li> <li>- Specifieke advisering van stakeholders aangaande het grondwater;</li> <li>- Bijdrage aan nationale ontwikkelingen, zoals het innovatiecontract Watertechnologie, specifiek met kennis ten aanzien van grondwater en ondergrond;</li> <li>- Bijdrage aan internationale ontwikkelingen, onder andere via de CSA voor een 'European Geological Service' (een programma van de gezamenlijk Geologische Diensten in Europa).</li> </ul> <p>Hiertoe wordt samengewerkt met universiteiten, met name de Universiteit Utrecht, Wageningen Universiteit en Technische Universiteit Delft, onder meer via gezamenlijk onderzoek en begeleiden van promovendi en studenten die BSc of MSc-thesis onderzoek doen.</p> <p>In 2023 zijn onder meer de volgende resultaten behaald:</p> <ul style="list-style-type: none"> <li>- Vergroting inzicht aanwezigheid en verspreiding nieuwe stoffen in grondwater (bijvoorbeeld PFAS en geneesmiddelen).</li> <li>- Gebruik van grondwaterdatering en isotopenanalyse voor inzicht in grondwatersysteem en beoordelen concentraties van antropogene stoffen.</li> <li>- Nadere bestudering milieurisico's van kunstmatige verwerking (van olivijn en basalt) als negatieve-CO<sub>2</sub>-emissietechnologie.</li> </ul>	

- Aanpak voor bepaling volumeverandering van het grondwater voor een jaar op grond van metingen. Hiermee kan de jaarlijkse weerrapportage van het KNMI gekoppeld worden aan veranderingen in de grondwatervoorraad en kan het CBS een nauwkeuriger waterrekening opstellen.
- Opzet voor een kwelindicator voor kwelafhankelijke natuur als aanvulling op droogte-indicatoren die alleen van de grondwaterstand uitgaan en draagt bij aan inzicht in het drie-dimensionale karakter ervan.
- Bepaling van heterogeniteit van aquifers uit boorgatmetingen en foto's van boorkernen.

Titel	VP Renewable Electricity (P321)
MTIB Thema	Klimaat en Energie / MMIP2, MMIP3
Contactpersonen TNO (DM en VPM)	<ul style="list-style-type: none"> <li>• Wim Boogaard (Division Director EMT Energy Supply)</li> <li>• Harm Jeeninga (Market Manager EMT Energy Supply)</li> <li>• Jan Willem Wagenaar (VP Manager Wind Energy)</li> </ul>
Contactpersoon Regie-voerder	<ul style="list-style-type: none"> <li>• Ministry of Economic Affairs and Climate. Directorate General Climate &amp; Energy <ul style="list-style-type: none"> <li>○ Eva de Leede: "Clusterleider windenergie op zee"</li> <li>○ Laura Jansen: "Beleidsmedewerker windenergie op zee"</li> <li>○ Ruben Prins: "Beleidsmedewerker windenergie op zee "</li> <li>○ Bart Tulkens: "Beleidsmedewerker energie-innovatie"</li> </ul> </li> <li>• TKI Offshore Energy <ul style="list-style-type: none"> <li>○ Bob Meijer: Director "TKI Offshore Energy"</li> <li>○ Bram van der Wees: Program manager "TKI Offshore"</li> </ul> </li> </ul>
<b>Programma jaar 2023 - Samenvatting</b>	
<p>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 the geopolitical arena provide an incentive to accelerate in obtaining these goals.</p> <p>The huge ambitions of offshore wind encounter barriers such as the speed of implementation and the integration in the energy system. Additional societal challenges are on the aspects of circularity and ecology. The Wind Energy R&amp;D programme aims to tackle these barriers.</p> <p>TNO Wind Energy is leading in developing innovative products and solutions for offshore wind farms, together with companies. The R&amp;D programme of TNO Wind Energy is part of the TKI Offshore Energy and seamlessly aligns with the MMIP 1 "Hernieuwbare elektriciteit op zee", which is based on Mission A: "Een volledig CO<sub>2</sub>-vrij elektriciteitssysteem in 2050". In order to support the implementation of the large amount of offshore wind energy, the primary goals for the next three years are to:</p> <ol style="list-style-type: none"> <li>1. Support the accelerated offshore wind development.</li> <li>2. Improve the integration of large quantities of wind energy in the system.</li> <li>3. Make wind energy generation more sustainable and circular.</li> <li>4. Integrate wind energy generation in the environment.</li> <li>5. Further improve the reliability and affordability of wind energy.</li> </ol> <p>For Solar Energy, this VP supports sustainable large-scale deployment of PV in the Netherlands at low cost and high value. Current outlooks foresee an installed capacity of about 200 GWp in 2050 ('Ruimtelijk potentieel van zonnestroom in Nederland', TKI Urban Energy 2021). Furthermore, this VP aims to strengthen the Dutch and European PV industry and contribute to bringing back manufacturing to Europe. Our R&amp;D covers a large part of the value chain and focuses on increasing the energy generation per surface area (which is related to the conversion efficiency but includes more factors), on spatial and physical integration of PV in remote areas and the built environment (making PV 'invisible'), and on making solar energy, safe, fully sustainable and circular. All these aspects are key to realise the climate goals in which PV plays a significant role.</p>	

**THE TNO STRATEGY FOR SOLAR IN A NUTSHELL**



The programme for Solar Energy is fully aligned with both MMIP1 and 2. The MMIPs are being updated, and their implications have been incorporated in this VP. For the next three years, the primary goals are to:

1. Create tools to improve the performance of sustainable (ecology) solar parks as reliable and predictable building blocks in the energy system;
2. Create technology solutions for high-volume manufacturing of silicon and perovskite customised PV products that can be integrated into elements for buildings, infra and mobility while maintaining the primary function of these elements with proven reliability and safety;
3. Realize cost competitiveness for recycling PV modules, resulting in easy access to high-value materials;
4. Be one of the key partners in establishing novel PV manufacturing in the EU;
5. Increase the efficiency of large area so-called silicon perovskite tandem PV devices.

**Highlights and Results 2023**

Supporting the acceleration of offshore wind development, TNO provides government and industry with high quality wind information across the North Sea by executing a long term measurement programme. In 2023, wind information from 4 measurement platforms was delivered according to plan and, particularly, a new LiDAR measurement platform became operational close to the future wind farms ‘Ten Noorden van de Waddeneilanden’ and Doordewind.

Further supporting the acceleration of offshore wind development, TNO aims to optimize wind farm operation by developing effective O&M strategies and by developing performance and health monitoring systems. Here, robotisation and automation is key. Indeed and according to plan, TNO and partners demonstrated in 2023 that autonomous drone-crawler operations for inspections and repair of wind turbine blades are technically feasible. Also, TNO demonstrated that a dedicated 5G network is able to transfer real-time and interactively local drone inspection footage to a remote control center. Last and according to plan, TNO demonstrated that using LiDAR measurements in combination with dedicated tooling it is possible to closely monitor the performance of wind farms. TNO delivered this platform to its collaborating partners Shell and Vattenfall.



Enabling research on flexibility in the energy system, 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, the battery became operational during 2023 and the electrolyser arrived in January 2024, i.e. a bit later than planned due to issues in the supply chain. Although first tests could not yet be executing in 2023, the team was able to develop a first Energy Management System and to have it tested alongside the facility. Also, preparations are ongoing for experiments to test the coupling of the wind turbines to the battery which are to be executed in a big European project to support the green energy transition of ports, such as the Port of Rotterdam. The potential of the SWITCH facility was widely communicated through a dedicated and very well attended webinar.

Improving the circularity of wind energy, TNO aims to deliver blade fibre recycle opportunities in combination with decommissioning of the blades. We had already proven that fibres from wind turbine blades can be recycled into car dashboards and in a European project a demonstration plant is now being built for scaling up this process. Alongside, TNO developed and demonstrated in 2023 a first version of the UWISE decommissioning tool with which end of life solutions for wind turbine blades can be evaluated.

To integrate wind energy seamlessly in the ecological system, TNO develops bird impact and monitoring systems and deterrence systems. For 2023, it was the specific aim to have several WT-Bird systems installed inside and outside the Netherlands to gain a wider knowledge on bird impact. Indeed, systems have been installed in Groningen together with RWE and in the USA and Taiwan. The collaboration with RWE specifically is to study the effectiveness of black blades in order to mitigate bird impacts. Last, TNO has applied advanced image recognition software to the WT bird system and results show that it is possible to track birds.

Increasing the affordability of wind energy, bigger turbines are being designed requiring larger blades with thicker airfoils. For 2023, we had the aim to develop the design tools for a 15+MW turbine and to assess the viability of sectional blades as a modular design approach. With respect to these sectional blades, progress is underway: first designs have been assessed and structural tests are ongoing at the TNO facilities. More specifically, new and innovative blade tips, as part of sectional blades, have been tested at the TIADÉ research turbine together with GE and LM Wind Power and LiDAR measurements have clearly shown that these tips result in a faster wake recovery, meaning more yield for downstream turbines. Last, and with respect to designing 15+MW turbines, TNO has implemented a dynamic inflow wind field (LES) method, together with GE and Whiffle, for more detailed wind turbine load calculations and TNO has developed a method to better simulate the air flow across thick airfoils. This latter methods is made available to all leading wind turbine manufacturers.

One of the major highlights for solar energy in 2023 was the fact the the SolarNL growth fund program was awarded. Through this initiative, over M€ 800 will be invested in the Dutch solar ecosystem over a period of 8 years. TNO has a substantial role in this programme with a budget of M€ 78. TNO will focus on supporting industry on developing roll to roll perovskite, tandem solutions (perovskite / silicon) as well as processes to apply solar on various surfaces (mass customization) in an aesthetically pleasing way. The program is expected to start in Q1 of 2024.

In 2023, a very successful communication campaign was launched "Bringing back Solar Industry to Europe. This campaign attracted more than 1 million hits on internet and over 1200 participants listed for the two webinars. The webinars, to which also



partners of TNO contributed, focused on production of solar panels in Europe as well as the next generation of solar cells. To support this, new graphic content was created which is available both on the TNO website and Youtube.

Automotive industry is rapidly changing its focus from petrol cars to battery electric vehicles. Integrating solar cells into the body of vehicle has in 2023 become a serious topic for automotive manufacturers worldwide. TNO has been able to use its position in previous year in which we have demonstrated the integration of solar cells in a hood and roof of EV's. Unfortunately, in 2023 Lightyear had to terminate its activities. However, other main clients from Europe and Asia have shown major interests in the TNO technology, leading to B2B projects for a wide range of clients.

<b>Titel</b>	<b>VP CO<sub>2</sub>-neutral industry (P323)</b>
MTIB Thema	Klimaat en Energie, Missie C; MMIP 6, 7 & 8
Contactpersonen TNO (DM en VPM)	Jaap Vente, Richard Braal
Contactpersonen Regie-voerder	Rob Kreiter (TKI-E&I), Jörg Gigler (TKI-Nieuw Gas), Peter Besseling, Paul Verbraak, Roy Dekker (EZX)

### Programma jaar 2023 - Samenvatting

The demand driven program “CO<sub>2</sub> 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<sub>2</sub> neutral Industry is structured in 8 clusters of product market combinations (PMC-Clusters). Below a concise description is presented, together with key highlights for 2023.



Short overview of relevant research topics in the PMC-Clusters in the VP CO<sub>2</sub> neutral industry 2023.

#### Industrial CO<sub>2</sub> capture:

Focusses on cost reduction, process stability, energy efficiency, CO<sub>2</sub> purity, overall emissions of industrial CO<sub>2</sub> capture units. Key words include, blue hydrogen, capture from flue gases and in-process capture. New directions include negative emissions.

#### Key highlight 2023:

In the INITIATE project (H2020) TNO is working with partners to showcase industrial symbioses by using steel gasses to produce ammonia and urea (fertilizer). Part of the project is the TRL7 demonstration of the TNO owned carbon capture technology SEWGS (Sorption Enhanced Water gas Shift). In 2023 the construction of 3 SEWGS columns at the pilot location in Lulea (at SWERIM) was completed successfully.

#### 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.

#### Key highlight 2023:

A 1 MW size heat pump has successfully been tested in the Carnot lab. This showed our capability to test industrial heat pumps. The test results proved that industrial heat pumps can generate steam reliably and efficiently. The results generated great interest from end-users, engineering & contracting firms and consultants.

**Energy Infrastructure:**

Focusses on (trans)national onshore infrastructure development, for new value chains (H<sub>2</sub>, CO<sub>2</sub>) coupled to offshore production of green hydrogen or CO<sub>2</sub> storage. Key aspects include supply and demand balancing including storage needs, cost efficiency, quality sensing, safety of operation, public acceptance and minimum negative ecological and societal impact

*Key highlight 2023:*

Modelling tools of dynamic network simulation and optimisation (PyDolphin, Aurora – for hydrogen system integration) have seen major upgrades. Aurora was extended with a dynamic underground storage model to allow better prediction of the security of supply of a gas network or hydrogen network, as well as a sensor optimization algorithm to allow optimal (minimal) sensor locations to sense the desired quantities in a complete network. PyDolphin has seen major upgrades, e.g. with blue hydrogen production, and the tool has been demonstrated in a project to integrate hydrogen production from an offshore wind park to be delivered to a steel factory to produce green steel with hydrogen use.

**Clean Hydrogen Production:**

This PMC-Cluster focusses on next generation electrolyser technology development for the low temperature and high temperature 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.

*Key highlight 2023:*

Novel components for PEM (proton exchange membrane) electrolysers are developed, tested and validated together with industry. These potentially solve some of the key challenges in the PEM electrolyser, being the use of platinum group materials (especially iridium) and PFAS materials (fluor based membrane where in Europe a potential PFAS ban is discussed).

**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 sequestered either as CO<sub>2</sub> or bio-char.

*Key highlight 2023:*

Torwash is essential to convert agricultural waste streams into suitable feedstocks to produce quality biofuels- and chemicals. Significant progress was made in the design of a new Torwash unit. A cold-flow mock-up is being constructed as a precursor to the final design, marking a critical step in the project's advancement;

**Synthetic Fuels & Chemicals:**

The processes to synthetically produce and convert carbon and nitrogen-based value added compounds, like ammonia, formaldehyde, methanol, dimethyl ether (DME), ethylene, propylene, and kerosene are hindered by low conversion and poor selectivity. This is the main topic of research in this program.

*Key highlight 2023:*

Commissioning and initial tests with the containerized pilot for sorption enhanced DME synthesis technology was successful. DME is a chemical best known in Europe as the propellant for hairspray. It is however a chemical containing oxygen so that it requires less hydrogen/energy to produce. DME is therefore an interesting synthetic alternative for LPG (off grid energy), diesel (it can be used in a diesel engine, without soot emission) and an industrial intermediate towards, olefins, aromatics, plastics and sustainable aviation fuel. In 2023, a project was started in which this pilot unit will be placed in a complete train from CO<sub>2</sub> and H<sub>2</sub> to a purified and sellable DME product.

**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.

*Key highlight 2023:*

**Ultradeep regeneration of sorbents shown to be feasible.** To make direct air capture using a sorbent possible, the material needs to operate at low CO<sub>2</sub> loading and for that ultradeep regeneration is required. This was successfully demonstrated by feeding hydrogen in the regeneration. The concomitant formation of carbon monoxide holds the promise for further cost-effective processing into chemicals and fuels.

**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.

*Key highlight 2023:*

Based on a model inventory, possibilities for a generic data- and scenario-base have been explored as well as connections between CITS (circular Industrial Transformation Model: circular value chains), CIMS (Chemelot Integrated Model system: net zero clusters) and CALLIOPE (energy and feedstock supply chains). The latter serves as base for the holistic model framework for industrial transformation decision making. At the same time these models have been further developed, tested and improved separately.

Titel	VP Luchtkwaliteit (P510)
MTIB Thema	
Contactpersonen TNO (SD en VPM)	Paula Bronsveld (VPM), Erlend Deckers
Contactpersoon Regie-voerder	Paul Rijkse, Maarten van der Geest (MinlenW)
<b>Programma jaar 2023 - Samenvatting</b>	
<p>The primary goal of this VP is to advance the knowledge and technology required for precise and accessible atmospheric emission data. Accurate measurements are a crucial basis for effective strategies to mitigate emissions, leading to cleaner air, climate change mitigation, and biodiversity restoration, in line with public environmental targets.</p> <p>Investments in the Air Quality program enhance TNO's capabilities in measuring, sensing, modeling, satellite observation, data assimilation, and emission inventories. The integrated approach of the VP, combining measuring and modelling capabilities, aims to provide widely applicable emission verification solutions for both the Netherlands and international contexts, supporting both governmental and business projects.</p> <p>The VP's long-term efforts towards 2027, supported by subsidies as well as and direct assignments, target specific developments such as: elucidating health-relevant particulate matter (PM) fractions, developing local and national monitoring and modeling capacities, in-depth understanding of exposure to PM and nitrogen compounds, creating a toolset for quantifying the impact of nitrogen-emitting sources and the implementation of a high-resolution modeling system for greenhouse gases, particulate matter, ozone, and reactive nitrogen.</p> <p>In 2023, some major developments were achieved within the VP Air Quality. In terms of modelling, our open-source chemical transport model LOTOS-EUROS was expanded to include an ultra-fine particle concentration map. A demo for a LOTOS-EUROS module for NH<sub>3</sub> flux calculations, DEPAC-1D, was data-validated in 2023. A prototype mitigation strategy tool was developed, which tests various emission reduction scenarios for PM<sub>2.5</sub>. Monitoring was expanded by integrating mobile measurements, taken by PM sensors on bicycles, into modelled concentration maps. A long-term urban monitoring station was also installed, and the collected samples will be analyzed for the health-relevant indicator Oxidative Potential. One dissemination highlight was a paper on the methane emissions of the Nordstream pipeline sabotage.</p>	

Titel	VP Circulaire Economie (P515)
MTIB Thema	Circulaire Economie
Contactpersonen TNO (DM/SD en VPM)	Jan Harm Urbanus, Richard Braal
Contactpersoon Regie-voerder	Bas Warmenhoven (IenW), Jacqueline Vaessen (Topsector Chemie)
<b>Programma jaar 2023 - Samenvatting</b>	
<p>The Circular Economy is an essential means to achieve the sustainable development goals, conform to the Paris agreement on climate change, and provide a reliable supply of secondary raw materials, specifically strategic &amp; Critical Raw Materials (CRM). A circular economy greatly reduces the use &amp; depletion of exhaustible raw materials by optimally re-using materials, components, and products, and by substituting with renewable raw materials. In doing so, the circular economy contributes to prevention of climate change, environmental pollution, and loss of biodiversity. It also has positive socio-economic effects (see “Mogelijke doelen voor een circulaire economie”, Policy Brief, PBL (PBL Plan Bureau voor de Leefomgeving), July 2021).</p> <p>In the past few years several documents and reports have been published by a.o. the EU, the Dutch government and/or Dutch ministries, and PBL that describe - at a high level - the (Dutch) policy and priorities concerning a more circular economy (a.o. KIA CE 2019, Grondstoffenstrategie 2022, ICER 2023, NPCE 2023, etc.). The activities in this VP aim to accelerate the transition to a more circular economy in the Netherlands, as well as to contribute to the potential of the circular economy for the Grondstoffenstrategie and strategic autonomy. This VP relates to the high level policy and goals in the following ways:</p> <ul style="list-style-type: none"> <li>• Committing to Circular Economy goals 2050 &amp; 2030 (respectively 100% circular economy and 50% reduction of use of abiotic raw materials)</li> <li>• Intensifying research concerning criticality and strategic autonomy (Grondstoffenstrategie 2022).</li> <li>• Supporting maximizing raw material efficiency, Design for Recycling, Circular materials &amp; processes (KIA CE).</li> <li>• Supporting ambition towards circular industry and circular build environment (Coalitie akkoord).</li> <li>• Supporting prioritized value chains (plastics, build environment, manufacturing industry, batteries / electronic devices (ICER 2023, NPCE 2023).</li> </ul> <p>The VP Circular Economy focused on 2 primary topics: 1) Circular Plastics and 2) Circular Strategies &amp; Critical Raw Materials.</p> <p><b>Circular Plastics</b></p> <p>The PMC-Cluster Circular Plastics focuses on accelerating the transition to a circular plastics economy. Through our systems thinking for and thought leadership in NL and EU on plastics value chains we connect stakeholders and jointly develop R-strategies, design guidelines, products and recycling technologies to improve resource efficiency and combat the triple planetary crisis (climate, biodiversity &amp; pollution). Our long-term goals (2027) are:</p> <ul style="list-style-type: none"> <li>• To establish scientifically robust and widely used integrated assessment tools and methodologies to predict the net environmental and economic benefits or burdens of circular plastic strategies;</li> <li>• To co-develop &gt;2 demo-facilities (TRL7) based on advanced recycling technologies (e.g. chemical recycling, dissolution);</li> <li>• At least 3 TRL5 scale-ups of innovative recycling technologies, feeding into the funnel for beyond 2027;</li> <li>• At least 1 prototype (TRL5) of a tool for inline polymer quality assessment during sorting and/or extrusion;</li> <li>• At least 2 prototypes (TRL5) of (packaging) products with high recyclate content and/or less prone to microplastics formation during use or recycling.</li> </ul> <p>Key highlights for 2023 are:</p> <ul style="list-style-type: none"> <li>• The whitepaper “From #plasticfree to future-proof plastics” written and published together with Fraunhofer, which elaborates on the operationalisation of all R-strategies;</li> <li>• A pilot design for Upwash, a TNO technology for pre-treatment of (sorted) plastic waste streams into a feedstock for (chemical) recycling. The design is based on an extensive experimental program with different plastic waste streams;</li> <li>• A machine-learning based model (v1.0) that predicts the sealing performance of packaging using recycled plastics, facilitating TNO and partners to design better packaging products;</li> </ul>	

- A proof-of-principle for the thermo-chemical treatment of mixed textile waste streams. The technology results in valuable products (e.g. bulk chemicals and syngas) from otherwise incinerated materials.

### **Circular Strategies & CRM**

Mid 2023, the PMC-Clusters Circular Value Creation and Circular Electronics merged into the new PMC-Cluster Circular Strategies & CRM (CSC). Both former clusters had complementary propositions on circular strategies and development of sustainable recycling processes. Combining them leads to one integral cluster covering the full product life cycle (from design to recycling) with a strong position on CRM. For the purpose of this report, the PMC-Clusters will be described separately over the first half of 2023.

In the Circular Strategies & CRM program, we aim to contribute to the circular economy, the materials transition, and to the reduction of (critical) raw materials problems. We focus on the materials required for the energy and twin transition, of which many are marked as “critical and strategic raw materials”. CSC will prioritize on underneath issues where we can still create a competitive advantage for Dutch industry & society. Our long-term goals for 2027 are:

1. Developing science-based assessment methods to determine integral impact (environmental, economic, social) of circular strategies and technologies, focusing on CRMs but as mutual collaboration with Circular Plastics to strengthen the model developments;
2. Assessing the potential of the circular economy for CRM, developing potential circular strategies for CRM, by developing a predictive model for the supply, demand, end-of-life treatments and (future) recycling technologies for CRMs in the EU and specifically the Netherlands;
3. Developing sustainable innovative recycling processes, impact driven technology development for CRM recovery from the urban mine. Focus is on electrification of the chemical recycling processes that target the recovery of CRMs.

Key highlights for 2023 are:

- A data & modeling strategy, implemented by the expertise group Circularity & Sustainability Impact (CSI, unit EMT);
- A proof-of-principle for electrochemical leaching and recovery of specific CRMs in a regenerative medium. This means that no chemicals are consumed for this recycling process, a major innovation step towards circularity of CRMs.

The successful merger of the CVC and CE clusters into CSC. As a result, our position in the knowledge domain on Critical Raw Materials is strengthened.



<b>Titel</b>	<b>VP Sustainable Chemical Industry (P603)</b>
MTIB Thema	Sleuteltechnologieën - Mission C / MMIP 6,7,8 / Mission CE
Contactpersonen TNO (DM en VPM)	Jan Harm Urbanus, Richard Braal
Contactpersoon Regie-voerder	Topsector Chemie: Jacqueline Vaessen
<b>Programma jaar 2023 - Samenvatting</b>	
<p>The demand-driven program Sustainable Chemical Industry (VP603 – SCI) is based on drivers from companies active in chemical industry’s value chains and are as such in line with the ambitions of the Topsector Chemie. The program focuses on developing technology in demand-driven Public Private Partnerships that are embedded in specific regional and national ecosystems with international collaborations. This VP works in close collaboration with other TNO VPs and Early Research programs (ERPs) and provide together a complete proposition for the chemical value chain. This VP is organized in the PPP’s Biorizon and Brightlands Material Center and a growing PMC-cluster Photons 2 Chemicals.</p>	
<p><b>Biorizon</b></p> <p>Biorizon’s mission is to enable commercial production of biobased aromatic building blocks, boosting biorefinery revenues and providing sustainable materials for the chemical industry. By 2027, it focuses on expanding its technology and expertise to offer a broader range of safe, sustainable building blocks, supporting a 100% circular economy by 2050. Biorizon’s goals for 2027 include pilot-scale production of novel furan-based (e.g. surfactants and polymer additives) and of drop-in (e.g. biophenol and maleic anhydride) biobased building blocks. Furthermore, Biorizon aims to validate novel safe and sustainable building blocks in two applications, to establish the Biorizon Application Center with partners in the region West-Brabant, and to support Dutch biobased developments with open access infrastructure that is today missing in our EU-region.</p>	
<p><b>Key highlights 2023:</b></p> <ul style="list-style-type: none"> <li>An important milestone was achieved in the advancement of bio-aromatic bio-MPA (methylphthalic anhydride), initially created within Biorizon and now commercialized by spin-off Relement. Relement teamed-up with TNO, Worlée Chemie, and Baril Coatings to successfully demonstrate a high-performance, biobased industrial coating incorporating bio-MPA. Replacing fossil-based phthalic anhydride, this is a step forward in sustainable coatings, recently showcased on an electric wheel loader - <a href="#">Biobased Industrial Coating Demonstrated in the Bright Coatings Project</a>.</li> <li>Capitalizing Biorizon’s expertise, know-how and facilities: Biorizon expanded its scope of renewable carbon solutions by delivering 8 first-of-its-kind biobased surfactant candidates to Henkel and 7 novel biobased plasticizers to Centexbel - <a href="#">Expanding the Renewable Carbon Horizon - Biorizon Event 2023</a>.</li> </ul>	
<p><b>Brightlands Materials Center</b></p> <p>Within this PPP this VP focuses on 2 program lines: Sustainable Buildings and Sustainable Mobility.</p> <p><u>BMC Sustainable Buildings:</u> Within Brightlands Materials Center’s Sustainable Buildings program, we focus on the development and validation of wet-chemical coatings and nanocomposite polymer films for use in windows and building-integrated photovoltaic (BIPV) panels.</p>	
<p><b>Key highlights 2023:</b></p> <ul style="list-style-type: none"> <li>In 2023, we established a pilot line for thermochromic window coatings at Brightlands Chemelot Campus. In the coming three years, we will optimize the pilot scale production of thermochromic coatings, produce 1 m<sup>2</sup> sized thermochromic windows, and install those in test buildings and office buildings to obtain technical performance data and user feedback.</li> <li>Furthermore, we successfully produced thermochromic pigments on lab scale and introduced them in PVB (polyvinyl butyral) and POE (polyolefin elastomer) for laminated windows in 2023. In the coming three years, this technology will be further optimized and scaled up to produce pilot scale thermochromic laminates for performance validation in test</li> </ul>	

buildings. Additionally, the technology will be diversified to other polymer materials such as polycarbonate sheets (light-weight glazing) and PET films (retrofit windows). Also, the potential for re-use of old window glass will be validated in the next three years for producing coated and laminated windows.

- For BIPV panels, we produced more than 200 pilot scale BIPV panels with sparkling colour coated cover sheets, which will be installed on a carport in Maastricht in 2024. In the coming three years, we will monitor the performance of these panels and develop a non-sparkling (matte) version of the same technology. Furthermore, we will develop BIPV covers that efficiently reflect sub-bandgap wavelength light to minimize heat up and ensure high efficiency and long lifetime.

**BMC Sustainable Mobility:** The Sustainable Mobility program line focuses on technology development of composites for implementation of circular and lightweight, structural thermoplastic composite (TPC) materials in the mobility sector, in order to accelerate the material and energy transitions in this sector. In the upcoming years, we aim to develop and demonstrate technology for recycling thermoplastic composites into materials that are technically and economically with virgin materials and are validated in selected target applications. We also aim to develop continuous fibre additive manufacturing (CFAM) technology and validate this technology in relevant target applications with respect to technical and certification requirements as well as the economic business case.

#### **Key highlights 2023:**

- In 2023, we have shown the applicability of the developed TPC recycling technology for a wide range of waste types with different polymers and types of reinforcing fibres, including reclaimed fibres from thermoset composite waste. We have improved the quality of the recycled granulate, allowing application in a wider range of manufacturing processes.
- We have also developed CFAM technology for e-mobility and aeronautic products, together with industrial partners in this field.

#### **Photons-2-Chemicals**

The photons-2-chemicals program focuses on the direct use of sunlight as a sustainable energy source for the production of chemicals and fuels. Currently, the program consists of two research lines: (1) the production of chemicals and fuels using CO<sub>2</sub> as carbon source (gas phase reactions at solid catalysts) and (2) the production of fine chemicals (liquid phase reactions using molecular catalysts).

#### **Key highlights 2023:**

- In 2023, we managed to establish a lab-scale process demonstrator comprising a plasmonic photocatalyst, a plate-shaped transparent flow reactor and a flux guide to perform CO and CH<sub>4</sub> production trials using concentrated natural sunlight as energy source. Outdoor production trials and scale up of this process to pilot scale production is a key target for the coming three years.
- For sunlight-powered CO production, we assessed the economics and compared it to other technologies suited for producing green CO/syngas (e.g. biomass conversion and electrochemical reduction of CO<sub>2</sub>).
- Furthermore, we developed Cu-based plasmonic photocatalysts for sunlight-powered methanol production, and successfully demonstrated their performance on lab scale using artificial sunlight. In the coming three years, we aim at further optimizing this catalyst and developing an integrated outdoor process demonstrator.
- Moreover, we obtained a proof of concept for syngas production via light-powered dry reforming of methane using a Ru catalyst, which will be further developed to a lab scale process demonstrator in the coming three years.
- For solution-phase fine chemicals production, we successfully validated a system consisting of an energy-efficient LED light source and a transparent flow reactor, which will be further tailored and equipped with a sensor for measurements of temperature and light penetration in the coming years.

Titel	VP Industrial Electrification and CCU (P616)
MTIB Thema	Sleuteltechnologieën / Chemie
Contactpersonen TNO (DM en VPM)	Martijn de Graaff, Richard Braal
Contactpersoon Regie-voerder	Topsector Chemie: Jacqueline Vaessen
<b>Programma jaar 2023 - Samenvatting</b>	
<p>The increasing amounts of renewable wind and solar derived electrical energy offer great opportunities for the industrial production of green hydrogen and the conversion of renewable raw materials (e.g. biomass, CO<sub>2</sub>) to added value chemicals and fuels. This program aims at the development and piloting of disruptive Industrial Electrification and CCU technologies, and associated value chains and business models. The focus of the program is on the unique combination of industrial electrification (Power-2-X) with carbon capture and utilization (CCU) employing predominantly renewable feedstock (biobased and CO<sub>2</sub>) and renewable electricity as energy supply.</p> <p>The main goals for the VP are:</p> <ul style="list-style-type: none"> <li>- Maintaining an international business network, working together on international value chain integration, system modelling and regulatory constraints for Power-2-X integration.</li> <li>- Co-development of industrially applicable low- and high-temperature electrochemical technologies focussing on process-integrated electrosynthesis of platform molecules.</li> <li>- Co-development of next-generation highly efficient and low-cost electrolyser technology reducing total system and production costs tapping into the high-tech sector.</li> <li>- Co-development of plasma synthesis technology for production of platform molecules.</li> </ul> <p>The program delivered the following concrete technical results in 2023:</p> <ul style="list-style-type: none"> <li>- Delivery of the whitepaper on high-tech manufacturing of electrolyser components and key insights on methanol and circular carbon in the framework of Power-2-X.</li> <li>- Delivery, commissioning and operation of the PERFORM electrochemical furfural to maleic acid installation, showing high performance in maleic acid production.</li> <li>- Commissioning and operation of the ZEUS CO<sub>2</sub>-to-Formic Acid installation, showing first results in larger scale formic acid production.</li> <li>- Optimized stack components (cell, IC plate, seal and coating technology) and design for SOE stack for performance improvement and SOE technology cost reduction.</li> <li>- Delivery of first experimental results using the new arc plasma system for methane to acetylene and subsequent ethylene production.</li> </ul> <p>Apart from technology developments, we also worked on the further development of the VoltaChem business community on Power-2-X and CCU. And on developing our methods for independently comparing Power-2-X routes and technologies using a combination of Techno Economic Analysis (TEA), Life Cycle Assessment (LCA) and Value Chain Assessment (VCA). Last but not least, we supported multiple large companies and SME's in assessing the feasibility of implementing their technology, and we worked further on identifying a new location and developing a new business and financial model for the Fieldlab Industrial Electrification (FLIE) in Port of Rotterdam.</p>	

<b>Titel</b>	<b>VP Smart &amp; Safe Traffic &amp; Transport (P407)</b>
MTIB Thema	Mobiliteit / Missie D+ (MMIP 9 & 10; deel-KIA Toekomstbestendige Mobiliteitssystemen)
Contactpersonen TNO (DS en VPM)	Arjen Adriaanse (Director of Science); Jannette de Bes, Marika Hoedemaeker, Isabel Wilmink (VP-managers)
Contactpersoon Regie-voerder	Topsector HTSM: Leo Warmerdam; Topsector Logistiek: Niels Agatz; Ministerie IenW: Marieke Smit (directie Innovatie en Strategie voor Mobiliteit), Michel Duinmayer (DGMO/Unit Strategie); Ministerie BZK: Arie Versluis (PDGRO/Geobeleid Kennis en Data).
<b>Programma jaar 2023 - Samenvatting</b>	
<p>Society faces enormous challenges with regard to traffic safety and efficiency, which are complex topics, influenced by a wide range of factors. Some of the key factors and areas of research that can help here include human factors, vehicle factors, road design, infrastructure, traffic regulations, environmental factors (weather etc.) and others. As our cities evolve and populations grow, the need for effective tools to assess and enhance safety on a macroscopic level becomes increasingly critical.</p> <p>The VP<sup>2</sup> Smart &amp; Safe Traffic &amp; Transport focuses on technology and policy for digitization in passenger mobility and logistics. The research Smart &amp; Safe T&amp;T focuses on knowledge and innovation of smart mobility and logistic solutions (digitalization and automation) for increased road safety, accessibility, inclusivity, efficiency and comfort. This is done in five different focus areas:</p> <ol style="list-style-type: none"> <li>1. Development and optimization of smart mobility systems and smart logistics systems (digitalized, connected and automated)</li> <li>2. Assessment of impact of smart mobility systems and smart logistics systems</li> <li>3. 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</li> <li>4. 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</li> <li>5. Concepts that optimise traffic safety ('zero casualties') and the efficiency of the mobility and logistics systems ('zero loss')</li> </ol> <p>In each of these areas a number of highlights of the work in 2023 in the VP smart T&amp;T can be mentioned here:</p> <p>Regarding the development and optimization of smart mobility systems and smart logistics systems (digitalized, connected and automated), there were several highlights, at the vehicle, traffic flow and societal level (from looking how a single vehicle should move to what impacts of innovations in mobility mean for society). During the Automotive week 2023, we successfully demonstrated in real life our automatic trailer mover developments. That is: a trailer driving and parking very precisely autonomously. In the Amadeus project we successfully integrated a new algorithm on lane merging with guaranteed recursive visibility (finding a current trajectory for the vehicle is done in such a way that at the next time stamp you will also find a feasible collision free trajectory) on the TNO car lab and demonstrated that it works. The DITM project (Digitale infrastructuur voor Toekomstbestendige Mobiliteit) investigated methodologies of structuring road layout information in a data model for operational use by AD(AS), specifically Intelligent Speed Assistance (ISA). Also, an overview of ISA requirements to validate the ISA lane level function at the traffic level was made. Furthermore, the project Smart and Attractive Travel Alternatives showed that 99% of all respondents would consider (digital) alternatives for short car trips. Responses to questions about motivations and barriers to choose a specific alternative or not varied quite a lot between respondents, which provides clues for how to approach different groups of travellers to influence their behaviour.</p> <p>For the assessment of impact of smart mobility systems and smart logistics systems, a highlight concerned the EU-project FAME in which an inventory of current best and worst practices in impact assessment of Connected, Cooperative and Automated Mobility (CCAM) was made. This overview is being used in the development of the EU common evaluation method. This evaluation method will be used in Horizon Europe projects testing and evaluating CCAM mobility concepts.</p>	

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<sup>2</sup> VP = Vraaggestuurd Programma – *demand driven (research) program*

Concerning the 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), the recently upgraded TNO human driving simulator was used with human test persons to provide more insight in human response to automated as well as manually driving vehicles, in various driving scenarios. This experiment provided data with which driver models can be made more driver (driving style) and situation dependent, and therefore more realistic. This was implemented into the agent based Large Scale Micro Simulator. The driver models were also validated using drone data of traffic behaviour. Furthermore, the SAFE-UP final event took place in May 2023 where TNO presented the achievements of our Monte-Carlo traffic micro-simulation. In this study TNO has analysed the behaviour of car-to-car interaction for the situation where one of the cars is an automated vehicle. The simulation showed that the introduction of automated vehicles on highways can have both positive and negative traffic safety effects. For this particular simulation, it was found that for lane changes and crossings the number of conflicts (i.e. safety) reduced and that for rear end situations the number of conflicts increased.

For the focus area of 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, the MOVE21 living labs project (Horizon Europe) delivered a report discussing the interim results of the reflective monitoring process for the three Living Lab cities (Hamburg, Oslo, Gothenburg) and intermediate results on the development of the Innovation Co-Creation Partnerships and on increasing innovation capacity and policy coherence.

Regarding concepts that optimise traffic safety ('zero casualties') and the efficiency of the mobility and logistics systems ('zero loss'), several highlights can be mentioned. A prototype of an optimisation method connected to Urban Strategy simulation modules was developed, which will make it possible to automatically optimize interventions across multiple domains, by translating e.g. policy goals into a set of interventions likely to contribute to these goals, and then assessing indicators related to the goals. A first version of the framework was tested on a use case in which adjustments in the road infrastructure and in the public transport network were optimised, in such a way that travel times are optimized, as well as traffic safety aspects. In the Safe to Use project, a misbehaviour detection algorithm (identification of different types of misbehaviour of an ISA system) was developed and tested on the test track with TNO car labs. We extended an existing misbehaviour detection algorithm for several faulty cases relevant for the safety of automated driving. The uniqueness of the algorithm is that it can separate the source and the magnitude of the attack/fault. In the AWARE2ALL EU project the Situation Awareness model "Attendee 2.0" was improved and implemented by TNO in MATLAB. Output of the model is the actual current Situation Awareness of a driver. A model like this to measure current SA did not exist yet.

Titel	VP Sustainable Traffic & Transport (P408)
MTIB Thema	Missie D+ (MMIP 9 & 10; deel-KIA Toekomstbestendige Mobiliteitssystemen)
Contactpersonen TNO (DS en VPM)	Arjen Adriaanse (Director of Science); Marika Hoedemaeker, Isabel Wilmink, Jannette de Bes (VP-managers)
Contactpersoon Regie-voerder	Topsector HTSM: Leo Warmerdam; Topsector Logistiek: Niels Agatz; Ministerie IenW: Marieke Smit (directie Innovatie en Strategie voor Mobiliteit), Michel Duinmayer (DGMO/Unit Strategie); Ministerie BZK: Arie Versluis (PDGRO/Geobeleid Kennis en Data).
<b>Programma jaar 2023 - Samenvatting</b>	
<p>Society faces enormous challenges with regard to Climate, Environment and Sustainability. See for example the Paris Climate Agreement to keep the global temperature rise below 2° Celsius, while striving for 1,52° Celsius.</p> <p>The VP Sustainable Traffic &amp; Transport (T&amp;T) contributes to solving these challenges by focusing on developing technologies and supporting policies for making the mobility sector more sustainable. In 2023, the research focused 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"). This is done in five different focus areas:</p> <ol style="list-style-type: none"> <li>1. 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)</li> <li>2. Assessment of impact of sustainable logistics systems and zero emission mobility systems</li> <li>3. Modelling and simulation tools to estimate impacts of sustainable logistics systems and zero emission mobility systems, at the vehicle, system (traffic) and societal level</li> <li>4. Model and governance concepts regarding the effectiveness of sustainable logistics and mobility.</li> <li>5. Concepts that optimise the efficiency of the mobility and logistics systems ('zero emissions').</li> </ol> <p>In each of these areas a number of highlights of the work in 2023 in the VP sustainable T&amp;T can be mentioned here:</p> <p>For the development and optimization of sustainable logistics systems and zero emission mobility systems, the XCARCITY project will develop realistic digital twins of car-low areas in Amsterdam, Almere and Rotterdam, to study how people use different smart mobility services. To be able to simulate car-low areas, work was done on implementing parking capacities in the traffic assignment model. Also, it was investigated how car ownership in car-low areas should be modelled.</p> <p>In the HIEFFICIENT project, which focuses on the vehicle level, an experimental setup for performing EIS (Electrochemical Impedance Spectroscopy) on a battery pack has been designed and implemented. The key result of the experiment was that the introduced AC component was of sufficient quality for the experiments. The response of the battery was well measurable with the measurement setup. These two results marked that we have a fully functional EIS setup. Between the parallel strings, EIS yielded different responses indicating either a difference in ageing between the cells or a difference in cell temperature. Such results have previously been obtained for single cells, but for a complete battery pack this is beyond the state of the art. Also, a single cylinder Hydrogen Combustion engine for maritime implementation has been prepared and engine measurements have been performed (Green Transport Delta – Waterstof project).</p> <p>For the assessment of impact of sustainable logistics systems and zero emission mobility systems, the Green Maritime Methanol 2.0 project published a policy paper summarising current knowledge on methanol and other options that are currently in consideration in the maritime energy transition. Aspects discussed in this paper are the impacts on climate change, air quality, and operations, the supply side availability and the role for the Dutch maritime sector. In the TULIPS project, TNO developed an improved carbon footprint method for combined passenger-freight operations, which was discussed with IATA (International Air Transport Association), the most important organisation in the airline industry when it comes to agreements on carbon foot printing. This means that this methodology might become a standard that all airlines will follow as recommended practice and potentially contributing to lowering CO2 emissions.</p> <p>For the modelling and simulation tools to estimate impacts of sustainable logistics systems and zero emission mobility systems, at the vehicle, system (traffic) and societal level, TNO determined with a simplified test setup which parameters are relevant for real world measurement protocols to address brake wear emissions (e.g. brake temperatures). Real-world measurements were done using radar and license plate cameras. Tests for brake wear emissions did not exist yet, and the approach developed in the EU-project VERA is already used in a project for DG GROW and for the MaVe project for IenW. Also, the</p>	

TEHUP model (Techno-Economic Heavy-duty Uptake Model) was further developed to include e.g. a longer ownership model; also, a new residual value module was added.

In the Green Transport Delta – Elektronen project, TNO developed the functionality of round trip efficiency of the Battery Management System (BMS). Battery manufacturers officially need a way to calculate this as part of the battery passport. In the EU Battery Competence Center project, TNO's first modular simulation tool has been developed and validated on real battery test data and it showed almost identical results. The tool predicts the performance of your battery cooling concept. This might interesting to bring further to customers like GINAF or Daamen/ heftruck leveranciers.

For the model and governance concepts regarding the effectiveness of sustainable logistics and mobility, TNO was involved in the Green Deal project NetZeroCities (which supports European cities to drastically cut down their greenhouse gas emissions to become climate neutral by 2030). In this project TNO was part of a local ecosystem, being asked as expert from the NZC consortium to support cities, by working on Climate-neutral City Contracts (CCCs, e.g. in Amsterdam and other Dutch cities), and by reviewing CCCs. Other highlights for 2023 include the organization of summer schools for the cities, which showed that it is a challenge for cities to develop an investment plan, which must be there for the CCC to be approved. NetZeroCities has supported TNO in creating a stronger cooperation on the national level, linking to the National Support Structure, so that TNO can offer its knowledge to help strengthen the investment plans and CCCs. Stronger connections with BZK, RVO, IenW, EZK and LNV have been made.

For the concepts that optimise the efficiency of the mobility and logistics systems ("zero emissions") at the vehicle, system and societal level, TNO developed two energy management algorithms for the batteries of heavy duty electric vehicles: Eco-comfort and Ecocharging. The eco-comfort algorithm finds the setpoints for the vehicle thermal systems that minimize its total energy consumption. To do so, the eco-comfort algorithm uses look-ahead information of the power train energy consumption and the weather conditions. The eco-charging algorithm finds a charging schedule for an electric vehicle fleet, such that the timing requirements of the fleet are satisfied and the battery ageing is minimized. These algorithms were verified in a simulation environment and will be further tested in a living lab and real road tests (URBANIZED project).

In another project, key influencing factors on electric vehicle (EV) adoption were collected, such as affordability of EVs and the availability of charging infrastructure, which can help to answer the question how low income groups can be helped to benefit from electrification in mobility. Based on the list of key factors, a system analysis was done by creating causal loop diagrams (CLDs), which show how factors previously identified interconnect on a systemic level and how they would affect EV uptake. The system analysis regarded two concepts regarding EV uptake: EV ownership and EV sharing, which were brought together in one overarching model. The model was then used for policy testing, where different policy scenarios were formulated and their outcomes regarding the potential impact on EV uptake, specifically by low income groups, were qualitatively discussed.

Titel	VP Duurzaam Bouwen (P502)
MTIB Thema	Klimaat en Energie
Contactpersonen TNO (DS en VPM)	Arjen Adriaanse en IJsbrand van Straalen
Contactpersoon Regievoerder	Programmacommissie Deltatechnologie (PCDT), Thematisch overleg via het Afsprakenkader TNO-RWS, Jelle Bluemink en Hans Weijers (BZK), Bart Brink (TKI Bouw & Techniek), David van der Woude (BZK), Debby Joosen (EZK), Marjolein van Splunder (EZK), Guus Mulder en Robert Jan van Egmond (TKI Urban Energy), Hans van der Weijde (TKI HTSM, M2i), Bas Buchner (TKI Maritiem) en Bob Meijer (TKI Wind op Zee)
<b>Programma jaar 2023 - Samenvatting</b>	
<p>VP Duurzaam Bouwen richt zich op het optimaal verduurzamen van de gebouwde omgeving en van maritieme en offshore constructies. Dit betreft civiele infrastructuur, woningen en gebouwen, windmolens op zee en schepen. Maatschappelijk relevante thema's zijn daarbij CO<sub>2</sub>-reductie, verminderen van de gasafhankelijkheid, betaalbaarheid, circulariteit, veiligheid, (voorspelbaarheid van) onderhoud en vervanging, en digitalisering. VP Duurzaam Bouwen bestaat uit vier deelprogramma's: <u>Infrastructuur</u>, <u>Bouwinnovatie</u>, <u>Energie in de gebouwde omgeving</u>, en <u>Maritieme constructies</u>.</p> <p><u>Infrastructuur</u></p> <p>Het doel van het deelprogramma <u>Infrastructuur</u> is het creëren van handelingsperspectief binnen het asset management van een onze (verouderende) infrastructuur door het verkleinen van onzekerheden, het kunnen prioriteren van de urgentie en het beperken van de stijging in kosten en duurzaam materiaalgebruik.</p> <p>Hoofdvraag binnen thema 1 (<i>veilige, beschikbare en betaalbare bestaande infrastructuur</i>) is of en wanneer kunstwerken moeten worden vervangen voordat de veiligheid in het geding komt. Het onderzoek richt zich daarom op het nauwkeuriger voorspellen van de restlevensduur van constructies. De rekenregels hiervoor zijn onder andere opgenomen in normen en richtlijnen voor staal- en betonconstructies (NEN 8702, NEN 8703, <i>fib</i> Modelcode). Hierdoor kunnen kosten voor beheer en onderhoud worden verminderd of beheerst, doordat niet te vroeg of te laat wordt vervangen of gerenoveerd.</p> <p>Het thema <i>data-gedreven beheer en onderhoud</i> (thema 2) richt zich op het benutten van gegevens en analyses om voorspellend onderhoud en efficiënter beheer van infrastructuuractiva mogelijk te maken. De inzichten (methoden en technieken) die hiervoor worden ontwikkeld, stellen beheerders in staat om hun assets efficiënt te managen.</p> <p>Binnen thema 3 (<i>verduurzamen van de infrastructuur</i>) zijn in 2023 in het Europese project ReCreate belangrijke stappen gemaakt voor het hergebruik van (geprefabriceerde) constructieve elementen. Ook zijn de contouren geschetst van een veiligheidsfilosofie waarbij een afweging tussen (in de basis) onvergelykbare grootheden moet worden gemaakt (constructieve veiligheid versus circulariteit). Op het gebied van asfalt is een haalbaarheidsstudie uitgevoerd naar de toepassing van olie gewonnen uit micro-algen als verjongingsmiddel in asfalt. Het onderzoek wordt in het kader van een Early Research Programma (ERP) in de komende vier jaar verder uitgediept.</p> <p>Het thema <i>klimaatadaptieve infrastructuur</i> (thema 4) omvat het ontwerp van resiliënt ('veerkrachtige') kunstwerken en systemen en richt zich op innovatieve concepten om het herstelvermogen van kunstwerken en systemen te vergroten (in het bijzonder civieltechnische en nature-based oplossingen). De kennisontwikkelingen voor dit thema bevinden zich in een beginnend stadium. In 2023 zijn oriënterende verkenningen gedaan voor de eisen die moeten worden gesteld aan de eisen aan klimaatadaptatie voor transportnetwerken. De basiseis hierbij is het snelle herstel van de mobiliteit na een calamiteit.</p> <p><u>Bouwinnovatie</u></p> <p>Doel van het deelprogramma <u>Bouwinnovatie</u> is bijdragen aan het optimaliseren van bouwproducten, bouwelementen en gebouwen op basis van integrale multicriteria aanpak gericht op veiligheid, duurzaamheid, betaalbaarheid en opschaling van de woning- en utiliteitsbouw.</p> <p>Het thema <i>veiligheid van gebouwen</i> richt zich op de kennisvraag hoe we ervoor zorgen dat bestaande en toekomstige gebouwen voldoende bestand zijn tegen de veranderende invloeden vanuit klimaatverandering, bodemdaling als ook materiaalgebruik. Om de effecten van bodemdaling beter in kaart te brengen, zijn eenvoudige modellen ontwikkeld om scheurvorming in metselwerkgebouwen op basis van actuele zettingsprofielen te voorspellen en is een verbeterde techniek</p>	



voor automatische lintvoegmetingen ontwikkeld om gebouwvervormingen in de tijd te volgen. Daarnaast is in 2023 nagegaan hoe verschillende inspectie- en monitoringstechnieken ingezet kunnen worden om de constructieve veiligheid van bestaande constructies op een alternatieve manier te beoordelen. Deze technieken zullen in de toekomst een rol spelen bij het vaststellen van alternatieve beoordelingsmethoden die TNO zal ontwikkelen.

Het effectief *verduurzamen van zorggebouwen* is een belangrijk thema voor de komende jaren om aan de klimaatdoelstelling te voldoen. Verduurzaming van zorgvastgoed krijgt steeds meer aandacht van de zorginstellingen binnen het Expertisecentrum Verduurzaming Zorg (EVZ). TNO faciliteerde in 2023 diverse activiteiten, en droeg bij aan actualisering van de kennis- en ontwikkelagenda, en wegnemen van kennisleemten inzake CO<sub>2</sub>-emissiereductie. Binnen het Innovatie Platform Ziekenhuizen lag in 2023 de focus op het standaardiseren van spreek- en onderzoekruimten in het kader van renovaties. In het kader van het VWS Onderzoekprogramma Duurzaam beschikbare zorg is nagegaan hoe de capaciteit en kwaliteit van de langdurige zorghuisvesting in kaart is te brengen en wat mogelijke innovaties op dit gebied zijn. De resultaten stellen zorginstellingen in staat om oplossingen voor verduurzaming toe te gaan passen rekening houdend met de benodigde capaciteit en kwaliteit.

Het thema *verduurzaming van steenachtige materialen* richt zich op de verduurzaming van constructies voor gebouwen en infrastructuur. In 2023 is een begin gemaakt met de ontwikkeling van een test voor de beoordeling van negatieve effecten van aanwezig sulfaat in beton te gevolge van toegepaste duurzame bindmiddelen. Om de levensduur van bestaande betonnen constructies te verlengen is in 2023 een overzicht uitgewerkt van inspectie-/monitoringstechnieken en kathodische bescherming tegen corrosie. Deze activiteiten zullen er aan bijdragen dat alternatieve bindmiddelen voor beton breder geaccepteerd zullen worden en de levensduur van bestaande betonconstructies verlengt kan worden.

Toepassing van *houtbouw en andere biobased materialen* wordt gezien als één van de oplossingen om de klimaatdoelen te halen en een circulaire economie te realiseren. Aangaande constructieve aspecten van houtbouw is hiervoor onderzoek uitgevoerd naar manieren om de robuustheid van houten constructies te beoordelen en naar de toepasbaarheid van de methode voor houtclassificatie op hergebruikt en inlands hout. Op basis van economische analyses is het effect van het gebruik van hout/biobased materialen op de CO<sub>2</sub> uitstoot/opslag inzichtelijk gemaakt. In het kader van levensduur zijn verschillende beoordelingsmethoden van houtelementen voor hergebruik vergeleken en is een testprotocol opgesteld voor biobased isolatiematerialen. Met deze resultaten kan TNO in de bijdragen aan de vereist opschaling.

#### Energie in de gebouwde omgeving

Doel van deelprogramma Energie in de gebouwde omgeving is een energiepositieve gebouwde omgeving in 2050. Hierbij richt TNO zich op het ontwikkelen van kennis en innovaties die in de praktijk leiden tot snellere, betere, slimmere en betaalbare verduurzaming van woningen en utiliteitsgebouwen, waarbij de gebruiker centraal staat.

Het doel van het thema *integrale verduurzamingsoplossingen* is om de sector te helpen de energietransitie te versnellen met de ontwikkeling van integrale verduurzamingsoplossingen die beter en betaalbarer zijn en waarbij de gebruiker centraal staat. In 2023 is gewerkt aan de ontwikkeling van verschillende integrale verduurzamingsoplossingen voor bestaande gebouwen, bestaande uit verschillende combinaties van warmtepomp, thermische collectoren, warmtebatterij, PCM (Phase Change Materials) buffers en PV panelen. Hierbij zijn verschillende technologische ontwikkelingen samengebracht om tot *integrale* systeemoplossingen te komen, met aandacht voor onder andere gebouwschil én installaties, verwarming én koeling en gebouw én energienetwerk. Ook is de thermoakoestische warmtepomp verder geoptimaliseerd en zijn modellen ontwikkeld voor een hybride warmtepomp en een lucht-water warmtepomp waarmee het mogelijk wordt om het volledige bereik van de warmtepomp te modelleren.

Het doel van het thema *sturen op werkelijke prestaties* is om de sector in staat te stellen gebouwen te realiseren die aantoonbaar energiezuinig, gezond en comfortabel zijn in de praktijk. TNO richt zich hierbij op het ontwikkelen van methodieken en datagedreven gebouwmodellen (*predictive twins*) voor het vaststellen, voorspellen, verbeteren en sturen (*model predictive control*) van *daadwerkelijke* prestaties op het gebied van energie, comfort en binnenluchtkwaliteit. In 2023 is de predictive twin SirinE, een gecombineerd ventilatie- en verwarmingsmodel voor het voorspellen van de energie- en binnenmilieuprestaties voor zowel woningen als kantoren, verder doorontwikkeld. Hierbij lag de focus op het beter modelleren van ventilatiesystemen, binnenluchtkwaliteit en gebruikersgedrag. Dat is belangrijk om de werkelijke prestaties van gebouwen beter te kunnen voorspellen. Ook is onderzoek gedaan naar de binnenluchtkwaliteit in woningen en benodigde interventies om de binnenluchtkwaliteit te verbeteren. Dit heeft geresulteerd in de opname van gezondheidkundige eisen in het Convenant Toekomstbestendig Bouwen.

Het doel van het thema *slimme gebouwen voor een robuust energienetwerk* is om de sector in staat te stellen gebouwen of gebouwclusters te realiseren die bijdragen aan een robuust en duurzaam energienetwerk, in optimale samenhang met andere gebouwaspecten zoals CO<sub>2</sub>- en energiebesparing, betaalbaarheid en comfort. TNO richt zich hierbij op het ontwikkelen van oplossingen voor het vergroten en ontsluiten van flexibiliteit van gebouw(installaties), zoals regelsystemen, standaarden voor warmtepompen en compacte warmteopslagsystemen. In 2023 zijn verschillende predictive twins ontwikkeld voor toepassing in een model predictive control (MPC) voor energieflexibilisering in woningen en kantoren en is gestart met het testen van één van deze MPC's in de praktijk. Ook is de werking van de componenten van een nieuw concept voor thermochemische warmteopslag is aangetoond ('proof of principle'). Hiermee zijn belangrijke stappen gezet om warmteopslag in de gebouwde omgeving mogelijk te maken.

Het doel van het thema *versnelling gebouwverduurzaming* is om de sector in staat te stellen processen en producten te standaardiseren en te industrialiseren om daarmee de verduurzaming sneller en goedkoper te maken. De contingentenaanpak<sup>3</sup> staat hierin centraal. TNO richt zich hierbij op de ontwikkeling van tools voor gebouwclustering waarmee de herhaalbaarheid en opschaalbaarheid van bestaande en nieuwe verduurzamingsoplossingen voor woning- en utiliteitsbouw kan worden verbeterd en gegarandeerd. In 2023 is met name gewerkt aan het extern bruikbaar maken van de clustertool om aanbieders van verduurzamingsoplossingen in staat te stellen zelfstandig contingenten te vormen. Ook zijn dertien zogenaamde beeldfeatures toegevoegd aan de clustertool (onder andere aanwezigheid van dakkapellen, uitbouw, ventilatievoorzieningen) en is een AI aanpak ontwikkeld om continue aspecten mee te kunnen voorspellen (onder andere kosten, energieprestatie, radiatorcapaciteit). Tenslotte is een blauwdruk “productgericht verduurzamen van woningen aan de hand van contingenten” voor woningeigenaren opgesteld.

#### Maritieme constructies

Doel van deelprogramma Maritieme constructies is om nieuwe en bestaande maritieme en offshore constructies, opererend onder de meest extreme omstandigheden, veiliger en betrouwbaarder te maken.

Het eerste thema richt zich op *het voorspellen van de levensduur en het monitoren van het gedrag* van maritieme en offshore constructies. Het doel is om gegeneraliseerde en gevalideerde modellen te ontwikkelen, voor zowel constructies van staal (funderingsconstructies, pijpleidingen, opslagtanks), van composiet (bijvoorbeeld windturbine bladen of opslagtanks) en voor dynamisch belaste elektriciteitskabels (die drijvende zonneparken verbinden met het grid). Om een goed beeld te krijgen van het gedrag van deze constructies is het van belang ze te monitoren, maar ook om de effecten van onzekerheden goed te kunnen voorspellen. Omdat hier grote hoeveelheden berekeningen voor nodig zijn, zijn zeer snelle modellen cruciaal. In 2023 is onderzocht welke analytische modellen hiervoor geschikt zijn. Daarnaast is een demo ontwikkeld van een meetsysteem (op basis van optische vezels) voor composieten bladen. Deze combinatie is belangrijk om de levensduur van deze constructies goed te voorspellen.

Het tweede thema betreft het ontwikkelen en demonstreren van een *veiligheidsmethodiek voor de introductie van alternatieve brandstoffen* (zoals waterstof, methanol en ammoniak) op basis van equivalente veiligheid. Centraal staan de ongeval scenario's, de waarschijnlijkheid van optreden, en de consequenties daarvan. Deze methodologie moet gevoed worden met technisch bewijs. Om deze te verkrijgen is in 2023 een testomgeving gerealiseerd, waar op kleine schaal experimenten met waterstof uitgevoerd gaan worden. Op modelgebied is de eerste versie van de virtuele testomgeving ontwikkeld voor de toepassing van waterstof aan boord van schepen, waarin alle onderdelen van de opstelling gemodelleerd. Bovenstaande ontwikkelingen richten zich voornamelijk op de toepassing van waterstof. Daarnaast werken we ook aan toepassingen voor methanol en ammoniak, die onderdeel zijn van de rapportage van P407 Smart and Sustainable Mobility.

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<sup>3</sup> <https://publications.tno.nl/publication/34637810/LIRIXX/mulder-2021-in.pdf>

Titel	VP Work and Youth Health (P204) <sup>4</sup>
MTIB Thema	Gezondheid en Zorg
Contactpersonen TNO (DM en VPM)	Seth van den Bossche, Sandra Eikhout
Contactpersoon Regie-voerder	Ministerie van Sociale Zaken en Werkgelegenheid: Fleur Clemens Ministerie van Economische Zaken & Klimaat: Joren Schep Topsector HTSM/Nanotech: Ronny van 't Oever Ministerie van Volksgezondheid, Welzijn & Sport: Kallista de Graaf
<b>Programma jaar 2023 - Samenvatting</b>	
<p>Het onderzoeksprogramma Work &amp; Youth Health richt zich op het maatschappelijk thema Gezondheid en Zorg en het thema Human Capital van het Missiegedreven Topsectoren- en Innovatiebeleid. Het programma omvat twee deelprogramma's: 1. <i>Future of Work</i> en 2. <i>Youth Health</i></p>	
<p>Het programma draagt direct bij aan de centrale missie van het maatschappelijk thema Gezondheid en Zorg: <i>"In 2040 leven alle Nederlanders tenminste vijf jaar langer in goede gezondheid, en zijn de gezondheidsverschillen tussen de laagste en hoogste sociaal-economische groepen met 30% afgenomen"</i>. De focus hierbij ligt op innovaties ter preventie van gezondheidsproblemen -en verschillen bij twee doelgroepen: de (potentiële) beroepsbevolking en kinderen/jongvolwassenen. Daarnaast draagt het programma bij aan de missie van de Human Capital Agenda Topsectoren: <i>"In 2030 kunnen we in Nederland met de beschikbare beroepsbevolking zorgen voor de ontwikkeling en toepassing van baanbrekende oplossingen die nodig zijn voor Nederland als klimaatbestendig, water-robust, duurzaam, gezond en veilig innovatieland"</i>. Hierbij ligt de focus op het vergroten van het adaptief vermogen en productiviteit van werkorganisaties, respectievelijk de duurzame inzetbaarheid van de (potentiële) beroepsbevolking.</p>	
<p>Het deelprogramma <i>Future of Work</i> omvat de volgende kennislijnen en doelen:</p>	
<b>Kennislijnen 2023</b>	<b>Doelstelling 2022-2025</b>
<i>Afstemming SZW</i>	
Inclusive work	Nederlandse arbeidsmarkt inclusiever maken, door middel van innovaties die inclusief ondernemerschap vergroten. Duurzame instroom verhogen, door versterking en innovatie van de uitvoeringspraktijk.
Labour market innovation	Adaptiviteit van de Nederlandse arbeidsmarkt en leven lang ontwikkelen (upskilling/reskilling) bevorderen, door ontwikkeling van skills-gebaseerde strategieën.
Occupational Exposome	Ontwikkeling effectieve preventieve maatregelen voor werk gerelateerde 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.
Stress & sensing	Verminderen van werk gerelateerde mentale gezondheidsproblemen door vergroten van inzicht in oorzakelijke factoren en het ontwikkelen van effectieve interventies.

<sup>4</sup> This VP integrates 5 former VPs: P204, P211, P511 & P207. Naast work & youth health vallen hieronder ook de onderzoeksgebieden Social Innovation en Human Health Nanotechnology.

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.
<i>Afstemming EZK</i>	
Smart working	Oplossingen leveren voor en het optimaliseren van duurzame (industriële) werkplekinnovaties voor verhoogde productiviteit m.b.v. slimme technologieën.
<i>Afstemming HTSM</i>	
Safe Chemical Innovation (HTSM)	Toepassingen ontwikkelen die gemakkelijk te implementeren zijn door de industrie binnen hun eigen product innovatie processen om nieuwe chemicaliën, (nano/geavanceerde) materialen en/of producten te ontwikkelen welke veilig en duurzaam zijn (SSbD).

Het deelprogramma *Youth Health* omvat de volgende kennislijnen en doelen:

<b>Kennislijnen 2023</b>	<b>Doelstelling 2022-2025</b>
<i>Afstemming VWS</i>	
Integrale aanpak 1 <sup>e</sup> 1000 dagen	Ondersteuning van (aanstaande) ouders, door doorontwikkeling van preventie- en zorgmodellen waarbij zelfmanagement, interactief leren en peer support centraal staan.
Preventie en Jeugdhulp op maat	Ondersteuning en versterking van kinderen, ouders en professionals in het (preventieve) veld voor jeugd, inclusief integratie van digitale innovaties middels doorontwikkeling I-JGZ platform.
Samenwerking en implementatie	Ondersteuning van organisaties om de transitie en transformatie van het jeugdstelsel goed vorm te geven. Landelijk implementeren van effectieve interventies op het terrein van scheiding en pesten. Opzetten van duurzame leernetwerken en ontwikkelen van implementatiestrategieën.

### **Highlights 2023**

#### *Future of Work*

- Succesvolle afsluiting van Horizon Europe BEYOND4.0-project: excellente beoordeling in eindevaluatie. In 2023 is tevens Horizon Europe SEISMEC opgezet: een grootschalig EU-project in samenwerking met oa Erasmus Universiteit, dat zich richt op de ontwikkeling van human-centric concepten voor 14 industriële sectoren. De focus ligt hierbij op human centric AI.
- Eerste bèta-versie van HARMLESS Decision Support System ontwikkeld, een Safe by Design aanpak voor nanomaterialen, samen met industriële (oa BASF, NOURYON) en consultancypartners.
- Start NWA traject waarbij TNO een Safe and Sustainable by Design aanpak ontwikkelt en toepast op plasma-technologie. Tevens Gov4Nano eindconferentie bij OECD in Paris, waarbij TNO het safe-by-design nano risk governance portal (NRGP) presenteerde.
- Nieuw EU Horizon project “Skills for Labour Markets in the Green and Digital Transition” (SkilMeeT). Ook is een landelijk innovatieprogramma Sharebouw en Techniek gestart, waarin met 4 regionale bouw innovatie hubs een human capital agenda wordt ontwikkeld ten behoeve van een toekomstbestendige leefomgeving.

#### *Youth Health*

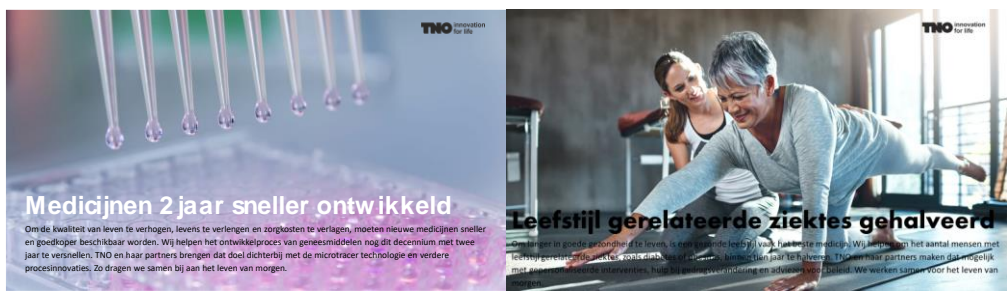
- Binnen lijn 1e 1000 dagen is voor CenteringPregnancy een economische analyse uitgevoerd en gepubliceerd. Deze publicatie heeft geleid tot een NZA tarief voor verloskundigen om Centering aan te bieden tijdens de zwangerschap.
- De ontwikkeling van de D-score heeft geleid tot uitreiking van de Lorentz-prijs aan Prof. dr. Stef van Buuren. Op basis van een studie in Bangladesh is de D-score in 2023 uitgebreid met het IDELA meetinstrument. Dit instrument meet ontwikkeling van kinderen tussen de 4 en 6,5 jaar.
- I-JGZ platform is verbeterd door TNO. 25 JGZ-organisaties maken inmiddels gebruik.
- Op het terrein van terugdringen overgewicht kinderen zijn nieuwe technologieën ontwikkeld om biomarkers bij kinderen accuraat te kunnen meten in zeer kleine hoeveelheden bloed. De analytische technieken en bijhorende biomarkertechnologieën werden getest en gevalideerd in real-life samples van betekenisvolle (klinische) cohorten.

<b>Titel</b>	<b>VP Biomedical and Digital Health (P203)</b>
MTIB Thema	Gezondheid en Zorg
Contactpersonen TNO (DM en VPM)	Sandra Eikhout (DM), Jasper Kieboom (VPM)
Contactpersoon Regie-voerder	Nico van Meeteren (Topsector LSH)

**Programma jaar 2023 - Samenvatting**

The research program Biomedical and Digital Health supports the mission driven innovation approach of the Dutch Ministry of Health, Wellbeing and Sports ('VWS'). The program 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. TNO research further contributes to reducing health issues that are the consequence of an unhealthy lifestyle or exposure to unhealthy environment (mission I). Our research also contributes to preventing chronic diseases and increase the proportion of people with a chronic illness or lifelong disability that can participate in society (mission III).**

Our research focusses on reducing the risk of disease development (prevention) and on improved disease management. We do so by developing breakthrough technologies and approaches such as lifestyle interventions, digital health technologies and drug development tools. The research program Biomedical and Digital Health significantly contributes to the two moonshots of TNO illustrated below:



The program has been executed with private partners, knowledge institutes, government and citizens (the quadruple helix), primarily through public-private-partnerships, fully or partially co-funded by the program. Funding from other sources has been added including funding from EU, National Growth funds and ZonMw funding. All projects aimed to develop and implement new technologies and approaches that can be used in the real world. This in turn has led to projects that are conducted as contract research for public and private partners.

As contribution to the above missions and moonshots the following examples of short-term results for 2023 have been achieved:

- Clinical validation of a prognostic biomarker signature for liver fibrosis and develop biomarker panels for new disease areas associated with stress, aging and cognitive decline.
- Demonstration of the applicability of accelerated mass spectrometry technology for drug testing in a pediatric clinical cohort.
- Generation of a demo-case of relevance of timing of lifestyle interventions for improved health result in shift workers
- Implementation of digital biomarkers in clinical trials.
- Technical solutions to make individual health data reusable in a privacy-by-design way that is fully transparent to reduce the impact of cancer by supporting early diagnostics.
- Supported the implementation of frameworks for patient centric digital health trials.

Titel	VP Veilige Maatschappij (P102)
MTIB Thema	Veiligheid
Contactpersonen TNO (DM en VPM)	Gwen Jansen-Ferdinandus (VPM), Tjarda Krabbendam-Hersman (DM)
Contactpersoon Regievoerder	Mr. H. Hanoeman en drs. B. ter Luun (Ministerie van Justitie en Veiligheid)
<b>Programma jaar 2023 - Samenvatting</b>	
<p>Rechtvaardigheid en veiligheid zijn een voorwaarde voor welzijn en economische ontwikkeling. Recht en veiligheid zijn 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 rechtvaardig en veilig te houden.</p>	
<p>Veiligheid is één van de vijf centrale maatschappelijke thema's binnen het missiegedreven innovatiebeleid van het kabinet. Een veilige samenleving is ook één van de vier beloften uit de TNO-strategie 2022 – 2025.</p>	
<p>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 toegepast wetenschappelijk onderzoek heeft een precompetitief karakter waarin ideeën worden uitgewerkt tot prototypen. Afhankelijk van de situatie kunnen deze prototypen via verschillende valorisatieroutes worden doorontwikkeld en geïmplementeerd maar 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 die onderwerpen die voor het justitie- en veiligheidsdomein het belangrijkste zijn.</p>	
<p>In 2023 stonden vijf inhoudelijke thema's en een programma rond verkenningen en innovatiemanagement centraal:</p>	
<ul style="list-style-type: none"> <li>- <i>Cyber en Kritieke Digitale Infrastructuur</i>: gericht op innovaties rondom cyber weerbaarheid, het versterken van misiekritische informatie- en communicatiesystemen en interceptie. Het onderzoek wordt uitgevoerd met verschillende onderdelen van het Ministerie van Justitie en Veiligheid in samenhang met het Vraaggestuurd Programma Cyber binnen TNO.</li> <li>- <i>Rechtstaat en Opsporing</i>: onderzoek naar de toepassing van AI, data en sensingtechnologie voor het versterken van organisaties in de strafrechtketen en onderzoek naar criminele fenomenen en gedrag voor de aanpak van ondermijnende criminaliteit. Het onderzoek vindt plaats in samenwerkingen met o.a. DJI, het OM en de Regionale Informatie en Expertise Centra (RIEC's).</li> <li>- <i>Data en Intelligence</i>: gericht op het (door)ontwikkelen van methodes zoals AI-taaltechnologie en Privacy Enhancing Technologies (PET) om deze geschikt voor toepassing binnen het justitie- en veiligheidsdomein te maken. Het toepassen van deze innovatieve concepten vindt plaats in samenwerking met het OM, de DJI, partijen uit de migratieketen en verschillende organisaties in de crisisbeheersing die worden gecoördineerd door het Ministerie van Justitie en Veiligheid.</li> <li>- <i>Security en Surveillance</i>: ontwikkeling van robotica technologie om nieuwe mogelijkheden en innovaties voor het justitie- en veiligheidsdomein te creëren. Daarnaast vindt toegepast onderzoek plaats met de Koninklijke Marechaussee, gericht op het verbeteren van opsporing en grenstoezicht. Tevens wordt binnen verschillende Europese onderzoeksprojecten onderzocht hoe terrorisme en radicalisering kunnen worden tegengegaan.</li> <li>- <i>Weerbaarheid Veiligheidsprofessionals</i>: gericht op sociale innovaties en op de ontwikkeling van immersieve leer-technologie (Augmented Reality en Virtual Reality) om veiligheidsprofessionals sneller en beter te laten leren en trainen. Daarnaast wordt onderzoek gedaan naar professionele fitheid samen met DJI.</li> <li>- <i>Verkenningen en innovatiemanagement</i>: binnen de verkenningen worden nieuwe technologieën met een potentieel grote impact op het justitie- en veiligheidsdomein verkend. Daarnaast wordt samen met DJI en het OM onderzoek gedaan naar het versterken van het innovatievermogen van organisaties.</li> </ul>	

Enkele highlights uit de resultaten van het onderzoek in 2023:

- Binnen het technologieontwikkelprogramma *Immersieve Leertechnologie* is een proof-of-concept ontwikkeld voor een adaptieve virtuele trainingsomgeving voor politiemedewerker. Binnen deze virtuele omgeving kunnen politieagenten op een immersieve en effectieve manier leren waar ze op moeten letten bij een plaats delict nog voordat ze daar ooit zelf aanwezig zijn geweest. De leeromgeving volgt het leergedrag van de politiemedewerker en geeft hierover terugkoppeling aan de leerling en instructeur waardoor de training beter kan worden afgesteld aan de individuele behoeften. Adaptieve XR-leeromgevingen bieden een kans om op een effectievere manier mensen op te leiden wat een belangrijke stap is in het tegengaan van personeelstekorten.
- In het programma *Innovatieve en veranderkundige concepten nieuwe Wetboek van Strafvordering* is een serious game ontwikkeld waarmee ketenpartners ervaring opdoen met de impact van de vernieuwingen in het Wetboek van Strafvordering. De game stelt de spelers in staat om op een laagdrempelige manier de ingrijpende veranderingen te ervaren. Dit leidt tot inzicht in de benodigde ontwikkelingen binnen de keten en de uitdagingen die daarbij komen kijken.
- In het kennisopbouwprogramma voor de Immigratie- en Naturalisatiedienst is een ketenbrede systeemanalyse uitgevoerd. Dit heeft geleid tot een beter begrip van de knelpunten in de kleine asielketen en hoe deze worden beïnvloed door verschillende factoren.



Titel	VP Kennisopbouw Politie (P106)
MTIB Thema	Veiligheid
Contactpersonen TNO (DM en VPM)	Gwen Jansen-Ferdinandus (VPM), Tjarda Krabbendam-Hersman
Contactpersoon Regie-voerder	Sven Hamelink en Kirsten Hehemann, Politie
<b>Programma jaar 2023 - Samenvatting</b>	
<p>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.</p> <p>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 missie gedreven innovatiebeleid.</p> <p>Op basis van de prioriteitsgebieden uit de Strategische agenda politie 2021-2025, de Science &amp; 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:</p> <ul style="list-style-type: none"> <li>• <b>Politiemedewerker van de toekomst:</b> hoe kan de politiemedewerker continu en op maat blijven leren; weerbaarder worden met het oog op hoge fysieke en mentale belasting en in staat zijn om te gaan met continue veranderingen in de organisatie en de maatschappij; en optimaal uitgerust worden voor het uitvoeren van zijn of haar taken?</li> <li>• <b>Politiedata en intelligence:</b> hoe kan de politie voorstelbare bedreigingen van personen goed inschatten, nog beter informatie-gestuurd werken door de kwaliteit en betrouwbaarheid van data te verhogen en vroege signalen en trends m.b.t. maatschappelijk ongenoegen of verborgen criminele fenomenen herkennen?</li> <li>• <b>Technologie in de operatie:</b> welke nieuwe methoden, technieken en toepassingen kunnen de capaciteit van de politieoperatie verhogen? Hoe haalt de politie meer waarde uit bestaande en nieuwe databronnen?</li> <li>• <b>Politiewerk van de toekomst:</b> hoe zien de criminele businessmodellen van de toekomst eruit en hoe kan de politie deze verstoren door samen met haar partners nieuwe manieren van informatieverzameling en interventie te realiseren?</li> </ul> <p>Hiernaast wordt ingezet op technologieontwikkeling voor o.a. robotica en privacy enhancing technologies.</p> <p>Binnen bovenstaande programmaliijnen 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.</p> <p>Enkele highlights uit de resultaten van het onderzoek in 2023:</p>	

- Politiedewerker van de toekomst: in de onderzoekslijn *weerbare professional is* onderzocht wat de effecten van het gebruik van wearable en app zijn op bewustwording en gedragsverandering op het gebied van stress, herstel en beweging na 5 weken. Het onderzoek laat zien dat persoonlijke monitoring bij kan dragen aan de weerbaarheid en inzetbaarheid van politiedewerkers.
- Politiedata en intelligence: in het programma is technologie ontwikkeld om locatie, tijd en risico op geweld bij protesten te detecteren. Het experiment geeft inzicht in de efficiëntie en effectiviteitswinst (snelheid en kwaliteit) in OSINT-werk door AI-ondersteuning.
- Technologie in de operatie: binnen dit thema zijn nieuwe video- en audiodetectoren gemaakt waarmee automatisch gebeurtenissen en afwijkende patronen kunnen worden gedetecteerd op basis van gegevens uit video, audio, geo-sensoren en RF-signalen.
- Politiewerk van de toekomst: binnen de onderzoekslijn *adaptief bewaken & beveiligen* is in samenwerking met de Koninklijke Marechaussee een roadmap ontwikkeld die de betrokken organisaties kan ondersteunen bij het op een gestructureerde wijze verkennen, plannen en communiceren van de relaties tussen strategische doelstellingen, innovatie en technologieontwikkelingen.

Titel	VP Radar and Sensor Systems (P104)
MTIB Thema	Veiligheid,
Contactpersonen TNO (DM en VPM)	Director Market A.I.: Patrick de Graaf VP Manager: Marcel van der Graaf
Contactpersoon Regievoerder	<p><i>TNO</i> Marktmanager: P. de Graaf (TNO, Unit DSS) VP Manager: M.W. van der Graaf (TNO, Unit DSS)</p> <p><i>Government</i>, Defensie algemeen: A.P. Venema (Mindef/HDB)</p> <p><i>Top sectors</i></p> <p>Director HTSM / Coordinator KIA Veiligheid &amp; KIA Sleuteltechnologie L. Warmerdam (HTSM) TKI Maritiem: B. Buchner (MARIN) TKI Dinalog: L. Brügemann (TKI Dinalog) HTSM Roadmap Security; L. Roffel (Thales Nederland B.V.) HTSM Roadmap Electronics: S.M. van den Berg (Thales Nederland B.V.)</p> <p><i>KIA Veiligheid</i></p> <p>Programmamanager KIA Veiligheid: B. Molmans (HTSM) Mission Space: A. Bos (S&amp;T Science and Technology BV) Mission Maritime High Tech: M. Janssen (Mindef/AMS) H. Hopman (TU Delft) Missie Landoptreden, J. Heeren (TNO)</p> <p><i>KIA Sleuteltechnologie</i></p> <p>Programmamanager KIA Sleuteltechnologie: K. Vermeer (HTSM)</p> <p><i>Themes</i> Radar en geïntegreerde sensorsuites: KTZ (TD) J. Bleijs MBA (Mindef/DMO/AMS) Smart Manning and Automation: KLTZ(TD) R. Jutte (Mindef/DMO/AMS/ Bureau Technologie Integratie) Smart operations KLTZ: P. Blank (Mindef/CZSK):LKol. M. Hädicke (Mindef/CLAS (RAS-unit)) Veiligheid in en vanuit de ruimte: LKol. B. Buijs (Mindef/CLSK/Space Security Centre) Maj. P. Wijnja (Mindef/DPLAN/ Air and space operations) Quantum Sensing:C.M. Rutgers (Mindef/DMO/JIVC/KIXS) Mission High Tech Landoptreden: B. Smeenk (Mindef/DPLAN/K&amp;I)</p>

**Programma jaar 2023 - Samenvatting**

The Netherlands must remain a secure and safe country for its citizens to work and live in. Developments like climate change, migration and changing geopolitics pose serious challenges to our society and to our defence and security organisations. It is the unfortunate fact that the best way to avoid a conflict is to prepare for it. P104 is an important element in the chain of measures to achieve this, through its research co-operation with its partners and industry.

P104 is and has consistently been organized and executed to contribute to the security and safety of The Netherlands. The war in Ukraine, which started February 2022, revealed new vulnerabilities that subsequently required the need for accelerated innovation on the battlefield. The extensive use of drones by both sides, the depletion of supply-chains and saturation attacks by conventional and high-end threats are some of the more prominent examples of this changed landscape. But consider also attacks and threats thereof on western infrastructure such as the attack on the Nordstream II pipelines, the leaky gas pipeline between Finland and Estonia, and the suspicious Russian ship movements in the North Sea. Investment in new defensive capabilities (or their renewal) is the daily news and industry is stepping up its R&D and production. Europe is taking action to become strategically less dependent. Consequently we foresee an increasing and long-term demand for all innovations in P104, and maybe even more.

The Vraaggestuurd Programma (VP) P104 aims to bring Science and Innovation at the Frontline. We aim to maintain and further strengthen the global leadership and competitiveness of our national defence and security ecosystem in specific niches, through industrially relevant R&D with an emphasis on the speed of innovation. We predict and translate future operational capabilities into relevant R&D of advanced materials, crucial high-tech components, rugged subsystems and complex

sensor and associated command & control (C2) systems, for our military to protect our territory and that of our allies. This is a combined effort executed in eco-systems, where e.g. TNO and industry work together with government as launching customer. Technological breakthroughs are pursued in areas that are strategically crucial to the Netherlands, where we have the right to play, where the knowledge cannot be obtained anywhere else, and/or where it leads to economic growth.

In 2023 the Dutch government revisited the innovation goals of the “Missiegedreven Topsectoren en Innovatiebeleid” 2019 for more impact. In May 2023 she published five new missions including an update of the “Missies Veiligheid”, the content of the latter being heavily influenced by the Ministry of Defence. We concluded that P104s scope and content was actually ahead of the updated missions and remains as relevant as before. Hence, the vast majority of the future activities are planned to continue in line with the latest 2024-2027 plan.

The research activities took place within their national as well as their international context. In the national context, the activities align with and implement the KIA Veiligheid and KIA Sleuteltechnologieën, the roadmaps Security and Electronics of the Topsector High Tech Systems en Materialen (HTSM), the Quantum Roadmap (MoD) and the Space Agenda (MoD). In the international context, the activities are predominantly performed with EDA and NATO partnering, with an increasing role of the EU (specifically for the European Defence Fund, EDF).

In 2023 research has been carried out as planned, and in a revolving set of roughly 40 projects within its eight constitutive themes: (1) Radar and integrated sensor suites; (2) Imaging systems for Defence; (3) Space Domain; (4) Smart Manning and Automation; (5) Collaborative Innovative UxVs; (6) Quantum Sensing; (7) Ocean Resiliency and Transparency; and (8) Advanced Materials. Another 40 projects are in various stages of acquisition.

We are proud to mention that the continuous efforts in radar concepts, front-end technology and signal processing over the past decade culminated in the latest generation of the Thales APAR blk-2 and NS50 radar systems, and that the production of [the first systems for integration aboard the German F126 frigate and the Dutch/Belgium Anti-submarine Warfare frigates and the Belgium/Dutch Mine Counter Measures vessels have commenced](#), see the figure below.

The ‘conditional full granting’ of the NGF proposal POLARIS in 2023 marks the start of a new phased-array sensor paradigm, targeting integration onto the Future Air Defence Frigate (FuAD) in the period after 2030. In addition we have, amongst many other 2023 results, conducted live-firing tests of medium calibre fuze sensors with Rheinmetall; Run several projects on the IC implementations of critical functions for modern radar front-end transmitters and receivers with numerous (international) partners; Investigated and demonstrated advanced radar wave-forms and signal processing concepts for situation-critical awareness and engagement support.



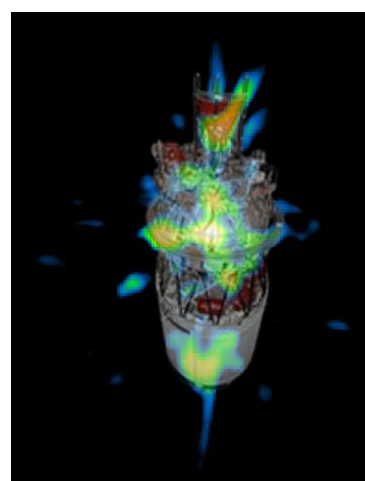
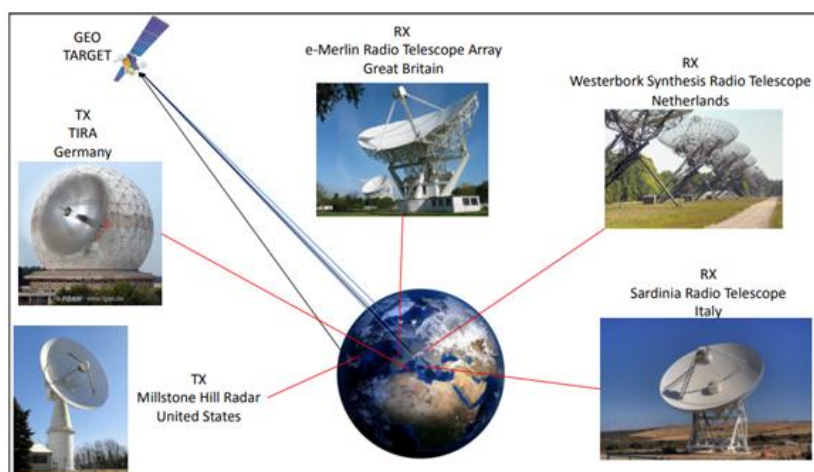
*Recent illustration of the 2023 Anti-Submarine Warfare (ASW) frigate that will replace the current M frigates. Preliminary studies started around 2010, with a first sketch released in 2013 during an event of the Nederland Radarland platform. High in the mast is the integrated sensor suite, comprised of the latest Thales APAR-block 2 X-band radar and an S-band radar. The concept of the new frigates includes unmanned aircraft and small vessels. (Source: Marineschepen.nl)*

An element highlighted in the latest geopolitical conflicts is that intelligence, surveillance and reconnaissance (ISR) is increasingly relying on information gathered by space based systems. Awareness of all that happens in the sky above us is hence of greater and greater importance for national and expeditionary security. This is recognised through the Space Agenda (MoD), and exemplified by for example the creation of the Defence Space Security Centre (DSSC), but also underlined by a successful

launch of the Huygens nano-satellite in January 2023, successor of BRIK-II, towards the ambition of own Dutch military assets in space. This at the same time makes clear that, due to increased congestion but also adversarial conditions, detailed knowledge of all that is above us is of importance, such as knowledge of space debris, space weather, re-entry coordinates, collision avoidance, orbital manoeuvres, satellite intelligence and (hostile) satellite approaches, amongst others. We contribute to the DSSC and are particularly proud of the 2023 results, obtained with our NATO partners, on many long base line multi-static radar measurements to characterise satellites and rocket bodies, demonstrating accurate estimation of orbit, size, shape and rotation speed of geostationary (GEO) and non-geosynchronous (MEO) objects, see the figure on next page.

The work on Imaging Systems, Smart Manning and Automation, Collaborative Innovative UxVs and Ocean Resilience and Transparency all contribute to sensory information that will enable unmanned platforms to operate. This is a necessary trend rooted in technological, societal and military developments, and encompasses 2023 results as wide as concepts for seabed security and warfare (a very current topic receiving much increased attention) to turbulence compensation for optical sensors on unmanned vehicles.

Quantum Sensing and Advanced Materials are enabling broader military and security goals. For quantum sensing, the biggest highlight was the creation of an actual magnetic map, supporting future quantum positioning, navigation and timing independent from GNSS. For Advanced Materials, a topic that was introduced as the result of the specific request for more attention in the updated KIA Veiligheid, we aim at public-private partnerships for defence for the development and manufacture of advanced materials to 1) provide protection, 2) reduce weight and 3) contribute to a variety of specific military requirements. This topic has been added to the P104 portfolio in 2023 and, ahead of schedule, saw its first project already launched.



**Radar multistatic experiment geometry depicting the radar transmitters illuminating a Geosynchronous satellite target and the radio telescopes receiving the signal from the satellite (left). Radar image with superimposed target signature (Right).**

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)
<b>Programma jaar 2023 - Samenvatting</b>	
<p>The highlights of the 2023 results of VP Cybersecurity &amp; Resilience can be structured along the following fields, domains and cooperations:</p> <p><b>Security Monitoring &amp; Detection:</b> <i>Detecting adversaries and vulnerabilities within infrastructures and software.</i> Our research focuses on how to detect adversaries in digital infrastructures, both in enterprise settings as well as within critical infrastructures. We envision a Security Anomaly Radar (SAR) which spots any unusual activities that might signal a cyber-attack based on data available from the infrastructure and organisation itself. We are also working to ensure that software is secure from the get-go by developing fuzzing tools that can be used for automated detection of new vulnerabilities in software. In 2023, a specific anomaly algorithm to detect a particular type of cyber-attack was successfully developed and validated by TNO in an operational setting. In fact, in collaboration with two stakeholders (1) all test cases were detected, (2) false positives rates were low enough for usage in practice, and (3) the detector output was explainable.</p> <p><b>Automated Security:</b> <i>Automated responses to cyber threats in order to (1) be able to counter the speed, complexity and intelligence of (targeted) attacks and (2) to counter the increasing scarcity in cyber security experts.</i> Picture a world where computer systems can fix themselves and protect us from cyber threats—that is what we are aiming for. We are developing smart technologies that lead to a system that can automatically analyse and handle cyber-attacks. We are also exploring ways for our systems to heal and protect themselves without needing constant human intervention. In 2023, we developed a fully automatic and adaptable IT cyber range. We also reached an important milestone by creating the very first security orchestrator worldwide that uses the new emerging OASIS Open standard for security playbooks (CACAO), which will be open sourced in Q1 2024, and made substantive technical contributions to the new <a href="#">CACAO v2.0 standard</a> that was publicly released in December.</p> <p><b>Quantum Safe Technologies:</b> <i>Migration to quantum-resistant cryptography and secure development of quantum networks.</i> The extreme power of quantum computers provides a tempting future outlook, though there is no certainty about when it will be available. It is known that quantum computers also pose a challenge for our current security methods. TNO aims to develop technologies that can withstand the power of quantum computers. We focus on developing and migrating to quantum-safe technologies, ensuring long-term resilience for sensitive information and infrastructure. Early 2023 we published together with the AIVD, EZK and CWI the <a href="#">PQC migration handbook</a>, which gives guidance to organizations for making the transition to a quantum safe infrastructure and is actively being used by various organisations.</p> <p><b>The Partnership for Cyber Security Innovation (PCSI)</b> <i>is a public-private partnership and plays an essential role in a secure and resilient digital society by innovation in the field of cybersecurity.</i> The PCSI was extended for three years as of July 1st 2023 and produced many interesting results from the ten projects that have run in 2023; one tangible impact has been a new training that was launched by the Security Academy, specifically targeted at <a href="#">the new role of Security Behaviour Coach</a>.</p> <p><b>National Security:</b> <i>The collaboration with NCSC and DTC led to a number of publications that support organizations to better tackle cybersecurity-related issues:</i> (1) Our <a href="#">guide</a> on how to use a Software Bill of Materials (SBOM), helps to get a better overview of the used software components and dependencies in an organization’s supply chain. The results were presented at the Dutch organizations PvlB and DICTU. (2) The release of our <a href="#">tool</a> that supports organizations in quantifying cybersecurity risks was picked up quickly by tech media like <a href="#">Tweakers</a>. (3) The results of our research on how to get entrepreneurs and the SME to demonstrate more cybersecure behaviour has been well received at the ONE conference and at a <a href="#">webinar</a> of the Overheidsbreed Cyberprogramma.</p>	

Titel	VP ICT (P706)
MTIB Thema	Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Berry Vetjens (DM) / Björn Håkansson (VPM)
Contactpersoon Regievoerder	Frits Grotenhuis, Directeur Topsector ICT
<b>Programma jaar 2023 - Samenvatting</b>	
<p>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 focuses on the common needs of our stakeholders and aims to reach the following goals. VP ICT contributes to three portfolio (PMC) clusters. Below the main highlights are outlined along those PMC clusters</p>	
<p><b>PMC Cluster Data Sharing and AI</b></p>	
<p>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 by enabling data spaces in and across domains, ensuring interoperability of data sharing systems, avoiding vendor lock-in and achieving national data-hub(s) ecosystems.</p>	
<p>In 2023, some of the highlights we achieved are:</p>	
<ul style="list-style-type: none"> <li>i) a pilot nitrogen measurements network based on data space technology, so farmers and policy makers can see nitrogen status-qua and can follow the results of the counter measures;</li> <li>ii) a pilot for consumer energy savings based on knowledge engine, so consumers can stay in better control of energy usage and bills;</li> <li>iii) interop profile for SSI wallets, to ensure better widespread wallet usage without lock-in;</li> <li>iv) a proof of concept for Digital Battery Product Passport, so (rare) metals can be traced and re-used and companies stay compliant with European legislation;</li> <li>v) establishment of the Alliance for Privacy-preserving Detection of Financial Crime, a collaborative initiative among various banks using Privacy Enhanced Technologies, so money laundering can be more easily detected and banks can avoid high penalties.</li> </ul>	
<p><b>PMC Cluster Fast and Open Digital Infrastructures</b></p>	
<p>Key enabling technologies and digitalisation developments including AI, data ecosystems, digital twins and the metaverse, depend on extremely scalable digital infrastructures. In fast and open infrastructures, we design the future digital infrastructure as the foundation for digitalisation in and of society. This infrastructure integrates network connectivity, storage and processing. Digital infrastructures are increasingly being made up of a composition of infrastructures, virtualized and software-defined; and cloud-edge federation across telco and cloud provide a seamless cloud-edge continuum. With fast and open infrastructures, we focus on the combination of performance, sustainability and sovereignty.</p>	
<p>In 2023, our key contributions were:</p>	
<ul style="list-style-type: none"> <li>i) facilitating research in open networking and telemetry services with our open source cloud infrastructure and multi-vendor 5G experimentation platform; We developed and tested features addressing 'Massive IoT' and 'Private Networks' where low energy devices are deployed and connected to (private) 5G networks at a.o. the Do IoT Tomatoworld greenhouse location. This can a.o. result in increased automation and more effective use of (less) nutrients in the greenhouse sector.</li> </ul>	

- ii) a 5G trial in the energy domain with a use case on drones that will contribute to more efficient inspection of windfarms
- iii) demonstrating the principle of 'platformless' application development in our Cloud Federation Testbed jointly with a.o. the national Gaia-X Hub and the Structura-X lighthouse project this as a step to reduce lock-ins for cloud users ;
- iv) development of reusable technology modules for volumetric capture and representation, haptics, scalability improvement and network-based media processing which allow companies to gain experience on the potential impact of immersive metaverse applications for their services; and
- v) developing and demonstrating 3GPP based seamless cross border roaming . Connectivity loss when switching between international networks was reduced from many seconds to about a tenth of a second, 40enabling cross border remote vehicle operations as was demonstrated in Sas van Gent at the Dutch-Belgium boarder in 5G-Blueprint.

#### **PMC Cluster Trusted ICT**

Our ambition with a trusted ICT approach is to develop applications on current and near-future quantum computing hardware such that our stakeholders can harness the power of quantum computers as soon as it becomes practically relevant.

With a focus on practicable algorithms for quantum optimization, in 2023 we achieved:

- i) various new implementations for experimental use cases using quantum hardware on topics relevant for various industries;
- ii) metrics for benchmarking of the performance of applications on multiple hardware platforms
- iii) a standardised overview of quantum cloud computing aimed towards the future users
- iv) development of various new algorithms that utilize the core of multiple quantum computers, also known as distributed quantum computing; and
- v) a multi-vendor ecosystem for quantum algorithms and application development with various industry partners.

These goals are aligned with national and stakeholder agendas, specifically the Nederlandse Digitaliseringsstrategie 2021, the KIA (Digitale) Sleuteltechnologieën 2020-2023 , the European Data Strategy for 2030, the European Vision for the 6G Network Ecosystem, Quantum Delta NL, and with strategic stakeholder viewpoints. The coming years we aim to consolidate this role and maintain our leading position in standardisation of digital technologies and within industry fora.



<b>Titel</b>	<b>VP Embedded Systems Innovation (ESI) (P707)</b>
MTIB Thema	Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Marc Zegveld (Managing Director TNO ISP), Jacco Wesselius (VPM)
Contactpersoon Regie-voerder	Ronald Fabel, TKI HTSM, Roadmap Systems Engineering
<b>Programma jaar 2023 - Samenvatting</b>	
<p>The Netherlands has a world-leading high-tech systems industry generating a consistent and increasingly positive economic and societal impact. They hold and keep their leading position by constantly improving the effectiveness of their engineering, manufacturing, and service throughout the full live cycle of their advanced products. It is the mission of ESI<sup>5</sup> to strengthen the Dutch high-tech industry by innovating and embedding cutting-edge methodologies into the industry to cope with the ever-increasing complexity of their products.</p> <p>To fulfil this mission, ESI:</p> <ul style="list-style-type: none"> <li>• participates in national and international agenda setting;</li> <li>• executes a research program on <i>engineering methodologies</i>, in close collaboration with the Dutch high-tech industry, tightly linked to academic research, leveraging the value of cooperation in international research consortia;</li> <li>• consolidates and publicly shares the results from this research;</li> <li>• prepares industrial deployment of the engineering methodologies by: <ul style="list-style-type: none"> <li>○ human capital development: defining and executing a competence development program for industry;</li> <li>○ preparing for scaling-up: bringing results (e.g., software tools) into open source and seeking partnerships with professional tool suppliers, service providers and industry.</li> </ul> </li> </ul> <p>The ESI research agenda addresses system-level multidisciplinary engineering challenges that are key to the high-tech industry. In 2023, the ESI research program consisted of five key program lines addressing challenges that are tightly coupled to the 2020 HTSM Systems Engineering roadmap<sup>6</sup>:</p> <ul style="list-style-type: none"> <li>• System Performance (meet and balance key system performance indicators);</li> <li>• System Dependability (meet quality and reliability requirements);</li> <li>• System Evolvability (be ready for upgrades and updates);</li> <li>• Exploiting System Context (analyse and optimize systems in their operating context);</li> <li>• System Architecting (translate market, product, technology choices into system concepts).</li> </ul> <p>These program lines are executed in long-term collaborations by ESI and industry/academic partners in projects that typically have a yearly rhythm with management reviews for go/no-go decisions, based on progress, results and impact (potential).</p> <p>In 2023, 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 <i>Industry-as-a-Lab</i> approach).</p> <p>Examples of successful methodology development and validation:</p>	

<sup>5</sup> The ESI department of TNO (inside the unit ISP) 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.

<sup>6</sup> [https://hollandhightech.nl/asset/public/Innovatie/Technologieen/z\\_pdf\\_roadmaps/Roadmap-Systems-Engineering-update-2020-final-v20200724.pdf](https://hollandhightech.nl/asset/public/Innovatie/Technologieen/z_pdf_roadmaps/Roadmap-Systems-Engineering-update-2020-final-v20200724.pdf)

- In a series of projects, TNO-ESI developed the PPS-methodology in collaboration with an industry partner. In 2023, the methodology was used to successfully diagnose performance issues of systems in the field in a fraction of the time that would typically be needed<sup>7</sup>.
- In the ASIMOV-project<sup>8</sup> (ITEA), research was performed on automatic calibration of high-tech equipment using AI and digital twins in collaboration with an international consortium. The project will end mid-2024. TNO-ESI and its industry partner are exploring opportunities to embed the results after closing the ASIMOV-project.
- In a series of projects, TNO-ESI developed the Renaissance-methodology and tool for rejuvenating legacy software. In 2023, ICT/Strypes<sup>9</sup> was the second partner to join the ESI-implementors council<sup>10</sup>. They will train their engineers for using the Renaissance methodology of ESI. By adding more implementation partners to the ESI-network, we will scale-up the adoption and thereby the impact of our innovative methodologies.

In addition, in 2023, a professional certification has been defined and put into practice for Renaissance to assure high-quality use of the VP ESI methodologies in the industry (the first set of certificates was handed out for the Renaissance practitioners and experts of Capgemini Engineering<sup>11</sup>).

In 2023, ESI deepened their inventory of industry needs (resulting in the Strategic Plan 2024-2027+, submitted that to TKI-HTSM). The vision of ESI is that the high-tech industry faces three key challenges: (i) system complexity will grow to new levels; (ii) international competition will force the industry to innovate these highly complex systems faster; (iii) there is a shortage of engineering experts, and this shortage will grow even further. In view of these challenges, ESI has formulated a vision statement for 2035:

*In 2035,  
Engineers in the high-tech industry  
will more than double their productivity and effectivity  
by their intense “side-by-side” collaboration with digital engineering assistants  
tapping into the organization’s system, domain, and engineering knowledge.*

This vision will guide the definition of the program for the coming years, giving more focus on the application of artificial intelligence (combining data-analysis and model-based reasoning) to develop “digital engineering assistants” for (systems) engineers in the high-tech industry.

To address the embedding of such new engineering methodologies and assistants in the industry, ESI will build upon the successful competence development programs of ESI. The human, process, and organizational aspects of innovating engineering in the high-tech industry will become a focus area in our research, bringing socio-technical aspects into our research program lines.

<b>Titel</b>	<b>VP Sleutelmethodologieën voor Transitie en Transformaties (P901)</b>
MTIB Thema	KIA Maatschappelijk Verdienvermogen / Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Rowie Huijbregts (VMP), Wimar Bolhuis (DM)
Contactpersoon Regievoerder	Paul Vetter (EZK)
<b>Programma jaar 2023 - Samenvatting</b>	

<sup>7</sup> [https://bits-chips.nl/artikel/taking-performance-analysis-to-the-system-level/?ct=t\(EMAIL\\_CAMPAIGN\\_2023\\_08\\_24\\_12\\_30\)](https://bits-chips.nl/artikel/taking-performance-analysis-to-the-system-level/?ct=t(EMAIL_CAMPAIGN_2023_08_24_12_30))

<sup>8</sup> <https://www.asimov-project.eu/>

<sup>9</sup> <https://strypes.eu/>

<sup>10</sup> <https://esi.nl/news/articles/strypes-implementation-partner>

<sup>11</sup> <https://esi.nl/news/articles/2023-renaissance>

VP P901 Transitie en Transformatie is gelieerd aan de roadmap Transitie en Transformatie van TNO Vector, Centrum voor Maatschappelijke Innovatie en Strategie.

TNO Vector biedt handelingsperspectief, als kracht voor goede besluitvorming, om de brede welvaart te vergroten.

Op dit moment staan we voor grote, wereldwijde uitdagingen die met elkaar samenhangen, zoals klimaatverandering, schaarste, sociale ongelijkheid, en disruptieve technologieën. Dit bedreigt onze brede welvaart. Overal ter wereld proberen samenlevingen en economieën zich aan te passen aan de eisen van deze tijd door ingrijpende veranderingen oftewel *transities* en *transformaties* door te voeren. *Innovatie* speelt daarbij een belangrijke rol.

TNO Vector ontwikkelt kennis, vaardigheden en methodologieën die in de praktijk samen met publieke en private partijen worden toegepast om transitie en transformatie de gewenste richting te geven en te versnellen.

In onze werkzaamheden staat ‘*maatschappelijke innovatie*’ centraal. Maatschappelijke innovatie verwijst naar vernieuwingen op maatschappelijk niveau die gericht zijn op het verbeteren van de manier waarop mensen samenleven, samenwerken en deelnemen aan de samenleving. In aanvulling op technologische innovatie, die zich richt op nieuwe of verbeterde technologieën, legt maatschappelijke innovatie de nadruk op nieuwe of verbeterde maatschappelijke systemen. Maatschappelijke innovatie betreft bijvoorbeeld vernieuwingen in economische, bedrijfskundige of bestuurskundige structuren, in ecosystemen en netwerken, in ruimtelijke inpassingen, in institutionele innovatiecapaciteiten, en in beleid en wetgeving.

In onze werkzaamheden staat daarnaast ‘*strategie*’ centraal. Strategie biedt een duidelijke richting en focus voor transitie en transformatie. Het helpt bij het stellen van doelen en prioriteiten, waardoor inspanningen gericht zijn op specifieke gebieden waar verbetering of verandering nodig is.

De roadmap en het VP Transitie en Transformatie zijn gestart op 1 januari 2022. In 2022 en 2023 stonden drie *aandachtsgebieden* centraal: stedelijke systemen, industriële systemen en innovatiesystemen. Dit zijn *socio-technische systemen* waarbinnen ‘multi-transities’ (moeten gaan) plaatsvinden oftewel meerdere transitie verbonden (moeten) zijn aan elkaar. Mid-2023 is een vierde aandachtsgebied toegevoegd: digitale systemen.

Om de beoogde impact van onze werkzaamheden te verduidelijken, zijn de namen van de aandachtsgebieden gewijzigd in 2023:

1. Waardengedreven duurzame steden en regio’s (voorheen stedelijke systemen);
2. Groene en soevereine industrieën (voorheen industriële systemen);
3. Transformatieve innovatiesystemen (voorheen innovatiesystemen);
4. Waardengedreven digitale samenleving (voorheen digitale systemen).

In VP Transitie en Transformatie zetten we in op kennis- en methodologie-ontwikkeling om propositie in deze vier aandachtsgebieden waar te maken. In 2022 en 2023 focusten we op een drietal ‘*sleutelmethodologieën*’<sup>12</sup> – ‘*Key Enabling Methodologies*’ (KEMs) in het Engels – om transitie en transformatie te bewerkstelligen en te versnellen: systeemanalyse, innovatie-orkestratie, en adaptief bestuur:

- Systeemanalyse: het analyseren en begrijpen van socio-technische systemen en het identificeren van interventies die bijdragen aan transitie en transformatie;
- Innovatie-orkestratie: het bijeenbrengen van stakeholders ten behoeve van innovatie en zorgdragen voor het maken en bestendigen van collaboratieve businessmodellen voor transitie en transformatie;
- Adaptief bestuur: het analyseren en ontwerpen van besluitvormingsstructuren en beslisondersteuning voor publieke en private partijen om transitie en transformatie richting te geven en te versnellen.

**Key highlights** (resultaten) in VP Transitie en Transformatie in 2023 waren (in willekeurige volgorde):

<sup>12</sup> Met de term ‘sleutelmethodologieën’ bouwden we voort op de KIA Sleuteltechnologieën 2020-2023, en meer specifiek op de Onderzoeksagenda naar sleutelmethodologieën (Key Enabling Methodologies, KEMs) voor missiegedreven innovatie.

- Bijdrage aan meerjarig Europees project en netwerk NetZeroCities. (Beoogd) resultaat: bevorderen van klimaatneutraliteit in Europese steden.
- Bijdrage aan meerjarig Europees project en netwerk AmsTErdam BiLbao citizen drivEn smaRt cities (ATELIER). (Beoogd) resultaat: bevorderen van energiepositieve districten in Europese steden.
- Samenwerking met gemeente Rotterdam voor veerkrachtige en duurzame vitale systemen. Resultaat: integrale aanpak en manier van werken voor de gemeente.
- Ontwikkeling 'Urban Assessment Framework' en toepassing in project NetZeroCities. Resultaat: instrument voor beslisondersteuning bij interventies in steden en regio's.
- Ontwikkeling 'Innovation Capacity Framework' en toepassing in project Vitale Systemen Rotterdam. Resultaat: instrument voor evaluatie van innovatiecapaciteiten van organisaties.
- Bijdrage aan scenarioanalyse en visievorming in traject 'Envisioning Industry'. Resultaat: gepubliceerde visie op de Nederlandse industrie in 2050.
- Onderzoek naar industriële systemen. Resultaat: onderzoeksagenda voor TNO Vector t.a.v. o.a. onderwerp 'strategische autonomie'.
- Bijdrage aan meerjarig Europees project en netwerk Research Infrastructure Technology Infrastructure for Impact (RITIFI). (Beoogd) resultaat: versterken van de Europese onderzoeks- en innovatie-infrastructuur.
- Samenwerking met AiNed t.b.v. monitoring van innovatieprogramma's. Resultaat: monitoringsstructuur (instrument) voor innovatieprogramma's op het gebied van kunstmatige intelligentie.
- Aanscherping conceptualisering 'transities' en 'transformaties'. Resultaat: conceptueel raamwerk voor TNO Vector voor bewerkstelling en versnelling van transities en transformaties.
- Aanscherping propositie 'adaptief bestuur'. Resultaat: Adaptive Governance Toolkit oftewel set van tools voor analyses van en interventies in bestuurlijke omgevingen.
- Aanscherping propositie 'systeemanalyse'. Resultaat: methodiek voor het in kaart brengen van systeemgrenzen.
- Aanscherping vraagsturing VP P901. Resultaat: VP plan 2024 en opzet externe klankbordgroep voor VP P901 (2024).

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, Frenk van den Berg
<b>Programma jaar 2023 - Samenvatting</b>	
<p>Our multi-annual R&amp;D program 2024 - 2027 supports our ambition to contribute to <b>preventing climate change and air pollution</b>, enable <b>secure broadband connectivity</b>, help <b>understanding the Universe</b>, and stimulate <b>economic growth in the Netherlands and Europe</b>. Therefore, we organise the VP along program lines directly connected to this ambition; Instruments for <b>Earth Observation</b> and related <b>Space Data Utilization</b>, technologies for <b>Satellite Communication</b>, and <b>Scientific Instrumentation</b> focusing on instruments for <b>Ground-based Astronomy</b> and <b>Space-based Astronomy</b>, and including instruments for <b>Big Science and Diagnostics for Fusion Energy</b>. In recent years ESA and the EU have increased priority for the theme <b>Space Situational Awareness</b>, including space weather, Near Earth Objects, and space surveillance and tracking including Space Traffic Management. Within the Netherlands <b>Space Situational Awareness</b> is a key topic in the Dutch Defence Space Agenda, that was released in November 2022. In 2023 the TNO units High Tech Industry and Defence, Safety and Security have decided to join forces by establishing a new proposition Military Use of Space, to optimally support the NLMOD. It is seen that TNO can contribute with its strong heritage in Optical systems and Radar Technology in the field of observation and diagnosis. The proposition will be further developed in coming years.</p> <p>The main parts of the VP Space &amp; Scientific Instrumentation 2023 are summarized below.</p> <p>The programme line Earth Observation focused on the design and development of new instruments, development of technology that supports today's instrument realisation, and space data utilisation.</p> <p>The programme line Satellite Communication has a strong focus on optical communication. For optical communication between satellites and from ground to satellite very stable and accurate optical systems are required, and adaptive optics compensates the disturbance of communication by the earth's atmosphere.</p> <p>The programme line Scientific Instrumentation, with the main activities in Space-based Astronomy and Ground-based Astronomy, focused on opto-mechatronics design &amp; 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 executed.</p> <p>Some highlights in 2023 are the award of a certificate of appreciation from NASA - National Aeronautics and Space Administration for TNO's work on the Ocean Color Instrument (OCI). This is the primary sensor for the upcoming NASA PACE mission. TNO supplied various optical mirrors and calibration equipment for the OCI. Furthermore the agreement to start a project with the Ministry of Environment of Uruguay to help them measure air quality and local emissions is a special milestone. TNO will study the feasibility of using satellite data for nationwide detection of pollution concentration-hotspots in Uruguay. TNO will also provide training to ministry employers in the use of their air quality simulations model called LOTOS-EUROS, which can be used alongside satellite data for air quality predictions. A special highlight is the successful launch of TNO's SmallCAT laser communication terminal from SpaceX at Vandenberg Space Force Base in California on 15th of April 2023 as a payload on the NorSat-TD satellite, followed by a successful demonstration of data transfer from a satellite to earth using this self-developed laser communication technology. This is the first time this has been done with a Dutch satellite instrument. In September 2023 TNO joined a European collaboration to develop global quantum internet enabled from space. The future global quantum internet is blocked due to signal losses in fiber over distance. Satellites are required so that cities and continents can be connected to eventually be part of the global quantum internet and fully benefit from its promising applications. To provide for this, TNO and the Institute of Communication and Computer Systems (ICCS) and a consortium of other European partners, join forces in the Horizon Europe Research Programme LaiQa-project (Leap in Advancing of critical Quantum key distribution-space components). In less than a year TNO has successfully designed, realized and tested an adaptive secondary</p>	

mirror (ASM) for demonstration and first on-sky heritage of TNO's adaptive mirror technology on the NASA Infrared Telescope Facility (IRTF). The demonstration at IRTF is planned for first half of 2024. Early 2023 TNO's Point Ahead Angle Mechanism (PAAM) concept for the Laser Interferometer Space Antenna (LISA) science mission was positively assessed by ESA on Technology Readiness. With this result TNO's PAAM mechanism is likely to be the product that will be used in LISA in the future. The Netherlands Space Office decided summer 2023 to provide funding to TNO to allow further testing of the current prototype in relation to radiation and vibration loads and enable TNO to supply the mechanism as a test model to the international LISA consortium.

Titel	VP Semiconductor Equipment (P612)
MTIB Thema	Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Rogier Verberk, Kees de Koning
Contactpersoon Regie-voerder	Frans List (leader HTSM Roadmap Semiconductor Equipment; ASML), S. Mentink (leader HTSM Roadmap Healthcare; Philips Healthcare), M. Blom (leader HTSM Roadmap Nanotechnology; Micronit); E. van de Ven, M. van Haeren (Min. EZK)
<b>Programma jaar 2023 - Samenvatting</b>	
<p>TNO's roadmap on Semicon &amp; Quantum and Medical Devices 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 it became a strategic asset for The Netherlands and Europe, in order to balance our dependency on other (chip manufacturing) countries.</p> <p>The Dutch semiconductor industry is leading in lithography, the most critical process step in chip manufacturing, and has dominating positions in equipment &amp; 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 opto-mechanics, 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.</p> <p>In 2024 the unique EUV testing infrastructure will be further upgraded and expanded to study induced plasma effects, oxidation 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&amp;D program integrated photonics (PIC) will be continued with a strong 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 centres, electric vehicles and fuel cell technology development. The development of metrology equipment for large scale PIC manufacturing will be continued, which started in 2022 by a consortium of Dutch SME's plus TNO, supported by national funding.</p> <p>TNO's innovations in scanning probe based (SPM) and acoustics based metrology concepts have gained attention by world leading chip manufacturers. Started in 2022 and expected to be expanding in 2024, 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 and assignments by private partners.</p> <p>Within the mission of QuTech, the development of a quantum computer that is accessible for end users via the web will continue in 2024. The multi-year project to establish a quantum communication channel for entanglement distribution between Delft and Den Haag will be concluded early 2024. During 2022 and 2023 TNO set 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 2024.</p> <p>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</p>	

management, and optoacoustic sensors based on PIC to boost the performance of photoacoustic and ultrasound devices. In 2024 we will further 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	Erik van de Burgwal (EZK), Casper Langerak (RVO), Marc Hendrikse (Topsector HTSM), Leo Warmerdam (HTSM)
<b>Programma jaar 2023 - Samenvatting</b>	
<p>In VP 'Flexible and Freeform Products' it is our ambition to strengthen Dutch industry by creating innovations based on our capabilities in flexible electronics and digital manufacturing and our strong position in Brainport to link up to local industry. Our innovations combine economic impact with a contribution to a healthy, sustainable and digital society. We enable a novel portfolio of products for the benefit of our industrial partners as well as the establishment of new start-up companies.</p> <p>Flexible electronics and digital manufacturing promise to provide technological solutions to important societal challenges such as energy storage, sustainable electronics industry, affordable healthcare and a digital society. They can also unlock significant new economic activity.</p> <p>However, progressing from the laboratory bench to the point where it provides the basis of a commercially successful business or product has become increasingly challenging due to increasing complexity of the technology as well as the environment where the product will be implemented.</p> <p>New approaches to innovation are needed such as a serial spinout model and focused programmatic initiatives that involve the relevant value chain. This is our unique approach.</p> <p>Our unique approach to innovation is applied to 6 growth platforms:</p> <ul style="list-style-type: none"> <li>➤ <b>New manufacturing technologies</b> for electronics production. The aim is to Increase electronics production capability in EU based on a sustainable, high performance manufacturing technologies. A new technology for high throughput high resolution printing for electronics was launched via a spin off, Phonontech BV. Also, a production concept for recyclable electronics manufacturing was shown. Next step is to show this in automotive applications.</li> <li>➤ <b>Medical device technology</b>, is focused on lowering the burden on hospital staff and lower health care costs by (1) automiising diagnostics via remote patient monitoring through a health patch, (2) Organ-on-chip technology to accelerate the development of new drugs. In 2023 a TNO spin off Aikon BV, was launched to commercialise remote monitoring of cardiac patients based on the health patch platform. A patch for monitoring core body temperature was shown to give comparable results to the golden standard.</li> <li>➤ <b>Energy storage</b> with the aim to enable and grow a Dutch eco-system for next generation of batteries and H<sub>2</sub> electrolyzers, mostly in the equipment and production technology for such devices. In 2023, the Circular Batteries NGF was awarded with the aim to show the scalability to Dutch cell technology in pilot line format. Technologically, we demonstrated with colleagues from Energy &amp; Materials Transition the reduction of the use of scarce catalyst Iridium in PEM electrolysis by a factor of 200 while maintaining significant conversion performance (~70%).</li> <li>➤ <b>Advanced packaging</b> with a focus on creating unique solutions for next generation of power and RF electronics. This roadmap is executed as part of the Chip Integration Technology Centre (CITC) in Nijmegen, a collaboration between TNO and Delft University of Technology and Holland Semiconductors. In 2023, first conceptual work was done on using additive manufacturing for power electronics, replacing environmentally unfriendly lithographic technologies</li> <li>➤ <b>Integrated photonics</b> with a focus on creatin solutions to heterogeneously integrate InP, SiN and its electronic driving chips in one package. This is mostly done in the framework of the Photonic Technology Integration Centre (PITC) , a collaboration between TNO, Tue, UT and photondelta. A concept for heterogeneous integration of InP and SiN chips is proposed making use of laser transfer technology developed for originally for microLED displays, with the aim to show the feasiblity in 2024.</li> </ul>	

- **Personalized food and pharma** with a focus on creating processing equipment for the protein transition in food industry and personalized pharma industry. In 2023, the first printer is installed in Erasmus hospital to check the validity of the technology for personalized child medication.

<b>Titel</b>	<b>VP Smart Industry (P617)</b>
MTIB Thema	Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Mark Courage MSc MBA, Dr. Adam Schmidt
Contactpersoon Regievoerder	Jan Post (leader HTSM Roadmap Smart Industry & Philips Consumer Electronics), opvolger Joren Schep (EZK)
<b>Programma jaar 2023 - Samenvatting</b>	
<p>In VP <b>“Smart Industry” (Dutch equivalent Industry 4.0 / 5.0)</b>, solutions and technologies for smart manufacturing are developed based on Key Enabling Technology (KET) <b>“Engineering &amp; Fabrication”</b>. Specific KET sub-technology domains are:</p> <ul style="list-style-type: none"> <li>• <b>Digital Manufacturing Technologies, including AI</b></li> <li>• <b>(Opto)Mechatronics incl. Robotics</b></li> <li>• <b>Sensors &amp; Actuators Technologies</b></li> <li>• <b>Imaging Technologies</b></li> </ul> <p>Smart Industry aims to create the most circular, interconnected, automated, and intelligent industrial manufacturing ecosystem in the Netherlands, capable of responding to changing market conditions and customer needs in real-time. Furthermore, it aims to improve efficiency, reduce costs, increase sustainability, boost quality, and ensure excellent customer satisfaction for manufacturing enterprises. Smart Industry is crucial for the Dutch and European manufacturing industry's earning power and strategic autonomy. It will increase the agility of the industry to cope with the challenges of tomorrow, like circular economy, resilient supply chains, ageing populations, sovereignty, etc.</p> <p>Within Smart Industry, TNO focuses on <b>Smart Manufacturing technologies and solutions</b> to boost the earning power of the industry, create strategic autonomy and increase labour productivity year on year with growth of 5% or more. Focus of TNO in this domain is on:</p> <ul style="list-style-type: none"> <li>• <b>Manufacturing throughput &amp; Quality:</b> <i>“Hyper efficient zero defect first time right”</i></li> <li>• <b>Manufacturing variability:</b> <i>“High-mix, low volume, high complexity”</i></li> <li>• <b>Digitalisation &amp; value chain integration:</b> <i>“Digitalisation, ecosystem assembly &amp; transparency”</i></li> </ul> <p>One of the trends observed in 2023 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 continued its efforts within the PMC sustainable factory (also called circular economy smart industry, CESI) for the development of new technology to enable and accelerate the movement towards a circular economy for the manufacturing industry.</p> <p>Due to the delayed start of the NXTGEN High-Tech Growth Fund, not all research goals as set could be achieved like the first proof of concept for autonomous manufacturing of free-form mirrors applied within the laser satellite communication (LSC) domain or novel autonomous manufacturing cells for NDT testing through ultrasound. However, with the relatively limited available national funding in NL for Smart Industry (compared to Belgium and Germany) and the scattered NL SI landscape, TNO and its partners excel in bottom-up innovation with wide industry acceptance and implementation. This is supported by TNO's strong backbone in the knowledge development related to dataspace, artificial intelligence, robotics, optics, opto-mechatronics and opto-acoustics. By establishing the Smart Industry Foundation, which is responsible for knowledge dissemination throughout the industry ecosystem, TNO can focus its R&amp;D activities more on innovation. With this focus, TNO can orchestrate and further develop the Dutch innovation ecosystem for Industry 4.0 in all the key aspects in the following years.</p> <p>The main highlights for VP Smart Industry for 2023 are:</p> <ul style="list-style-type: none"> <li>• <b>Establishment of Smart Industry Foundation and orchestration of the digitalisation transition:</b> Together with Koninklijke Metaalunie, FME and EZK, TNO founded the foundation smart industry. The Foundation coordinates the European Innovation Hubs (EDIH's) and its 50 fieldlabs. The foundation is vital for the knowledge dissemination ecosystem, bottom-up innovation and the future acceleration of the digitalisation of the Dutch industry. Furthermore, research was conducted towards the future of fieldlabs and the impact of the smart industry on the performance of enterprises that embrace the transition. It was found that Smart Industry manufacturers outperform those who do not digitalise and implement the smart manufacturing technologies. The results of both research studies will be shared beginning 2024.</li> </ul>	

- **National growth fund NXTGEN High Tech (NGF NGHT):** In mid-2023, NGF NGHT started. Smart Industry is the enabling technology for the NGF NGHT to develop the manufacturing of new high tech products and machinery within NL in Semicon, Energy, Composites, Agri/Food and MedTech domains. This is to establish new value chains and control points. The first results of the strong consortia between TNO, knowledge institutes and the industry w.r.t. new autonomous manufacturing cells, operator support systems and digital blueprints will be shared by the end of 2024 / beginning of 2025.
- **Start realisation of smart manufacturing demonstrator hubs:** In 2023, the first steps were taken to establish the footprint for two TNO smart innovation manufacturing demonstrator hubs, which act as test beds for SMEs creating “test-before-invest” autonomous manufacturing solutions (NGF NGHT, EU horizon TEF and TKI). Next to the initial setup of minimum viable test facilities, a catalogue was developed for AI and testbed services. The first testing together with industrial parties is expected in mid-2024.
- **Autonomous manufacturing for sustainable mobility & smart sensing:** A proof of concept for in-line quality control of composite and metal structures through direct velocity mapping (ultrasound non-destructive inspection) for application in lightweight safety-critical structures to boost new mobility solutions was developed. This resulted in another patent for the inspection of anisotropic materials. Due to the delayed start of NGHT, the first results of the proof of concept(s) are expected in 2024. In addition, TNO invented revolutionary hydrogen and catalyst temperature optical fibre measurements, which can be integrated into fuel cells and electrolyzers. This accelerates data acquisition for sustainable manufacturing in the energy transition domain. In 2023, these smart sensors were tested on lab-scale, resulting in more than 10 patent applications. Within 2024, these sensors will be tested on a more industrial pilot scale.
- **Autonomous manufacturing cells for High Tech Equipment for new value chains:** In 2023, a new proof of concept for autonomous manufacturing for Edge sealing of composites was developed. The technology was developed within the EU Penelope project. The invention, called 3D Nesting, was utilised for autonomous quality control of composite edge sealing and installed in an industrial production case. For autonomous manufacturing in the LSC domain, not all goals could be achieved due to the delayed start of NGHT. However, substantial productivity improvements have been found for manufacturing free-form optics by utilising a high-speed spindler. Furthermore, a knowledge development trajectory was started to reduce calibration time based on a “plug and play optics” concept, which is the start of a roadmap from manual manufacturing of free-form optics towards mass customisation. This is to position the NL manufacturing industry in the LSC and Quantum internet domain.
- **Artificial Intelligence for manufacturing:** A first whitepaper was developed for AI applications in the manufacturing environment within AIM-NET: AIM-NET AI IN MANUFACTURING. In addition, TNO developed a revolutionary concept based on generative AI for generating instant work instructions. In 2023, the technology was invented and developed to a minimum viable product, which will be tested in 2024 within several industry use cases to determine the actual productivity potential for manufacturing entities.