TNO Onderzoek 2024 - Overzicht Vraaggestuurde programma's volgens het MTIB

Unit	Roadmaps	Vraaggestuurde Programma's (VPs)	MTIB Thema
EMT	System Transition	P325 System Transition	
	Sustainable Subsurface	P307 Geo-energy	
		P310 Karakterisering Grondwater	
	Renewable Electricity	P321 Renewable Energy	
	CO2 Neutral Transition	P323 Co2 Neutral Industry	
	Environment & Sustainability	P510 Luchtkwaliteit	
		P515 Circulaire Economie	
	Sustainable Chemical Industry	P603 Sustainable Chemical Industry	
		P616 Industriële elektrificatie en CCUS	
MBE	Smart and Sustainable Mobility	P407 Smart and Sustainable Mobility	
	Buildings & Infrastructures	P502 Duurzaam bouwen	
HLW	Prevention & Productivity	P204 Future of Work	
	Biomedical & Digital Health	P203 Biomedical Health	
DSS	Information & Sensor Systems	P104 Radar & Sensorsystemen	
	National Security	P102 Veilige maatschappij	
		P106 Kennisopbouw politie	
ISP	Digital Innovations	P103 Cyber Risk & Resilience	
		P706 ICT	
		P707 ESI	
	Transitions and Transformations	P901 Transitions & Transformations	
HTI	Space & Scientific Instrument.	P607 Space & Scientific instrument.	
	Semiconductor Equipment	P612 Semicon & Quantum	
	Flexible & Free-form Products	P615 Flexible and Freeform Products	
	Smart Industry	P617 Smart Industry	

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

	Publiek
	Publiek / Privaat

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

Programma jaar 2024 - Samenvatting

De energiesysteemtransitie is een zeer complexe aangelegenheid. Voor beleidsmakers op alle niveaus die werken aan effectief beleid, voor bedrijven die toekomstbestendige strategieën willen ontwikkelen en voor de samenleving als geheel. Voorbeelden van complexiteiten zijn: realisatiesnelheid van de energietransitie, conflicten in ruimtegebruik, inpassing nieuwe technologieën, interactie-effecten (ecologie, economie, etc), financiering en gedragsaspecten. Met de kennisopbouw in het VP System Transition wil TNO de actoren onafhankelijke en feitelijke kennis en inzichten bieden die hen in staat stellen beslissingen te nemen.

Dit Vraaggestuurd Programma (VP) omvat twee verschillende onderdelen: Het eerste onderdeel betreft het innovatieprogramma (inzet van Rijksbijdrage ca. € 6 miljoen), dat bijdraagt aan de IKIA en de missies, met name aan missie Systeemintegratie van de topsector Energie. De belangrijkste doelgroepen van de ontwikkelde kennis en diensten zijn bedrijven in de energietransitie (zoals de netwerkbedrijven en energie-intensief MKB), lokale en regionale overheden en energieconsultants.

Een voorbeeld van kennisopbouw in dit kader is een onderzoek naar de verschijningsvormen en planbaarheid van 'Energiehubs': gebieden waarin de energievraag lokaal optimaal wordt afgestemd.

Het tweede onderdeel betreft het onderzoeksprogramma Energietransitiestudies (omvang € 5 miljoen), met als doel het leveren van kennis voor met name beleidsmakers in de energietransitie op alle niveaus en publieke instellingen die daarbij ondersteunen . Dit deel wordt gefinancierd door een programmasubsidie van het ministerie van Economische Zaken en Klimaat (EZK). Dit programma omvat onder andere zogenaamde Kennis voor Energiebeleid (KVE-) projecten, waarin TNO onderzoek doet ter ondersteuning van het energie- en klimaatbeleid van EZK. In dat kader is onder andere een analyse uitgevoerd van de verdere aanscherping van de Europese energiebesparingsdoelen (REPowerEU), waaruit bleek dat het huidige en het aangekondigde beleid niet voldoende zijn om de voorgestelde energiebesparingsdoelen te halen en dat aanvullend beleid nodig is.

De twee onderdelen van het VP leveren als resultaat rapporten (bijv. als bijlage bij Kamerbrieven), whitepapers, webtools en software (onder andere rekenmodellen). Veel van de resultaten worden gepubliceerd op de website www.energy.nl.

1.1 Doelstellingen per PMC-Cluster[1]

Societal transition	• Ontwikkeling van methodieken en interventies om huishoudens, energy communities en bedrijven effectief te betrekken bij de energietransitie en duurzame producten/diensten te ontwikkelen voor deze doelgroepen • Operationalisatie van afwegingskaders en analysemethoden om te komen tot een inclusieve en rechtvaardige energietransitie: distributie-effecten en burgerparticipatie • Ontwikkeling van perspectieven op een maatschappij en economie met duurzame consumptiepatronen en economische structuur in Nederland • Opbouw van inzicht over en perspectief op de financiering en betaalbaarheid van de energietransitie

[1] Product-markt-combinatie of 'propositities'

Electricity transition	• Ontwikkeling van concepten voor de opzet en regulering van nieuwe 'agile' elektriciteitsmarkten • Ontwikkeling van tools voor gebiedsgerichte energieplanning • Ondersteuning van het gedistribueerde energienetwerk door operationalisatie van onder andere energy hubs en inpassing en facilitering van energy communities
Heating & cooling transition	• Ondersteuning en feitelijke informatie om de lokale energietransitie te versnellen met de ontwikkeling van analysetools en methodieken. • Tools om de energietransitie op bedrijventerreinen te ondersteunen. • Opbouw van de feitenbasis ten aanzien van utiliteitsgebouwen. • Opbouw van modellen- en kennisbasis om de impact en oplossingen voor de groter wordende koudebehoefte op de energietransitie te kunnen duiden.
Molecule transition	• Ondersteuning van beleidsmakers en strategen bij de transitie van fossiele brandstoffen en – grondstoffen naar groene waterstof en niet-fossiele koolstoffen met raamwerken, analyses en tools
Integrated assessment of energy transition	• Ondersteuning van de transitie door onderbouwde 'pathways' te schetsen van het evoluerende energiesysteem naar GHG[2]-neutraliteit op nationaal, Europees en mondiaal niveau • Analyse van beperkingen, schaarste en interactie-effecten van de energietransitie met andere domeinen, zoals milieu, economie, grondstoffen • Inschatten hoe innovatieve technologieën kunnen bijdragen aan de energietransitie

[2] Greenhouse Gas - broeikasgassen

Titel	**VP Geo Energie (P307)** [3]
MTIB Thema	Klimaat en Energie / MMIP4: Duurzame warmte en koude in de gebouwde omgeving (individueel en collectief), MMIP 6,7 (Verduurzaming warmtevraag Industrie, CO2 opslag, grootschalige energieopslag)
Contactpersonen TNO (DM en VPM)	Maurice Hanegraaf
Contactpersoon Regie-voerder	TKI UE: Robert Jan van Egmond, TKI Geo Energie: Jorg Gigler, EZK: Ronald Schillemans, Pieter Jongerius

Programma jaar 2024 - 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 Realisatie risico'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 HTO, CCS, abandonneren putten):
4. Verlagen kostprijs voor *aanleg en aansturing van warmtenetten* en optimalisatie van warmte & koude vraag 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 missie gedreven ecosystemen samen met industrie, Nederlandse kennisinstellingen (i.e. Deltares, KWR, academica). De missies worden o.a. gedreven door kennisagenda's die samen met industrie en kennis instellingen worden gedefinieerd. De benodigde innovaties worden vervolgens grotendeels (ca 50% van het SMO-budget) gerealiseerd in nationale en internationale onderzoeksprogramma's zoals het lopende WarmingUP GOO, SafeGeo, Diepe Bodemlus (WGO-BES), DRAGLOW, PERFORM, RESULT, ELFO, SafeGeo, DHARA etc. Hieronder enkele voorbeelden van resultaten uit 2022 & 2023 en verwachte impact in 2024:

Ad 1. Verlaging van Pre-Dril risico's: Er is uitgebreide tooling ontwikkeld om breukreactivatie en seismiciteit door afkoeling bij doubletten in zandsteen reservoirs te analyseren en thermo-mechanische experimenten zijn ontworpen en uitgevoerd in het iM4RockLab (TNO-Utrecht). Dit werk is in 2022 & 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 Ammerlaan (Dhara project). Mogelijk wordt de validatie uitgebreid met meerdere putten.

Ad 3. Vergroten veiligheid (Well technologie → veiligheid & kostenverlaging): Er zijn circa 6000 olie & gas putten in Nederland en een groeiedn aantal geothermie putten. Ook zijn putten voorzien voor waterstof en CO2 opslag. Een veilige afdichting is essentieel en kostbaar. Afdichtende en mechanische eigenschappen van bentoniet, zout en Sorel-cement zijn onderzocht. Een

[3] VP307 zich richt op de bijdrage van de ondergrond aan de energietransitie inclusief collectieve warmtesystemen. De naam van VP307 is vanaf 2021 gewijzigd in Geo Energie omdat er binnen TNO Energietransitie in 2021 een nieuwe roadmapstructuur is ingesteld en dit beter aansluit bij de programering van het VP. VP307 maakt nu ondeel uit van de Roadmap Sustainable Sub surface van de Geologische dienst Nederland (GDN).

grootschalige laboratorium opstelling is gerealiseerd voor de opbouw van kennis over cementhechtingskwaliteit en leksnelheid tussen cement en een zachte formatie in 2022. Ook zijn er in 2022 en 2023 veldtesten gedaan in een put van Nobian op diepte. De resultaten worden voorgelegd aan SODM. Hopelijk zal dit proces leiden tot acceptatie van bentoniet als afdichtingsmateriaal voor putten. Dit is een kosteneffectieve en veiligere methode voor het abandonneren van putten voor de olie & gas industrie, Geothermie en CO2 opslag.

Ad 4. Verlagen kostprijs warmtenetten: De ontwikkeling en het gebruik van de WarmingUP design toolkit voor het ontwerp van warmtenetten en case studies voor RES ontwikkeling door verschillende industriële partners in WarmingUP; de design toolkit is uitgebreid met multi commodity capabilities voor een flexibel optimalisatiekader voor hybride systemen. De design toolkit is in 2022 en 2023 uitgebreid getest door operators en adviesbureaus. In 2024 wordt in samenwerking met een software consultant de designtoolkit verder ontwikkeld en publiek beschikbaar gemaakt. De design toolkit zal worden uitgebreid met nieuwe functionaliteiten zodat ook de koelvraag meegenomen kan worden.

Ad 5. Voor waterstof opslag zijn robuuste simulatoren ontwikkeld (technisch-economische MOLE simulator is opgeleverd, die gebruikt kan worden voor CAES, UGS en UHS), en waterstof gekoppelde reacties zijn ontwikkeld in de TNO's REACT simulator. Deze software wordt verder ontwikkeld in 2024 en gevalideerd aan de hand van praktijkdata van een waterstofopslag project in Oostenrijk (= grrotschalige veldtest H2 opsalg in een acquifer). H2 opslag in acquifers kan voor nederland een interessante optie zijn naast opslag van H2 in zout. Dit is alleen in Noord-Nederland mogelijk. TNO is een van de belangrijkste kennispartners in dit internationale project voor waterstofopslag in acquifers. Dit is de eerste grootschalige veldtest in de wereld en de TNO bijdrage wordt 50% gefiancieerd door de EU en 50% met SMO middelen.

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

Programma jaar 2024 - Samenvatting

De beschikbaarheid van voldoende grondwater van goede kwaliteit is een belangrijke randvoorwaarde voor de Nederlandse samenleving. De grondwaterstand is van groot belang voor bijvoorbeeld natuur, landbouw, bebouwing en infrastructuur en heeft een directe relatie met bodemdaling. De kwaliteit van het grondwater bepaalt in grote mate de waarde van dit natuurlijk kapitaal. Verder is grondwater een efficiënte drager van thermische energie en kan gebruikt worden voor warmte- en koude-opslag in de energietransitie.

In dit Vraaggestuurd Programma (VP) richt de 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.

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. Eventueel gebruik van grondwater in de energietransitie is onderdeel van het VP307, geo-energie. Tussen VP 307 en dit VP (310, KarDySaG) vindt afstemming plaats om de relatie met grondwaterkwaliteit en -kwantiteit goed te adresseren. De kennisontwikkelingsactiviteiten in dit VP 310 KarDySaG leiden tot:

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

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

In 2024 worden de volgende resultaten voorzien:

- Uitbreiden website grondwaterkwaliteitinbeeld.nl;
- Koppeling website grondwaterstandeninbeeld.nl aan BRO-grondwaterstanden - overzicht meetpunten waar via telemetrie actuele data beschikbaar zijn;
- Eerste bevindingen ten aanzien van grondwatertemperatuurveranderingen sinds de jaren 1980.

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

Programma jaar 2024 - Samenvatting

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

For Wind Energy, the research programme aims to provide the innovations, knowledge and technology required to implement wind power in the Netherlands against the lowest societal costs. 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 additional incentive to accelerate obtaining these goals.

The upscaling of offshore wind encounters barriers such as costs, speed of implementation, use of offshore space, safety, ecology, human factors, and integration in the energy system. Also, onshore wind is addressed, but the activities are less technical and more environmental, societal, and addressing regulation.

TNO Wind Energy is leading in developing innovative products and solutions for offshore wind farms. Together with companies, TNO develops knowledge and innovations that assist the implementation of offshore wind farms. By including the companies in an early stage of development, the inventions are expeditiously implemented by the companies and, therefore, have their impact on building the offshore sector before 2030. An example is the Dutch offshore industry, enabling the Dutch energy transition and creating activities worldwide by installing and maintaining offshore wind farms.

The R&D programme of TNO Wind Energy is part of TKI Offshore Energy and seamlessly aligns with the MMIP1 of Mission A. The MMIP has been updated, and its implications have been incorporated in this VP. For the next three years, the primary goals are to contribute to the implementation of offshore wind by

1. Support the accelerated offshore wind development. In 2024, we will deliver high-quality wind measurements from four measurement platforms across the North Sea and a rain atlas, allowing operators to predict wind turbine blades' erosion better.
2. Improve the integration of wind power in the energy system. Specifically, in 2024, we aim to test and demonstrate wind coupling to batteries at the SWITCH facility.
3. Increase the circularity of wind energy. Specifically, in 2024, we aim to deliver a new tool to assess different end-of-life scenarios for wind turbine blades.
4. Expand ecological research and move towards inclusive wind farm design. Specifically, in 2024, we aim to test and validate bird deterrence methodologies, such as black blades.
5. Reduce the costs of wind power even further. Specifically, in 2024, we aim to prove the value of wake steering beyond the wind farm level, i.e., at the wind farm cluster level. The North Sea will become much more densely populated with wind farms.

To achieve these goals, the VP has structured an R&D program, which aims for innovations in offshore wind energy. The innovations support the Dutch industry's competitiveness and remove barriers to the accelerated implementation of offshore wind power with many green jobs. The main pillars (PMC clusters) of the programme are

- Offshore wind farms: Support the fast implementation and reliable operation of offshore wind farms towards 2030 and reduce the energy cost of offshore wind power.
- WE System Integration: Improve the implementation of wind in its surrounding system in terms of power, ecology, and society. Increased flexibility, conversion, storage, and market are essential themes in power system integration.
- New Technologies: Develop a new wind energy system concept for the period after 2030, for which a viable business case does not exist yet. Experimental validation is explicitly part of this pillar.

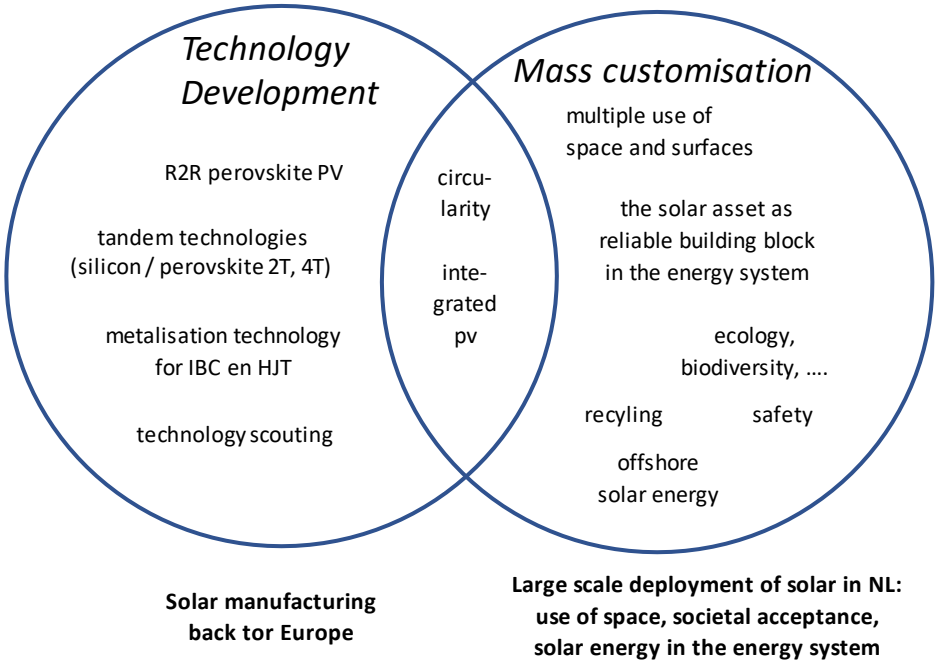
The facilities that are used to accelerate the knowledge and technology to implementation are

1. A research wind turbine in collaboration with industry
2. An environmental field lab for measurements of bird behaviour around wind turbines
3. The SWITCH field lab, in collaboration with Wageningen Research for system integration

Because the wind industry is becoming more mature, the upscaling of wind power in the Netherlands raises new challenges, and our roadmap needs to be validated and revised periodically; TNO Wind Energy is currently regauging its strategy. This process is a work in progress and is not completed yet. Nevertheless, we have already tried to incorporate the main trends in this VP plan. However, it may be that the goals and PMCCs/PMCs will change slightly shortly.

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&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.

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. Ensure successful pilots of floating PV on the IJsselmeer and the North Sea;
3. 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;
4. Realize cost competitiveness for recycling PV modules, resulting in easy access to high-value materials;
5. Be one of the key partners in establishing novel PV manufacturing in the EU;
6. Increase the efficiency of large area so-called silicon perovskite tandem PV devices.

Titel	VP CO2-neutral industry (P323)
MTIB Thema	Klimaat en Energie, Missie C; MMIP 6, 7 & 8
Contactpersonen TNO (DM en VPM)	Richard Braal, Jaap Vente
Contactpersonen Regie-voerder	Rob Kreiter (TKI-E&I), Jörg Gigler (TKI-Nieuw Gas), Peter Besseling, Paul Verbraak, Roy Dekker (EZK)

Programma jaar 2024 - Samenvatting

The demand driven program "CO_2 neutral industry" responds to the societal need for a carbon neutral industry as formulated in the Climate Agreement. The government's central goal with the National Climate Agreement is to reduce greenhouse gas emissions in the Netherlands by 55% by 2030 compared to 1990 levels. An integral knowledge and innovation agenda (IKIA) was established, following the Dutch climate agreement. Five "missions" were defined containing 13 MMIPs (multi-year mission driven innovation programs). Following the missions and MMIP the VP CO_2 neutral Industry is structured in 8 clusters of product market combinations. Below a concise description as well as the concrete development goals for 2024 are presented.

Short overview of relevant research topics in the PMC-Clusters in the VP CO_2 neutral industry 2024.

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

Key deliverables 2024

- Guidelines formulated that can be used as a European standard for the emission measurement of an amine degradation products.
- Long term (up to 6 months) membrane performance of O_2 removal technology (DORA) to prove durability and amine degradation reduction at a waste incinerator
- Construction of the SEWGS pilot TRL7 completed and ready for testing. Reactors loaded with an industrially sourced adsorbent material.
- First process design for (Vacuum) Temperature Swing Adsorption based CO_2 capture process tailored to medium scale emitters

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 deliverables 2024

- Demonstration of a 30% increase in Carnot efficiency of the thermoacoustic heat pump to deliver 190°C steam by using 3D printed heat exchangers.
- Successful commissioning of three commercial compression heat pumps in the Carnot lab and in an industrial settings.
- Basic engineering design of a TRL 6 close loop heat pump assisted distillation field test unit and cost estimate for the pilot scale setup
- Verification of the performance of a pervaporation membrane unit for glycol dewatering through lab and bench scale testing and the preparation for on-site piloting
- Basic engineering design of the HyFlexFlOx Hybrid burner system at 75 kWth scale.

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

Key deliverables 2024

- PosHYdon offshore hydrogen production pilot system tested at Investa, Alkmaar, prior to offshore installation. Offshore operation and testing started in 2024.
- High pressure test installation and test equipment operational for fatigue testing of pure hydrogen on materials up to 1000 bar in addition to permeation testing in 2023
- Dynamic network model for compositional tracking in a distribution network to support smart billing- by network operators validated.
- Scale-up plan for offshore hydrogen production from 1 MW PosHYdon test towards 500 MW DEMO2 project.

Clean Hydrogen Production: The technology development of the next generation low temperature (proton and anion exchange membrane) and high temperature (solid oxide) electrolysers is focused on cost reduction, performance improvements, circularity, reduced iridium usage and high precision manufacturing. In addition, relevant Dutch innovations from component to system level, are supported.

Key deliverables 2024

- Circularity: Low iridium technology for the PEM electrolyser with a performance and durability comparable to the current state of the art.
- Upscaling: Pressurized PEM electrolyser stack validated at the MW-test center, and Dutch components tested at scale
- Upscaling: Construction and validation of high pressure, reproducibly produced Solid Oxide Electrolyser stacks
- System integration: 2 offshore electrolysis innovations identified and validated together with (Dutch) high Tech industry
- Innovation roadmap for AEM including 2 innovations for improved (performance, durability, cost) AEM electrolysers.

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, and higher value added chemicals like aromatics. The maximum climate impact is reached when the excess carbon is sequestrated either as CO_2 or bio-char.

Key deliverables 2024

- Production of 10 liters of lignin-based maritime fuel with bio-based methanol.

- TRL 5 experimental validation at a scale of ~2.5m^3/h of pure H_2 by combining MILENA and SEWGS technologies
- TRL 3 experimental validation for a SAF production method that directly produces the required molecular weight distribution, supported by a positive economic feasibility
- TRL 4 demonstration of a continuous TORWASH process broadly suitable for seaweeds
- A strategy to develop a sustainable fertilizer based on functionalized bio-char

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

Key deliverables 2024

- Addition of DME purification and storage facilities to the TRL-6 test set-up so that the CO2 to DME line is complete, and make this set-up ready for long term testing.
- Evaluation of novel technology options for the production of syngas.
- Proof of principle of the next generation membrane assisted ammonia cracker, that produces hydrogen in a more sustainable and considerable more efficient way.

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 deliverables 2024

- Strategy definition for the new cluster of Adaptive Industry
- Pseudocapacitor stability confirmed for ≥ 10k cycles with an energy density of 50-80 Wh/kg and ≥95% efficiency, ,
- Identification of use cases and technologies in electricity driven separations.

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 deliverables 2024

- Model and approach for energy ,feedstock and value chain analysis in industrial clusters, integrating the existing CIMS, CITS and CALIOPE model systems.
- Map of global, national and regional carbon streams with focus on the refinery and chemical sector and scenario's for the impact on the position of these sectors towards 2050.

Whitepaper discussing the future of the process industry in The Netherlands within the context of a net zero and circular society and providing scenario's for the industry portfolio in 2050.

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

Programma jaar 2024 - Samenvatting

The Netherlands is facing pressing environmental challenges related to anthropogenic emissions. Approximately 11.000 premature deaths can be attributed yearly to bad air quality. Climate change may lead to catastrophic sea level rise, droughts, and more frequent extreme weather around the globe. Significant biodiversity loss is expected if the critical loads for atmospheric nitrogen deposition keep being exceeded in the Dutch nature areas. To curb these impacts and to comply with European legislation, the Dutch government has committed to a strict set of agreements:

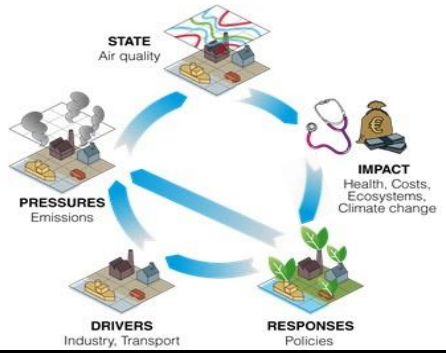
- In 2020 the "Schone Lucht Akkoord (SLA)" was signed, which aims for 50% air quality-related health gain in 2030 and focuses on the WHO recommended values for **particulate matter and NO_2**.
- In 2016 the Netherlands committed to the Paris climate goals and therefore now aims to reduce **greenhouse gas** emission by 49% in 2030 through the "Klimaatwet".
- In 2021 the "wet stikstofreductie en natuurverbetering (WSN)" was accepted, which sets a target of 74% area of the Dutch Natura2000 reserves to be below the critical deposition load (KDW) for deposition of **reactive nitrogen** in 2035.

Because the targets of these agreements are ambitious, TNO focusses, within the VP Air Quality, on the development of technological solutions for an innovative, state-of-the-art verification and monitoring infrastructure for atmospheric emissions. This infrastructure will provide a thorough understanding of the current situation and the effect of policies, which is critical in order to design and track the progress of effective policies for reducing harmful emissions.

With a wide range of competences in the field of designing and operating measuring and modelling systems for atmospheric emissions, TNO is well equipped to work on providing crucial new parts for this infrastructure. Within this effort, TNO also seeks synergy with Dutch scientific partners such as RIVM, KNMI, SRON, TUD, RUG, WUR, VU, UU and GGD and several European partners.

Some important targeted short-term results for 2024 are:

- **Particulate matter (PM) and ultrafine particles (UFP):** health relevant ranking and source apportionment at an urban and rural site based on physicochemical composition, chemical reactions during transport and/or health-related indicators (like oxidative potential) as compared to mass concentrations.
- Soot and/or UFP sensors in at least **2 urban sensor networks** plus upgrade of urban modelling capacity for separation of PM from industrial, traffic and wood burning emissions.
- Tests performed of the new TNO toolset (measurements and models) for **quantification of regional nitrogen emission, concentration and deposition levels** near Natura 2000 regions.
- Set-up of **inverse modelling based source apportionment** for greenhouse gas emissions for (several regions in) the Netherlands.



Titel	VP Circulaire Economie (P515)
MTIB Thema	Circulaire Economie
Contactpersonen TNO (DM/SD en VPM)	Alex Leighton (VPM), Peter Wolfs (DM)
Contactpersoon Regie-voerder	Bas Warmenhoven (IenW)

Programma jaar 2024 - Samenvatting

The Circular Economy is an essential means to achieve the sustainable development goals, conform to the Paris agreement on climate change, and to provide a reliable supply of secondary raw materials, specifically strategic & Critical Raw Materials (CRM). A circular economy greatly reduces the use & 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, July 2021).

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, a.o.:

- Committing to Circular Economy goals 2050 & 2030 (respectively 100% circular economy and 50% reduction of use of abiotic raw materials)
- Intensifying research concerning criticality and strategic autonomy (Grondstoffenstrategie 2022).
- Supporting maximizing raw material efficiency, Design for Recycling, Circular materials & processes (KIA CE).
- Supporting ambition towards circular industry and circular build environment (Coalitie akkoord).
- Supporting prioritized value chains (plastics, build environment, manufacturing industry, batteries / electronic devices (ICER 2023, NPCE 2023).

The VP Circular Economy focuses on 2 topics: Circular Strategies & CRM, and Circular Plastics.

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.

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. Metals play a central role in successfully building Europe’s clean energy technology and digital technology value chains and meeting the EU’s 2050 climate-neutrality goal. Europe’s lack of resilience for its growing metals needs has become a strategic concern. Optimized circular strategies and recycling are the most important strategy for Europe and the Netherlands in guaranteeing future sustainable supply of Critical Raw Materials (CRMs). Current recycling technologies for CRMs are hardly in place, heavily polluting and far from efficient. Technology development is crucial to make sure that we can recycle CRMs from the EU and NL urban mine in a sustainable way.

Envisaged outcome:

- Increased security of supply of CRMs for industry & government, creating a proactive position at global- and EU level, contributing to the earning power of Dutch industry, supporting and securing the position of Dutch industry in European renewable energy industry.
- The Netherlands as European front runner in sustainable recycling of CRMs, a.o. creating new business and employment opportunities.

In the coming years, CSC will prioritize on underneath issues where we can still create a competitive advantage for Dutch industry & society:

1. Developing science-based assessment methods to determine integral impact (environmental, economic, social) of circular strategies and technologies,
2. Assessing the potential of the urban mine and circular economy for CRM, developing potential circular strategies for CRM,
3. Developing sustainable innovative recycling processes, impact driven technology development for sustainable recycling technologies and strategies for CRM.

Circular Plastics

The Circular Plastics program focuses on creating a more circular plastic value chain by 1) impact-based systemic modelling of the plastics value chain, 2) development of products with improved circularity, including recyclability, 3) effective recycling technologies and 4) understanding the health effects of microplastics and strategies how to mitigate microplastic formation and exposure to microplastics. The priorities of the circular plastics program for 2024 include (1) the further development of systemic models, including recyclate quality; (2) the development of a machine learning based sealing model for recycled packaging; (3) the scale-up (dissolution) and broadening of the feedstock base (thermal cracking) of recycling technologies and (4) the development of microplastics mitigation methods, including experimental understanding of polymer quality in the life cycle of design, production, use and recycling.

Technologies will be assessed using techno-economic assessment (TEA) and life cycle assessment (LCA), while underlying methodologies will be improved by adding the quality of the recycled plastic and the impact of microplastics into the impact assessments.

PRISM (Plastics Recycling Impact Scenario Model) is used to produce scenarios that provide insight in the technical feasibility, environmental impact (CO2 emissions), material reduction and economic costs to meet the targets set by the government, e.g. 50% circular in 2030, 100% circular in 2050, and/or implementation of a circular plastics norm. Based on the circular scenario, back-casting can be performed to take the right measures to reach the target (e.g. investment in recycling technologies, stimulating measures, CO2 tax). PRISM gives also insight in which recycling technology should be applied for which plastic waste stream, optimized for a minimum of CO2 emissions and taking into account the recycled material needs (volume and quality) of the market. In this assessment, PRISM takes into account that plastics can be mechanically recycled for a couple of times after which chemical recycling is needed due to plastic degradation.

PRISM is part of the Chemical Industry Transformation Model (CITS) model, which takes into account the total life cycle and gives insight about CO2 reduction and costs of circular design, reuse, repair, and recycling of plastic products. In this way, targets set for instance on reuse can be made and CO2 reduction and cost can be determined.

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

Programma jaar 2024 - Samenvatting

The drivers for the program Sustainable Chemical Industry are derived from the drivers of the value chain for the chemical industry 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 program works in close collaboration with other TNO research programs and Early Research Programs. Together they constitute a complete proposition for the chemical value chain. This program is organized in the PPP's Biorizon, Brightlands Material Center, and a growing program line Photons 2 Chemicals.

Biorizon

Biorizon and specifically the program line Horizon 2 holds a robust global IP position, unique know-how, and research facilities supporting their Diels-Alder technology platform, offering diverse opportunities to access bio-aromatic products. This enables cross-sectoral value chains, boosting revenues for biorefineries, providing sustainable building blocks for the chemical industry, and promoting applications for a circular society.

In 2020, TNO established Relement, a spinoff focused on commercializing Biorizon's production technology for 1st gen. bio-aromatic bioMPA. Capitalizing on developed knowledge and technology, Biorizon's currently focusses on development of furan-based and next-generation bio-aromatic building blocks, expanding the range of novel and existing bio-aromatics that are required for a circular society. While supporting Relement in commercial production of 1st gen bio-aromatics by 2025, the goals for 2027 include pilot-scale production of furan-based (e.g. surfactants) and next-gen bio-aromatics (e.g. biophenol), validating novel safe and sustainable building blocks in two applications, establishing the Biorizon Application Center with partners in West-Brabant, and supporting Dutch biobased developments with open access infrastructure that is today missing in our EU-region.

For 2024, Biorizon (Horizon 2) aims to realize infrastructure to accelerate development and scale-up of bio-aromatic building blocks and Dutch biobased developments in general. Within the product market combination (PMC) Furan's Technology the focus is on further improving yields in furfural production and scaling up biobased surfactants, while within PMC Bio-Aromatics the aim is to create sustainable alternatives for phenol and phthalic acid building blocks and develop safe and sustainable plasticizers and polyols for e.g. textile and composite applications.

Brightlands Materials Center

Within this PPP this VP focuses on 2 program lines: Sustainable Buildings and Sustainable Mobility.

BMC's Sustainable Buildings programline focuses on the development and validation of innovative optical materials for sustainable buildings. These materials are either coatings or polymer films with specific solar control functionalities, which are applied in windows and building-integrated photovoltaics (BIPV). To date, we have developed proprietary coatings and PVB polymer films with thermochromic functionality. They are transparent in the visible, and switch from a solar infrared light (= solar heat) transmissive to a solar heat blocking state and vice versa. They are applied in windows for intermediate climates with relatively cold winters and warm summers, e.g. The Netherlands, and result in a reduction of energy consumption, CO_2 emissions and costs for heating and cooling of buildings. By application of these coatings and films in windows in the Netherlands, 8% additional energy savings can be realized on top of HR++ glass. This translates to cost savings of € 23.70 per m² of window per year. When all windows in the Netherlands would be exchanged for HR++ windows with additional thermochromic functionality, CO_2 emissions could be reduced by 4.5 Mt p.a. In the past two years, we have installed 1 m² sized demonstrator windows comprising thermochromic films in test buildings to monitor their performance. Based on the results of these tests, we are currently further optimizing the functional performance of the thermochromic films and progressing towards an improved window for real-life testing in 2024 and 2025. The thermochromic coatings have been optimized on lab scale (up to A4 sized demonstrator) and in 2023 we have established a tailored pilot facility at the Brightlands Chemelot

Campus. This facility will be used to assess the techno-economics of pilot scale production, and to prepare 1 m² sized demonstrator windows for real-life performance monitoring in test buildings in 2024 and 2025. Furthermore, demonstrator windows will be installed in office buildings to receive feedback from end users, e.g., on comfort and aesthetics, as input for further optimization. In addition, the technology will be diversified into other markets (e.g., glazing for electric vehicles and polycarbonate glazing), and circularity aspects of the technology will be investigated in 2024 and 2025 (e.g., application on old re-used window glass, retrofit application). In the coming years, re-use of old window glass for production of new windows – which is of vital importance for reduction of energy consumption and CO_2 emissions during production of glass windows - will be a more prominent topic of research within the program. Questions such as (i) Is the surface quality of old glass sufficient for the application of coatings and films? and (ii) How can we remove coatings and laminates to enable re-use of old window glass? will be addressed.

Related to BIPV, we will transfer our colored coatings for BIPV covers from test buildings to occupied buildings in Maastricht in 2023. In the coming years, we will focus on multifunctional coloured BIPV coatings (e.g., combination of colour and anti-soiling functionality) and on coatings and encapsulants that contribute to a reduction of operating temperature of BIPV panels resulting in better performance and increased product lifetime.

The Sustainable Mobility programline focuses on development of technology for implementation of circular and lightweight, structural thermoplastic composite (TPC) materials in the mobility sector. The ability to use these lightweight, structural materials in a wider range of products and components will enable accelerating the energy transition in this sector by lowering fuel consumption and extending range of electric vehicles, resulting in reduction of CO_2 emissions. Development of recycling technologies for these materials further supports the sustainability transition. In 2023, we have shown the applicability of the previously developed thermoplastic composites recycling technology for different waste types, including different polymers and different types of reinforcing fibers such as natural fibers (e.g. flax), carbon fibers, and reclaimed fibers from thermoset composite waste. We have also improved the quality of the recycled granulate, allowing application in a wider range of manufacturing processes and ensuring higher product performance in the end application. In 2024, we will work on making the process more robust and enabling the combination of different waste sources into a recycled granulate with well-defined specifications suitable for industrial application. In 2023, we have worked together with different industrial partners to develop materials and processing technology for continuous fiber additive manufacturing for e-mobility and aeronautic products. In 2024, we will continue this work to validate use case demonstrator products with high mechanical and thermal requirements.

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_2 as carbon source (gas phase reactions at solid catalysts) and (2) the production of fine chemicals (liquid phase reactions using molecular catalysts). To date, we have developed plasmonic catalysts for the sunlight-powered conversion of CO_2 to CO, CH_3OH and CH_4. We have demonstrated the corresponding chemical conversions in batch and continuous flow processes on lab scale using artificial sunlight and are currently in the process of progressing towards a real-life outdoor demonstrator for CO and CH_4 using natural sunlight as energy source, combined with artificial LED lighting for (semi-)continuous processing. This will take place in 2023-2024. Based on the performance of this outdoor demonstrator, catalyst, reactor and other process components will be further optimized. Furthermore, alternative (lighting) technologies for processing in absence of sunlight will be evaluated based on energy efficiency and cost price. The developed catalysts for CH_3OH production will be further optimized on lab scale to ensure high activity, product selectivity and lifetime. Furthermore, the feasibility of novel sunlight-powered processes will be assessed e.g., production of chemicals and fuels with more than 1 carbon atom, dry reforming of methane to produce syngas and cracking of ammonia. For photochemical production of fine chemicals, we validated combinations of available transparent flow reactors and LED light sources for development of integrated photochemical set-ups. Based on the results from this study, we will design a tailored system comprising an LED light source, a transparent flow reactor and sensors for multipoint in operando monitoring of temperature and light intensity.

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

Programma jaar 2024 - Samenvatting

The increasing amounts of renewable wind and solar derived electrical energy offer great opportunities for the industrial production of green hydrogen and the conversion of renewable raw materials (e.g. biomass, CO2) to added value chemicals and fuels. This program aims at the development and piloting of 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 CO2) and renewable electricity as energy supply.

In 2024, we will continue further developing the proof-of-principles and proof-of-concepts towards higher TRL and market maturity together with regional, national and international stakeholders from industry and government. Focus of the activities in 2024 and the expected results will be:

- *Value chain development for fuels, fertilizers and materials*: Comparison of upcoming Power-2-X and CCU technologies by a multi-variable analysis (GHG Emissions, Techno-Economic Analysis, Business Case Assessment and Feedstock & Energy Availability Assessment).
- *Electrosynthesis of high-value chemicals using biobased feedstock:* Improve lifetime, material stability and reactor design of earlier developed stack reactor for maleic and valeric acid production at >1000 cm^2 scale.
- *Capture integrated electrochemical CO2 conversion*: Long-term testing (>1000 hours) of electrochemical CO2 to Formic Acid technology under relevant industrial conditions (currents, impurities, gas stream compositions).
- *High temperature electrolysis of CO2 and Water (Solid Oxide Electrolysis)*: Construction and validation of robust short 3-cell Solid Oxide stack (30x30 cm2), suitable for high pressure conditions (3-10 bars), with emphasis on improved performance and manufacturability.
- *Electrolyzer industrialization*: Development and testing of components and manufacturing approaches for electrochemical CO2 conversions.
- *Plasma synthesis technology*: Definition of scale-up strategy for plasma technology, based on experiments in the related R&D projects.

Furthermore, we continue our support of the Fieldlab Industrial Electrification (Rotterdam Harbor Industrial Complex) and collaborate closely with Brightsite (Geleen-Chemelot). In these regional testing facilities the developments from this program, amongst others, can be further piloted and brought towards demonstration together with industry and public stakeholders. Through this approach we aim to accelerate the development and implementation of results, so that our contribution to the 2030 and 2050 climate targets is maximized.

Titel	**VP Smart and Sustainable Mobility (P407)**
MTIB Thema	Mobiliteit / Missie D+ (MMIP 9 & 10; deel-KIA Toekomstbestendige Mobiliteitssystemen)
Contactpersonen TNO (DS en VPM)	Marieke Martens (DS), Marika Hoedemaeker, Isabel Wilmink, Jannete de Bes (VPMs)
Contactpersoon Regie-voerder	Topsector HTSM: Leo Warmerdam Topsector Logistiek: Niels Agatz Topsector Water & Maritiem: Bas Buchner Ministry of IenW: Michel Duinmayer and Marieke Smit (IenW-DGMO/Unit Strategie) Ministry of BZK: Arie Versluis (PDGRO/Geobeleid Kennis en Data) en Ellen Driessen (kenniscoördinator bij BZK)

Programma jaar 2024 - Samenvatting

The demand driven programme Smart and Sustainable Mobility focuses on knowledge and innovation of smart solutions for technology and policy in order to make the mobility and logistic sector safer, more sustainable and more efficient. The challenge is to increase road safety and improve the efficiency of mobility and logistics and at the same time to make it environmentally sustainable, with very low to zero emissions, powered by renewable energy. Research and development takes place at three system levels: the vehicle, the traffic & transport system and mobility in the wider social system context.

In this programme, TNO develops knowledge, technology, tools and instruments to support the development, implementation and impact assessment of innovative technologies and mobility and logistics concepts. In addition, orchestrating innovation is applied to help accelerate the deployment of promising technologies and concepts. All this is done together with public and private partners. We work with scenario based testing, both in the field and in simulation environments (including hardware/software in the loop testing). Where available, we generate, use and enrich datasets to do fact-based analyses.

Below we present some of the **key intended results** for 2024.

- The development of an automotive battery pack with an innovative cooling concept to improve the life span of the battery. The result is used for validation of the Battery Modular Simulation Tool, which is a design tool in the development process of batteries.
- In 2024, there is insight into the business case of automated transport at yards (Modi, Cat4Yard). Also, clarity will be given as to what is the impact of logistics measures to achieve the CO_2 emission goals in the Paris agreement. And there will be a sharp picture of the effects (increased efficiency and reduced mileage) when multiple parties are controlled from decentralized logistics.
- The EU project SUNRISE will develop and demonstrate a commonly accepted, extensible safety assurance framework for the testing and safety validation of a wide scope of CCAM systems.
- In the DITM project, transition paths will be studied to analyse how digital infrastructure supports the driving task (of the vehicle and/or driver) and the consequences for where automated driving can take place. The use case Intelligent Speed Assistance will be implemented in the Large Scale Micro Simulator, to evaluate the added value of information provided by sources outside the vehicle, e.g. to improve road safety. Also, a use case with advanced driver assistance systems (ADAS) in a safety-critical situation will be studied. Related research focuses on the quality or security of the information delivered to or detected by vehicles, e.g. to develop a Proof-of-Concept of software which identifies when information for vehicles is incorrect, or inconsistent between sources, which could for instance lead to a vehicle using or displaying an incorrect speed limit (‘misbehaviour detection’).
- The current (car dominant) mobility narrative will be examined and new narratives for a future sustainable and equitable mobility system that resonate with many stakeholders will be explored, to help to achieve the desired transition. Related to this, the XCARCITY project researches how to design car-low areas by applying digital twins of cities and their transport networks. This includes the development of a Proof-of-Concept for modelling car ownership specifically for car-low areas, and further development of impact assessment models to be used for low-car city use cases and the development of suitable indicators (e.g. for spatial impacts, and for accessibility per target group).

- In MOVE21 (Horizon Europe), the Digital Twins on mobility hubs (for people and goods) will be further refined and used in the Living Labs Oslo, Gothenburg and Hamburg. The public transport model, the hub module and the logistics module will be examined and expanded.
- In 2024 we will further develop the concept of Innovation Capacity in cities in the EU-project MOVE21. Training sessions will take place to develop further capacities and skills within the Living Lab Cities - Oslo, Gothenburg, Hamburg - related to innovation. This connects to cross-sectoral coordination (e.g. space, energy, mobility), both within government organisations and in cooperation with stakeholders. Lessons learned will be collected in the MOVE21 guide on improving city's capacities for promoting sustainable mobility and logistics innovation.
- Regarding vehicle emissions, on-road measurement methods of non-exhaust emissions will be developed and tested, emission factors will be updated accordingly and health impact can be determined. A method to link charging demand – in time and space – to available capacity in the E-grid will be developed. And the first results for the Green Maritime Methanol 3.0 project on maritime safety (corrosion tests) and supply chain development will become available.

Titel	VP Duurzaam Bouwen (P502)
MTIB Thema	Klimaat en Energie
Contactpersonen TNO (DS en VPM)	Arjen Adriaanse en IJsbrand van Straalen
Contactpersoon Regie-voerder	Rob Hofman (RWS), programmacommissie Deltatechnologie (PCDT), 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).

Programma jaar 2024 - Samenvatting

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_2- en energiebesparing, betaalbaarheid en comfort. In 2024 worden onder andere verschillende regelingen (zogenaamde '*model predictive controllers*') voor energieflexibilisering ontwikkeld en gedemonstreerd en wordt onderzoek gedaan naar de mogelijke rol van compacte warmteopslag in het totale energiesysteem.

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. In 2024 wordt de tool voor gebouwclustering uitgebreid met aspecten om het verduurzamingsproces te versnellen (onder andere installatietechnische aspecten) en wordt de contingentenaanpak (zowel de aanbod- als de vraagzijde) gevalideerd in de praktijk.

<u>Maritieme constructies</u>

Voor het behalen van de klimaatdoelen zijn maritieme en offshore constructies van groot belang. Hierbij gaat het om bijvoorbeeld het opwekken van offshore hernieuwbare energie (met name wind, zon) en de energietransitie van het transport over water (emissieloze scheepvaart). Om bij te dragen aan deze transities, richt dit deelprogramma zich op de ontwikkeling, het ontwerp en het onderhoud van de grootschalige assets die hiervoor nodig zijn. Dit vraagt om begrip van het constructieve gedrag, van detail- tot systeemniveau, inzicht in het effect van de belasting- en omgevingscondities en inzet van veiligheidsanalyses om op een verantwoorde manier deze transitie te maken. Hiervoor ontwikkelt TNO modellen die gecombineerd worden met metingen en experimenten, die zowel in het lab als in het veld worden uitgevoerd. Het onderzoek richt zich op een tweetal thema's.

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). Hier speelt de combinatie van deterministische en probabilistische modellen, aangevuld met monitoringsdata een belangrijke rol. Specifiek in 2024 is het doel om een *proof-of-concept* te maken van de probabilistische aanpak voor de levensduurvoorspelling van composieten windturbine bladen en bestaande modellen voor de levensduurvoorspelling van staal uit te breiden en te valideren voor lasverbindingen. Binnen dit thema wordt nauw samengewerkt met VP P321 (Renewable Electricity).

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. Daarom ligt in 2024 de nadruk op het verkrijgen hiervan. Specifiek gaat het om de effecten van lekkage en onderwater afblazen (venting) van methanol, lekkage van vloeibaar waterstof en het gedrag van staal in corrosieve omgevingen (methanol en ammoniak). Binnen dit thema wordt nauw samengewerkt met het VP P407 (Smart & Sustainable Mobility).

Titel	VP Future of Work (P204)
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: Dorien Höppener, Liliane de Ruiter-Nanninga

Programma jaar 2024 - Samenvatting

Het onderzoeksprogramma Work & 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 hoofdlijnen: Future of Work en Youth Health. Het programma draagt direct bij aan de centrale missie van het maatschappelijk thema Gezondheid en Zorg: "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". Daarnaast ligt de focus op duurzame inzetbaarheid en sociale innovatie, in het licht van het thema Human Capital.

Future of Work (afstemming SZW, EZK, HTSM)
Het deelprogramma Toekomstbestendig werk omvat innovaties voor een gezonde werkomgeving en een toekomstbestendige arbeidsmarkt. De doelgroep omvat de (potentiële) beroepsbevolking, werkgevers, overheid en HR/OSH-professionals. Een adaptieve en inclusieve arbeidsmarkt met een hoge kwaliteit van werk leidt tot meer brede welvaart, maar is bovendien noodzakelijk om grote maatschappelijke transities (energie, klimaat, digitalisering, gezondheid etc.) mogelijk te maken.
Alle kennislijnen worden afgestemd met het ministerie van SZW, met uitzondering van de kennislijnen smart working (ministerie van EZK) en safe chemical innovation (topsector HTSM).
We ontwikkelen kennis en innovaties via de volgende lijnen:

Inclusive Work: Doel van deze kennislijn is om de Nederlandse arbeidsmarkt inclusiever te maken en behouden, door (technologische) innovatie en het versterken van inclusief ondernemerschap en de uitvoeringspraktijk. Beoogde resultaten in 2024 zijn: 1) uitvoering van, in 2023, opgezette Leernetwerken t.b.v. het benutten van en het opschalen naar gepersonaliseerde inclusieve technologie en AI (zoals CST en groen-App) ter bevordering van doorstroming naar regulier werk en levenlang leren en ontwikkelen. 2) Implementeren en monitoren (Realist Evaluation) van systeeminterventies binnen nationale en Europese Living Labs, die bijdragen aan de in- en doorstroom van kwetsbare groepen op de arbeidsmarkt (Synclusive, Economische veerkracht voor vrouwen) en 3) Formuleren van een actieplan voor domein-overstijgend datagedreven werken samen met publieke en private samenwerkingspartners.

Labour Market Innovation: Doel van deze kennislijn is om de adaptiviteit van de Nederlandse arbeidsmarkt en Leven Lang Ontwikkelen (upskilling/reskilling) duurzaam te bevorderen, door de ontwikkeling van skills-gebaseerde strategieën. Beoogde resultaten in 2024 zijn: 1) Discrepantie tussen mogelijke overstap o.b.v. skills en daadwerkelijke overstap begrijpen (Trends & Gaps), 2) Inzicht in routes om motivatie en continue ontwikkeling van werknemers te versterken (LLO), 3) Versterken van de kennispositie o.g.v. ecosystemen/learning communities (Ecosystemen), 4) Inzicht in de rol van Labour Market Innovation in het verwezenlijken van grote maatschappelijke transities via systeembenadering (Arbeidsmarkt in transitie).

Occupational Exposome: Doel van deze kennislijn is om bijdrage te leveren aan innovatie van effectieve preventie van werkgerelateerde aandoeningen, in het bijzonder aandoeningen als gevolg van blootstelling aan gevaarlijke stoffen. Hiervoor is van belang inzicht te krijgen in blootstellingskarakterisering en gezondheidseffecten van gecombineerde blootstellingen, in gevoelige groepen en in ziektemechanismen. Beoogde resultaten in 2024 zijn: 1) Onderzoek naar de praktische inbedding van sensoren en Virtual Occupational Hygiene Assistant (VOHA) in de arbeidshygiënische praktijk, 2) Toepassen van big data technieken t.b.v. preventie van blootstellingen op de werkplek 3) Onderzoek naar de effecten van gecombineerde blootstellingen door gebruik te maken van TNO cohorten en andere databronnen en 4) Onderzoek naar het gebruik van intern exposoom markers (biomarkers) met als doel toepassing in de praktijk.

Occupational Safety Innovation: Doel van deze kennislijn is om het aantal arbeidsongevallen en incidenten bij bedrijven te verminderen door de ontwikkeling van innovatieve digitale veiligheidsmanagement systemen. Hiermee kunnen we gevaren sneller, efficiënter en real time identificeren, verborgen patronen traceren in big data en informatie geven aan gebruikers om (potentieel) gevaarlijke situaties sneller te herkennen en incidenten te voorkomen. Beoogde resultaten voor 2024: De bouw van een veiligheidsontologie (LLM), het identificeren van SMART standards voor Digital Twins, respectievelijk het ontwikkelen van een Digital Twin-raamwerk voor safety-risicoanalyse.

Work changes & Well-being: Doel van deze kennislijn is de stijgende trend van mentale gezondheidsproblemen in Nederland om te buigen. Beoogde resultaten voor 2024 zijn: 1) Het vergroten van inzicht in factoren die mentale gezondheid van werknemers beïnvloeden (bijv. digitalisering, hybride werken, kenmerken van de arbeidsmarkt) door toepassing van een systeem dynamische aanpak en het ontwikkelen van prognostische modellen, 2) Het ontwikkelen van innovatieve (digitale) interventies voor het verminderen van mentale gezondheidsrisico's en het versterken van mentale groei van werknemers, waarmee werknemers, organisaties, sectoren en beleidsmakers kunnen worden ondersteund en 3) Het opschalen van interventies en/door het koppelen van interventieniveaus.

Monitor & Foresight : Doel van de kennislijn is om ontwikkelingen in de Nederlandse arbeidssituatie via verschillende datastromen te monitoren en structurele verkenningen te doen naar de (potentiële) impact van technologische en maatschappelijke veranderingen op werk en arbeidsmarkt in bredere zin. Beoogde resultaten voor 2024 zijn: 1) Continuering en toekomstbestendig houden van data-infrastructuur TNO (ism CBS), 2) Toekomstverkenningen, oa de impact van generatieve AI op arbeidsinhoud en -omstandigheden en de ontwikkeling van een innovatierader en 3) Data-innovatie (oa genereren nieuwe databronnen, AI toepassing).

Healthy Living Environment : Doel van de kennislijn is om kennis, instrumenten en interventies te ontwikkelen die bijdragen aan een gezondheidsbevorderende leefomgeving. Vanuit multidisciplinariteit wordt diepte-expertise, breedte-innovatie én technologie vanuit verschillende TNO expertisegebieden en units (o.a. gezondheid, duurzaamheid, gebouwde omgeving) bijeengebracht. Beoogde resultaten voor 2024 zijn: 1) Uitbreiden van kennis en technologie ten behoeve van beleidsondersteuning en praktische implementatie rond de gezonde leefomgeving, in relatie tot diverse maatschappelijke transitie-uitdagingen (wonen, mobiliteit, duurzaamheid en gezondheid) 2) Doorontwikkeling van het DiLAN instrument op het thema beweegvriendelijke leefomgeving i.s.m. SUMS/MBE (Urban Strategy) 3) Focusgebied ontwikkelen tav gezondheid in relatie tot binnen- en buitenluchtkwaliteit (i.s.m. EMSA/MBE) 4) Verdere ontwikkeling op de koppeling met energietransitie/-armoede (i.s.m. unit EMT).

Smart Working (EZK): Doel van de kennislijn is het oplossingen leveren voor en het optimaliseren van duurzame (industriële) werkplekinnovaties voor verhoogde productiviteit m.b.v. slimme technologieën. De beoogde resultaten voor 2024 zijn: 1) Operator Support (OS) Technologie: optimaliseren van hybride AI technologie om werkplekken adaptief te maken t.b.v. behoeften, skills en prestatie van medewerkers en ter ondersteunen van werkgevers bij het semi-automatisch genereren van werkinstructies 2) Mens-Robot Samenwerking: optimaliseren van technologie (AI, sensoren, AR visualisatie) en kennis o.h.g.v. job quality om de interactie tussen mens en robot intuïtief en effectief te maken 3) Exoskeletten: benutten van kennis o.h.g.v. sensing, control en human body impact om de toepasbaarheid en effectiviteit van exoskeletten te verbeteren en het optimaliseren van technologie (sensoren, AI) om de adaptiviteit van ervan te vergroten d.m.v. het vaststellen van acceptatie en middel- en lange termijn gezondheidseffecten van exoskeletten, 4) Uitbreiden van Inclusieve organisatiecontexten voor Industrie 5.0: een Europees Platform voor Industry 5.0 en de Nederlandse scholingsinitiatieven binnen Smart Industry en het verbinden aan Logistics waarbij de Learning Factory en Teaching Factory concepten worden onderbouwd met digitale technologie en 5) Het opstellen van het Innovatieprogramma opgesteld met Intospace: een breed innovatieprogramma rondom het Logistieke landschap van de toekomst in samenwerking met Intospace.

Safe Chemical Innovation (HTSM): Doel van de kennislijn is om "Safe and Sustainable by Design (SSbD)" toepassingen te ontwikkelen welke 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). Innovatie hierop is hoog nodig door de energie transitie en de noodzaak om alternatieven te vinden op fossiele brandstoffen gebaseerde kunststoffen. De beoogde resultaten voor 2024 zijn: Het ontwikkelen van innovatieve instrumenten, begeleiding

en training voor innovatieve MKB-organisaties, sectororganisaties en industrie om veilige innovatie van bestaande chemicaliën en (nano/geavanceerde) materialen mogelijk te maken, in de absentie van begeleiding en regelgeving.

De hoofdlijnen van het programma zijn in samenspraak met regievoerders SZW, EZK en HTSM tot stand gekomen, mede op basis van raadpleging diverse externe strategische agenda's. Onder meer vanuit het ministerie van SZW en de Nederlandse Arbeidsinspectie is tevens matching voorzien in de vorm diverse programmasubsidies (Maatschappelijk Programma Arbeidsomstandigheden MAPA, Kennisprogramma NLA-KIS). Tot slot zal vanuit het programma opnieuw directe aansluiting plaatsvinden bij het ERP/VP AI, met nader te bepalen use-cases.

Youth Health (VWS)
Het deelprogramma Jeugd: Gezond, Veilig en Kansrijk opgroeien richt zich op kinderen en jongeren vanaf preconceptieperiode tot jong volwassene met als doel dat ieder kind zo goed mogelijk kan participeren in de maatschappij. Specifieke aandacht gaat uit naar het bereiken van kwetsbare gezinnen. We ontwikkelen kennis en innovaties via de volgende lijnen:

Integrale aanpak eerste 1000 dagen: Wij richten ons op het ondersteunen van (aanstaande) ouders, door doorontwikkeling van preventie en zorgmodellen waarbij zelfmanagement, interactief leren en peer support centraal staan. In 2024 wordt ingezet op een geïntegreerde aanpak en overgang van Centering tijdens de zwangerschap naar Centering in de JGZ, en op doorontwikkeling van het model voor leefstijl-verbetering. Tevens zetten we in op landelijke implementatie van het preconceptieprogramma Nietof-welzwanger. Tot slot richten we ons op de doorontwikkeling van de D-score, een nieuwe maat om ontwikkeling van kinderen te kunnen monitoren. In 2024 ambiëren we een pilot op te zetten naar gebruik D-score op individueel niveau.

Preventie en Jeugdhulp op maat. Hierbij richten we ons op het ondersteunen en versterken van kinderen en ouders en professionals in het (preventieve) veld voor jeugd. We richten ons op hoe om te gaan met uitdagingen en ingrijpende levensgebeurtenissen en op de persoon toegesneden instrumenten en inter-venties tbv een gezonde leefstijl en mentale weerbaarheid. In de komende jaren zal onder andere bij leerlingen in het voortgezet onderwijs onderzocht worden hoe stress verminderd kan worden en starten we met een (door NWA gefinancierd) groot programma om toxische stress bij jonge kinderen beter te signaleren en ouders hierbij ondersteuning te bieden. Binnen deze lijn richten we ons ook op het integreren van digitale innovaties voor de zorg voor jeugd middels het doorontwikkelen van het I-JGZ platform. In de komende jaren zal verder worden ingezet op modulaire inzet van digitale innovaties zodat alle JGZ-organisaties onafhankelijk van hun ICT-systeem (o.a. digitaal dossier), gebruik kunnen maken van slimme data-gedreven digitale innovaties, ontwikkeld door TNO (bijv. JAMES, Slimme richtlijnmodule). Hierbij zal ook vooral ingezet worden op het geven van inzicht aan ouders en jongeren zelf.

Samenwerking en implementatie: Met kennis van samenwerkings- en implementatievraagstukken rich-ten we ons op het ondersteunen van organisaties om de transitie en transformatie van het jeugdstelsel goed vorm te geven. Op het gebied van scheiding en pesten werken we aan het landelijk implementeren van effectieve interventies. Onze focus ligt op het opzetten van duurzame leernetwerken en ontwikkelen van strategieën om innovaties te implementeren. In 2024 wordt ingezet op concrete handelingsadviezen voor het gebruik van het framework.

Titel	VP Biomedical and Digital Health (P203)
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 2024 - Samenvatting

The research program Biomedical and Digital Health supports the mission driven innovation approach of the Dutch Ministry of Health, Wellbeing and Sports ('VWS'). It supports the central mission: aiming for Dutch citizens living 5 year longer in good health and reducing the health differences between the higher and lower social classes. TNO research contributes to reducing health issues that are the consequence of an unhealthy lifestyle or exposure to unhealthy environment (mission I). Our research will also contribute to preventing chronic diseases and increase the proportion of people with a chronic illness or lifelong disability that can participate in society as desired (mission III).

We do this by reducing the risk of disease development (prevention) and by helping to manage disease by developing ground-breaking technologies and approaches such as lifestyle interventions, digital health technologies and drug development. The research program Biomedical and Digital Health significantly contributes to the two moonshots of TNO illustrated below:

To help achieve the moonshots, newly developed technologies and knowledge will be implemented in the context of the quadruple helix that includes collaborations with other research programs, academic and industrial partners, health professionals in field labs, healthcare insurance companies, governmental and local policy makers, and citizens in order to provide systems solutions. The research is conducted used through public-private consortia and projects with industry (e.g. in services for industry and growth fund ('Groeifonds') projects).

To contribute to above missions and moonshots some examples of short-term results for 2024 are:

- The 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.
- To demonstrate applicability of accelerated mass spectrometry technology for drug testing in a paediatric clinical cohort.
- Demo-case of relevance of timing of lifestyle interventions for improved health result in shift workers
- Implement digital biomarkers in clinical trials and healthcare.
- Explore 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.
- Orchestrate innovation by supporting 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 Regie-voerder	Mr. H. Hanoeman en drs. B. ter Luun (Ministerie van Justitie en Veiligheid)

Programma jaar 2024 - Samenvatting

Veiligheid en rechtvaardigheid zijn een voorwaarde voor welzijn en economische ontwikkeling. Veiligheid en recht 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 veilig en rechtvaardig te houden. Hierbij is een integrale aanpak van groot belang om impact te kunnen maken op een dynamisch en complex speelveld.

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.

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. TNO zet middels het VPVM in op een meerjarige onderzoeksprogrammering voor justitie- en veiligheidsorganisaties. Het doel van deze meerjarige programmering is innoveren door toepassingsgerichte wetenschappelijke kennis op te bouwen en technologie te ontwikkelen op díe onderwerpen die voor het justitie- en veiligheidsdomein het belangrijkst zijn én die niet al door marktpartijen worden opgepakt.

In de periode 2024 – 2027 wordt onderzoek uitgevoerd op vijf inhoudelijke thema's die gevoed worden door een verkenningen programma waarin breed inzetbare technologieën, methodieken en andere innovatieve concepten worden verkend, geduid en ontwikkeld.

De inhoudelijke themalijnen zijn:

- Kritieke Infrastructuur
- Rechtstaat en Opsporing
- Data en Intelligence
- Security en Surveillance
- Weerbaarheid Veiligheidsprofessionals

Hieronder volgt een korte samenvatting van de onderzoeken binnen de themalijnen en het verkenningen programma.

Kritieke Infrastructuur: het onderzoek in dit thema is gericht op innovaties rondom (digitale) weerbaarheid, het versterken van missiekritische informatie- en communicatiesystemen en digitale interceptie. Het onderzoek wordt uitgevoerd met het Nationaal Cyber Security Centrum (NCSC), de Nationaal Coördinator Terrorismebestrijding en Veiligheid (NCTV) en andere onderdelen van het Ministerie van Justitie en Veiligheid.

Rechtstaat en Opsporing: binnen dit thema wordt voornamelijk onderzoek gedaan 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. de Dienst Justitiële Inrichtingen (DJI), het Openbaar Ministerie (OM) en de Regionale Informatie en Expertise Centra (RIEC's).

Data en Intelligence: onderzoek binnen dit thema is gericht op het toepasbaar maken van innovatieve methodes en technieken om de slagkracht van organisaties in het justitie- en veiligheidsdomein te vergroten. Hierbij ligt de focus in 2024 met name op AI-methodes zoals taaltechnologie, systeemanalyses en Privacy Enhancing Technologies (PETs). Het onderzoek vindt plaats in samenwerking met het OM, de DJI, de IND, het COA, de DT&V en verschillende organisaties in de crisisbeheersing die worden gecoördineerd door het ministerie van Justitie en Veiligheid.

Security en Surveillance: binnen dit thema wordt onderzoek gedaan naar de toepassing van robotica en sensingtechnologie om nieuwe mogelijkheden en innovaties voor het justitie- en veiligheidsdomein te creëren. Samen met de Koninklijke Marechaussee (KMar), politie en DJI wordt onderzocht hoe deze innovaties kunnen worden ingezet voor het verbeteren van opsporing en grenstoezicht.

Weerbaarheid Veiligheidsprofessionals: het onderzoek binnen het thema weerbaarheid veiligheidsprofessionals is gericht op sociale innovaties om veiligheidsprofessionals professioneel fit te houden en sneller en beter te laten leren en trainen. In dit onderzoek wordt onder andere samengewerkt met de DJI.

Verkenningen en technologieontwikkeling: binnen de verkenningen worden nieuwe technologieën en andere innovatieve concepten met een potentieel grote impact op het justitie- en veiligheidsdomein verkend. Wanneer uit de verkenning blijkt dat een onderwerp inderdaad een grote impact kan hebben én er sprake is van kennisbehoeften die (nog) niet door marktpartijen kan worden ingevuld, wordt een verdiepend ontwikkelprogramma opgezet. Deze programma's kunnen zowel gericht zijn op het ontwikkelen van technologische oplossingen als op het ontwikkelen van breed inzetbare methodieken of andere concepten. De verkenningen die in 2024 worden uitgevoerd worden nader bepaald in nauw overleg met het Ministerie van Justitie en Veiligheid. Daarnaast worden in 2024 verdiepende ontwikkelprogramma's uitgevoerd op de onderwerpen PET, robotica en AI voor beslisondersteuning.

Naast het VPVM wordt ook binnen het VP Kennisopbouw Politie (VP KOP) kennis opgebouwd voor het justitie- en veiligheidsdomein. Deze onderzoeken worden in nauwe samenhang geprogrammeerd.

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

Programma jaar 2024 - Samenvatting

Veiligheid is een essentiële voorwaarde voor het welzijn van de samenleving. Maatschappelijke en technologische ontwikkelingen zorgen voor een continu veranderende omgeving waarbinnen de politie als grootste veiligheidsorganisatie opereert om de rechtsorde te handhaven en hulp te verlenen aan hen die deze behoeven. Om in deze dynamische omgeving effectief te blijven, is het van groot belang dat de politie (digitaal) fit en innovatief is.

Het Vraaggestuurd Programma Kennisopbouw Politie (VP KOP) heeft als doel om bij te dragen aan het vermogen van de politie om haar taken effectief uit te blijven voeren zowel op de korte als de lange termijn. Door kennis op te bouwen over relevante trends en ontwikkelingen kan de politie proactief gebruik maken van de nieuwste inzichten en (technologische) mogelijkheden. Het VP KOP sluit aan op het maatschappelijk thema Veiligheid uit het Missiegedreven Innovatiebeleid.

Op basis van de prioriteitsgebieden uit de Strategische agenda politie 2021-2025, de Science & Technology agenda van de politie en voortbouwend op de kennis en ervaringen uit de eerdere kennisopbouw programmering is een meerjarige onderzoeksprogrammering opgezet voor 2022 t/m 2025. Deze programmering richt zich op vier kernprogramma's en een doorsnijdend technologie ontwikkelprogramma.

Kernprogramma's:

- Politiewerk van de toekomst: hoe gaat als gevolg van maatschappelijke en technologische ontwikkelingen de omgeving waarin de politie haar taken uit moet voeren veranderen? Hoe ziet de criminele business(modellen) van de toekomst eruit en hoe kan de politie daar op effectieve wijze - zowel in het fysieke als ook digitale domein – tijdig op interveniëren én met haar partners de gezamenlijke slagkracht vergroten?
- Politiemedewerker van de toekomst: hoe kan de politiemedewerker continu en op maat blijven leren; weerbaarder worden en blijven voor veranderingen en hoge belasting; en optimaal uitgerust worden voor het uitvoeren van zijn of haar taken?
- Politiedata en intelligence: hoe kan de politie veilig en snel informatie uitwisselen in ad-hoc coalities; nog beter informatiegestuurd werken met effectieve processen en betrouwbare data; en zwakke signalen uit data gebruiken om te anticiperen op opkomende fenomenen en crimineel gedrag?
- Techniek in de operatie: welke nieuwe methoden, technieken en toepassingen kunnen de capaciteit van de huidige politieoperatie verhogen? Hoe kan de politie méér, beter en eerder detecteren en observeren óók onder uitdagende omstandigheden? Zowel in het fysieke als ook digitale domein. Hoe haalt de politie meer waarde uit bestaande en nieuwe databronnen?

Technologie-ontwikkelprogramma:

- wat betekenen specifieke technologische ontwikkelingen voor het werk van de politie? Hoe moet de technologie worden ontwikkeld om effectief en efficiënt toepasbaar te zijn bij de politie?

Binnen bovenstaande programma's wordt kennis opgebouwd hoe innovatieve concepten 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 wanneer criminele organisaties compleet nieuwe manieren van werken hebben geadopteerd. Centraal binnen het hele programma staat een multidisciplinaire aanpak waarbij mens, proces en techniek als integraal geheel worden benaderd. Hierbij werken politie en TNO samen met (inter)nationale partners.

De opgebouwde kennis wordt geoperationaliseerd in de vorm van handelingsperspectieven, use cases, methoden en prototype technieken. Dit stelt de politie in staat om de opgebouwde kennis direct te benutten én gericht te investeren in de verdere ontwikkeling en ingebruikname.

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 Regie-voerder	*TNO* Director Marker (a.i.): P. de Graaf (TNO, Unit DSS) Programme Manager: M.W. van der Graaf (TNO, Unit DSS) *Government,* Defensie algemeen: A.P. Venema (Mindef/HDB) *Top sectors* Director HTSM / Coordinator KIA Veiligheid & 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.) *KIA Veiligheid* Programmamanager KIA Veiligheid: B. Molmans (HTSM) Mission Space: A. Bos (S&T Science and Technology BV) Mission Maritime High Tech: M. Janssen (Mindef/AMS) H. Hopman (TU Delft) Missie Landoptreden, J. Heeren (TNO) *KIA Sleuteltechnologie* Programmamanager KIA Sleuteltechnologien: K. Vermeer (HTSM) *Themes* 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. Rugers (Mindef/DMO/JIVC/KIXS) Mission High Tech Landoptreden: B. Smeenk (Mindef/DPLAN/K&I)

Programma jaar 2024 - Samenvatting

The Netherlands should 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. New solutions are required and need to be fielded at an increasing pace. We should become less dependent on knowledge and technologies from potentially unfriendly nations (strategic autonomy).

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 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 C2 systems, to carry out successful defence and security operations. This is a combined effort of the Triple Helix where TNO and industry work together with government as launching customer. For this, technological breakthroughs are built 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.

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

In the period 2024 – 2027, research will be carried out in projects within the following constitutive themes:

Radar and integrated sensor suites is the largest and most established theme in this programme. The focus is on the development of knowledge, sensor technologies and sensor concepts that will contribute to the creation of an operational AAW (Anti Air Warfare) and IAMD (Integrated Air and Mission Defence) capacity on board of the Dutch frigates in the period after 2030, to counter future and evolving threats. Leading in this is the national "Roadmap Radar and Integrated Sensor Suites 2030" that is governed by the Platform Nederland Radarland and is carried out within the Triple Helix and in an established R&D ecosystem. This proven PPP-concept implies a bundling of public and private investments and a very intense cooperation with end users which has already lead to innovative successful export products and capabilities for the Dutch armed forces. In 2024, we will continue: to innovate on system concepts and bring adaptivity to the next generation of radar suites supporting effective kill chains; creating RF front-end technologies for the transmission and reception of advanced waveforms; to bring signal processing to the next level for the detection and classification of complex targets; and will keep our experimental test and validation facilities up-to-date. The projects running under this theme deliver a major contribution to the Mission 'Maritieme high-tech voor een veilige zee' and in particular to Deelprogramma 1: 'Smart Kill chains – Radar and geintegreerde sensorsuites'. Next to the work on the larger radar and integrated sensor suites, we observe an increasing interest in small radar systems for remote sensing applications and proximity fuzes.

Noteworthy is the 'conditional full granting' of the NGF proposal POLARIS in 2023. This proposal will serve to investigate and demonstrate critical integration technologies that enable an entirely new phased-array sensor paradigm: it unites universities, knowledge institutes and industry. Start of the programme is foreseen in 2024.

Imaging systems for defence focusses on image capture systems for defence and high-end security. This theme addresses improvements in the use and manufacture of image capture systems, contributing to (automatic) detection, classification and tracking for Situational Awareness and ISR. We expect an increasing knowledge demand with sensor applications on UxVs rapidly gaining importance. In 2024, atmospheric turbulence compensation and automatic target recognition capabilities will be investigated.

Space Domain policies have rapidly matured. In line with NATO strategy, the national Space Agenda as released in November 2022 forms our guidance. Space Domain Awareness can only be obtained by the MoD through combining data sources, including (possibly multistatic) radar sensors and heterogeneous fusion of observations from satellites and other relevant platforms such as aircrafts, drones, aerostats and ground sensors. This involves generating the relevant data through specific hardware facilities (combining ground stations as well as satellites in space) but also the process to combine data and create intel. The Space Domain theme explores the different ways in which the Dutch government can be supported to establish this. In 2024, new processing techniques including sensor fusion to improve the imaging and classification capabilities for complete situation awareness of space objects with ground-based radars will be explored; CONOPS requirements will be categorised and a technology roadmap for the future architecture of space-based missile early-warning systems will be established.

Smart Manning and Automation addresses the continuing trend of (naval) staff reduction and increase in system complexity. Therefore, SM&A develops technology to increase the degree of automation of naval vessel systems to assist, integrate, or replace the human operator with the execution of increasingly complex tasks. R&D activities envision an Integrated Mission Management (IMM) capability connecting crew and information systems on-board with emphasis on linking the external and internal battle through a flexible interoperable architecture. Existing stovepipe systems such as Combat Management System, Bridge Management System and Platform Management System together with available onboard information are seamlessly integrated and made available. In addition, situational awareness and combat decisions are extended and improved by integrating cooperative manned/unmanned systems with the IMM for both the internal and external battle. Research topics include: man-machine interaction for operator assistance, adaptive task allocation and cooperative man-machine tasking for operator integration, and the design of runtime autonomous systems for operator replacement. The Manning & Automation roadmap of TNO, DMO/AMS, Damen, Thales, and RH Marine provide guidance to the activities.

Collaborative autonomous UxVs targets design and development of runtime adaptive systems with strong focus on collaborative teams and teaming of autonomous military UxVs. We envisage to realize an optimized, seamless, effective and responsible coordination and control of autonomous unmanned systems in a dynamic adversarial environment. To this end, a functional and interoperable architecture will be defined and a collaborative mission autonomy capability for unmanned

systems will be developed. We focus on: realization of autonomous mission-planning and coordinated mission execution for unmanned systems in dynamic environments; formalization of military mission goals and operational conditions and constraints; representation of actual characteristics and capabilities of resources and systems in complex missions under adversarial conditions; reasoning methods for collaborative autonomous mission planning and execution for distributed unmanned systems. Application is foreseen in naval and land platforms (including the national ecosystem CUGS). The Naval Manning & Automation roadmap of COMMIT/AMS, portfolio Robotics and Autonomous Systems (RAS) provide guidance to the activities.

Ocean Resilience and Transparency seeks to advance dual-use and emerging technologies in the naval-maritime sectors and ocean environment to secure critical maritime infrastructure, such as undersea cables and pipelines, enabling resolute measures that ensure its safety and resilience. The underwater domain (including the seabed and critical maritime infrastructure) is particularly prone to threats as it is largely unmonitored, uncontrolled, and concealed. Current solutions are not sufficient or efficient enough to deal with these new threats. Unmanned systems are foreseen to be the backbone of future solutions enabling European navies, coast guards, border security agencies and police forces to deal with numerous simultaneous missions in larger areas of at-sea operations. The modelling of underwater sound is critical for these operations; this modelling (and the standardization) is predominantly performed in an international context and applied to civil use cases, of which the protection of underwater mammals is most notable. In 2024, we will study tagged marine mammal responses to ship sounds; finalize integration of the ship sound model; study the effects of bubbles on sound propagation; create a planning tool for optimal deployment of drones; demonstrate covert monitoring of illegal ship activity in Scheveningen harbor.

Quantum sensing sensing explores various quantum sensing techniques in the context of military-relevant applications as they may transform the military battle field in the future, or even disrupt the balance of power. To anticipate on this future, we develop understanding of the potential added value in military use cases in parallel to the process of improving technical understanding of this fast-changing and diverse field. Of the four focus areas defined in the Quantum Roadmap of the Ministry of Defence, P104 concentrates on 1) Quantum Sensing Solutions, to improve classical electro-magnetic sensors and 2) Quantum Sensing Solutions for Positioning, Navigation and Timing (PNT) (the latter addressing requirements to operate in GPS-denied conditions). Feasibility of a PNT testbed is currently investigated. In 2024, we will investigate Cold Atom Interferometers, make the first magnetic map, demonstrate a quantum-assisted D/A converter, model superconducting SQIFs and increase the TRL of an NV-center magnetometer.

Advanced materials for defence[4] ***(New)*** investigates advanced materials and the manufacturing of these, to 1) provide protection, 2) reduce weight and 3) contribute to a variety of specific military requirements. For the protection of military personnel, platforms and infrastructure, aspects such as resilience against blast, ballistic protection, shock, fragmentation etc. will be considered. Weight reduction is aimed for in view of reducing the physical constraints of military personnel and the reduction of fuel consumption (in line with the MoD's ambition to reduce its energy needs). Specific military material requirements that are under considerations are their signature characteristics, strengthening platform structural integrity and fire safety. In 2024, we will scale up structural elements to a light-weight armoured vehicle, replace metal with composite implementation for a relevant land vehicle, increase the TRL level for the military vehicle seat-of-the-future and investigate all options to expand the relevant eco-system, particularly through setting up public-private partnerships.

[44] Internal TNO this part of the VP is currently labelled as P107. For efficiency reasons, P104 and P107 will be managed as one programme.

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

Programma jaar 2024 - Samenvatting

The goal of the *Vraaggestuurd Programma* (VP) Cyber Risk Management and System Resilience (CRM&SR) is 'to make the Netherlands digitally more secure and resilient while at the same time monetizing the economic opportunities of cybersecurity'. A focussed and effective approach with respect to cybersecurity and quantum-safe technologies is crucial to safeguard the reliability and confidentiality of data and ICT networks and systems. We initiate, stimulate and orchestrate cooperation in research on cybersecurity and post quantum cryptography while taking into account the insights and feedback from customers and stakeholders.

Cybersecurity is a complex societal challenge. Innovation is fragmented and perspective for action for the various actors (government, knowledge institutions, business) is lacking. In order to be able to create breakthroughs in complex social issues and ensure that innovations are optimally implemented, a deep understanding of the bigger picture - the system - and of the interdependent and interacting parts of that system is necessary. In 2023 we have started to explore the possible benefits of a systems approach towards cybersecurity innovation. In 2024 we expect this exploration to result in a rudimentary system strategy for cybersecurity innovation as well as a more structural research agenda to improve and further develop this approach.

The topics of supply chain security and IT/OT security will continue to grow in importance, hence we will extend our research activities in this field in 2024 . The need to be able to develop secure products and software is emerging as new area for our stakeholders, partly driven by EU regulation and as a by-effect of the increased servitization of our manufacturing and software industries. We aim to develop a research agenda around this topic late 2023 and early 2024.

In the field of automation of cybersecurity operations and the monitoring and detection of cyber-attacks we will work on an OpenSOC model in cooperation with knowledge institute VTT from Finland, infrastructural modelling capabilities, mapping of the impact of a cyber-attack to the business and on development of new methods to detect advanced cyber-attacks. Next to the office IT/SOC environments we will develop tools, methods and technology for operational technology (OT) and industrial control systems (ICS) to detect cyber-attacks using both network and sensor data to respond to OT threats and attacks, adequately and automatically. Furthermore, we will focus on safe and robust use of AI for detection, adversarial emulation, as well as response generation & evaluation. Finally, we aim to improve incident response and recovery-time with automated response and data sharing-within cyber-ecosystems.

It has become evident that quantum computing will create new threats and opportunities in the years to come. In 2024 we will develop tools and guidelines to aid organisations in specific steps identified in the PQC Migration Handbook such as crypto asset discovery to help identify cryptographic assets to be migrated and decision tree development to help choose the best fitting PQC protocols given requirements. Together with dcypher and other organisations we explore setting up a public-private PQC expertise center as a landing place for such tools to help drive the innovation on PQC migration. Additionally, we will continue work on developing proof-of-concepts of and migration towards the quantum-safe Public Key Infrastructure (PKI). Finally, we will develop orchestration technology that enables new quantum communication technology to be integrated smoothly into the current digital infrastructure. We will continue to work and build on the knowledge and the technologies that will help the Dutch industry and government to migrate safely to a world where quantum computing and quantum communication will play an increasing role.

The VP CRM&SR connects to the challenges and topics that have been formulated in the Dutch Digitalization strategy, the Dutch Cybersecurity Agenda (NCSA) and the Mission Cybersecurity of the Knowledge and Investment Agenda (KIA) theme Security as well as with the theme Key Enabling Technologies. In 2024 we will continue our collaboration with dcypher and QuTech. TNO is also actively involved in the CS4NL - Breed Gedragen Programma Cybersecurity, that was started in 2022 and which aims at improving cybersecurity across the Dutch Topsectors. In international context TNO participates in the relevant EU working groups, taskforces and events. The development and execution of the knowledge program VP CRM&SR happens in close cooperation with VP *Veilige Maatschappij* (VM), VP ICT, the program line Cyber Security and TNO research programs with businesses, the departments of Security and Justice, Defence and with the Police.

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

Programma jaar 2024 - Samenvatting

TNO aims to guide industrial and societal stakeholders in the digitalisation of their business or domain. We do this by integrating the enablers identified in national and European ICT agendas into first-time engineering solutions. These industrial and societal 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.

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 and federation of data sharing systems, avoiding vendor lock-in and achieving national data-hub(s) ecosystems. On top of data sharing we are starting to develop Reliable Digital Twinning, Digital Product Passport, Norm Engineering and Communicative AI (Large Language Models)

In 2024, we aim at:

1) building a pilot in a Dutch public-private SSI ecosystem;
2) providing a Digital Product Passport blueprint;
3) providing tools to evaluate Large Language models on responsible use ;
4) piloting interconnecting international and cross regional data spaces; and
5) developing requirements on interoperability between PET platforms and providers to ensure scaling up of PET technologies.

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. Digital infrastructures need to be built responsibly if they are to serve and drive the digitalisation of society and economy. Digital infrastructures are increasingly being made up of a composition of telco, cloud and edge infrastructures, creating a seamless cloud-edge continuum. With fast and open infrastructures, we focus on the combination of performance, sustainability and sovereignty. In 2024, our key contributions will be:

1) facilitating research in open networking and telemetry services with our open source cloud infrastructure and multi-vendor 5G experimentation platform;
2) developing and experimenting with 5G/6G 'vertical network enabler' technologies to enable advanced uses cases in agrifood, smart industry and mobility sector (e.g. automotive, rail);
3) developing first specifications for 6G system architectures in cooperation with partners of Future Network Services growth fund program;
4) setup a National Cloud Federation testbed with SME Dutch Cloud Providers to explore cloud switchability and workload portability jointly with a.o. the national Gaia-X Hub and the Structura-X lighthouse in Gaia-X;
5) first development to include sustainability parameters in orchestration mechanisms for cloud and edge;
6) exploitation of social XR building blocks in international research as well are some commercial platforms.

Our ambition with a **trusted ICT** approach is to deliver practicable implementations of relevant applications on current and near-future quantum computing hardware. With a focus on practicable algorithms for quantum optimization, in 2024 our key contributions will be:

1) various new implementations for experimental industry-led use cases using (simulated) quantum hardware;
2) expand the open-source software stack[5] with new implementations and algorithmic building blocks;
3) development of various new algorithms that utilize the core of multiple quantum computers, also known as distributed quantum computing (this goal from 2023 is delayed to 2024);
4) expand the multi-vendor ecosystem QAL[6] with various industry partners; and
5) strengthen the position of the Netherlands in the European quantum algorithm ecosystem by joining and starting various EU collaborations.

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. Until 2025, we aim to consolidate this role and maintain our leading position in standardisation of digital technologies and within industry fora.

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

Programma jaar 2024 - Samenvatting

The target of the *Vraaggestuurde Programma (VP)* ESI is to drive advances in high-tech systems development by *embedding cutting-edge engineering methodologies in the Dutch high-tech systems industry to cope with the ever-increasing complexity of their products*: (i) creating impactful and industrially applicable methodologies and (ii) providing support to the high-tech industry to apply the results.

The Dutch high-tech industry is responsible for a large portion of Dutch private R&D expenditure. Many companies are world-wide market and innovation leaders. They bring systems to the market with ever-higher performance and dependability, more and more functionality, better cost performance ratios, and tighter integration in customer processes. To strengthen their market position, the industry needs to deliver innovations continuously (shorten time-to-market) and dependably.

The complexity of high-tech systems grows steeply due to product diversification and customer-specific products, tight integration, and optimization in customer processes (system of systems), AI, etc. Combining the growing complexity with the need for continuous innovation and high dependability asks for (i) systems engineering methodologies to improve the efficiency, effectiveness, quality, and cost of product development and (ii) a highly qualified workforce capable to apply such methodologies in the industry, addressing aspects such as:

- multi-disciplinary architecting and design;
- efficient and effective product innovation process (e.g., model-based methodologies, AI-for-engineering, virtualization and simulation, etc.);
- the full product life-cycle context (continuous updates and upgrades during the full product life cycle);
- creation of systems in industrial eco-systems (OEMs, suppliers, innovation partners, service providers, etc.);
- integrating of systems into systems-of-systems (i.e., tight integration in customer-specific workflows and system);

[5] TNO - Quantum · GitHub

[6] Quantum application development for tomorrow's business solutions - Quantum Application Lab

- continuous and lifelong knowledge and skill development (human capital development).

The industry has a large human capital challenge: (system) engineers that can deal with the complexity of high-tech systems are scarce. This asks for break-through innovations for systems engineering methodologies based on the following vision:

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.

Updated ambitions for 2027

The program of VP ESI is based on the needs of the industry partners of ESI. It is a multi-year program that evolves as the needs of the industry and the state-of-the-art evolves. In 2022, an extensive process was performed to align the research agenda with its industry and academic partners. The process confirmed the directions of the VP, strengthening the focus on platforms and system diversification, and on the integration of systems in customer-specific systems (of systems) and processes. A specific challenge and ambition were added, regarding integration of artificial intelligence in high-tech equipment and the application of artificial intelligence for their development:

- **Engineer4AI:** Methodologies to deal with the opportunities and challenges of the integration of AI/ML, adaptivity and autonomy in high-tech equipment (e.g., dependability consequences);
- **AI4Engineering:** Applying AI to optimize the efficiency and effectiveness of R&D-teams (hyper-automation for R&D).

The need for the latter topic is strengthened by the critical scarcity of (systems) engineers that are capable to deal the complexity of high-tech systems. This asks for break-through innovations for systems engineering methodologies based on the vision on page 35: engineers will collaborate with digital engineering assistants to enhance their productivity and effectivity (including lowering the threshold for new engineers to enter the industry).

A new topic at the research agenda is:

- Systems engineering for **sustainability and circularity**. The industry faces market demands and standards, regulations and laws that force them to put a strong emphasis on the sustainability of their products and systems. The industry therefore needs (model-based) systems engineering methodologies for sustainability.

Furthermore, an additional aspect will be addressed:

- Research on **human and organizational aspects**, strengthening the *embeddability* of methodologies in industrial systems engineering practice.

Results for 2024

In summary, the following results are targeted for in 2024:

Agenda Setting:

- In September 2023, a strategic plan 2024-2027 for TKI-HTSM has been submitted.
  To prepare for writing this program, industry partners have been visited to update the overview of their longer-term business needs.
  In the second half of 2023, interviews will be organized with the academic partners of ESI to find academic research groups and results that can be beneficial for the industry and to bring insight in the industry needs into academic research groups.

In 2024, we want to bring the results from the industry and academic inventories together to seek opportunities for future academic-industry collaborations.

- In 2023, a core team has been formed to create the Dutch Systems Engineering Platform. In 2024, we will bring this platform together. One of the key deliverables will be an update of the HTSM Systems Engineering roadmap.

Research Projects:

- The MASCOT program (NWO project) was not submitted in 2023. Since various good research proposals were part of the proposed program, in 2024 we will explore options to submit research proposals for parts of the program.
- Participate in European programs to address strategic challenges. Currently proposals are prepared for the KDT program on:
  - Efficient and effective verification and validation of diversified product portfolios (SPRINT proposal);

  and in ITEA:
  - Model-based Systems Engineering for Sustainability (early engineering phase decision-making) (D-STRIBUTE proposal).

    ESI is exploring further collaboration opportunities in international consortia.

  ESI is participating in European projects that will end mid-2024:
  - ASIMOV: to analyse the value of applying Digital Twin based training of Artificial Intelligence for automatic calibration of high-tech equipment;
  - Transact: to analyse system performance across the system-edge-cloud continuum.

- In 2021-2023, a study was performed on the application of Model-Based Systems Engineering (MBSE) together with the industry and academic partners[7]. A successor study will run to dive deeper into industry MBSE-pilots and to align with international MBSE practitioners.

Research targets per strategic program line for projects in 2024, where we foresee a shift of emphasis in the coming years, based on the results from our consultation of the industry in 2023 (indicated with ➔ **XXX**)

- **Performance (➔ System Qualities):** Systematic reasoning on system performance (to diagnose and to optimize) covering functional, software, and platform levels, including execution architectures and systems-of-systems. In the future we will extend the scope of this program to research on a broader set of system qualities.
- **Dependable Systems (➔ Life Cycle Excellence):** Effective verification and validation of diversified product portfolios (customer specific configurations, covering many versions) using models and change impact analysis to optimize V&V efficiency while assuring the quality of released systems (updates).

  Design methodologies for system diagnostics (including further strengthening of our program on diagnostics with Twente/UT).

  For the future, we see the need to extend this research program to address designing systems with the full system life cycle in mind: manufacturability, installability, serviceability, and prominently sustainability and circularity.
- **Evolving Systems (➔ System Diversity):** System and software architectures addressing the modularity needs in business processes across the full product life cycle (incl. manufacturing, service, legacy challenges, etc.). Methodologies are needed to deal with the large diversity of systems in the field (variants over time and customer/application-specific variants), e.g., configuration management, efficient and effective testing, upgrading, servicing, manufacturing, etc.

[7] https://publications.tno.nl/publication/34639873/jgHNmz/TNO-R2022-R11504.pdf

- **Systems in Context (➔ Systems-of-Systems):** Methodologies and architectures to integrate high-tech equipment into customer processes and systems of systems, addressing system-of-system level concerns such as performance, dependability, system evolution etc.
- **Systems Architecting:** Model-based systems architecture and systems engineering methodologies (e.g., MBSE) to realize customer and business value through customer value modelling, modularity, platforms, system variant management, aligning systems and SW architectures, etc.;

In all running programs lines, we foresee a growing trend to extend the application of AI-techniques in these programs [AI4Engineering] and to study the consequences of applying AI in high-tech equipment [Engineer4AI] to realize te 2035-vision described above.

Sharing, professionalizing, dissemination, and competence development:

- Exploiting the added value by seeking synergies in research with various partners and exchanging experiences and results;
- Building a network of service providers as implementation partner of the results of the VP, organized in an Implementers Council;
- New courses, course offerings, and updating existing courses.

International positioning and visibility:

- Strengthen the international cooperation network of systems engineering research centres by aligning strategies, roadmaps, exchange of results and exploring opportunities for joint initiatives.
- Participate in European projects together (as we do with DLR, KDT and Fraunhofer in new KDT proposals).

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

Programma jaar 2024 - Samenvatting

VP P901 Transities en Transformaties is gelieerd aan de roadmap Transities en Transformaties van TNO Vector, het Centrum voor Maatschappelijke Innovatie en Strategie.

TNO Vector ontwikkelt kennis en vaardigheden die in de praktijk worden toegepast om transities en transformaties te versnellen en richting te geven. De wereld kent grote, onderling verbonden, uitdagingen die de brede welvaart onder druk zetten. Samenlevingen en economieën over de hele wereld ondergaan ingrijpende transities en transformaties om zich aan te passen aan de eisen van deze tijd. Een van deze verschuivingen omvat stedelijke transformatie, waarbij stads- en regioplanning wordt herzien om duurzame assets en infrastructuur en leefbaarheid te bevorderen. Tegelijkertijd vindt er een energietransitie plaats, waarbij fossiele brandstoffen worden vervangen door hernieuwbare energiebronnen, bijvoorbeeld in industriële processen. Bovendien is technologische ethiek van cruciaal belang, met de ontwikkeling van missiegedreven en ethische richtlijnen voor opkomende technologieën en innovaties. Tot slot speelt de digitale transformatie een grote rol om gemeenschappen, overheden en bedrijven te verbeteren en een meer verbonden en inclusieve samenleving te bevorderen. Deze inspanningen streven ernaar om waarden als duurzaamheid, leefbaarheid, innovatie, verdienvermogen en soevereiniteit in de samenleving en economie te verankeren.

TNO Vector biedt handelingsperspectief, als kracht voor goede besluitvorming, om de brede welvaart te vergroten. Aanvullend op technologische en sociale innovaties worden voor publieke en private partijen maatschappelijke innovaties belangrijker. Ze verbeteren de inbedding van technologische vernieuwingen en verhogen zo hun impact en rendement. Maatschappelijke innovaties ontstaan uit een transdisciplinaire werkwijze en kunnen systematische en structurele maatschappelijke veranderingen bewerkstellen. Het betreft innovaties in multi-level governance, in economische en bedrijfskundige structuren, in ecosystemen en netwerkvorming, in ruimtelijke inpassingen, in institutionele innovatiecapaciteiten, en in beleid en wetgeving. Daarnaast vragen transities en transformaties om strategische analyses naar trends en ontwikkelingen en visievorming, zoals op strategische autonomie, infrastructuur, innovatie-assets and internationale waardeketens.

De roadmap Transities en Transformaties van TNO Vector is gestart op 1 januari 2022. In 2022 en 2023 stonden drie aandachtsgebieden centraal: stedelijke systemen, industriële systemen en innovatiesystemen. Het zijn socio-technische systemen waarbinnen multi-transities (moeten gaan) plaatsvinden, oftewel meerdere transities verbonden (moeten) zijn aan elkaar. TNO Vector hanteert een socio-technische systeembenadering en transdisciplinaire werkwijze om te komen tot passende en haalbare interventies en handelingsperspectief voor publieke en private partijen. Mid-2023 is een vierde aandachtsgebied toegevoegd: digitale systemen. We werken in de periode 2024-27 aan proposities binnen de domeinen (1) steden en regio's en (2) industrie, en aan het vergroten van de (3) innovatie- en (4) digitaliseringskracht, binnen Nederland én Europa. Om de beoogde impact te verduidelijken, zijn de namen van de aandachtsgebieden gewijzigd:

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 P901 Transities en Transformaties zetten we in op kennis- en methodologie-ontwikkeling om proposities in deze vier aandachtsgebieden waar te maken. In 2022 en 2023 focusten we op een drietal 'sleutelmethodologieën' om transities en transformaties te bewerkstelligen en te versnellen: systeemanalyse, innovatie-orkestratie en adaptief bestuur. 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. In 2024 blijven we inzetten op de drie lijnen:

- Systeemanalyse: het analyseren en begrijpen van complexe socio-technische systemen en het identificeren van interventies die bijdragen aan multi-transities en transformaties;

- Innovatie-orkestratie: het bijeenbrengen van stakeholders ten behoeve van innovatie en zorgdragen voor het maken en bestendigen van collaboratieve businessmodellen voor multi-transities en transformaties.
- Adaptief bestuur: het analyseren en ontwerpen van besluitvormingsstructuren en beslisondersteuning voor publieke en private partijen om multi-transities en transformaties richting te geven en te versnellen.

De wens is dat in de komende jaren 2024-27 er kennis- en methodelijnen bijkomen, passend bij de vier aandachtsgebieden, en voor bepaalde lijnen een investering vanuit VP P901 niet langer nodig is omdat een andere financieringsvorm beter past of de lijn is uitontwikkeld. Voor 2027 is het streven voor TNO Vector om 5 ‘volwassen’ kennis- en methodologielijnen in portfolio te hebben, in te zetten binnen de aandachtsgebieden via de roadmap en breder in TNO projecten in verschillende domeinen.

Voor 2027 zijn, samenvattend, de volgende strategische doelen gesteld:

- VP P901 draagt bij aan waardengedreven duurzame steden en regio’s; groene en soevereine industrieën; transformatieve innovatiesystemen; en een waardengedreven digitale samenleving. Dit zijn de multi-transities waar wij aan werken. Dat doen we middels kennis- en methodologie-ontwikkeling en toepassing op het vlak van (maar niet beperkt tot) socio-technische systeemanalyse, innovatie-orkestratie, en adaptief bestuur.
- (Mede) door VP P901 is TNO Vector leidend in het bieden van handelingsperspectief voor publieke en private partijen in multi-transities en transformaties;
- (Mede) door VP P901 beheert TNO Vector 5 volwassen kennis- en methodelijnen, waaronder in ieder geval systeemanalyse, innovatie-orkestratie, en adaptief bestuur.

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

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Our multi-annual R&D program 2024 - 2027 supports our ambition to contribute to **preventing climate change and air pollution,** enable **secure broadband connectivity,** help **understanding the Universe**, and stimulate **economic growth in the Netherlands and Europe.** Therefore, we organise the VP along program lines directly connected to this ambition; Instruments for **Earth Observation** and related **Space Data Utilization,** technologies for **Satellite Communication**, and **Scientific Instrumentation** focusing on instruments for **Ground-based Astronomy** and **Space-based Astronomy,** and including instruments for **Big Science and Diagnostics for Fusion Energy**. In recent years ESA and the EU have increased priority for the theme **Space Situational Awareness**, including space weather, Near Earth Objects, and space surveillance and tracking including Space Traffic Management. Within the Netherlands **Space Situational Awareness** 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.

Our main objective in the area of Earth Observation and Space Data Utilization is to maintain and strengthen the Dutch position with regard to monitoring the composition of the Earth's atmosphere. We want to contribute to help monitor the Paris agreement and give detailed insight in emissions and spread of air pollutants and greenhouse gases. We have the long-term goal for in-orbit-demonstration of a small and very accurate instrument with related downstream models, specifically focused on measurement of greenhouse gasses and air pollution. In addition to the instrument, given the focus in the commercial EO market on information products, we will work on the development of data processing methods that can enable global information services that provide actionable information to decision makers in governments.

For 2024 the focus will be on the continuation of development of instruments that measure CH_4, NO_2, NH_3, SO_2, CO_2, CO and aerosols. We will work on improving our LOTOS-EUROS and TOPAS models by including more air quality trace gases and CH_4.

In the domain of Satellite Communication our aim is to develop state-of-the-art optical terminals for ground, air and space usage for the value chain of global satcom providers. We follow four main use cases: Secure & Robust Comms for worldwide Mobile Security Operations; Cyber Proof/Quantum Resilient Comms over Ground Networks for Secure Connectivity; Ultra-High-Speed Global Secure Connectivity Network (constellations); Data Relay for Earth & Space Sciences from (deep) Space. Each of these use cases have their own timeline of development, where the first laser satcom constellations are in industrial development right now, but deep Space data relay using laser satcom is foreseen to be further away in the future.

We will work on our four main drivers; fast, secure, multi-point and far communication. For fast communication the long-term goal is ultra-high data throughput of 10 Tbit/s feeder link to a GEO satellite. Secure communication focusses on links with ultimate protection, suitable for the quantum era with a long-term target of a Quantum Key Distribution service with satellite nodes, which is resilient to hacking attacks. Multi-point communication facilitates simultaneous communication with multiple senders and receivers with a long-term target of a multi-beam optical space terminal in GEO-orbit, receiving data from various nodes (space, aerial, naval) and transmitting towards multiple users. With far communication TNO looks at data links over very long distances with a long-term target of a link to a deep space science mission, such as a planetary or asteroid mission.

These various use cases provide a very promising opportunity for Dutch industry to extend its space-related activities into a commercial market: in this development we will position Dutch high-tech companies as potential suppliers for the terminals and their subsystems based on user requirements from this market. In 2024 TNO will intensify its investments in Space-Based Quantum Internet.

For the domain of Ground & Space Based Astronomy and Scientific Instrumentation we intend to strengthen our position with regard to developing high-grade instruments to perform world-class science, both in space and on ground.

Our long-term goal for Ground-Based Astronomy is to contribute to the development of the Thirty Meter Telescope (TMT) optics with a 3m diameter deformable mirror foreseen to be reached in the coming five to seven years from now. Steps towards that goal are deformable mirrors of increasing size, better support structures and laser guide stars for the big telescopes in the world (UH88, EST, ELT, GMT, MAORY, GEMINI, KECK). For 2024 the goal will be to test a deformable mirror of 60cm diameter (UH-88) and/or a deformable mirror of 24cm on the NASA IRTF to create our first on-sky-heritage.

In the space-based astronomy domain we use ESA's long-term planning for space science missions, 'Cosmic Vision 2015–2025', and the Voyage 2050 Senior Committee advice 'Voyage 2050' as a guideline. The coming years we will work on pointing mechanisms for the LISA (detection of gravitational waves) mission.

In addition, we aim to contribute to nuclear fusion technology by applying our optical systems design expertise to develop technologies for diagnostic instrumentation in the extremely challenging environment of the nuclear fusion chamber.

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

Programma jaar 2024 - Samenvatting

The goal of TNO's roadmap on Semicon & Quantum is to stimulate the Dutch and European industry to take strategic positions in critical value chains. TNO's technology leadership helps companies to innovate faster than its competitors, or it is the foundation of new startups. We focus on three of the most strategic value chains in the high-tech industry, each with significant economic impact (high export value), geo-political value (contributing to the sovereignty of Europe), a good fit to the Dutch ecosystem and culture, high societal impact, and beyond state-of-the-art technological challenges resulting in knowledge spillover to other sectors: semiconductor industry, quantum technologies, and medical photonics.

Consumer electronics, mobile devices, industrial processes, communication equipment, the car industry, artificial intelligence and nearly all potential solutions to societal challenges rely on computer chips (IC's) to generate, process, and store data. All chips from all over the world are manufactured by the use of Dutch equipment. Besides a healthy industry by itself, this position has demonstrated to be

a strategic asset for both The Netherlands and Europe.

Lithography equipment by ASML and Carl Zeiss is a control point in the global value chain of chips, and thus to AI, mobile connectivity, autonomous vehicles, and IoT. Our program on Systems Lifetime and Productivity helps to strengthen this position by pushing the productivity of DUV and EUV lithography equipment by more advanced thermal management, contamination control, material sciences, metrology, optics and optomechatronics. Developing and utilizing unique technology infrastructure like EUV beam lines, and optical and vacuum test rigs are an integral part of this strategy, especially in the development of high-NA EUV equipment. Our program starting in 2024 is on the replacement of PFAS containing materials and components demonstrates that not only performance but also sustainability is important now. For the current generation lithography systems studies will be performed to understand complex gas/liquid interactions and thermal conditions, the latter one having a spin-off program on in-chip cooling, which has the potential to significantly reduce the energy consumption of Data Centers.

Within the Metrology program new equipment concepts (incl. optical, acoustic and scanning probe microscopy) are currently being tested on the next generation of semiconductor devices, in collaboration with world leading chip manufacturers. In 2024 we hope to bring Dutch equipment development industry on board, towards yet another strategic vendor position. With Dutch equipment vendors we research new metrology concepts for heterogeneous integration (the next big transition in chip manufacturing industry where multiple chips (incl. photonic integrated circuits) will have to be stacked, or be placed on chiplets). For the coming year, the focus will be on new technologies meant for SEMI process integration loop in order to detect process anomalies based on physical or chemical defects by high precision characterization in device/multi-device(system) levels and on the encapsulated environment.

Within the mission of QuTech, we continue the development of quantum computing and quantum internet. 2024 Milestones include steps towards future hybrid HPC and quantum computers (partners include SURF), and establishing a world's first quantum communication channel for entanglement distribution between Delft and Den Haag. Also in the next three years: further hardware improvements including further optimizing supporting (optical) equipment by using photonics integrated circuits, as well as increasing the amount of qubits for computing by a factor of 100 by creating scalable architectures.

Based on this knowledge position in quantum technologies and systems engineering, in 2024, TNO will, for the first time, manufacture quantum chips for European companies. The Quantum-sensing program will continue the development of N-V based sensors and use-case testing. The Testbed Facility uniquely equipped with technology developed fully within TNO, in partnership with academia (e.g. TU Delft), and commercially acquired, becomes available for third parties collaboration in 2024.

TNO's research on Medical Photonics focusses on accelerating photonics- and acoustics based innovations that can help people to stay healthy, diagnose diseases earlier, facilitate remote patient management, and supporting affordable and easily accessible healthcare for the ageing population. To achieve this we collaborate with instrument vendors to develop diagnostic optical devices for use in home, primary and secondary care, including multispectral fundus camera's for early diagnosis of eye diseases as well as systemic diseases, wearable diagnostic photonic devices for remote patient management, and optoacoustic sensors based on photonic integrated circuits to boost the performance of photoacoustic and ultrasound devices.

Titel	**VP Flexible and Freeform Products (P615)**
MTIB Thema	Sleuteltechnologieën
Contactpersonen TNO (DM en VPM)	Ton van Mol
Contactpersoon Regievoerder	Erik van de Burgwal (EZK), Casper Langerak (RVO), Marc Hendrikse (Topsector HTSM), Leo Warmerdam (HTSM)

Programma jaar 2024 - Samenvatting

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.

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.

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.

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.

Our unique approach to innovation is applied to 6 growth platforms:

- **New manufacturing technologies** for electronics production with a focus on creating a sustainable production technology for electronic products and further leveraging printing technologies towards other markets such as displays, packaging, and integrated photonics. Key results for 2024 include first customer collaborations on the 3D printed electronics platform, starting new directions with customers on LIFT technology and shaping and growing our activities in Sustainable Electronics.
- **Medical device technology**, focused on platforms for remote patient monitoring, lab-on-chip for advanced diagnostics and organ-on-chip (OoC) to accelerate the development of new drugs. Key results for 2024 include submission of a NGF 4rd round MedTech proposal, creation of spinoffs for PillarWave and our ExG patch platform (Aikon-Health) and continuing development of innovative medtech functionalities for remote patient monitoring. For OoC development we will set up strategic collaboration in the Dutch ecosystem.
- **Energy storage** with the aim to enable a Dutch eco-system via NGF programs (batteries) & SRP (H_2 electrolyzers), mostly in the equipment and production technology for such devices. Key results for 2024 include further development of the battery program in connection with HTSM (e.g. results around 3D scaffolding tech., Si anode / solid state electrolyte integrated process flow, sALD deposition tech,) and broadening business interest in battery activities outside subsidy programs. For electrolysers we will grow the program and realize a market-driven shared research program with focus on integrated concepts for electrolysis stacks.

- **Advanced packaging** 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. Key results for 2024 include a new power electronics packaging concept based on additive technologies and RF antenna integrated in a chip package, made with thin film technologies.

- **Integrated photonics** with a focus on creatin solutions to heterogeneously integrate InP, SiN and its electronic driving chips in one package. This roadmap is executed as part of the Photonics Integration Technology Centre (PITC), a collaboration between TNO and University of Twente, Eindhoven University of Technology, and PhotoDelta. Key results for 2024 include a concept for connecting electronics and photonics on board level and a panel-level based process toolbox for integration of chips.

Personalized food and pharma with a focus on creating processing equipment. Key results for 2024 for personalized food include advancements in coupling of rheological properties to print process and settings of the printer, developing the multi-nozzle gear pump technology to scale up of the technology, a more modular processing system for alternative meat products and fieldlab tests for personalized nutrition in a military setting. is needed and will be developed. For personalized pharma we will work on accurate dosing of tablets and on non-destructive inline validation of 3D printed tablets.

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

Programma jaar 2024 - Samenvatting

In **VP "Smart Industry" (Dutch equivalent Industry 4.0 / 5.0)**, solutions and technologies for smart manufacturing are developed based on Key Enabling Technology (KET) "**Engineering & Fabrication**". Specific KET sub-technology domains are:

- **Digital Manufacturing Technologies**
- **(Opto)Mechatronics incl. Robotics**
- **Sensors & Actuators Technologies**
- **Imaging Technologies**

Smart Industry aims to create in the Netherlands the most circular, interconnected, automated, and intelligent industrial manufacturing ecosystem 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 earning power and strategic autonomy of the Dutch and European manufacturing industry. 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.

Smart Industry technologies and solutions strive to boost the earning power of the industry and increase labour productivity year on year growth of 5% or more, with a focus on:

- **Manufacturing throughput**: *"Hyperefficient smart manufacturing"*
- **Manufacturing quality**: *"Zero defect first time right"*
- **Manufacturing variability**: *"High-mix, low volume, high complexity"*
- **Value chain integration**: *"Ecosystem assembly & transparency"*
- **Overall manufacturing system**: *"Digital baseline, increase capabilities & improve cycle"*

Key objectives for VP Smart Industry for 2024 are:

- **Deliver national standards and blueprints for digitalization for smart manufacturing:** common approaches for shopfloor connectivity, data models (describing products, processes and resources), digital twinning, digital twin capabilities and data sharing across organizations and value chains (data spaces).

- **Further develop the TNO technical portfolio of Industry 4.0 solutions, which containts**: industrial application concepts adaptive operator and decision support systems, hybrid human-robot work cells, zero-programming concepts for flexible robotization, precise vision and ultrasound quality assurance, inspection and meteorology tools for zero-defect manufacturing, adaptive dashboards and data analytics tools, digital product passport and interoperable data connectors.
- **Accelerate the digitalization of the Dutch industry:** support the implementationindustry 4.0 solutions into the ecosystem of the Dutch industry by increasing the involvement of technology integrators and technology providers. In addition, orchestrating the national Smart Industry ecosystem through participation in large-scale national Growth fund programs (NXTGEN High Tech, Mobility fund, Aviation in Transition), National program office Smart Industry (FME, Metaalunie, TNO), EU projects, associations (Open Industry 4.0, IDTA, IDSA) and collaboration with other RTO's.
- **Smart manufacturing demonstrator hubs:** establish the first footprint for two smart innovation manufacturing demonstrator hubs which act as test beds for SME's creating "test-before-invest" autonomous manufacturing solutions (NGF NGHT, EU horizon TEF and TKI).
- **Autonomous manufacturing for sustainable mobility**: develop proof of concept(s) for in-line quality control of composite and metal structures through direct velocity mapping (ultrasound non-destructive inspection) and operator support systems for application in lightweight structures to boost new mobility solutions.
- **Autonomous manufacturing for High Tech Equipment for new value chains**: develop proof of concept(s) for autonomous manufacturing for Laser SatCom, Semicon and Energy Transition (for example NGF NGHT). In addition, execute a proof of concept on an industrial scale with revolutionary hydrogen and catalyst temperature optical fibre measurements. This accelerates data acquisition for sustainable manufacturing in the energy transition domain.
- **Artificial Intelligence for manufacturing**: develop a roadmap for industrial quick wins and implementation for applied AI solutions for manufacturing.