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TNO-rapport

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Meerjarenprogramma 2015-2018
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Voortgangsrapportage 2016

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Inhoudsopgave

1 Introduction

This report describes the developments of TNO's Demand Driven Programs (called VP; Vraaggestuurd Programma) over the year 2016 and contributions to the different Roadmaps of HTSM. This yearly progress report (as well as the yearly update of the plans) is mandatory for TNO to account for the usage of Public Funding (called Rijksbijdrage TNO). The audience of this report are the Ministry of Economic Affairs and the Topsector HTSM with its Roadmaps, while this report will be published by TNO on its website as well.

The plans for 2016 were described in TNO's report 'Meerjarenprogramma 2015-2018, Thema High-Tech Systemen en Materialen, Bijstelling 2016' of September 21st, 2015.
Since the end of 2015 a separate HTSM Smart Industry Roadmap is available. The VP Social Innovation with a focus on Smart Working is specifically linked to Smart Industry. The research line Industrial Instrumentation, for practical reasons part of VP High-Tech Semicon, also contributes to Smart Industry. However, Smart Industry activities are performed within other HTSM Roadmaps as well, for instance the Additive Manufacturing Fieldlab described in the Roadmap Printing. Smart Industry activities within the Roadmap ICT are described in the 2016 progress report of the Demand Driven Program ICT.
The table below shows the relations between TNO's Demand Driven Programs and the HTSM Roadmaps. The activities of the Holst Centre are described in the VP Flexible and Freeform Products, specifically for the HTSM Roadmaps Components and Circuits, Lighting and Solar.

HTSM Roadmap / TNO Demand Driven Program (VP)	Security	Components and Circuits	Smart Industry	Automotive	Nano-technology	Hightech Materials	Space	Advanced Instrumentation	Semiconductor Equipment	Lighting	Solar	Printing	Healthcare	Embedded Systems
Cyber Risk Manag. & System Resilience	x													
Radar & Sensorsystemen	x	x												
Social Innovation			x											
Automotive Mobility Systems				x										
Human Health RM Nano					x									
Environmental Technology						x								
HTSM Building Innovation						x								
Space and Scientific Instrumentation							x	x						
High-Tech Semicon			x		x (QuTech)				x					
Flexible and Freeform Products		x								x	x	x	x	
ESI														x

2 VP Cyber Risk Management & System Resilience

2.1 Roadmap Securitty

2.1.1 Samenvatting

Het VP Cyber Risk Management & System Resilience richt zich op het in samenwerking met bedrijven en bedrijfsmatig aangestuurde overheidsinstellingen (in het bijzonder uitvoeringsinstanties) ontwikkelen van innovaties voor veilige IT-infrastructuren. Door snelle technologische ontwikkelingen en daarmee toename van kwetsbaarheden hebben partners behoefte aan kennis over de dreigingen, hoe daarmee om te gaan en hoe schade te voorkomen. Met het VP Cyber is het cybersecurity onderzoek in 2016 geïntensiveerd. Samen met publieke en private partners is gewerkt aan inzichten, tooling en technieken om de weerbaarheid tegen cybersecurity dreigingen te vergroten. Door dreigingsinformatie te analyseren, krijgen organisaties bijvoorbeeld inzicht in de werkwijze van hackergroepen en in de kenmerken van specifieke soorten malware. Dit stelt hen in staat om in een vroeg stadium te anticiperen op cyberdreigingen en schade aan hun systemen te voorkomen. Een dashboard is ontwikkeld waarin cyber kwetsbaarheden continu zichtbaar zijn; technieken zijn ontwikkeld om het zogenaamde dark web, waarop illegale handel plaatsvindt, beter te kunnen lezen; onderzoek is gedaan naar het technisch veilig maken van systemen die op afstand bestuurd kunnen worden; en onderzoek is gedaan naar de menselijke factor bij cyberdreigingen. Hiernaast is samen met de financiële sector gewerkt aan de digitale weerbaarheid door o.a. de ontwikkeling van detectietechnieken en metrieken. En samen met de energiesector zijn vorderingen geboekt bij het verbeteren van de digitale veiligheid van smart grids.

Het onderzoek vindt plaats in Shared Research Programma's (SRPs) en Publiek Private Samenwerking (PPS), waarin wordt toegewerkt naar oplossingen die in potentie een TRL-level van minstens 6/7 kunnen bereiken. Zo kan effectief overdracht van kennis naar het bedrijfsleven plaatsvinden.

VP Cyber Risk Management & System Resilience valt onder de HTSM Roadmap Security.

2.1.2 Korte omschrijving

ICT speelt een steeds grotere rol in onze samenleving. Kenmerkend zijn de snelle technologische ontwikkeling en brede adaptatie, die naast kansen ook kwetsbaarheden met zich mee brengen. Hoewel schattingen uiteenlopen is het duidelijk dat de exploitatie van deze kwetsbaarheden de maatschappij jaarlijks veel geld kosten (Anderson et al., 2012). Het VP Cyber Risk Management & System Resilience richt zich op het ontwikkelen van innovaties voor veilige IT-infrastructuren en doet dat in samenwerking met bedrijven en bedrijfsmatig aangestuurde overheidsinstellingen, in het bijzonder uitvoeringsinstanties.

Door middel van onderzoek en toolontwikkeling draagt TNO bij aan een beter begrip over de mogelijkheden en gevaren die ICT biedt. We zetten in op technologische uitdagingen die te maken hebben met bedreiging van de veiligheid van onze samenleving. Hierbij staan naast vernieuwing ook praktische toepasbaarheid en implementatiemogelijkheden centraal. We zoeken zowel naar oplossingen die bijdragen aan het vergroten van de weerbaarheid van bedrijven tegen cyberdreigingen in algemene en technische zin, als naar oplossingen die

cybercriminaliteit helpen beheersen en voorkomen, of de schadelijke effecten van incidenten beperken.

In 2016 lag de focus op: Cyber Threat Intelligence (CTI o.a. ontwikkelen van een capability model); dark web tooling; beïnvloeden van systemen-op-afstand; en de human factor in cybersecurity. Denk hierbij aan het vergroten van de technische mogelijkheden om threat intelligence uit verscheidene bronnen te delen in samenwerkingsplatforms, aan het ontwikkelen van tools om informatie van het dark web te kunnen gebruiken als bron, aan het technisch veiliger maken van systemen die op afstand bestuurd kunnen worden, en aan het beïnvloeden van gedrag van werknemers om intrinsiek veilig te werken.

Daarnaast is voor de financiële sector gewerkt aan het verbeteren van detectie van targeted attacks door anomalie detectietechnieken; het ontwikkelen van cyber resilience metrics; en onderzoek naar security in toekomstige financiële transacties. In onderzoek gericht op de energiesector stonden electricity smart grids centraal: verbeteren van risico assessments, kwetsbaarheidsmodellering; en het ontwikkelen en testen van nieuwe security maatregelen in smart grids.

De opgebouwde kennis wordt toegepast in Shared Research Programma's (SRPs) en Publiek Private Samenwerkingen (PPS). Daarin wordt toegewerkt naar oplossingen die in potentie een TRL-level van minstens 6/7 kunnen bereiken. Zo kan effectief overdracht van kennis naar het bedrijfsleven plaatsvinden. Om continu attractief te blijven voor het bedrijfsleven worden in het programma zowel onderwerpen met een lager als met een hoger TRL niveau onderzocht. Dit stimuleert tevens de continuïteit en voortgaande ontwikkeling van het onderzoeksprogramma.

De uitvoering van het VP Cyber Risk Management & System Resilience vindt plaats in nauwe samenwerking en afstemming met het onderdeel Cybersecurity & Societal Resilience van VP Veilige Maatschappij.

2.1.3 Highlights

Cyber Threat Intelligence

Door de realisatie van het Cyber Threat Intelligence (CTI) lab in nauwe samenwerking met Eclectic IQ is een goede kennisbasis gevormd van de tools, protocollen en concepten die binnen het CTI werkveld beschikbaar zijn, evenals een beeld van het gebruik hiervan door verschillende disciplines binnen het werkveld. Naast CTI betreft dit onder meer Security Operations Centers (SOC) en Cyber Emergency Response Teams. De labomgeving is een goede basis voor vervolgonderzoek binnen het CTI werkveld. Onderzoek van verschillende typen open CTI bronnen hebben de mogelijkheden en beperkingen van deze bronnen in kaart gebracht. De binnen het onderzoek gerealiseerde dashboards laten zien dat het met goede brondata mogelijk is om het aandeel van Nederland in bepaalde typen dreigingen te meten. Dit biedt mogelijkheden voor de doorontwikkeling richting sectorale dreigingsbeelden. Het ontwikkelde kwetsbaarheden dashboard biedt interessante mogelijkheden als operationele tool binnen het CERT werkveld door een continue beeld beschikbaar te hebben van de meest relevante kwetsbaarheden. Innovatieve technologie als machine learning algoritmen kunnen dergelijke dashboards nog verder verbeteren. Op 21 december 2016 zijn de onderzoeksresultaten gedeeld met 120 stakeholders, wat momenteel leidt tot aanvullende partnerschappen.

Aanpalend heeft een verkenning plaatsgevonden voor cybersecurity

informatiedeling voor de Topsectoren. Cybersecurity informatiedeling vindt op dit moment plaats voor vitale sectoren met het oog op nationale veiligheid. Dit vindt nog niet plaats voor Topsectoren met het oog op economische veiligheid. Resultaat van de verkenning is een beschrijving van de huidige situatie en een concept hoe cybersecurity informatiedeling voor de Topsectoren opgezet kan worden. In samenwerking met ING, ABN AMRO en Rabobank is een CTI capability model ontwikkeld dat nu ook wordt gebruikt door deze banken om hun CTI verder te professionaliseren.

Dark web
Door nauwe samenwerking met de pharma industrie is de tooling om het dark web beter te kunnen 'lezen' sterk verbeterd. Een op deep learning gebaseerde tekstminingtechnologie is geïmplementeerd voor het herkennen van verzendinformatie in ruwe marktplaatsposts; het herkennen van medicijnnamen (ook als deze foutief gespeld zijn of mogelijk niet bekend zijn); en het herkennen van hoeveelheden verhandelde pharma. Deze technologie is geïncorporeerd in de dark web monitor, die daarnaast ook is voorzien van nieuwe grafische middelen om netwerkstructuren weer te geven en te verkennen. Met de nieuwe tekstminingtechnologie is handel in pharma op het dark web nog beter in kaart gebracht.

Aanpalend zijn projecten uitgevoerd rond MALPAY en onderzoek naar New Payment Methods in relatie tot fraude en witwassen (onderzoek samen met IFCC, het Institute For Financial Crime). Meer specifiek vind er binnen het MALPAY project (promotie)onderzoek plaats naar de economic of financial malware, waarbinnen met consortium partners zoals NHTCU (de National High-Tech Crime Unit van de Politie) en kennispartner TU Delft wordt samenwerkt. In dit meerjarige programma, is dit jaar gefocust op methodologieën van TOR-based research, cash-out strategieën bij financiële fraude en waardenketens binnen financial malware. Daarnaast is in afstemming met IFFC onderzoek uitgevoerd naar New Payment Methods en diens rol bij financiële fraude en witwassen. Dit jaar is daarin een definitiestudie uitgevoerd en zijn risico-indicatoren van New Payments Methods geïdentificeerd.

Beïnvloeden van systemen-op-afstand
De Internet of Things (IoT) trend is één van de belangrijke ICT technologie ontwikkelingen van de komende jaren. De berichtgeving in de publieke media gaat nu vooral over problemen: het ontbreken van standaarden voor interoperabiliteit, het slechte beveiligingsniveau van Internet connected apparaten zoals bewakingscamera's en Distributed Denial of Service (DDoS) aanvallen enzovoort. Voor onze bijdrage aan de kennisvernieuwing bij TNO en bij de Waterschappen roeien we wat tegen de stroom in: we richten de spotlight op de mogelijke kansen van IoT. Specifiek de nieuwe mogelijkheden van sterke moderne end-to-end beveiliging om daarmee de tekortkomingen van ICS/SCADA op te lossen voor watermanagement toepassingen in de kritieke infrastructuur in Nederland. Om de Waterschappen geïnteresseerd te krijgen in het uitvoeren van een proefproject voor zowel een publieke als een private variant van Long Range Wide Area Networks (LoRaWAN) is een projectvoorstel geschreven die voor alle partijen interessant zou moeten zijn. Voor leveranciers om een nieuwe generatie van sensorapparatuur te kunnen ontwikkelen, voor KPN om te laten zien wat hun LoRaWAN kan betekenen voor klanten, voor Waterschappen om een hoger beveiligingsniveau te halen voor het uitlezen en aansturen van vitale objecten en voor TNO om één van de eerste grote LoRaWAN projecten te kunnen doen.

Human Factor in Cybersecurity

Iedere digitale security dreiging heeft niet alleen een technisch, maar ook een menselijk aspect (Lee, 2012). Daardoor kan het begrijpen van de beslissingsprocessen en persoonlijkheidskenmerken van zowel de daders (Arief, Adzmi, & Gross, 2015) als slachtoffers (Arief & Adzmi, 2015; Patterson, Hobbs, & Palmer, 2013) van cybercrime bijdragen aan meer resilient organisaties. Dit begrip kan namelijk gebruikt worden om effectieve interventies voor bescherming van organisaties tegen cyberaanvallen te ontwerpen (Duijn & Sloot, 2015; Lee, 2012). Menselijke aspecten, zoals begrip en alertheid, zijn onderdeel van de ontwikkeling van een veilige cybercultuur. Onderzocht is of een populatie van werknemers effectiever 'cyber bewust' gemaakt kan worden door gebruik van wetenschappelijke modellen uit de gedragswetenschappen. Dit betreft zowel de identificatie van risico's op het werkelijkheid worden van cyberdreigingen die met de persoonlijkheid van de werknemer samenhangen, als beïnvloeding van de heersende cultuur richting intrinsiek gedreven veilig werken. Denk hierbij aan cyberaanvallen die specifiek op personen zijn gericht, zoals Advanced Persistent Threats (APT's), die veelal een combinatie zijn van technische en sociale aspecten, (spear)phishing en andere vormen van social engineering. Wanneer met gedragsgerichte interventies (zoals cultuurtransitie en resilience) hetzelfde niveau van cyberveiligheid kan worden bereikt als met de huidige technische (afgedwongen) interventies, wordt de flexibiliteit van organisaties verhoogd. In 2016 zijn de dimensies en factoren in human factors in cyber, inclusief dadergedragingen en -kenmerken, situationele factoren, aanvalskenmerken, interventiemechanismen, en slachtoffergedragingen en -kenmerken in kaart gebracht. En de opgeleverde state of the art op dit gebied, vanuit zowel informatica als sociaal wetenschappelijk perspectief, is gepubliceerd in een Nederlands vaktijdschrift en vormt de kennisbasis voor het verdere onderzoek in 2017.

Verbeteren van detectie van targeted attacks door anomalie detectietechnieken
Samen met ING, ABN AMRO, Rabobank en Achmea zijn nieuwe methoden ontwikkeld, getest (met real-life data) en toegepast om targeted attacks beter te kunnen detecteren, zowel in netflow verkeer als in DNS verkeer. Dit wordt vooral gedaan op basis anomalie detectie technieken. Uit dit project is een paper gepubliceerd (W.J.B. Beukema, T. Attema and H.A. Schotanus, “Internal Network Monitoring and Detection using Host Clustering”. Accepted for: 1st International Workshop on Formal methods for Security Engineering – ForSE 2017, Porto, Portugal, 2017).

Het ontwikkelen van cyber resilience metrics
Samen met ING, ABN AMRO en Rabobank is een library ontwikkeld met cyber resilience metrics. Deze metrics meten voor de daadwerkelijke performance van resilience en security en niet alleen de aanwezigheid van resilience controls. Deze metrics worden nu door de individuele banken geïmplementeerd en het plan is om de library in 2017 ook te publiceren voor gebruik door andere partijen binnen Nederland.

Security in toekomstige transacties
Samen met ING, ABN AMRO en Rabobank is onderzoek gedaan naar de security van toekomstige transacties. Hierbij is o.a. gekeken naar use cases die gebruik maken van blockchain technologie en is onderzoek gedaan naar gebruikers perceptie van deze nieuwe transactie methodieken.

Risico assessment, vulnerability modelling en nieuwe security maatregelen in smart grids
Met 9 partners (onderzoeksinstituten, leveranciers en eindgebruikers zoals Alliander) is in het EU FP7 project SEGRID (segrid.eu), geleid door TNO,

onderzoek gedaan naar betere methodieken om risico assessment te doen in electricity smart grids. Hierbij is een SEGRID Risico Management Methodiek (SRMM) ontwikkeld. Eén van de verbeteringen is ingebracht als change request in de ETSI TVRA en door dit standaardisatieorgaan ook geaccepteerd als change. In de volgende versie van de standaard zal de aanpassing worden doorgevoerd. De methodiek wordt in 2017 gepubliceerd en er is een artikel geschreven voor een special issue over risico assessment (april 2017) dat wordt uitgegeven door de IEEE (dit artikel is nog onder review).

Met deze 9 partners is tevens onderzoek gedaan naar vulnerability modelling. Het doel is om door modellering van netwerken vulnerabilities in het ontwerp van deze netwerken vast te stellen zodat deze kunnen worden beoordeeld en zo nodig kunnen worden opgelost door het nemen van aanvullende maatregelen. Hiertoe is een tool, initieel ontwikkeld door KTH (Stockholm), verbeterd en aangepast voor gebruik in operationele smart grid omgevingen. Aanvullend zijn nieuwe security maatregelen ontwikkeld op het gebied van o.a. privacy by design, Improved denial-of-service protection in software-defined networks, improved system integrity through intrusion tolerant server replication, improved resource management for (D)TLS (Datagram Transport Layer Security).

2.1.4 Dynamiek

Het Topsector VP Cyber Risk Management & System Resilience is in 2016 voortgekomen uit VP Security 2015 en haakt onveranderd aan bij de Roadmap Security van Topsector HTSM. Bij die gelegenheid is ook het cybersecurity onderzoek geïntensiveerd en in omvang uitgebreid. Het VP wordt uitgevoerd in nauwe samenwerking en afstemming met het onderdeel Cybersecurity & Societal Resilience van het VP Veilige Maatschappij dat valt onder Thema Maatschappelijke Veiligheid.

In 2017 wordt in VP Cyber in het bijzonder doorgepakt op innoveren op Cyber Threat Intelligence en Human Factors in Cyber. In aansluiting op de lopende ontwikkelingen worden verder methoden ontwikkeld voor het valideren van security technologie en wordt onderzoek gedaan naar een veilige toepassing van de blockchain technologie. Met de banken wordt de Roadmap verfijnd en worden nieuwe projecten opgestart. Voor de energiesector gaat het Europese SEGRID project zijn laatste jaar in.

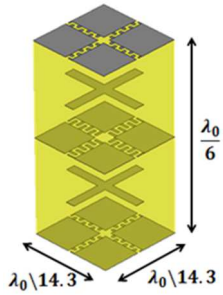
3 VP Radar & Sensorsystemen

3.1 Summary

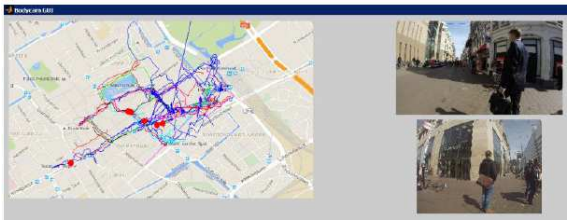
The TNO applied research carried out in VP Radar and Sensor Systems (P104) is reported in two HTSM Roadmaps, namely:

- the HTSM Roadmap Security;
- and in the HTSM Roadmap Components and Circuits.

The program for the HTSM Roadmap Security focused in 2016 on projects that contributed to the national Roadmap *Radar en Geïntegreerde Sensorsuites* and in particular to the sensor suite for the next two generations of frigates of the Royal Netherlands Navy. An artist impression of a future frigate is shown on the left. National projects have been implemented together with Thales Netherlands, supply chain partners and universities. Projects at an international level are carried out in different consortia. Several fundamental research topics are picked up in 2016 which are enabling for systems to be introduced around 2030. For example one of those topics is the development of new 3D antenna structures using artificial materials. An example of a *frequency selective surface* using such materials, is shown on the right. Frequency selective surfaces are necessary in the future to isolate wireless systems from interference. The result of the fundamental research in 2016 will probably enable participation in an European consortium on the digital factory including 3D manufacturing using artificial materials.

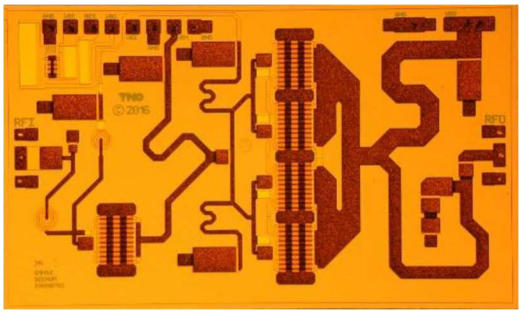


An extension of the knowledge portfolio is implemented in 2016 to support the national defence related and security industry and users on a wider scope, in particular with the new program lines *Sensors and Systems for Security*, *Technology for Passive Sensors*, and *Mission Critical Systems*. TNO focused in 2016 on *sensors and systems for security in complex environments* for the purpose of maintaining public order, guarding and securing and tracking. The premise is that this requires a high knowledge of the scope and the environment as well of the sensors. Anno 2016, social security on the one hand, and external security or defence on the other are mutually more and more intertwined. This manifests itself in various forms of cooperation in operation, but also in research and development.



The domain of S3 lends itself ideally for such technologies with body Cams, UAVs and high-tech video content analysis (an example is shown in the picture on the left). Useful sensors are also found in mobile devices that arrive from the consumer society. These developments lead to sensors and mobile ad hoc devices mounted on (autonomous) vehicles or in the hand or worn on the body by professionals or citizens. These developments required a big step in technology, particularly for determining the current position and viewing angle. As a result from these trends, technological developments and acquisition plans to implement such systems a

new game aroused between government, business and citizens. It is crucial in this game to find a balance between privacy and security.



TNO has a long standing world-class position in the area of the design of monolithic microwave integrated circuits (MMICs). These MMICs are crucial components in all kind of systems that receive or transmit RF energy, like communication systems and radar systems. The activities in 2016 in the HTSM Roadmap Components and Circuits were focused on the design and realization of MMICs on GaAs, GaN and SiGe technologies. In particular for the development of the new generation of Active Electronically Scanned Array antennas (AESA is also often referred to as phased-arrays) for radar and for 5G communication systems. MMIC technology has a major impact on cost, functionality and performance of AESA's. On the right an example of a GaN circuit developed in 2016 aimed at reducing the costs of packaged GaN chips and making it commercially available from a European manufacturer.

3.2 Short Description

The impact of the VP in the HTSM Roadmap Security is aimed at strengthening the global leadership and competitiveness of our national defence and security industry and associated technology suppliers, in particular in the area of radar and passive sensors. We aim to achieve this by strengthening the market position and knowledge position of the national (defence/security) industry, the related industries in the supply chain hereof and of TNO respectively. The basic objective is to generate impact on export opportunities and employment, based on industrially relevant R&D and speed of innovation. We achieved this by consistency in joint roadmaps, an open exchange of knowledge and by increase in scale.

The products and technologies in this domain distinguish themselves compared with others due to the nature of the defence/security domain. Therefore, cooperation is crucial in a Triple Helix[1] between knowledge institutions, industries and supplying technology companies and military/security stakeholders (both national and European level), whereby all together, at an early stage, the development of an optimal knowledge base which is innovative, trend-setting and leading the way to go is.

In fact, we should add to the Triple Helix definition the term 'monopsony' as coined by Joan Robinson in 1933. After all, if there is 1 customer (in our field of work the Royal Netherlands Navy), and there are multiple providers, there has been a monopoly customer. If you fill out the Triple Helix Government role from that point of view, or from the point of view as a launching customer, then it is clear that the only appropriate success formula to increase the earning power of the Netherlands in this technology domain (after all one of the main objectives of HTSM policy) is a formula like Platform Nederland Radarland.

[1]The concept of the Triple Helix of university-industry-government relationships initiated in the 1990s by Etzkowitz (1993) and Etzkowitz and Leydesdorff (1995), encompassing elements of precursor works by Lowe (1982) and Sábato and Mackenzi (1982), interprets the shift from a dominating industry-government dyad in the Industrial Society to a growing triadic relationship between research-industry-government in the Knowledge Society.

The goals of this VP are:

- to develop high-tech components and subsystems that fulfil the requirements of our national defence/security industry; and
- to develop security systems for surveillance and security in complex environments.

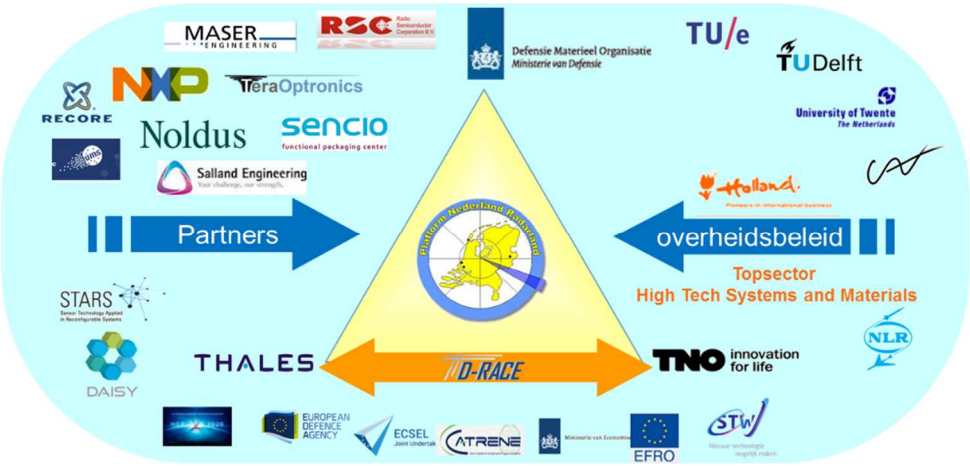
The technologies developed in the military/security domain are aimed to have a wide social relevance for both military and non-military applications. The technologies and products should generate also demonstrable spill over effects to other economic sectors and should be related to a great diversity of activities at related companies and SMEs.

3.3 Highlights

3.3.1 Roadmap Security

Radar and Integrated Sensor Suites

Dominant is our national *Roadmap Radar and Integrated Sensor Suites* which is governed by *Platform Nederland Radarland*. Contracts and activities within this context are carried out by several partners within the Triple Helix, a snapshot of the ecosystem in 2016 is given in the figure below.



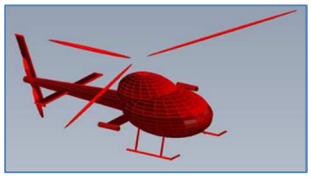
Netherlands industry as well as research institutes have a top position in the world and are strong innovative players. The Netherlands is world market leader in radar and in command and control systems for navies. Radar is ideally suited for detecting and recognizing objects of so called non-cooperative objects at very long distances. Examples include the use of radar for military applications, security applications such as coastal and port security, peacekeeping and humanitarian missions such as anti-piracy and disaster. Furthermore, also predicting extreme weather and the control and supervision of traffic and transport can be typically applications. Market research shows significant global market potential.

Typical activities that we targeted together with our partners in the ecosystem and that were sponsored by the VP Radar & Sensorsystemen, are:

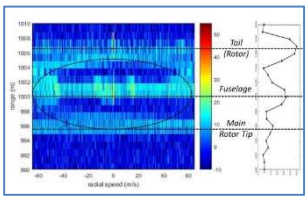
- Sponsored contracts with Dutch defence industry and SMEs.
- Contracts of the European Defence Agency (EDA) carried out together with Dutch defence industry and other EU defence industries and research institutes.

- Contracts within the scope of national funded programs (FES) and regional funded programs (EFRO) carried out with national industry, national universities and SMEs.
- Contracts within the scope of the Security calls of Horizon2020 carried out with national defence related companies, other national companies and universities and international industry and universities.
- Contracts within in Joint technology Initiatives ECSEL and CATRENE of the European Commission carried out with national defence related companies, other national companies and universities and international industry and universities.

In the framework of the European Defence Agency we partnered with almost all major European defence companies and RF semiconductor manufacturers such as UMS, OMMIC, Thales, SAGEM, SELEX, SAAB, AIRBUS etc. and with research companies like FOI in Sweden, Fraunhofer in Germany, III-V labs in France etc. In the field of early detection of small airborne targets, which are considered as an upcoming terroristic threat, we are a partner in the ACACIA project of EDA. ACACIA is a 3-year project that started in 2014 that focuses on emerging waveforms, signal processing and advanced classification techniques using micro-Doppler analysis and compressive sensing for the detection, identification and classification of small airborne targets. The pictures on the right show a typical result of ACACIA: a picture of a helicopter target model (top) and its simulated range Doppler (bottom).



In the field of military disruption tolerant radio networks we were partner in MIDNET, MIDNET is on robust routing-concepts for distribution of data/information on military radio networks, in a mobile, wireless disruptive environment to improve network performance. MIDNET is completed in 2016.



Above activities are fully aligned with the Strategic Research agendas of the European Defence Agency (EDA), in particular in the fields of radar (EDA CapTech Radio-Frequency Sensors Technologies), miniaturized electronics (EDA CapTech Components) and electro-optical systems (EDA CapTech Electro-Optical Sensors Technologies). These strategic research agendas of the EDA are partly initiated and set up from above mentioned Roadmaps.

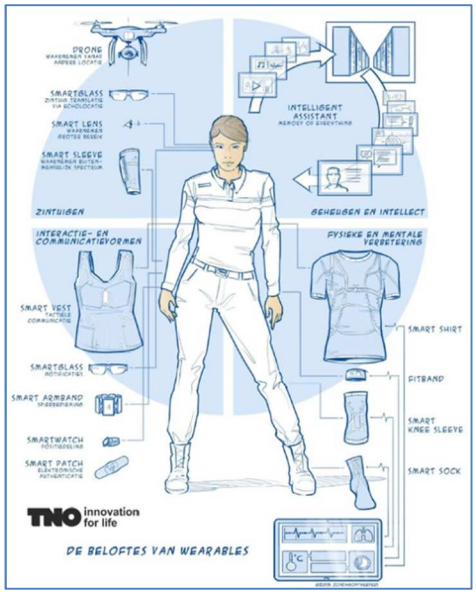
Within the scope of CATRENE, an EU EUREKA cluster for micro and nano-electronics, we partnered in EAST. EAST is a contract on defining, researching and demonstrating signal generation and distribution in array antennas. Especially for 5G systems, but the same technology can also be used for military systems. On the right a breadboard version of the phase-adjustable PLL concept designed by TNO. The Dutch partners within EAST are NXP, Bruco, BESI, TUD, TUe and Anteverta.

Sensors and Systems of Securrity
Our key question in this domain is: which types of security system are most appropriate in any complex situation and why? Answering this question helps in the first place our national end users, but also helps companies to develop their own unique selling point that better matches with their particular customer segment.

Within this scope the following activities in a role as innovation factory are carried out since 2012 and are continued in 2016:

1. Robust upscaling for large-scale deployment of Video Content Analysis (VCA) in complex systems for securing and monitoring, surveillance and detection.
2. Evaluating relevant physical signals using intelligent sensors from human wearable observation platforms.
3. Systems for body cams; and in the role of *innovation catalyst*.
4. Security systems for surveillance and security in complex environments.

In the role of *innovation factory* we worked together on specific technical innovations with the research and development departments of end-users and industry such as CROON and the Royal Dutch Marechaussee. This has led to technical scientific publications and software. In the role of *innovation catalyst* we worked with end users and industry to establish the necessary boundary conditions to successfully implement innovations. This has led to support the national police in their ambition to set up an operational Fieldlab, and writing several publications on relevant technological innovations. As an example: TNO has provided the Police with a "Vision on wearables". This helps the police to better articulate their needs to industry (picture on the right).



In the field of sensors and systems for Security, Dutch industry produces very high quality products, both for the Dutch market and internationally. However, there is a number of barriers to do business easily in other countries. For example, there is no clarity on how the performance of surveillance systems should be established, and there is a great need for good test datasets. It is therefore necessary to actively support the harmonization of the market at European level. ERNCIP offers the opportunity here for. Through ERNCIP, TNO can have very quickly access to the state of the art surveillance systems, which increases the likelihood that Dutch products developed together with TNO, also fulfil a need at European level.

Due to the restructuring of the VP some European projects are reported over 2016 in this VP that were originally started in the former VP Security (P103). It concerns the projects INSPEC^{2}T and HECTOS.

The H2020 project “INSPEC^{2}T”. INSPEC^{2}T (Inspiring CitizeNS Participation for Enhanced Community PoliCing AcTions) aims to transform the opportunity of a seamless collaboration between citizens and LEAs inside a community to a reality, through means and practices that can advance the meaning of Community Policing (CP). CP allows the police and the community to work together in new ways to solve problems of crime, disorder and safety, in order to improve crime prevention and quality of life for everyone in that community. The project’s objective is to develop a sustainable conceptual framework and supporting technology for CP. The framework and supporting technology will be tested in 5 pilot cities in Europe, Groningen (the Netherlands) is one of these cities. INSPEC^{2}T is carried out together with several European research companies, typical security SMEs and end-users, in total 18 partners from 8 different nations.

HECTOS, Harmonized Evaluation, Certification and Testing of Security Products, is on identifying mechanisms to evaluate the performance of security products, as well as compliance with interoperability, regulatory, ethical, privacy and other requirements. The project will develop elements for a Roadmap for the development of new harmonised product certification schemes. This is necessary because that there are very few test, evaluation and certification procedures in Europe for physical security products that are mutually recognized by different Member States. HECTOS is carried out together with the main European research institutes in the security area like FOI, Fraunhofer, NPL, Safran, Iconal, DIN and the university of Warwick.

Technology for Passive Sensors
Technology for Passive Sensors is a new program line that started up in 2015/2016. The target for this program line is aimed at supporting Dutch SMEs in the field of electro-optical systems. Within the scope of EXCEL we partnered in EXIST. EXIST is on research into new technologies for CMOS image sensors that are needed in the next generation of various applications. The Dutch partners within EXIST are SMEs.

3.3.2 Roadmap Components and Circuits

TNO has in the context of D-RACE a very close cooperation with Thales Netherlands. D-RACE steers actively on the implementation and progress in the *Roadmap Radar and Integrated Sensor Suites* that is detailed until 2020. Running programs include the development of GaN amplifiers with the world's highest reported output power (GaNS) and the development of advanced GaAs HEMT transistor layouts to reduce the size of MMIC circuits while maintaining its performance (STRICT). For protection, integrated limiters with receivers were developed that show unprecedented protection levels, up to very high power level within a 1x1 mm^2 integrated circuit. The feasibility to set up a supply chain for such limiters in investigated in 2016.

In the context of DAISY, another great national project funded in this Roadmap by regional structural funds, we worked together with NXP, Thales Netherlands, various technical universities and SMEs. DAISY focused on the next generation miniaturized but also affordable sensor modules. DAISY is a good example of the social relevance of this VP. The knowledge is also made available, through the participating of SMEs, in other sectors on the market. Within DAISY integrated SiGe transceivers are developed and manufactured. The first phase of DAISY was completed in 2015, the second phased is started in the end of 2016.

We do see an increasingly more important role of national industries and universities: NXP is the only Dutch manufacturer of high frequency integrated circuits and is an increasingly important player as a developer of unique and thereby crucial and strategic technology. We work together with all three technical universities. The relevant chairs of these universities are seen from the perspective of the Roadmap as a provider of long-term scientific knowledge and to address new promising developments in an early stage.

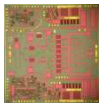
At international level we do see an increasing role of UMS in France, especially for GaN an SiGe applications.

In the framework of the European Defence Agency, the European JTI's PENTA and ECSEL and the H2020 Framework program we cooperate with almost all major

European defence companies and RF semiconductor manufacturers such as UMS, OMMIC, Thales, SAGEM, SELEX, SAAB, AIRBUS etc., with research companies like FOI in Sweden, Fraunhofer in Germany, III-V labs in France etc. and with European companies and research institutes in the semiconductor area.

A new TKI Toeslag project is started in 2016 with a duration of 3 years. In this project we work together with UMS in France, Thales Netherlands and NXP on fundamental research for extreme high-power GaN amplifiers and fully integrated phase drivers on SiGe. The intention is to be the first world-wide outside the USA to demonstrate the highest achievable output power at chip level.

The activities in the Roadmap Components and Circuits are focused on the design and realization of high frequency electronic circuits on GaAs, GaN and SiGe technologies. The targets are discussed and agreed with our stake holders and are tabled below.

	Roadmap Demand	**Example**	**TNO's Contribution**
GaN	Dealing with increasingly stringent environmental requirements such as spectrum boundary and increasing integration		Pulse shaping for X-band power-amplifiers in low-cost package, on-chip integration of drain-switch function and of the limiter function (i.e.: European project SWAP-C)
	More output power, single-chip, ITAR-free		Development of 25W – 100W HPA's chips in low-cost package, ITAR free, globally competitive properties, fabricated in Europa, set-up supply chain (i.e.: TKI Toeslag)
GaAs	Low-cost alternatives for GaN power amplifiers		New design methodology for GaAs-based HPA's based on new transistor layouts resulting in more power/mm2 (i.e.: STRICT2: Sponsor contract)
	Low-cost phased drivers		Low-cost phased driver with output power sufficient to drive GaN high-power amplifiers and mounted in low-cost plastic packages
SiGe	Lower-cost fully integrated transmit-receive modules		Chipset for next generation fully integrated X-band SiGe transceivers in low-cost high-volume packages (i.e. DAISY2: EFRO funding)
	Breakthrough to fully integrated transmit chains		Integration of distributed signal generation in order to minimize volume and cost. Improve spectrally pure signal generation, integrated transceiver switch (i.e.: het CATRENE project EAST)
	Set up of a SiGe supply chain together with a European supplier		Feasibility of a European SiGe supply chain with first product an integrated SiGe limiter

A number of projects launched in 2014, 2015 were continued in 2016, in addition some new projects were started in 2016. These include the European projects SWAP-C and EAST, the national projects PHSDRVPRT, GaNS and STRICT, the binational projects SiGe supply chain and the TKI Toeslag project on the Power Fundamentals for Radar.

- GANS3 on research into reducing the cost of GaN-based S-band power amplifiers using COTS plastic QFN housings.
- STRICT2 researches stacked transistors based on GaAs technology for use in power amplifiers for future communication and sensor applications.
- SWAP-C is within the scope of EDA (European Defence Agency) on the development of new transmitter architectures that enable significant cost reduction of transmit/receive modules for future phased array radars and is carried out with Thales and SAAB in Sweden.
- EAST is an CATRENE project on defining, researching and demonstrating signal generation and distribution in array antennas with main partner NXP.
- PHSDRVPRT is on the design and development of a GaAs phase driver together with Thales and UMS.
- The SiGe Supply chain is aimed at demonstrating the feasibility of a European supply chain for SiGe integrated circuits. Partners working together with us are UMS, Thales and NXP.
- The TKI Toeslag project on the Power Fundamentals for Radar is aimed at demonstrating the highest obtainable output power (100W) of a GaN MMIC outside the USA and a SiGe circuit to dive this GaN MMIC. We carry this out together with UMS, NXP and Thales who provide a significant in-kind contribution.

3.4 Dynamics

A major reshuffling of activities between VP Security (P103) and VP Radar and Sensor Systems (P104) at the end of 2015 resulted in an extension of the scope of VP 104 as indicated in the table below.

Program lines in VP P104 Radar and Sensor Systems	
Before 2016	**2016 and further**
Radar and Integrated Sensor Suites, stakeholder Platform Nederland Radarland	*Radar and Integrated Sensor Suites*, stakeholder Platform Nederland Radarland
Radio Networks, stakeholder Dutch Defence Industry	
(in development: *Technology for Passive Sensors* with stakeholders Dutch SMEs in the field of electro-optical systems)	*Technology for Passive Sensors* with stakeholders Dutch SMEs in the field of electro-optical systems)
	Sensors and Systems for Security (transferred from VP P103 Security) with stakeholders Dutch Industry, Dutch Airports, Dutch National Police and local Police forces (Groningen, The Hague) and the Royal Dutch Marechaussee

Program lines in VP P104 Radar and Sensor Systems	
Before 2016	**2016 and further**
	(in development: *Mission Critical Systems* with stakeholders Dutch Maritime Defence industries and Royal Dutch Navy)

Publications

Radar:

- A journal publication on the FSS hardware demonstrator is in preparation.
- The work on the derivation of guidelines for WAIM design is currently being finalised and, depending on the conclusions, a paper on this topic might be prepared.
- J. de Wit, P. van Dorp, and A. Huizing, Classification of Air Targets Based on Range-Doppler Diagrams. EuRAD Conference, 2016.
- W.L. van Rossum, L. Anitori, P. van Dorp, J.J.M. de Wit, R.I.A. Harmanny. Classification of Human Gaits using Interrupted Radar Measurements. *Submitted to* 2017 IEEE Radar Conference.

Sensors and Systems for Security:

- Bangma, M. R., J. W. Streefkerk, and J. G. M. de Jong. Beloftes en Barrières voor Blauw: visie op de toepassing van wearables voor het operationele politieproces. No. TNO 2016 R10199. TNO, 2016.
- van der Zee, S. C., et al. "Actuele ontwikkelingen in leugendetectie." Security Management, Maart, 2 (2016).
- Bouma, Henri, et al. "Measuring cues for stand-off deception detection based on full-body nonverbal features." SPIE Security+ Defence. International Society for Optics and Photonics, 2016.
- Van der Zee, et al, “Toekomstverkenning leugendetectie: Relevante toepassingen en implementatievormen in het Nederlandse veiligheidsdomein”, TNO 2016 R10924.
- Wijn, R. et al, “Telling friend from foe: Environmental cues improve recognition of hostile intentions.”, Journal of Legal and Criminological Psychology (accepted).

Inspect ^{2}T:

- Kerstholt, J.H., Vries, A. de, Mente, R. & Huis in ’t Veld, M., 2015. Politie en burgers: van informatie delen naar volwaardige samenwerking, Tijdschrift voor Veiligheid, Vol. 14, p. 78-88.
- Vries, A. de (2016). De BuurtWhatsApp: ogen en oren van de buurt. Zorg&Welzijn, 38-39.
- Koops van ’t Jagt, P. ,Volkema,E., Schultz,S., De Vries, A. (2016). StudentAlert: Whatasapp met de politie:Evanluatie StudentAlert bij de politie eenheid Noord-Nederland / Groningen. Rapport TNO & Politie (vertrouwelijk).

4 VP Sociale Innovatie

4.1 Roadmap Smart Industry

4.1.1 Samenvatting

Smart Working is een deelprogramma van het Smart Industry initiatief. In Smart Working wordt gekeken naar wat op de arbeidsplek gedaan kan worden om Smart Industry verder mogelijk te maken. De centrale vraag is hoe met robotisering en digitalisering om te gaan. Pas als robotisering en digitalisering aansluiten bij wat medewerkers wensen, bij hun taken, en bij hoe werkprocessen verlopen en organisaties functioneren, pas dan kan Smart Industry succesvol worden uitgerold.

Smart Industry zet in op het automatiseren en verbinden van alle productieprocessen. Dan is het van belang oog te hebben voor het feit dat al diegenen die betrokken zijn bij het produceren, ook optimaal kunnen werken en optimaal ondersteund worden door robots, cobots, toegang tot big data en/of cognitieve support systemen. Een optimale digitale ondersteuning vergt ook dat het werk zelf anders wordt ingericht. Smart Working streeft naar het ontwerp van robot en ICT oplossingen waarin mensen en organisaties optimaal kunnen functioneren vanuit het perspectief van (systeem)performance en vanuit mens perspectief: fysiek, cognitief en psychosociaal. Smart Working hanteert als uitgangspunt een maximale autonomie van de medewerker; is gericht op ontstaan van nieuwe kennis op de werkvloer die maximaal wordt gedeeld.

Wetenschappelijk gezien ligt de uitdaging in het Smart Working project in het koppelen van verschillende sociaal wetenschappelijke inzichten over de inzet van medewerkers aan de nieuwste technologische ontwikkelingen. Daarmee gaat het programma verder dan technology assessment (Van Est & Kool, 2015). Het is de expliciete bedoeling om concrete vormen van robotisering en digitalisering te ontwerpen vanuit een Human Factors en Organisatieperspectief. Vooruitgang op het onderwerp van Smart Working is alleen mogelijk als de disciplines human factors, organisatiekunde en technische disciplines geïntegreerd aan oplossingen werken (O'Sullivan en De Looze 2010; De Looze e.a. 2015).

Het programma heeft in 2016 belangrijke vooruitgang geboekt. Een mini-lab is opgezet om met medewerkers na te gaan hoe cognitieve operator support systemen dienen te worden ingericht. We zijn actief in twee Smart Industry Fieldlabs om deze onderwerpen te implementeren (Fieldlab Flexible Manufacturing, Fieldlab Sociale Innovatie). Het EUWIN project (European Workplace Innovation Network) is afgerond en heeft geleid tot een verbinding met 10.000 bedrijven over heel Europa. We kunnen met EUWIN bouwen aan nieuwe EU initiatieven.

Op de nieuwe onderwerpen zijn we er in geslaagd om samenwerkingsverbanden op te zetten waarmee we in de komende jaren SMO trajecten kunnen realiseren. Op het cobotiseringsonderwerp hebben we ROBOMATE opgestart over exoskeletten en cognitieve operator support systemen. Het HORSE project is gericht op de integratie en ontwikkeling van nieuwe concepten op het gebied van mens-robot interactie en intuïtieve mens/machine-interfaces in nieuwe fabrieken. Het project is gestart met de definitie van behoeften in drie use cases bij drie verschillende eindgebruikers. Andere robotprojecten zijn ROBOSURF en (G)EEN MOER AAN. Op het digitaliseringsonderwerp hebben we het USE-IT-WISELY project waarmee we een betere inzet van IT in werkprocessen in de industrie realiseren. Daarnaast hebben we een rapportage over blockchain en sociale innovatie opgeleverd. Met deze kennis werken we nu aan nieuwe initiatieven met

Centric, de Gemeente Amsterdam en nog andere partijen. Voor 2017 en later zullen deze twee onderzoekslijnen de centrale focus vormen voor het VP.

4.1.2 *Korte omschrijving*

Het algemene doel van het VP Sociale Innovatie is het bevorderen van duurzame innovaties in werkplekpraktijken in bedrijven die Smart technologieën toepassen. Dit wordt gerealiseerd door voldoende inzicht te verkrijgen in de mogelijkheden voor betere interactie tussen robots/ICT systemen en medewerkers, kennisontwikkeling te stimuleren en beter te standaardiseren zodat kennisdeling wordt vergroot. In 2016 is dit doel verder uitgewerkt en voor de komende jaren.

Dit algemene doel is vertaald in de volgende specifieke doelstellingen:

1. Bedrijven/organisaties productiever maken door effectieve semi automatisering en slimme samenwerking van mensen met robot en ICT systemen te ontwikkelen en te implementeren.
2. Proactief ontwerpen van werkplekken en high-tech ondersteuningsmiddelen ten behoeve van effectiviteit en gezonde bevordering eigen initiatief.
3. Nagaan wat de digitaliseringsmogelijkheden zijn voor organisaties op basis van de blockchaintechnologie.
4. Nagaan wat de consequenties zijn van platformeconomie.

Daarbij hebben we de volgende meer strategische ambities:

1. Verder ontwikkelen en integreren van projecten en leads in een coherent onderzoeksprogramma dat mede wordt gestuurd door private stakeholders en financiers uit de Topsectoren.
2. Uitbouwen en verzilveren van onze sterke EU (FP7) positie in Horizon 2020.
3. Vernieuwing van het programma door dit nadrukkelijk te koppelen aan technologische innovaties en aan nieuwe digitalisering.

Voor het programma is van belang dat de verbinding met de HTSM en ICT groepen verder versterkt wordt in de samenwerkingsprojecten. Ook is een sterkere verbinding met de Topsectoren nodig: dat gebeurt al met HTSM via het Fieldlab Sociale Innovatie en met Logistiek via de Human Capital Tafel Logistiek. Er zijn echter nog meer verbindingen nodig.

4.1.3 *Highlights*

FP7 SIMPACT

Het SIMPACT project is een driejarige samenwerking met 8 andere onderzoeksgroepen uit heel Europa en afgesloten in 2016. Het werk heeft zich met name gericht op de ontwikkeling van een instrument voor ex ante impact-assessment. Het instrumentarium is in 2016 ontwikkeld en in drie organisaties (A&O Fonds Gemeenten, Social Impact Factory en Inspiring Scotland) toegepast. Op basis van het onderzoek is het instrumentarium bijgesteld, uitgewerkt in een aparte toolbox en in verschillende eindrapportages beschreven. Het project is afgesloten met een eindconferentie.

Logistiek Connekt

Samen met de Werkgroep Sociale Innovatie van de Topsector Logistiek (Human Capital Tafel Logistiek – HCTL) is een plan uitgewerkt voor de ontwikkeling van skills en sociale innovatie op een termijn van 10 jaar. Het plan is in drie focusgroepen besproken. Op een miniconferentie is een actieplan besproken en vastgesteld. Met de financiering 2016 is een methodologie voor cohorte-analyse opgesteld en uitgewerkt. Een tienpuntenplan is nu opgesteld dat leidend zal zijn

voor de sector in de komende jaren. Deelnemende partijen zijn de TLN, EVO, FNV, STL en KvK.

Factory of the Future -13 (HORSE)
Dit project wordt uitgevoerd door een consortium van 15 bedrijven, waaronder TNO, KUKA, TU München, TU/e en Thomas Regout International. Het doel is de ontwikkeling van een nieuw flexibel model voor een slimme fabriek waarin mensen, robots en machines op een flexibele manier industriële taken realiseren. Hierbij gaat het om de integratie en ontwikkeling van nieuwe concepten op het gebied van mens-robot interactie en intuïtieve mens/machine-interfaces. Het project is gestart met de definitie van behoeften in drie use cases bij drie verschillende eindgebruikers. Daarna volgt de ontwikkeling van nieuwe productiesystemen en het project eindigt met de implementatie en validatie van de nieuwe wijze van productie bij de drie eindgebruikers en de Competence Centres bij CEA (Frankrijk), TNO (NL) en in Slovenië. Aspecten van veiligheid, gezondheid en performance indicatoren vormen hierbij de validatiecriteria.

NWO Intrapreneurship
In 2016 is dit project haar tweede jaar ingegaan. Met de bedrijven (Randstad, DSM, Latexfalt) zijn casestudies uitgewerkt. Een vragenlijst is opgesteld op basis van de IBM die in 2015 is ontwikkeld. Deze zal in 2017 worden toegepast. De samenwerking met het INSCOPE verband is verder uitgewerkt. Met de Universiteit Utrecht is er reeds een dissertatietraject gestart samen met Prof Stam.

Fieldlabs Smart Industry
Binnen Smart Industry is gewerkt aan het opzetten van een Fieldlab Flexible Manufacturing, voor de high-tech sector de low volume high mix, high complexity producten. Binnen dit Fieldlab zullen flexibele mens-robot systemen worden ontwikkeld en getest. In samenwerking met Fontys, Omron, Bronkhorst, TE Connectivity is gewerkt aan een (TKI) voorstel voor het ontwikkelen van een zelflerende en zelfconfigurerende assemblage cel waarin zowel mensen als robots werken, ondersteund door ICT. Binnen dit project zal TNO kennis ontwikkelen op het gebied van dynamische taakallocatie (mens-robot-IT) en op het gebied van adaptieve feedforward en feedbacksystemen voor de operators. Bij bedrijven is de behoefte om ook bredere doelgroepen (jongere onervaren medewerkers, flexkrachten en ouderen) optimaal en flexibel te kunnen inzetten in het primaire proces. Volledige automatisering is niet mogelijk: binnen flexible manufacturing speelt samenwerking tussen mens robot en operator support systemen een cruciale rol. Hiervoor is nieuwe kennis nodig op het gebied van arbeid en organisatie. In dit project wordt binnen TNO samengewerkt met TNO ICT en TNO optomechatronica.

In 2016 is het Fieldlab Sociale Innovatie gestart in nauwe samenwerking met het Programmabureau Smart Industry. Naar verwachting zullen zowel het Ministerie van EZ als van SZW een startfinanciering geven. Verdere duidelijkheid komt in begin 2017.

EUWIN – European Workplace Innovation Network
In 2016 is het laatste jaar van het Europese leernetwerk sociale innovatie ingegaan. Dit leernetwerk is zeer succesvol gebleken en heeft drie aparte Europese bijeenkomsten opgeleverd. Meer dan 10.000 bedrijven zijn verbonden aan het netwerk. De Europese Commissie heeft gevraagd om het netwerk overeind te houden na de financieringsperiode. De infrastructuur is daarvoor aangemaakt. Naar een verdienmodel wordt momenteel gekeken.

4.1.4 Dynamiek

Het programma Smart Working is een voortzetting van het Speurwerkprogramma Sociale Innovatie (P207), onderdeel van de Roadmap Prevention, Work & Health, maar nu ook gekoppeld aan HTSM (Smart Industry). Het programma werkt naast de doorlopende projecten, aan een reeks nieuwe projecten in de nieuwe thema's robotisering en digitalisering.

De volgende deelprojecten uit 2015 zijn in 2016 voortgezet.

- CORTEXS: nieuwe organisatievormen in de zorg; mogelijkheden van digitalisering in zorgprocessen. (afronding 2017).
- SIDRIVE: sociale innovatie in zeven maatschappelijke gebieden. (afronding 2017).
- SIMPACT: economische onderbouwing van sociale innovatie. (afgerond in 2016).
- USE-IT-WISELY: ontwikkeling van een betere inzet van IT in werkprocessen in de industrie.
- SIB: NWO/TLN: Logistiek (afronding 2018).
- HORSE: ontwerpen van mens-cobot-ICT toepassingen voor de industrie, oprichting van competence center in Nederland. (afronding 2017).
- NWO Intrapreneurship (afronding 2018).

Voor nieuwe projecten zetten we in op de onderwerpen "Cobotisering en Smart Working" en de "Blockchain". De vraagstellingen zijn:

- Hoe ontwerpen we cobots vanuit Human Factors- en WPI organisatieperspectief, maar tevens hoe de effectieve inzet van cobots in het werk verloopt? Daardoor beter benutten van kansen die robotisering en digitalisering voor mens en organisatie bieden.
- Wat betekent de blockchain voor vernieuwing van organisaties en van het werk?

Lijst met publicaties (selectie peer reviewed)

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5 VP Automotive Mobility Systems

5.1 Roadmap Automotive

5.1.1 *Samenvatting*

Binnen TNO Thema Leefomgeving is het VP AMS (Automotive Mobility Systems) gericht op het versterken van de concurrentiepositie van de Nederlandse Automotive- en Mobiliteitsindustrie met het Ministerie van Economische Zaken (EZ) als regievoerder. Het VP AMS sluit daarmee rechtstreeks aan op de Roadmap van de TKI HTSM Automotive.
Het VP AMS richt zich vooral op het ontwikkelen van innovatieve oplossingen voor het verbeteren van de voertuigveiligheid, zuiniger en schoner maken van voertuigen en verbeteren van de duurzaamheid, efficiëntie en betrouwbaarheid van het verkeer.
Hierbij wordt intensief samengewerkt met de Nederlandse en de internationale automotive industrie.

5.1.2 *Korte omschrijving*

Het VP AMS is onderverdeeld in twee samenhangende deelprogramma's.

- *Automated Driving*: ontwikkeling van oplossingen en methodes voor voertuigautomatisering t.b.v. veiliger, schoner en meer efficiënt verkeer.
- *Low Carbon HD Transport*: ontwikkeling van oplossingen voor reductie van CO2 uitstoot van commerciële voertuigen in het verkeerssysteem.

Binnen deze deelprogramma's wordt gefocust op oplossingen voor specifieke klanten en markten in zgn. PMC's. Door expliciet een koppeling met een beoogde toepassing en markt te maken wordt meer focus verkregen in de kennis en technologie ontwikkeling. Bedrijven en andere stakeholder uit de markt worden zo vroeg mogelijk in de ontwikkeling van de oplossing betrokken.

Vraagsturingsproces 2016
Het Vraagsturingsproces is vooral ingericht door actieve participatie in het Roadmapteam van de TKI HTSM Roadmap Automotive.
Dit Roadmapteam, onder voorzitterschap van AutomotiveNL, is samengesteld uit vertegenwoordigers van de bedrijven en kennisinstellingen die samenwerken in de het Automotive TKI programma van HTSM.

Het Roadmapteam is verantwoordelijk voor opstelling en actualisatie van de TKI HTSM Automotive Roadmap en borgen dat deze gedragen wordt door haar stakeholders. Het Roadmapteam initieert eventueel initiatieven voor TKI grondslag of Toeslag projecten en beoordeelt of projectvoorstellen passen op de TKI Roadmap en adviseert daarover aan de Roadmaptrekker.
In 2016 is de HTSM Automotive niet gewijzigd (http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/automotive).
Het programma in het VP AMS sluit naadloos aan op de focus gebieden Green en Smart Mobility in deze Roadmap.

5.1.3 *Highlights*

Het onderzoek binnen het VP AMS is gefocusseerd op de ontwikkeling van oplossingen ten behoeve van specifieke product markt combinaties (PMC's). Met deze focus sluit het VP onderzoek aan op de concrete behoefte van haar

(industriële) stakeholders. De resultaten van het programma in 2016 worden hieronder samengevat per PMC/Product line.

Automated Driving

Next Generation AGV (Automatic Guided Vehicle)

Ontwikkeling en implementatie van slimmere AGV's. Deze AGV's zijn ondersteund door V2X communicatie en worden bestuurd vanuit een gedistribueerd control concept. Er wordt gewerkt aan een stapsgewijze transitie naar een grid-loze operatie van AGV's.

- Strategische samenwerking met een grote industriële partner (AGV fabrikant).
- Het Europese project CargoANTs is afgesloten. TNO's innovatieve besturingssoftware is getest op een TNO testplatform (auto) omdat een AGV helaas nog niet beschikbaar was.
- Een AGV wereldmodel is verder ontwikkeld geïntegreerd in het TNO iVSP testplatform gefocusseerd op drie onderwerpen: (1) situational awareness, (2) voertuiglocatiebepaling en objectdetectie en (3) Mapping en trajectory planning.
- Een nieuw RaakPro project Intralog is gestart.

Car technology

Ontwikkeling van efficiënte testmethodologie, validatie en certificering ondersteund door een real-life scenario database. Daarnaast wordt gewerkt aan adaptieve automatische voertuigfuncties (incl. bestuurderstoestand en bestuurdersprofiel schatting en voertuig toestandschatting).

- In EU project AdaptIVe zijn is de evaluatiemethodiek van safety functies (traffic jam assist) verder verbeterd.
- In EU project EMC^2 is een demonstrator gerealiseerd. Hiermee zullen twee demonstraties worden uitgevoerd: automatic emergency braking (high criticality) en online scenarios classification (low criticality).
- In SRE project Pre-automated Driving is een radar test setup gerealiseerd om vanuit een rijdend voertuig een kritische scenario te identificeren. Scenario detectie algoritmes voor wisselen van rijbaan of afslaan zijn ontwikkeld en getest.
- Samen met het TNO Enabeling Research Programma 'Complexity' wordt geïnvesteerd in het EU project Crystal. De ICT infrastructuur voor het analyse van data uit automatisch rijdende voertuigen is gerealiseerd en event detectie algoritmes zijn hiervoor ontworpen.
- Een STW SafeVRU samenwerking met de TU Delft is gestart. Het project richt zich op de on de ontwikkeling van oplossingen voor veiligheid van de interactie tussen geautomatiseerde voertuigen en fietsers en voetgangers.
- Het EU project iCAVE is gestart. Dit project richt zich op een dual mode automated transport system.
- Een generiek automatiseringsframework voor coöperatief rijden is ontwikkeld. Het framework ondersteunt belangrijke functies als: situational awareness, voertuig state estimation, weg en beeld classificatie, trajectorie generatie en fout definitie, volledige voertuig control tot aan de frictie grens en verbeterd classificatie van manoeuvres.

Truck Platooning

Ontwikkeling en commerciële implementatie van 2-Truck Platooning in Nederland.

- EcoTwin demonstratie op de Eurpean Truck Platooning Challenge.
- De safety case die veilig platoonen borgt is gedemonstreerd aan de RDW, dit heeft geleid tot vrijstelling.

- Het TKI project EcoTwin III is gestart met partners DAF, NXP en Ricardo. Dit project zal zich richten op het verkorten van de volgafstand naar 0,3 sec. time headway.
- In het EU project RoadArt is een fault tolerant control en fail safety strategie ontwikkeld als ook een voorspellend model voor het leidende voertuig in een platoon.

Het project EcoTwin III wordt hier uitgebreider toegelicht.
DAF,TNO, NXP en Ricardo zijn een samenwerking aangegaan om, binnen 5 jaar, het concept van 2-Truck Platooning technisch mogelijk te maken en om toestemming te verkrijgen om hiermee te rijden op het Nederlandse wegennet.

Dit doel zal stapsgewijs worden bereikt door jaarlijks meer functionaliteit aan het concept toe te voegen en het in steeds complexere situaties toe te passen. Er zal worden samen gewerkt met belangrijke technologie partners op het gebied van ontwikkeling en testen van de nieuwste technologie en partners worden betrokken voor niet-technische uitdagingen.

In de 1e helft van 2016 is het zogenaamde Follow-Me EcoTwin II voertuig ontwikkeld en gedemonstreerd tijdens de European Truck Platooning Challenge op 6 april. Te midden van alle andere Europese truckfabrikanten, vertegenwoordigers van de EU, internationale gasten en de Minister van I&M, heeft het consortium laten zien vooraan mee te doen op het gebied van coöperatief automatisch rijden. In de 2e helft van 2016 is de samenwerking voortgezet in het Follow-Me EcoTwin III project.

De samenwerking heeft als doelstelling om automatisch rijden stap voor stap naar hogere SAE Automation levels te brengen voor toepassing van de technologie op het hoofdwegennet. De activiteiten concentreren zich op de communicatietechnologie, de benodigde sensoren, stabiele regel algoritmes voor aandrijving en sturen van het voertuig en functies voor automatisch volgen. Bijzondere aandacht gaat uit naar het betrouwbaar, veilig en foutbestendig en fail-safe maken van de technologie en de hiervoor benodigde methoden, modellen en tool development.

http://www.daf.com/en/news-and-media/articles/global/2016/q1/27-03-2016-daf-and-tno-demonstrate-ecotwin#

Public Transport

Uitrol van automatisch rijdende bussen en trams op basis van een gelimiteerde ondersteuning vanuit de infrastructuur.

- Eerste demonstratie van een people mover op de openbare weg heeft plaatsgevonden.

Low Carbon HD Transport

Real World Performance

Oplossingen en tools voor het verbeteren van real-world brandstofverbruik en emissies van heavy duty voertuigen.

- Om mogelijke opties om de CARB2020 eisen (90% NOx reductie t.o.v. Euro VI) te identificeren is een simulatiestudie is uitgevoerd. De prestatie van mogelijke uitlaatgasnabehandelingssystemen/configuraties zijn geëvalueerd.
- TNO heef de realisatie van een testopstelling voor Waste Heat Recovery systemen ondersteund op de TU/e. Een schatter voor de verdamping is gerealiseerd en gevalideerd.

Flex Fuel Controls

Controls oplossingen voor verhoging van het verbrandingsrendement en voor verdere verlaging van CO2 uitstoot door toepassing van low-carbon fuels.

- Het TNO XCCI model is gevalideerd voor verschillende EGR bedrijfspunten.
- Een gecoördineerd airpath control voor RCCI is in ontwikkeling. Initiële simulaties laten goede resultaten zien.
- Een literatuuronderzoek naar de haalbaarheid van een Blend-Ratio schatter voor dual fuel is uitgevoerd.
- Een korte studie naar toepassing van de klopsensor als vervanging van een cilinderdruksensor is uitgevoerd.
- TNO kennis en ervaring o.g.v. RCCI wordt omgezet in een vision paper.
- Een methaan kanalisator model is ontwikkeld en gevalideerd op basis van data uit het Europese HD gasproject.
- Het in –cilinder verbrandingsmodel van DYNAMO+ is uitgebreid met dual pilot injectie. De warmte vrijstelling en emissies kunnen worden berekend. Data uit het TKI project Advanced Combustion is gebruikt voor validatie.
- In het TKI project Advanced Combustion is het ontwikkelplatform gerealiseerd (gemodificeerde DAF motor met FPGA/CPU bypass control). Het single CPS concept is succesvol geïmplementeerd.

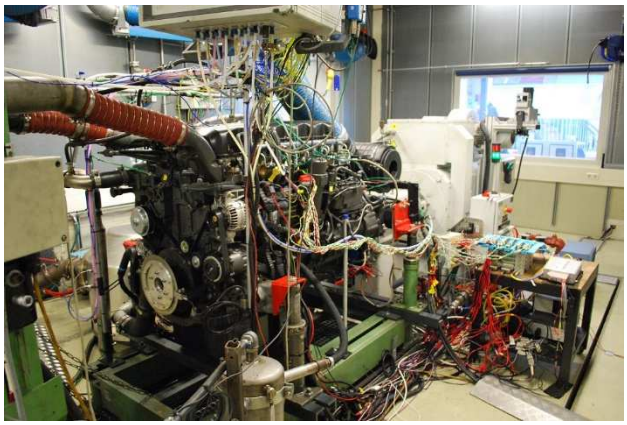
Een real-time NOx schatter is gerealiseerd en de werking gedemonstreerd over een groot aantal stationaire werkpunten. De functionaliteit van extremum seeking is gedemonstreerde in simulaties.

Het project Flex Fluel wordt hier uitgebreider toegelicht.
Het Flex Fuel Control team werkt aan geavanceerde verbrandingsconcepten die een dieselmotor in een zeer efficiënte en schone verbrandingsmodus op een mengsel van twee brandstoffen laat lopen: Reactivity Controlled Compression Ignition (RCCI). Hierbij wordt met een klein beetje diesel (<10% totale energie) een mengsel van aardgas ontstoken. Dit concept is gebaseerd op gecontroleerde zelfontsteking en is uiterst gevoelig voor bedrijfscondities zoals temperatuur. Naast een extreem hoog thermisch-rendement, is het meest in het oog springende kenmerk dat dit concept met meerdere brandstoftypen (inclusief biobrandstoffen) overweg kan. Dit faciliteert een transitie via aardgas naar duurzame brandstoffen.

In een strategische samenwerking met een grote fabrikant van vrachtwagens hebben we afgelopen jaar aangetoond dat RCCI bedrijf mogelijk is tot vollast. Hiermee heeft TNO de internationale standaard gezet. Dit is mede gerealiseerd

door motoraanpassingen op gebied van het lucht- en brandstofpad: een speciale drukvulgroep en cilinder individuele sturing van luchttoevoer en injectie van aardgas. Met deze motor demonstratie van het RCCI concept is een belangrijke milestone behaald. We hebben hiermee aangetoond dat de technologie onder reële omstandigheden goed functioneert en de uitstoot van CO2 met maar liefst 20 procent afneemt. Ook dat hierbij geen NOx uitlaatgasnabehandeling meer nodig is. Echter, verdere vermindering van de methaan slip is nog noodzakelijk.

Parallel is ook de modelgebaseerde toolchain verder ontwikkeld: onze modellen zijn gevalideerd met experimentele data en laten zien dat ze in een breed werkgebied het RCCI gedrag goed voorspellen. Deze modellen zijn belangrijke input voor de ontwikkeling van onze regelstrategieën: next-cycle combustion control. Met deze regelconcepten zetten we een cruciale stap richting introductie van RCCI op de weg. In 2017 gaan we laten zien dat het concept ook in extremere omstandigheden werkt. Hierbij spelen recente ontwikkelingen een belangrijke rol: TNO's innovatieve cilinderdruk gebaseerde regeling bepaalt per verbrandingscyclus de optimale brandstofmix. Deze regeling maakt gebruikt van real-time model informatie: zgn. virtual sensors. Afgelopen jaar hebben we de haalbaarheid van een single cylinder pressure sensor concept gedemonstreerd. Vanuit zowel de on-road als off-road markt is hier veel aandacht voor: reductie van systeemkosten en complexiteit. Daarnaast zal met een internationaal consortium de potentiele methaan reductie van directe aardgas injectie bij RCCI onderzocht worden.



Predictive Powertrain Controls

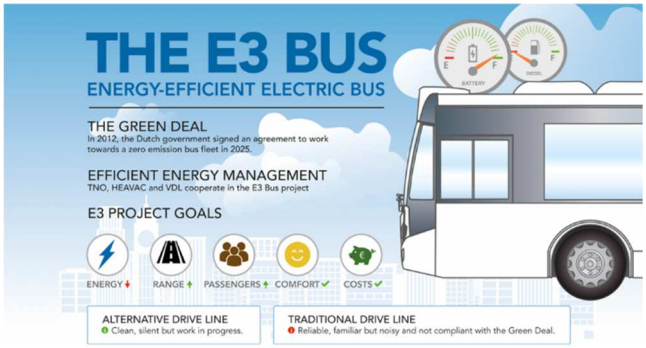
Controls oplossingen voor optimaliseren van energiemanagement in het voertuig door toepassing van voorspellende informatie over route, verkeer, bestuurder, etc.

- In het EU project ConVENienT afgerond met testen van de DAF motor in de Hoogte-Klimaatkamer.
- In het EU project Transformers is een structuur om simulaties uit te voeren aan complexe voertuigcombinaties ontwikkeld en zijn eerste simulaties uitgevoerd. TNO heeft een aangepaste communicatie naar de trailer geïmplementeerd in een DAF truck. TNO heeft de rol van Daimler in het project overgenomen en heeft hiervoor een testplan opgeleverd. Het project wordt verlengd en activiteiten voor traffic simulaties zijn uitgesteld.
- Het EU project ORCA is gestart. In ORCA wordt een concept ontwikkeld voor een hybride 30-40 tons distributietruck dat concurrerend moet zijn met bestaande dieselvoertuigen. TNO is coördinator en richt zich inhoudelijk op energieoptimalisatie in relatie tot het mission-profile.
- In het TKI project E3 Bus is afgerond. In een gezamenlijke presentatie van de partners zijn de resultaten gepubliceerd.

- Een software architectuur voor toekomstige predictive energy management systemen is ontwikkeld. Een real-time predictive energy management strategie is ontwikkeld met bijbehorende HiL verificatie. Validatie op basis van DAF LF hybride truck metingen.
- Een grid-coupled Vehicle Energy Management strategie is ontwikkeld. Twee tools zijn ontwikkeld: een Excel gebaseerd en een neuraal netwerk gebaseerde energievoorspeller. Een strategie voor kosten geoptimaliseerde laadstrategie is hiermee gerealiseerd.
- De TNO kennispositie op het gebied van batterij opslag is opnieuw geüpdatete en een state of the art analyse is uitgevoerd. Een meetprogramma voor batterijveroudering is uitgevoerd.

Het project E3 Bus wordt hier uitgebreider toegelicht
In 2016 sloot de Nederlandse OV sector een bestuursakkoord[2] met de overheid voor in de transitie naar volledig zero-emissie busvervoer in 2025. Een van de belemmering die tijdens de transitie overwonnen moet worden is dat prestaties van batterij elektrische bussen gevoeliger zijn voor omgevingsfactoren zoals het weer. Bij koud weer zal de actieradius van de bus tot 50% geringer kunnen zijn door normaal doordat alle energie voor het verwarmen van de bus uit de batterij komt, doordat er geen restwarmte van de dieselmotor beschikbaar is. De vervoerders zullen dus rekening moeten houden met deze extra afhankelijkheid.

In het E3 Bus[3] project onderzochten VDL Bus & Coach, HEAVAC en TNO naar oplossingen om deze afhankelijkheid te verminderen.
De resultaten, van dit in 2016 afgeronde project, laten zien dat een breed scala aan oplossingen mogelijk zijn. Warmtepomptechnologie gecombineerd met energiemanagement leidt tot aanzienlijke besparingen en een robuustere inzet. Met een verbeterd ontwerp van de bus (minimalisatie van lekken en betere isolatie) zijn additionele besparingen te realiseren. Opvallend resultaat was dat er op het gebied van comfortbeleving van passagiers nog weinig kennis is in de sector. Onderzoek onder passagiers resulteerde in de conclusie dat er nog veel potentieel tot energiebesparing ligt door rekening te houden met voorkeuren van passagiers. TNO ontwikkelde verschillende analyse instrumenten waarmee combinaties van maatregelen kunnen worden beoordeeld. Koppeling hiervan met historische weersdata van het KNMI, liet bovendien zien dat de klimaatverandering al effect heeft op het energieverbruik van bussen.



[2] http://www.ipo.nl/files/9514/6072/3581/Bestuursakkoord_zero_emissie_bussen_DEFINITIEF_in_pdf.pdf
[3] https://www.tno.nl/en/focus-areas/urbanisation/mobility-logistics/clean-mobility/energy-efficient-electric-bus-e3bus/

Multi Level Energy Optimization
Analyse en optimalisatietools voor energieoptimalisatie op vloot niveau. Bestrijkt zowel voertuig-, logistieke-, mission profiles als andere systeemoptimalisatie.

- Een module voor berekening van NOx en deeltjesemissies is toegevoegd.
- De cost-benefit assessment module is uitgebreid en toegevoegd als een module.
- Een cohort module is toegevoegd zodat ook de vervanging van de vloot over de tijd kan worden meegenomen in de berekeningen.
- Een testversie van een formele optimalisatiemodule is ontwikkeld en getest op de nationale vloot.
- Een databasesysteem is opgezet waarin modellen en data kan worden opgeslagen en die de complexe analyse kan ondersteunen. Het systeem kan zowel met eigen TNO data als vreemde data van klanten en overheden omgaan. Beschikbare datasets zijn geïmporteerd.
- Een aantal specifieke cases (hybride powertrain uit TRANSFORMERS project, WHR, IEM, etc.) zijn doorgerekend. Verdere stappen zijn gemaakt voor modellering van logistieke opties en supply chain management.
- Een aantal concrete casestudies zijn uitgevoerd (optimalisatie voertuigvloot in logistieke sector, value chains en identificatie van business cases voor “groene groei”).
- Een visiedocument is opgesteld.

5.1.4 *Dynamiek*

Samenwerking binnen de Topsectoren
Het VP AMS focusseert zich volledig op een onderzoeksprogramma dat past binnen de ambitie van het TKI HTSM Automotive. De deelprogramma’s sluiten op de volgende wijze aan op de Roadmap van het TKI.

Automated Driving
Dit deelprogramma sluit aan bij de trend in de automotive sector dat steeds meer voertuigfuncties geautomatiseerd worden en dat voertuigen tijdelijk of in de toekomst zelfs voor langere tijd geautomatiseerd kunnen rijden. TNO richt zich in dit programma vooral op technologie en randvoorwaarden die (coöperatief) automatisch rijden mogelijk maakt en op wat dit betekent voor de bestuurder en voor andere (kwetsbare) weggebruikers.
In 2016 is het concept voor Truck Platooning verder ontwikkeld en gedemonstreerd in samenwerking met twee voertuigfabrikanten tijdens de European Truck Platooning Challenge. De focus in het TNO programma ligt op (hoog)dynamisch maneuvreren en volgen, veiligheid van kwetsbare verkeersdeelnemers, effecten op de bestuurder van (automatisch) ingrijpen, robuuste controls en test en validatiemethodes met als doel het versnellen van de implementatie van automatisch rijden.

Low Carbon HD Transport
Nederland heeft een sterke transportsector met belangrijke OEMs en toeleveranciers in trucks, bussen en speciale zware voertuigen en een sterke logistieke sector. Dit deelprogramma richt zicht op reductie van de CO_2 uitstoot in het (integrale) transport systeem.
In 2016 is het rendement van dual fuel (diesel-gas) RCCI concept verder verbeterd en is het lastbereik waar RCCI kan worden toegepast verruimd. Daarnaast is het TKI project o.g.v. energiemanagement voor elektrische bussen afgerond en is een

nieuwe TKI project o.g.v. geavanceerde verbrandingstechnologie voor HD dieselmotoren gestart.

Samenwerking met Nederlandse universiteiten
De bestaande samenwerkingsverbanden van TNO met diverse Nederlandse universiteiten is in 2016 voortgezet. Belangrijkste initiatieven zijn:

- DAVI: samenwerking met TU Delft en ander partijen o.g.v. automatisch rijden.
- ASD PDeng opleiding: 2 eindopdrachten van trainees en een in-house project.
- Afstudeerders en promovendi: TNO blijft ruimhartig opdrachten verzorgen. Dit jaar is een door TNO gesponsorde AIO gepromoveerd.
- Samenwerking met de TU/e op het gebied van control technologie, multi-sensor processing en wereld modellering.
- Samenwerking met UTwente op het gebied van veilige en betrouwbare coöperatieve control technologie.
- TNO en TU/e gaan verder samenwerken op het gebied van toepassing van duurzame brandstoffen in geavanceerde verbrandingsconcepten.
- UHD's en deeltijd hoogleraren: de samenwerking wordt uitgebreid. Doel is om in elk deelprogramma een verankering bij een universiteit te borgen. Op 1 januari 2016 is TNO Senior Scientist Frank Willems benoemd als deeltijd hoogleraar Integrated Powertrain Control aan de TU/e. https://www.tue.nl/universiteit/faculteiten/werktuigbouwkunde/nieuws/06-01-2016-frank-willems-benoemd-tot-deeltijd-hoogleraar/

Nationale samenwerkingsverbanden

- TKI HTSM Automotive: in 2016 is door TNO opnieuw een significante grondslag gegenereerd, vooral in contractonderzoek vanuit de internationale automotive industrie. Tevens zijn in 2016 twee nieuwe TKI projecten gestart: Advanced Combustion met partners DAF en Sensata en EcoTwin III met partners DAF, NXP en Ricardo. Ook zijn er drie nieuwe TKI projecten in voorbereiding die in 2017 zullen starten.
- AutomotiveNL is de sectororganisatie voor de Nederlandse automotive industrie met als doelstelling het bevorderen van een bloeiend en groeiend automotive netwerk in Nederland door realisatie van een internationale automotive hotspot voor Smart Mobility en Future Powertrain. AutomotiveNL heeft een innovatieprogramma dat de inhoud van de Roadmap TKI HTSM Automotive afdekt. AutomotiveNL is belangrijke partner voor TNO in de realisatie van projecten binnen de TKI.

Internationale samenwerkingsverbanden

- ERTRAC, the European Technology Platform for Road Transport. ERTRAC werkt aan een gemeenschappelijke Strategic Research Agenda, waaraan TNO ook haar bijdrage levert. Andere NL partners zijn DVS en SWOV.
- iMobility (vroeger genaamd eSafety) forum. Deze groep werkt aan een gemeenschappelijke Strategic Research Agenda op het gebied van mobiliteit.
- EARPA, Vereniging van Road Transport R&D Providers. Vanuit TNO wordt secretariaat ingevuld en heeft de programmadirecteur mobiliteit en logistiek zitting in de board. Focus ligt op automotive RenD. TNO is trekker en heeft key posities in de meeste Task Forces. Verder vindt hier consortiumvorming voor EU projecten plaats.
- EGVIA, the European Green Vehicles Initiative Association. EGVIA is het samenwerkingsverband van Europese bedrijven en kennisinstellingen op het

gebied van schone voertuigtechnologie. TNO participeert actief in EGVIA in het voorbereiden (en uitvoeren) van pre-competitief Europese onderzoek.

- ERTICO ITS Europe is een multi-sector, Public Private Partnership die zich richt op de ontwikkeling en implementatie van Intelligente Transport Systemen. TNO is lid van dit partnership. Met ERTICO worden regelmatig projectvoorstellen in het EU Kaderprogramma geschreven.

In 2016 participeerde TNO binnen VP AMS in 19 Europese projecten binnen het Europese onderzoeksprogramma. In deze projecten wordt samengewerkt met een groot aantal internationale partners.

6 VP Human Health RM Nano

6.1 Roadmap Nanotechnology

6.1.1 Summary

Large expectations surround the potential for manufactured nanomaterials to be key elements in the development of innovative materials, products and applications. Manufactured nanomaterials are already produced in large amounts and it is expected that in the next decades numerous new nanoproducts will enter the market every year. For companies it is important to produce sustainable products and comply with the Regulations. The activities of VP Human Health RM Nano consisted of various EU projects and 1 National Project. These projects are in different phases of their development and are focused on either human health risk assessment and risk management of exposure to nanomaterials or safe innovation to assist employers in taking into account the safety of their (nano)product during the innovation of new materials and products. There is still a great uncertainty to perform a proper risk assessment of manufactured nanomaterials and nanomaterial-enabled products. Risk assessment procedures currently recommended by the European Chemicals Registry Agency (ECHA) are not adequate for a proper risk assessment of manufactured nanomaterials due to the small sizes of the materials. The current exposure limits of conventional materials cannot be easily translated to manufactured nanomaterials and the continuous development of new nanomaterials asks for suitable models that are able to assess the risks of nanomaterials over the complete life cycle. To assess the risks of the nanomaterials currently on the market, as well as the next generation of nanomaterials, it is essential to develop user friendly tools for industry and SMEs to help companies to support safe innovation and compliance with the regulations, and quantitative models for risk assessment. To reach this goal, there should be sufficient data for nanomaterials gathered in a harmonized way. By knowing the risks of MN over the whole life cycle and having user friendly tools, sensors and Risk Management Measures, the human health of the worker, consumer and generic population can be adequately assessed and minimized, which will be an enabler for safe innovation.

6.1.2 Short description

VP Human Health RM Nano started in 2015 to build new knowledge and networks on human health risk management of manufactured nanomaterials and supports safe innovation of nanomaterials. This program was a follow-up of the activities performed in the Roadmap Health and Safe Work (2011-2014). Large expectations surround the potential for manufactured nanomaterials to be key elements in the development of innovative materials, products and applications. Manufactured nanomaterials are already produced in large amounts and it is expected that in the next decades numerous new nanoproducts will enter the market every year. For companies it is important to produce sustainable products and comply with the regulations. However, there is still a great uncertainty to perform a proper risk assessment of manufactured nanomaterials and nanomaterial-enabled products due to the small sizes of the materials. The current exposure limits of conventional materials cannot be easily translated to manufactured nanomaterials and the continuous development of new nanomaterials asks for suitable models that are able to assess the risks of nanomaterials over the complete life cycle. One of the greatest challenges facing regulators in the ever changing landscape of novel nanomaterials is how to design and implement a regulatory process, which is robust enough to deal with a rapidly diversifying system of manufactured nanomaterials

over time. To assess the risks of the nanomaterials currently on the market, as well as the next generation of nanomaterials, TNO focused their research on the following topics:

1) User friendly tools for industry and SMEs to help companies to support safe innovation and compliance with the regulations.
2) Quantitative models for risk assessment. To reach this goal, there should become available sufficient data for nanomaterials gathered in a harmonized way.

By knowing the risks of MN over the whole life cycle and having user friendly tools, the human health of the worker, consumer and generic population can be adequately assessed. This will be an enabler for safe innovation.

6.1.3 *Highlights*

The activities of VP Human Health RM Nano consisted of various EU projects and one National Project (Table 1).

Table 1 EU projects of VP Human Health Risks Nano

EU project	Period	Website
NanoREG2	Sep 2015 -Aug 2018	http://www.nanoreg2.eu/
GUIDEnano	Nov 2013 - April 2017	http://www.guidenano.eu/
SUN	Nov 2013 - Oct 2017	http://www.sun-fp7.eu/
FutureNanoNeeds	Jan 2014 - Dec 2018	http://www.futurenanoneeds.eu/
NanoSolutions	Apr 2013 - Mar 2017	http://nanosolutionsfp7.com/
NanoFase	Sep 2015 - Aug 2019	http://www.nanofase.eu/
NanoNextNL	Jan 2011- Dec 2016	http://www.nanonextnl.nl/
CaLIBRAte	July 2016 - June 2019	http://www.nanocalibrate.eu/
EC4SafeNano	March 2016 – Feb 2019	In preparation
NanoStreeM	Jan 2016 - Dec 2018	http://www.nanostreem.eu

Within the FP7 project **GUIDEnano**, the main goal is to deliver the GUIDEnano tool at the end of the project in April 2017. The GUIDEnano tool is a web-based risk assessment tool, which will help the nano-enabled products users to design and apply of the most appropriate risk assessment & mitigation strategy for a specific product. The second beta version was launched in September 2016, in which all main issues are addressed: i.e. life cycle assessment, exposure, environmental fate, human and environmental toxicity and risk assessment. For the tool, TNO developed an exposure assessment model. Furthermore, TNO worked out together with LEITAT the so called activity cards, i.e. description of activities that can be used to calculate the exposure by the tool. In case of too high risks, Risk Management Measures (RMM) could be applied to reduce the risks, which have been developed by TNO. During the project the GUIDEnano tool is tested several times in collaboration with industry partners and improved based on our findings.
The **NANoREG II** project, builds around the challenge of coupling Safe-by-Design (SbD) to the regulatory process, demonstrates and establishes new principles and ideas based on data from value chain implementation studies to establish SbD as a fundamental pillar in the validation of a novel manufactured nanomaterial. Within this project, TNO performs activities with focus on translating a stage-gate innovation model into a workable safe innovation approach. A workable approach demands integrated attention for scientific and technological issues, but also for the creation of trusted environments to share information among actors. TNO is a partner in the database solution team which harmonizes all database activities in NANoREG II. These database activities will support the Safe Innovation approach by providing the right data at the right time during the innovation process. The team

further includes BFR (Germany), IDEA Consult (Bulgaria), KI (Sweden) and IOM (UK). TNO is responsible to deliver a database/structural model and report describing the relationships between functionality, physicochemical properties and hazard, and allowing for integration in the safe innovation approach.

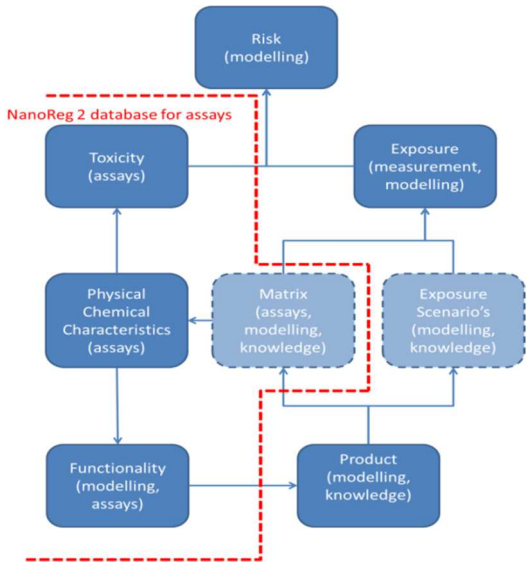


Figure 1. Overview of how information on risks (toxicity, exposure) and products (functionality) relates to each other via physical-chemical, matrix information and exposure scenario's in the NanoREG II project.

In the **SUN** project the life cycle inventory of the two cases, nanocopper and nanosilver, have been finalized by TNO. For the case on nanocopper the results of the workshop at the end of 2015 were implemented. The inventories have been used to assess the environmental impact of those two cases. TNO assisted in the development of a method for integration of Life Cycle Assessment (LCA) in the socio-economic assessment of the SUN Decision Support System. The methods behind SUNDSS were described in a paper called "Sustainable Nanotechnology Decision Support System: Bridging Risk Management, Sustainable Innovation and Risk Governance" co-authored by TNO. The continuous drop method was used to test the dustiness of case study powders. All previously collected data regarding the dustiness of powders were stored in the international dustiness library.
Furthermore, TNO performed a release experiment with two types of car bumpers, applying different types of mechanical abrasion under different circumstances. TNO identified the unique properties of nanoparticles, current dermal models and their nanospecific weaknesses and finally we propose a conceptual nanoparticle-specific dermal model based on the dermal Advanced REACH Tool (dART). A data gap analysis was performed, identifying which scenarios need more exposure measurement data. Nano-specific Risk Management Measures (RMM) were reviewed and effectiveness factors were proposed for modeling purposes. The Exposure Control Efficacy Library (ECEL) has been adapted for nano and available nano-specific data have been entered.
The **FutureNanoNeeds** project expanded in 2016 a previously developed Tier 1 approach (an adopted EUSES-based material flow analysis from 2014/5) to include a more in-depth assessment (Tier 2). The Tier 2 includes two levels to assess release of nanomaterials. The level 1 assessment applies the existing BUONAPART-E methodology for a selected Life Cycle stage. It was developed by IUTA and three case studies were worked out to illustrate its application, i.e. (i) MoS2 Fullerenes as lubricant, (ii) Si_Ge-powder as Thermoelectrics generator and (iii) Si-nanoparticles for Battery applications. The level 2 involves the application of

a Bayesian Belief Network (BBN) to forecast release of NMs at process level. The process “shredding” was selected because mechanical recycling during end-of-Life was found to be an important ‘hotspot’ (from Tier 1) for next generation NMs. To develop the BBN model, two expert workshops were organized with consortium members and a selected group of external experts, followed by four follow-up meetings. It is a user friendly model (with a limited number of inputs) that will be made available online through the FNN portal. Also, it can easily be adopted for processes such as milling, drilling, etc. Other work performed in 2016 included a review of new methods and devices to detect, characterize and quantify exposure to next generation of nanomaterials. In addition, a manual on best practices for a safe nanotechnology action plan is currently under development.

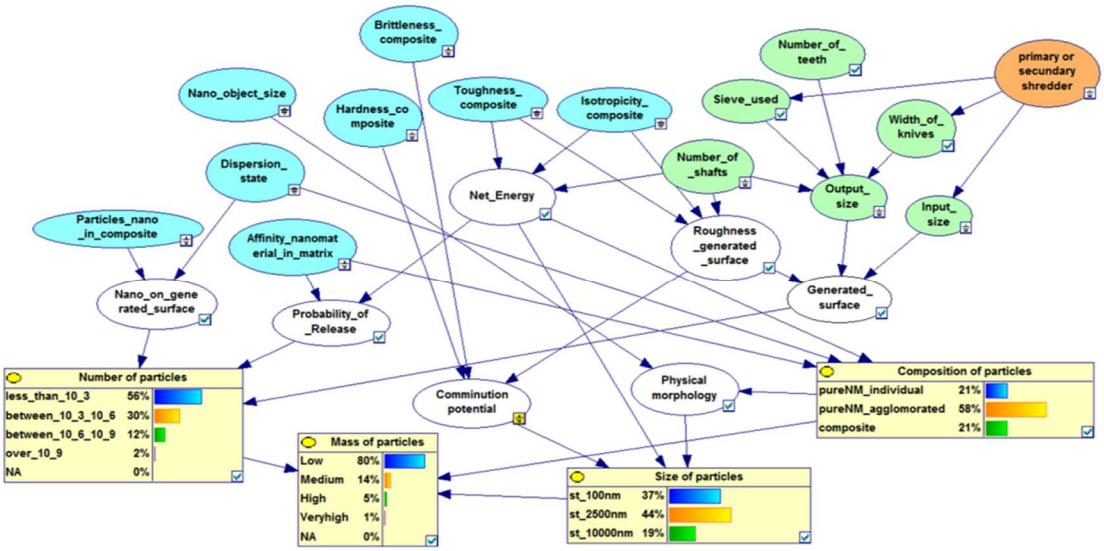


Figure 2. The BBN model for shredding activities (e.g. PV panels during recycling).

In 2016 a multi-compartment fate model specifically made for nanomaterials within the **NanoSolutions** project was published by the Dutch RIVM: SimpleBox4Nano. In the model nanospecific parameters have been included which determine the distribution of nanomaterials over the several environmental compartments. SimpleBox4nano does, however, not include the effect of the nanomaterials on the human population and the environment. A model that includes this is USEtox, also a multi-compartment model. USEtox, which is used to derive life cycle assessment (LCA) characterisation factors for human health and the environment. However, USEtox lacks the nanospecific parameters and the idea rose to let SimpleBox4Nano deliver input for USEtox. Differences have been mapped and work is underway to ‘tweak’ SimpleBox4Nano so that at least the compartments are comparable. The tweaking and the filling the adjusted SimpleBox4Nano has taken place in a two day workshop in December 2016. Effect factors for specific Nanosolutions nanoparticles have been derived: MWCNT-Core, MWCNT-Carboxylate, MWCNT-Ammonium, MWCNT-PEG, Ag-Carboxylate, Ag-Ammonium, Ag-PEG, TiO2-Core, TiO2-Carboxylate, TiO2-Ammonium, TiO2-PEG, TiO2-rods, TiO2-rods-Carboxylate, TiO2-rods-Ammonium and TiO2-rods-PEG. These have been communicated to the work packages WP11 and WP12 that needed them for comparison with the result of the predictive tool they have developed. Since CdTe QD based ink was chosen as a case study for a full life-cycle assessment in the project, much effort was devoted to deriving health effect factors for CdTe. In the end, it was not possible to derive substance-specific health effect factors for the (PEGylated) CdTe nanoparticles, and it was suggested to use a range of values based on the values already derived for other nanoparticles.

In the **NanoFase** project, TNO works on the specification for the NanoFASE model system through participation in discussions on the framework scoping. Integration of air and water models and interaction with Simplebox4Nano was discussed in a separate meeting at RIVM (NERC, RIVM, TNO). The database design has been discussed during the six month meeting in Volendam (NL) where it was agreed to follow a mass balance approach similar to e.g. Gottschalk et al. (2015) and Sun et al. (2015) but add a dedicated spatial distribution component to support the envisaged environmental fate modelling in NanoFASE. In a dedicated meeting specific tasks for each partner were identified and agreed to improve the current state of the art. For TNO that implied a focus on unravelling the PMC-box (Production-Manufacturing and Consumption) in the environmental release model. TNO focused on the quantification of production, manufacturing and consumption of nanomaterials. This means that TNO will quantify annual totals for the production, manufacturing and consumption of specific nanomaterials (exact ENMs to be covered still to be agreed upon) per country in the EU28. There have been several discussions with IUTA concerning the measurement strategy of the traffic related transport emission tests and which data the tests should provide for subsequent use in the models as input parameters. Based on the discussions a detailed study design was set up for the laboratory release tests and wet/dry deposition experiments. TNO has discussed with IUTA what kind of information should come out of the experiments to be able to incorporate it in modelling and improve the model. TNO has discussed with INERIS in how far they can benefit from each other's work and integrate. As a preparatory step, the M7 module was tested with the newest version of the LOTOS-EUROS model.
Within the **caLIBRAte** project, many of the key "nano-specific" model developers, data hosts, and case-study builders in Europe have gathered to collaborate to establish, test, refine and calibrate relevant models for implementation in a common risk governance framework. TNO is also one of the partners and as such leader of the work package on human risk assessment (HRA) models. In strong collaboration with RIVM (The Netherlands), GAIKER (Spain), FIOH (Finland), NCRWE (Denmark) and TUT (Finland), input and output criteria were identified for human exposure, hazard, and risk assessment models at the different Cooper innovation stage gates (Table 2). Stakeholders (Regulators, large industries, SMEs, insurance companies) were invited for addressing these criteria. A selection of existing HRA tools has been made, including tools specifically for risk assessment, hazard assessment and exposure assessment. A review of current hazard, exposure and (integrated) HRA models is done considering their input requirements and their applicability at the Cooper innovation stage-gates. In addition, further refinement of the selected HRA models is planned, involving the possible inclusion of novel technologies (HTS cell based assays and systems toxicology).

Product innovation stage & model tier							
Cooper stage	Idea	Scoping (or Preliminary Assessment)	Build business case (or Definition)	R&D (or Development)	Testing and validation	Launch	Horizon scanning/ Monitoring
Description of stage	Ideas	Preliminary investigation, estimation of benefits and costs, sketch business concept	Detailed investigation, prove of principles, socio-economic assessments, competitiveness benchmarking, build business case	Product R&D, feasibility, prototypes	Market tests (volume, price), product validation (functionality and costs), business plan validation	Market launch	Post-market surveillance
Safety activities	No risk activi-ties	Screening for uncertainties and potential risks, potential risk situations and scenarios are formulated	A theoretical (i.e. only using subjective and existing objective data) risk assessment, risk treatment options are prepared for gate 3	The risk assessment and risk treatment options are updated with the development results for gate 4	The risk assessment and risk treatment options are updated with the results of market testing and production upscaling prepared for gate 5	The risk assessment and risk treatment options are updated with the feedback from the market introduction for gate 6, the post launch review	Risk monitoring
Model tier	0	0	0	0 / 1	1 / 2	1 / 2 / 3	1 / 2 / 3

Table 2: Stage gate model of innovation against safety activities.

Per November 1st, 2016 the European project **EC4SafeNano** has started. Within this 3 year project, 15 well known European institutes - active in the field of nanosafety - will build a virtual institute to assist governments and industries with their nanosafety issues. The project starts with an inventory of needs related to nanosafety experienced by governments, industries and other stakeholders. Simultaneously, the resources to answer to this needs are mapped and collected. Through the participation of TNO, also the Dutch Nanocentre (www.nanocentre.nl) will be connected to this European initiative. TNO leads WP1, in which the needs are mapped. In addition, TNO leads the technological innovation (related to nanomaterials) network and a network that connects national Nanocentres. **NanoStreeM** is focused on nanomaterials in the semiconductor industry. The aim of the project is to assess and control possible health and environmental risks caused by nanomaterials. The project, led by imec from Belgium, has started January 1st, 2016 by making several inventories:

- Nanomaterials present in the semiconductor industry, with distinction between purchased NM and, as by-product, generated NP.
- Description of the processes in which these NP play a role and priority setting based on duration and frequency of the activities.
- The main Exposure Scenarios.
- Available risk assessment approaches.

TNO is mainly involved in the inventory of risk assessment approaches. At the moment these approaches are explored in more detail for their applicability to assess the main exposure scenarios. The result of this activity will be a guidance, which will be tested by the industry partners.

6.1.4 *Dynamics*

Expectations about the social and economic potential of manufactured nanomaterials are high. The Dutch Cabinet seeks to exploit the social and economic opportunities in a sustainable way. It focuses on increasing knowledge and the precautionary principle. It was also stressed that these developments should be in line with the risks, so the opportunities are exploited in a responsible manner. This requires user friendly tools for industry and SMEs to help companies to support safe innovation and compliance with the regulations over the complete life cycle in various stages of the development process. At European level, nanotechnology is one of the key emerging technologies that have been identified

by the European Union in the 2020 strategy. Large investments are being made in the development of new industrial applications, which provides a growing number of nanoproducts which enter the European market (http://ec.europa/environment/chemicals/ nanotech/index.htm). In particular, nanotechnology offers substantial possibilities for improving the competitive position of the EU and for responding to key societal challenges. Ensuring the safe and sustainable development and application of the nanotechnologies is thus a key objective and requires quantitative models for human risk assessment and accurate, fast and low-cost sensors and measurement methods/instruments to detect nanomaterials and their risks in air and other environmental media. Risk Management Measures are needed to assist industry and SME to reduce human health risks caused by exposure to nanomaterials. Scientifically there are still many challenges to assess the risks of nanomaterials. Nanosafety in Europe 2015-2025 concludes that the various costs related to safety to the industry can be substantially reduced by enabling the manufacturing companies to focus their investment on safe materials by encouraging safe innovation. The main achievement will be the development of integrated risk assessment and decision frameworks to enable forecasting the potential impacts of nanomaterials on human health and the environment and adequate risk management. Environment, Health and Safety solutions mapped to the specific requirements of market driven value chains will provide industry at all stages in the innovation chain with the confidence that the materials that they are using will not present future business risks (reputation, litigation) resulting from unforeseen safety problems with their materials. This will maximize and support the uptake of these materials in the development of new processes and products.
This VP has a lot of interaction with European universities, research institutes and industry via the EU projects. In 2016, 3 new EU H2020 projects were granted: NanoSTreeM (started January 1st, 2016), CaLIBRAte (started July 1st, 2016), and EC4SafeNano (started March 1st, 2016). In those projects, connection with industrial partners was made by working on industrial case studies. From a stakeholder perspective this VP is well aligned with the Topsector HTSM. The research is well aligned with the Risk Assessment and Technology Assessment (RATA) program of NanoNextNL with focus on the exposure, toxicity and the prediction of the risks of nanomaterials. In addition, the research performed on worker exposure measurements was included in CEN standardization documents (WI 137052, WI 137053, WI 137056 and WI 137057-061), in which TNO played a key element and TNO is well equipped to perform those measurements. The Dutch NanoCentre (www.NanoCentre.nl) is used to bring relevant research findings to SMEs and industry. The authorities are informed via Knowledge and Information Centre Nano (KIR nano) and by personal communication with the Ministries of SZW and I&M. From business perspective, our research and network led to several orders from Ministry (for instance an order on the support of the phys/chem database to make this database an international standard to store data) and from several industrial partners.

7 VP Environmental Technology

7.1 Roadmap High-Tech Materials

7.1.1 *Summary*

The research in the 'Environmental technology' program supports the transition in company and citizen involvement in the responsibility for environmental sustainability. The research in the 'Environmental technology' is organized two research lines (subprograms) Sense4Environment (S4E) and Circular Economy (CE). In Sense4 Environment the goal is to continue to develop and validate materials for low-cost, wearable, reliable and highly sensitive sensors for air pollution, for example for benzene. Furthermore TNO will continue to work on the establishment of a cooperation on the calibration and validation of sensor networks. In 2017 noise is one of the issues to be incorporated sensor network calibration/validation.

In Circular Economy knowledge is developed for disruptive technologies that fit in the concept of a Circular Economy. Knowledge is developed to contribute to technical feasibility, and to economic and environmental advantages of these new technologies for a more Circular Economy. For Circular Economy the main change for 2017 is more focus on specific sectors, i.e. the building sector, metal-electro and agro-food. As a result, there are more opportunities to develop knowledge in a more programmatic approach with private parties and other knowledge organizations, increasing the impact of the research activities.

7.1.2 *Short description*

Companies and citizens become more involved in the responsibility for the environment in addition to governments. This transition must be steered and made robust to end with a resilient society where environmental sustainability adds value to the economic system. From this perspective, environmental sustainability is seen as a source of new competitive advantage of firms, industry sectors and nations in the future. The majority of commercial enterprises believes that sustainability in terms of environmental impact, industrial safety or occupational health and working conditions require the greatest amount of action if profitability and competitiveness are to be assured in the future. Previous work by TNO, commissioned by the Ministry of Infrastructure and Environment, concluded that in the Netherlands additional added value of over 7 billion EUR a year could be generated by 2025 and 54,000 new jobs created for the next five years if both government and companies would focus on encouraging the build-up of circular supply chains.
The research in the 'Environmental technology' is organised two research lines (subprograms) Sense4Environment (S4E) and Circular Economy (CE).

Sense4Environmnet combines expert knowledge of environmental impacts and new sensing and modelling output. In this way TNO is able to offer smart solutions for a broad array of environmental high concern issues. With recent advances in low-cost, wearable, personalized, environmental sensors and ICT we foresee a shift from monitoring and subsequent policy making to directly managing the environment. There is also a growing field of individual citizens that are heavily involved in environmental sciences through application of low-cost, personal sensors (Quantified Self movement and Dutch test with iSPEX for fine particles exposure are interesting examples of this trend). Citizens are getting conscious about effects of pollution and are asking for smart and direct insights in their actual venues and vicinity. This is of special interest for the chronically ill, but also for

employees in high risk environments, and will increase the quality of life and independence of the general public.

In Circular Economy knowledge is developed for disruptive technologies that fit in the concept of a Circular Economy. Here the program is focusing on Circular Economy in specific sectors, i.e. the building sector, metal-electro and agro-food. Data driven models and tools enable stakeholders to make informed decisions on the use of secondary resources and the related potential to generate economic value and to decrease the environmental footprint.

The part of the program that is linked to the Topsector High-Tech Systems and Materials focuses on the development and validation of new material solutions for environmental sensing and circular products.

7.1.3 *Highlights*

Sense4Environment has focused on the development of low-cost, wearable sensors for the detection of benzene and particulate matter, both for health exposure and safety applications. In addition research has been undertaken on the development of a flexible 'plug and play' sensorplatform for easy connectivity and data collection.

The benzene sensor is based on the formation on the formation of a fluorcent exciplex with DBMBF2. We have an experimental set-up with a detection unit Andor CCD combined with 375 nm excitation LED to observe benzene in flow unit. Different coatings have been tested. Best results were obtained with PVDF silica coatings. Sufficient short response times have been reached and the detections range of ppm seems feasible. This development will be continued in 2017. TRL reached: 3.

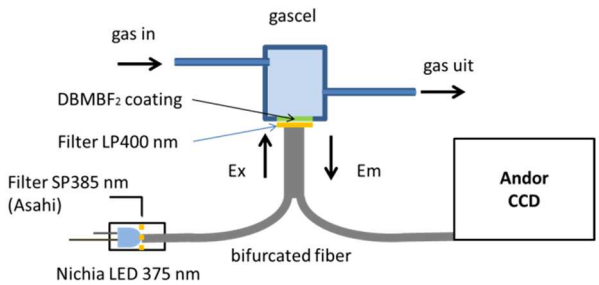


Figure 1. Schematic overview of the Benzene Sensor.

The application of the low-cost, small, lightweight personal Particulate Matter Sensor (PMS) is that it can be worn permanently in work and health related environments and can be used for early warning or real time intervention purposes. This also means i.e. low energy consumption, limited nuisance for the user, easily interpretable feedback. In 2016 a start was made with some exploratory research into the feasibility of 3D printed µ-fluidic channel based virtual impactors for the fractionation of particles in air. We have shown that µ-channels for gas treatment can be printed and determined some critical issues in the production process. Current TRL is 2 and we expect to reach TRL 3 early 2017. Patent is pending (PLT2016035 Particulate Matter Sensor).

The research on Circulair Economy for building materials has resulted in a Proof of Concept to utilise waste incinerations ashes as a binder in concrete. This development enables upcycling of this waste stream instead of today's relative low value utilization of ashes to replace sand (road embankment or filler in concrete).

The lab results show that treated incineration ashes behave similar to fly ash in binding speed and strength. Fly ash is an accepted alternative for Portland cement. This incineration ash alternative for Portland cement has the potential for a significantly improved environmental footprint of concrete, although process optimization on the treatment process is needed.

For metal-electro, the research in the RECLAIM project has been finished end 2016. RECLAIM's main objective was the reclamation of indium, gallium, yttrium and europium from Photovoltaics, Solid-State Lighting and Electronics waste. Emerging green technologies such as photovoltaics (PV) and Solid-State Lighting (SSL) heavily depend on the use of raw materials like gallium, indium and rare-earth elements, and future demand is forecasted to be larger than the supply of these metals. Within the four years duration of the project (2013-2016), two recycling technologies have been developed until pilot scale plant and one technology to demonstrator scale. The hydro-metallurgic process to recover scares metals from electronic waste developed in RECLAIM, is now being filed for patenting. Development of business cases and pilots builds on assessment of environmental impacts and costs over the life cycle performed by TNO.

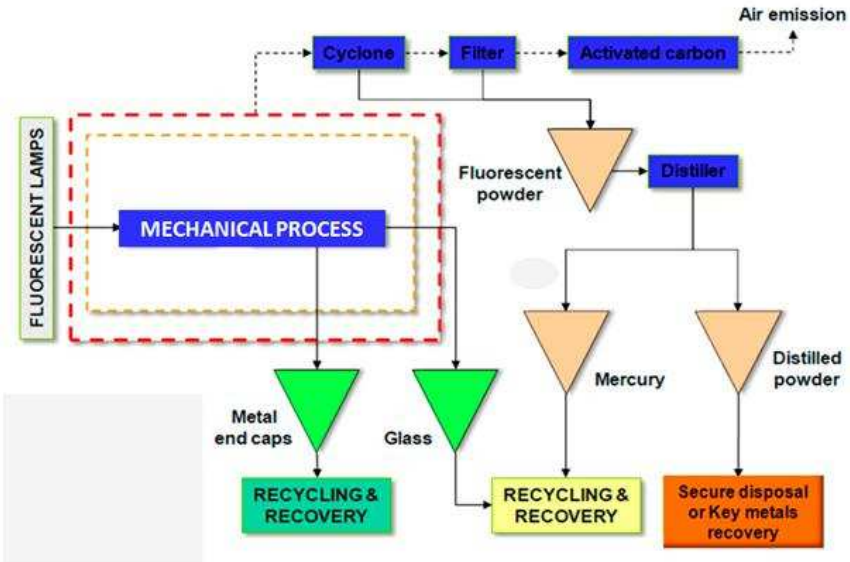


Figure 2. General overview of the RECLAIM's treatment route for FLs.

7.1.4 *Dynamics*

The research in Sense4Environment is continued along the strategic and ambition for this program as defined in the past years (for 2015-2018). The development on a benzene-sensor will be continued. Furthermore TNO is working for 2017 on the establishment of a cooperation with RIVM and UU IRAS on the calibration and validation of sensor networks. Noise is one of the issues to be incorporated sensor network calibration/validation. Sense4Environment is a driving force in the further development of CASTEL (Centre for Alligned STudies on Environment & Life) with shared facilities with University Utrecht and Deltares. In particular an initiative is under development for an open innovation research program. Partners include sensor and service providers (CGI, KPN, Philips, and possibly AMS) and various SMEs on health services, IoT and air cleaning equipment).

For Circular Economy the main change for 2017 is more focus on specific sectors. As a result, there are more opportunities to develop knowledge in a more

programmatic approach with private parties and other knowledge organizations, increasing the impact of the research activities. Within this VP, the focus is on high-tech building materials and on electronics. The development on hydro-metallurgic technologies to recover scares metals from electronic waste will be continued. The research in 2016 in the FP7 RECLAIM project has generated a patent, and in 2017 the technology will be further developed in cooperation with private companies and other research institutes. For the building sector the activities to generate knowledge to replace Portland cement by binders from waste (secondary resources) will be continued. One of the developments is to utilise ashes from waste incineration for this purpose.

8 VP HTSM-Bouw Innovatie

8.1 Roadmap High-Tech Materials

8.1.1 Summary

Construction materials: the research focuses on stony materials based on waste materials (slag, fly and bottom ashes, demolition waste), and lower water and energy consumption. The development of these products has to take into account the costs and required performances maintained over time. TNO focuses on two topics in 2016: the influence of aluminum and zinc residues in aggregates and a new masonry stone.
Bottom ash contains some aluminum and zinc. Based on experiments, TNO has shown that the strength performances decrease in case of a small amount of aluminum (less than 1%) in concrete. This decrease is more than expected and should be considered in the development of concrete products based on aggregates from waste materials.
TNO has developed a masonry stone based on used bricks by using an alkali as an activator. The advantage of this process is that the temperature can limited to around 80 °C. To be able to use those stones in practice the following performances has been checked: cohesion of the end-product, presence of cracks, aesthetic aspect (i.e. homogeneity of color, dull-/shininess, roughness/smoothness, presence of a glazed top layer), presence of efflorescence and presence of a whitish patina. This research has identified various promising combinations of process parameters to get a masonry stone which can be used in practice. In addition, TNO has also identified the needs for future research regarding the topic of alkali activated binders.

Asphalt: within the VP a mathematical model has been developed (within the BAT project) for predicting/evaluating open road surface mixtures on the basis of temperature changes and traffic loads. With the aid of the model it can be predicted for novel mixtures (when the properties are determined in the production) how they will perform in the time, and what conditions (frost and traffic load) create a risk in the time for the occurrence of damage.
In addition, it has been established within the healing research that the macroscopic observed healing strength of bitumen is a combination of two underlying mechanisms (wetting and intrinsic healing). However, some of the underlying parameters are very fundamental in nature and it is unclear whether they can be measured. The aim is to describe the macroscopic healing on the basis of measurable parameters. We have chosen a model-based interpretation of the healing process by describing the dominant wetting process. One possibility for this is to make use of an AVRAMI-model to describe the wetting process on the basis of measurable material properties.

8.1.2 Short description

Innovations of building materials is necessary in order to limit the sharply increasing cost of maintenance and renovation, minimize the downtime of infrastructure, reduce energy consumption, close of material chains (circularity) and minimize environmental impact. This requires reduction of the use of materials, replacement of raw materials through re-use and bio-materials, increasing service life through better understanding of degradation at the material level and adaptation/addition of functionalities. The main role for TNO in this area is to predict and improve the performance of key materials in the built environment (construction materials,

asphalt, responsive materials) through analytical techniques and advanced modelling.

Construction materials: focus is on concrete. For degradation mechanisms limited predictive models are available. Improvement of the fundamental understanding and modelling of the behavior and degradation will be an important activity.

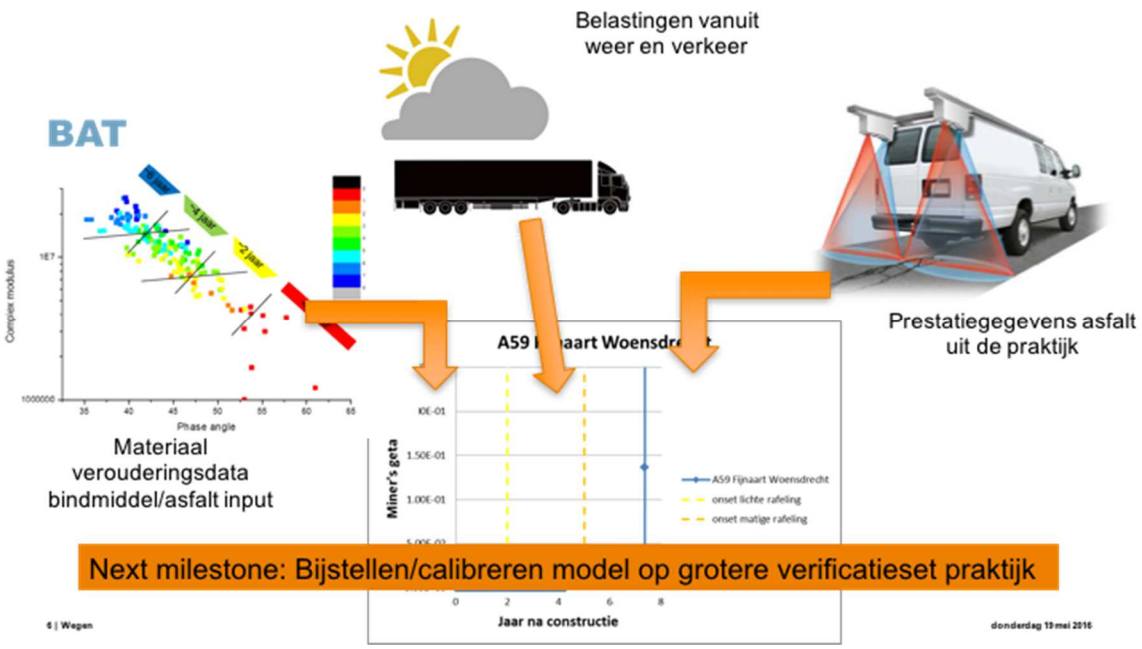
Asphalt: prediction and improvement of asphalt behavior is achieved by further developing models for life time predictions on the basis of physical and chemical processes. This provides the basis for improving the service life of road surfaces and for enhanced qualification methods.

Responsive materials: release of biocides, effective maintenance via signaling materials, corrosion process and inhibitors, and switchable glues were part of the initial program, but it was earlier decided to focus on construction materials and asphalt.

8.1.3 Highlights

Construction materials: the re-use of waste materials as concrete aggregates will become more important in the near future, but negative influences on the properties of the concrete products have to be eliminated. It is shown that small amounts of aluminium and zinc particles might already results in a significant drop of the strength properties.
The industry shows interest in the use of alkali activated binders based on waste materials. To support industry, TNO focused on the determination of various relevant (long term) properties of concrete based on those binders by testing and modelling. TNO has developed a masonry stone based on used bricks by using an alkali as an activator. The advantage of this process is that the temperature can limited to around 80 °C. To be able to use those stones in practice the following performances has been checked: cohesion of the end-product, presence of cracks, aesthetic aspect (i.e. homogeneity of color, dull-/shininess, roughness/smoothness, presence of a glazed top layer), presence of efflorescence and presence of a whitish patina. This research has identified various promising combinations of process parameters to get a masonry stone which can be used in practice. In addition, TNO has also identified the needs for future research regarding the topic of alkali activated binders.

Asphalt: within the VP a mathematical model has been developed (within the BAT project) for predicting/evaluating open road surface mixtures on the basis of temperature changes and traffic loads. With the aid of the model it can be predicted for novel mixtures (when the properties are determined in the production) how they will perform in the time, and what conditions (frost and traffic load) create a risk for the occurrence of damage in the time.
In addition, it has been established within the healing research that the macroscopic observed healing strength of bitumen is a combination of two underlying mechanisms (wetting and intrinsic healing). However, some of the underlying parameters are very fundamental in nature and it is unclear whether they can be measured. The aim is to describe the macroscopic healing on the basis of measurable parameters. We have chosen for a model-based interpretation of the healing process by describing the dominant wetting process. One possibility for this is to make use of an AVRAMI-model to describe the wetting process on the basis of measurable material properties.



The first validation steps are promising, but the next step is to validate/verify the model on a larger scale. The model is already being used now for supporting contractors in selecting low-risk mixtures for long-term (DBFM) projects. In our own research the model is used to benchmark our own developed innovative binder/asphalt mixtures and compare it with existing mixtures. One such a mixture has been benchmarked with this model. This new mixture asphalt seems to age more slowly in the first stage of life, but this difference seems just temporary so that at present the benefit is minimal compared to a conventional mixture.
We cooperate with BOSKALIS, LATEXFALT, RWS and TU Delft in the development of the model and the underlying knowledge. In addition, there is a graduation completed in co-operation with the Delft University of Technology in the field of the sensitivity of binders for the aging.

In addition, we further investigated bio-based binders. Different source materials of lignin have been examined in order to evaluate the effect of variation in the raw materials. It has been found that for different lignin raw materials binders could be realized but the properties are subordinate to the modified lignin binders.

8.1.4 *Dynamics*

Construction materials: there will be a stronger focus on the determination of the performances and understanding of the underlying mechanisms.

Asphalt: TNO has strengthened its position as a knowledge partner in the research field of road construction. TNO has become an attractive partner for knowledge development especially for contractors and suppliers in the sector. At the CROW Infra Days the results of aging research and the methodology were shared to generate (contractors) interest in further development, with serious interest of an important player as a result.

9 VP Space & Scientific Instrumentation

9.1 Roadmap Space

9.1.1 Summary

The focus of VP Space is on areas where TNO has a strong heritage (e.g. optical and radar instruments for earth observation and the ESA science program), and on areas in which TNO has license to operate based upon a very strong technical background obtained in different fields (e.g. laser communication). In 2016 a coherent set of new technologies, components, and design methods have been further developed to keep TNO in a leading technology position in the relevant focus areas. This position has been acknowledged on several occasions by ESA and other space organizations. New earth observation spectrometer components and the necessary manufacturing technologies were developed, and new instrument concepts were developed jointly with corresponding data analysis and modeling systems. Research and development of a “green fuel” for space has also shown significant progress, raising the interest from ESA.

9.1.2 Short description

It is our vision that the worldwide space activities will become more commercial instead of mainly institutional. I.e., we will see more small projects/satellites/instruments for new (commercial) organizations apart from institutional, big projects/instruments/satellites. Partnership networks will grow from mainly European to genuinely worldwide. However, the Dutch ecosystem should work even closer together in order to become a strong player in the international highly competitive field.

It is the ambition of TNO to continue to develop instruments (like Spectrolite, see below) and systems that can be manufactured and sold by the national space industry (if possible on a recurrent basis). The choice of instruments we develop should be driven by market needs, which implies that there should be a strong link to the downstream area. For a strong national business case there is the need for robust data processing systems resulting in remote sensing and scientific information produced in a consistent manner on a daily basis, and applied for commercial use by the national remote sensing information industry.

The technology development program is focused at enabling a relevant contribution to specific applications (within the ESA missions, scientific facilities), in cooperation with the main scientific and industrial partners. The results will be presented at conferences, and discussed with candidate end customers and partners; strategic patent portfolios will be built up whenever that is technically possible and beneficial.

9.1.3 Highlights

Recent progress in optics manufacturing technology has allowed us to develop very compact high performance spectrometers in a cost effective manner. Compact, low-cost spectrometers offer multiple advantages: a compact instrument can be flown on a much smaller platform (e.g., a nano or micro satellite), a low-cost instrument opens up the possibility to fly multiple instruments in a satellite constellation, improving both global coverage and temporal sampling (e.g., to study diurnal processes), a constellation of low-cost instruments thus provides added value to the larger scientific and operational satellite missions. Last but not least, a low-cost

instrument may allow breaking through the ‘cost spiral’: lower cost will allow taking more risk and therefore lead to faster progress. In other words, it may lead to a much faster development cycle than usual for current earth observation instruments. TNO has developed a compact one-channel hyperspectral imager (named ‘Spectrolite’). The design of Spectrolite offers the flexibility to tune its performance (spectral range, spectral resolution) to a specific application. A Spectrolite breadboard was transformed into an airborne instrument to participate in a test flight over Berlin, as part of the AROMAPEX campaign. This campaign, which was held in April 2016 to monitor the air quality over Berlin and to inter-compare different airborne instruments, provided an excellent opportunity to test the Spectrolite breadboard under atmospheric conditions. The measurements were successful and results obtained during the AROMAPEX campaign over Berlin are used in the next steps of the development.

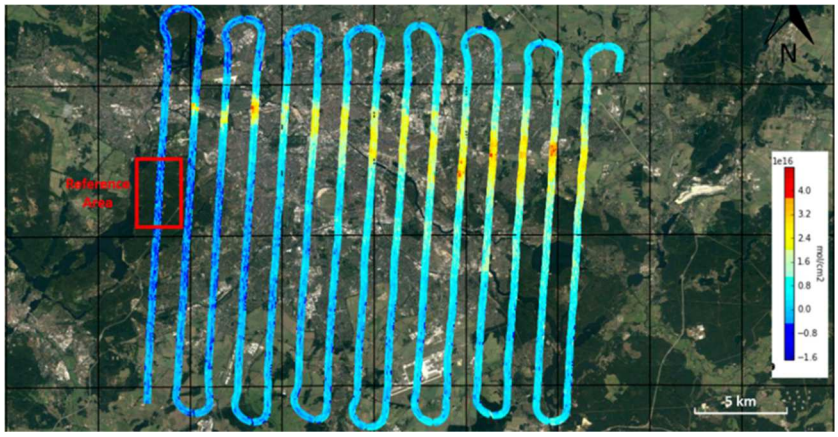


Figure 1. Spectrolite NO_2 measurements over Berlin.

Another compact instrument is based on a new interferometric measurement principle for the detection of gas concentrations developed by TNO in 2014. This so called HIGS instrument (working acronym) is dedicated to specific gases, and has a very small volume (few liters). It is expected that the gases that can be detected, will be measured with improved performance needing vastly reduced post processing. The instrument requires nm level positioning accuracy and high performance optics. In 2015 a demonstrator was developed enabling the measurement of NO_2 gas concentrations. First measurements (both in lab and outside) identified the subsystems that needed further development: 1) IFM prism, 2) band pass filter, 3) OPD setting, 4) calibration and metrology. Last year these subsystems have been improved. The aim of the 2016 project was to increase the confidence in the measurement principle by performing on sky measurements and by that also generating exposure of this novel concept in the outside world.

Figure 2. HIGS measurement of NO2 emission by ships at Hoek van Holland.

In the beginning of the year a first

measurement campaign did not deliver the desired results for a number of reasons: 1) insufficient thermal stability, 2) poor weather conditions and NO_2 variations, 3) non-optimized band pass filter, 4) slow measurement speed, 5) elevation angle. Therefore, it was decided to focus on improvement of the demonstrator (solving the issues mentioned above) before starting a new measurement campaign. First measurements look promising. A more extensive campaign, in order to quantify performance, is planned in Q1 2017.

One of the critical elements of an earth observation spectrometer is the so called slit-homogenizer. This component fulfils an important role in levelling out sharp differences in light intensities in flight direction (for example caused by cloud edges). It requires an optically coated component with sharp physical edges, making manufacturability a big challenge. Furthermore, the required accuracy in the mounting of the parts is extremely challenging as well, especially due to the difficult environment in which this component has to function and survive (vacuum, high vibration loads, thermal cycles).

TNO has developed a coating procedure and production process, tested on a breadboard, showing that the extreme requirements can be met. The slit homogenizer is based on new manufacturing processes, new coatings, and new optical alignment procedures. The slit homogenizer, and other unique components (like polarization scramblers and low roughness mirrors) will be applied in Sentinel 5, and they will give TNO a leading technology position for future earth observation spectrometer projects.

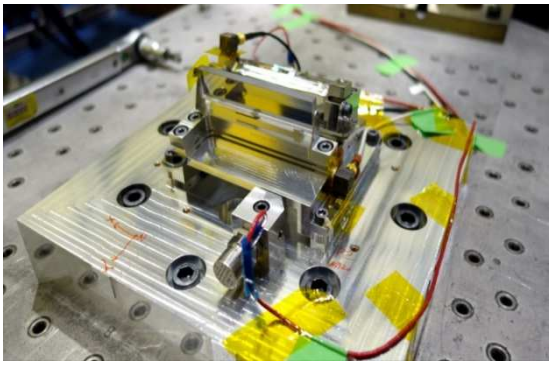


Figure 3. Slit homogenizer breadboard.

Part of the space research at TNO was dedicated to improving atmospheric modelling, particularly in relation to aerosols. Aerosols in the atmosphere are of major interest due to their large impact (e.g. on human health). Objectives of our research were: 1) prepare TNO's LotosEuros model for future measurements from (polarimeter) satellites, 2) set up an inversion scheme to predict dust emissions, 3) create an operational dust forecast for WMO Sand and Dust Warning Advisory and Assessment System, 4) deliver a prediction tool for surface solar irradiance. The four activities all concern the subject of aerosols. One of the outcomes is that we can now model mineral dust aerosol and calculate its impact on solar radiation and dust deposition. Mineral dust is a key aerosol in large part of subtropical Northern Hemisphere and it concerns other issues than traditional health and climate alone, e.g., transport, safety, and (sustainable) energy. We applied known technologies

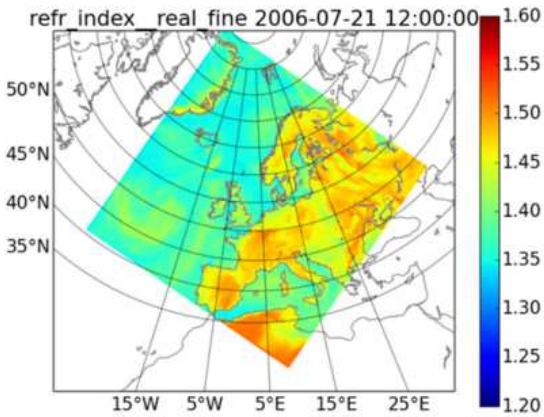


Figure 4. Aerosol Concentrations.

on other knowledge domains and developed innovative applications for the established model. The scientific worlds of retrieval groups and atmospheric modelling groups were further apart than expected. It took a year to understand the partial disagreement between model and retrieval approaches. However, future collaboration with SRON will improve scientific progress.

In the field of propulsion systems, in 2016 we developed a H_2O_2 fuel blend that has potential as a monopropellant outperforming hydrazine. We found a method that seems suitable to stabilize the blend. However a 100% stability is not obtained yet, due to impurities in the fuel. In addition to the H_2O_2 fuel blend we investigated if we can also use nitrous oxide. This proved to be successful and two mixtures were identified that have the potential to outperform hydrazine and of which the oxidizer and fuel are mixable and stable. The activities for testing the propellant on engine level were investigated using a test engine. Results are discussed and presented to ESTEC chemical propulsion group. In the green propulsion Roadmap of ESA several projects on alternative propellants (exceeding 10 MEuro in total) are now being defined. The executed project positions TNO for tendering on these projects as prime or subcontractor.

9.1.4 Dynamics

The three research lines for TNO Space have been closely matched with our business lines; the dynamics in the relevant parts of the future space market drive the knowledge development.

Earth observation instruments

Earth observation (in particular for atmospheric characterization) remains the most important business line of TNO Space, where we contribute strongly to the leading position of a Dutch earth observation ecosystem consisting of industry and institutes. Up to now the main customer is ESA, and unique (one-off) instruments are developed in accordance to the ESA Roadmap, including the Copernicus program. As mentioned above, in the near future this will change to a broader range of applications for a broader range of customers, and opportunities for building series of (smaller) instruments will occur. There have been opportunities (some of which have changed over the year) for TNO to propose new instrument concepts successfully, and more will occur in the near future. Customers will focus on the remote sensing information rather than only the instrument; this requires development of end-to-end solutions: instruments, including specific coverage of the earth/atmosphere, calibration and data retrieval.

In this end-to-end approach more Dutch partners are involved, aiming at more integrated cooperation.

Playing a dominant role in the design, realization and calibration of future instruments seems crucial for the survival of this innovation area. TNO and partners play an dominant role in developing subsystems of Sentinel 5, in combination with the actual calibration of the instrument. In the race of continuous stretching the required performance of these instruments by ESA, and meeting these requirements, one of the main present focus areas of TNO is the development of innovative components and technologies that meet these requirements.

A different large instrument where TNO has the realistic ambition to play a significant role, together with Dutch industry, is BIOMASS, a novel P-band synthetic aperture polarimetric radar instrument, aiming at measuring forest biomass to assess terrestrial carbon stocks and fluxes. Here we are teaming with the major

European prime contractors, and TNO's research is aimed at pre-developing the technologies for BIOMASS to the TRL-level that is required to make a successful proposal and preliminary reduce development risks to an acceptable level.

Instrumentation for space borne astronomy
Instrumentation for space borne astronomy is another important business line for TNO's Space program. Our research activities are guided by ESA's Cosmic Vision program, which contains a Roadmap for at least the next 20 years.
Regarding the Long-term mission eLISA will be of particular importance.

Optical satellite communication
A promising possibility for Dutch industry to extend space activities into commercial markets is found in the market of optical satellite communication. Since optomechanical subsystems are the core of the optical communication systems, our current leading position in this area will enable Dutch industry to enter an interesting commercial market which is attractive due to its recurring character, broad market segmentation and its growth rate.

Together with Dutch Industry and RUAG –Switzerland (now Thales Alenia Space), and partly funded by ESA, TNO has started the development of optomechanical modules for laser satellite communication, which is aiming a strong recurring business for the Dutch industry involved.

Activities related to VHDR (Very High Data Rate) Uplink systems are in progress. In the near future there will be a need for technology for Ground terminal Downlink systems from Low Earth Orbit (LEO) as well. The next generation Inter-satellite Communication offers new possibilities to extend the position of TNO and industrial partners in this field.

9.2 Roadmap Advanced Instrumentation

9.2.1 Summary

There are two main topics in the VP for Advanced Instrumentation:

- Technology for Ground-based astronomy. The focal points in technology development are Adaptive Optics and Segmented Mirrors for the next generation astronomical telescopes.
- Technology for Big Science facilities; via Het Huygens Huis TNO aims at partnering with Dutch industry and scientists in research and development for European Big Science facilities like ITER, CERN, ESRF, and the future European Spallation Source (ESS).

9.2.2 Short description

Fully in line with the HTSM Roadmap Advanced Instrumentation TNO underlines the ambition to promote the Dutch ecosystem by strengthening the collaboration between companies, universities and institutes with the aim to increase the return-on-investments in three ways:

- Improved economic return-on-investment by supporting Dutch (SME) companies in the development of world-class instruments.
- Improved scientific return-on-investment by stimulating that Dutch (SME) companies are highly involved in science projects enabling quicker, more robust and more effective instrumentation.

- Improved societal return-on-investment by stimulating that the developed technology know-how is used by (Dutch) SMEs and mass production firms to develop and market instruments that help solving societal issues regarding health, ageing, mobility, energy and safety, etc.

Therefore, it is crucial for TNO to cooperate with a network of scientific organizations and industry. Scientific institutes (like Astron, NOVA, DIFFER and NIKHEF) and universities are involved in providing the scientific rationale for the big facilities, in defining the instrumentation needed and in applying the instrumentation for world-class research. The industry has the skills and development capabilities to build high-end equipment in larger series, while TNO has experience in designing and prototyping instrumentation for space and science.

9.2.3 *Highlights*

The European Extremely Large Telescope (E-ELT) is a revolutionary scientific project for a 40m-class telescope that will allow to address many of the most pressing unsolved questions about the Universe. The E-ELT will be the largest optical/near-infrared telescope in the world and will gather 13 times more light than the largest optical telescopes existing today. The first mirror of the E-ELT will consists of 798 hexagonal 1,4 meter mirror segments. The M1 Support Segment developed by TNO VDL and NOVA will extremely accurately support each of these segments.

The requirement to keep the maximum Surface Form Error during operation within 25 nm is extremely challenging. TNO aims at developing new technologies enabling support structures that meet these extreme requirements, with a special emphasis on low-cost and structures which are easy to maintain.

Figure 1. E-ELT M1 Support structure developed by TNO, VDL, NOVA with many lost-cost/high performance components.

In optical systems, for example astronomical telescopes, all sorts of disturbances can introduce aberrations that reduce the optical performance. With deformable mirror (DM) technology these aberrations can be compensated and the optical performance can be regained. TNO has no experience yet on building an entire DM system, which is our goal. Therefore, the following development steps are required in order to raise the TRL to a point required for obtaining a competitive position in this market: 1) development and testing of the DM actuator principle, 2) development and testing of the manufacturing, assembly and integration strategy of the face-sheet (deformable optical surface) onto the actuator array; 3) development of the support structure of the DM.

The original SMO plan was focusing on the opportunity of an on-sky demonstration of our DM with the US CHARA telescope system. However, mid 2016 this opportunity was cancelled (at least for the short-term). Therefore, the project had to refocus. Two breadboard test were setup to 1) test a strip of actuators on performance and 2) test the chosen integration strategy. Also all additional preparations were made for the eventual realization of a full DM, i.e. design, drawings, procurement of tooling. The DM itself was produced in the framework of the ESA TRP AOCC.

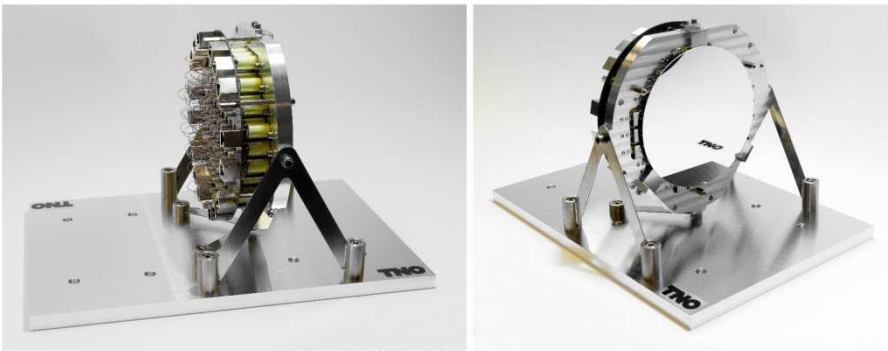


Figure 2. Deformable mirror breadboard.

9.2.4 *Dymanics*

The TNO research activities on advanced instrumentation are dictated by the foreseen opportunities for Dutch industry and science. Currently TNO is focusing on the following areas:

- The European Extremely Large Telescope (E-ELT) under development by ESO. In particular, we address the support structures of the M1 mirror segments, aiming at substantial recurrent business for Dutch industry. Related to the M1 support structures, TNO and industry are also targeting the Precision Actuator (PACT) development, which should also lead to strong recurrent business, and the M2 and M3 support structures, which involve large one-off developments, using heritage of the M1 support structure development.
- An on-sky demonstration of our adaptive optics technologies, like deformable mirrors.
- Nuclear fusion facility ITER and particle accelerators. In particular TNO is focusing on diagnostic systems and contamination control for ITER, and its broader application in ITER systems.
- KM3NeT, a future European deep sea research infrastructure hosting a new generation neutrino telescope with a volume of several cubic kilometers that will

be located at the bottom of the Mediterranean Sea. Here were are building a strong cooperation with the NIKHEF institute.

10 VP High-Tech Semicon

10.1 Roadmap Semiconductor Equipment

10.1.1 Summary

It is difficult to imagine the modern world without electronics. The internet, electronic banking, mobile communication, GPS, digital archiving and retrieval, and surveillance, to name a few, rely on advanced electronic circuitry, particularly integrated circuits (chips). The trend towards the data-based, service providing industry, the 4th industrial revolution, is speeding up the already increasing need for data transport, processing power, and data storage. Today, about 10% of the total energy consumption in developed countries is already used for ICT. The continuously growing connectivity of modern society urgently calls for the continuation of Moore's Law towards less power hungry devices, and even game changing computational concepts, such as quantum computing or bio-inspired computing and photonics-based computing. The Netherlands holds a strong position in especially the development and sales of equipment for this semiconductor industry. TNO's program reflects these national priorities.

In 2016 most of TNO's activities were related to two major challenges of the international semiconductor industry:

(a) The introduction of EUV lithography (EUVL). For further shrinking of the critical dimensions, required to continue Moore's Law, the industry is waiting for EUV lithography. Obviously, a successful introduction of EUV lithography is of significant importance to the Dutch economy. TNO contributes directly to this challenge by working together with ASML and Carl Zeiss and their suppliers, but also indirectly by contributing to the so called EUVL infrastructure. This infrastructure includes reticles and pellicles for EUVL and all related technical challenges like particle-free handling and molecular contamination control.

(b) Improvements in lithography and processing have led to devices with critical dimensions as small as 10 to 20 nm. Current metrology techniques can no longer keep up with this progress in manufacturing. TNO works on new technologies for metrology or inspection.

Besides these relatively well defined challenges, TNO continued the research on technologies for more long term solutions. At this time processing methods on new physical principles are being in the phase of fundamental research. Examples are quantum computing, integrated photonics and maybe bio-nano technology in the far future. This may move the architectures of processors based on the classical binary calculation methods towards quantum computing architectures. This step could be followed by a trend towards bio-nano technology and life sciences inspired architectures. TNO invested some trends towards new types of devices, materials and principles.

This kind of early stage research is always executed in close collaboration with an Early Research Program and/or as part of a Joint Innovation Center (e.g. ERP 3D Nanomanufacturing, QuTech). The topics of integrated photonics and bio-nano-technology are new or revived topics to this program, whose potential and TNO's fit to these topics are being investigated in cooperation with PhotonDelta (TU/e) respectively TU Delft.

10.1.2 Short description

Due to successful applications of European and national projects, nearly all SMO budgets of this program are used for so called mixed funding projects. This results not only in a larger total budget to spend on the topics of interest, but it also stimulates colleagues of TNO and other organizations to work more together. A fraction of the budgets is, on purpose, not allocated to mixed funding projects. This part of the budget is used to stimulate creativity and to do a first examination of new topics or ideas of colleagues. Such a small activity is referred to as a “kiem”.

An overview of the mixed funding projects in scope of Semiconductor Equipment:

European mixed funding projects, running in 2016
- ENIAC E450EDL
- ENIAC EDL meerwerk
- ENIAC E450LMDAP
- ECSEL SeNaT

European mixed funding projects granted in 2016
- ECSEL-JTI 3D AM (opened and start finance in 2016)
- Empir3D nano (opened and start finance in 2016)
- H2020 FET Proactive VIRUSCAN
- ECSEL TakeMi5
- Nanoarchitectronics

National mixed funding project, running in 2016
- STW HIM
- MFIG NanonextNL Valorisation Grant
- STW UPON
- Focusgroep EUV

TKI projects, where a small contribution was needed from SMO
- TKI HPAM - ASML
- TKI parallel AFM - Swiss Litho
- TKI Free surface Immersion - ASML

10.1.3 Highlights

EUV Beam Line 2

The highlight of 2016 is the installation of the EUV Beam Line 2. This required an investment of 10 M€, and a huge effort of TNO colleagues and industrial partners USHIO and ASYS. But just before Christmas 2016 TNO announced in a press relieve ‘first light’ of this setup. This setup will be a unique facility to expose mirrors, reticles, pellicles, or other materials to high intensities of EUV light. TNO believes this will accelerate R&D on all of those materials and components needed to make EUVL a success. Further testing and validation of the setup will continue until June 2017. This investment was only possible with support of TNO, the Toekomstfonds of EZ, Nanolab NL, and European projects.

Development of a RF CCP
To proof EUV hardness of materials, experiments should be done under EUV conditions. However EUV sources are scarce and also expensive in use, especially if multiple materials should be exposed under EUV conditions. Alternatively the impact of an EUV light beam can be mimicked with another type of exposure technique. The impact of the EUV light is caused by the type of plasma it produces in a dedicated vacuum environment. This vacuum environment can easily be made, but the type of plasma is more difficult.

In this knowledge development project, a capacitive coupled plasma (CCP) source, driven by an RF power source, is built in an existing vacuum setup. The system is operational, however the exact conditions are probably not exact the conditions expected with an EUV source. With EUV we expect ion energies with a peak intensity around 5 eV, while we cannot get the RF CCP ion energy lower than 13 eV. Currently this is the only non-EUV exposure system, which approaches the EUV plasma in a similar vacuum environment. The RF CCP source is operational and discussions with potential customers are ongoing. With this project TNO gained experience in RF plasma technology, next to its knowledge position in microwave plasma technology.

OCT for backside reticle inspection
Particles on the backside of a wafer or reticle can affect the overlay performance of an EUV lithography system, which is a potential yield killer. When particles are larger than a burl of an electrostatic clamp, these particles can deform the wafer or reticle when clamped. Burls have a typical height of 10 um, so the OCT system should detect particle heights of 10 um and larger. Currently only 2D inspection methods are used to find these particles, but these inspection methods don’t say anything on the height of the particle, and a reticle can be rejected unnecessary.

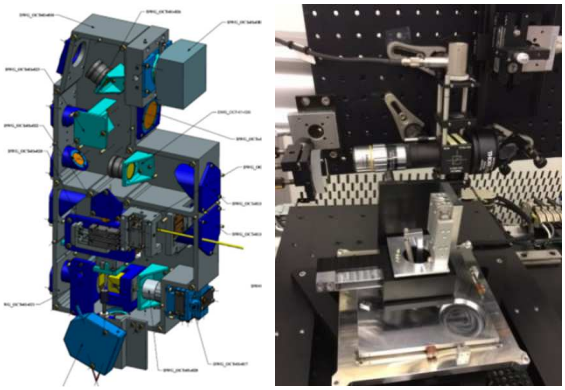


Figure (left) the design of the OCT measurement head, and (right) the experimental setup.

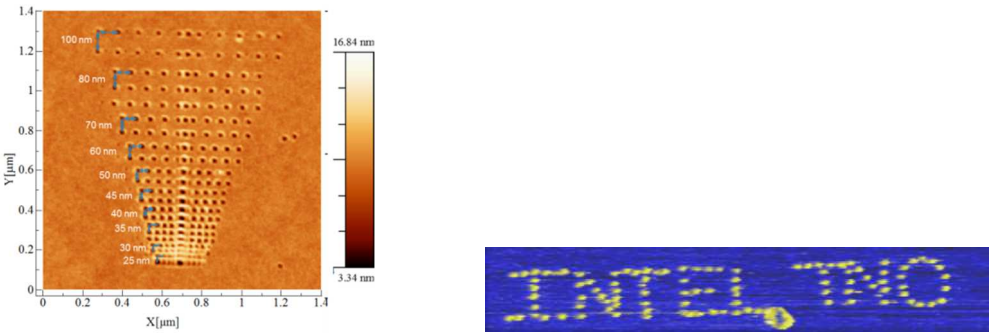
TNO built a test setup to show that Optical Coherence Tomography (OCT) is an accurate enough and high speed method to detect particles on the backside of a reticle or wafer. The installed camera and image processing were conform expectations. The used components are standard off the shelve components and therefor the image quality is currently not as good as possible with dedicated components. Interestingly, this project demonstrated how a technology developed for the less capital intensive market of Industrial Instrumentation may find an application in the Semiconductor industry.

Contact holes with AFM

The fabrication of contact holes (vias) in next generation of devices is seen as a challenging production step in current IC fabrication processes. Especially the ability to add versatility in both contact hole shape and hole pattern is not straightforward. TNO investigated the feasibility of patterning contact holes using scanning probe technology on a representative sample provided by Intel.

Within the project, TNO experimentally derived a recipe (cantilever type, system settings, …) to pattern holes meeting the following requirements:

1. Pitch between holes varying from 25 to 100 nm
2. Hole depth of 18 nm in etch resistant top coat layer
3. Ability to define pattern to show versatility



The left figure shows the final result of the hole patterning in which one can clearly see the varying pitch values. The right figure shows the TNO logo, illustrating the versatility of the method.

Imaging without front-end electronics

Single photon detection is applied in large number of fields, such as big science, astronomy and semiconductor industry. Silicon pixel detectors that are developed for high energy particle and X-ray detection have found, next to their application in large scale high energy particle systems, an application outside this field as well. Pixel detectors are commonly used in the medical fields (PET, mamography) as

well as applications in material sciences (XRD, XRF). The development of pixel systems goes hand in hand with a large effort of micro-electronics R&D as the pixel detectors usually require a dedicated ASIC in the front-end read-out.

In this study the possibility of combining pixel diodes structures and optical ring resonators to establish a pixelated radiation detector without front-end electronics is studied. Radiation can be sensed when it loses its energy in matter through ionization and when the resulting free charge carriers modify the optical properties of the matter. The concept of such a sensor uses optical waveguides and resonators on Si and SiO2 microstructures with integrated diodes to create a radiation detector with optical read out. In recent R&D efforts, diodes and optical resonators have been combined to create optical switches. Theses switches are of high interest for the telecom industry and the design driver here is the speed of the switch. In contrast, this study is focused on the sensor application of the optical ring resonators.

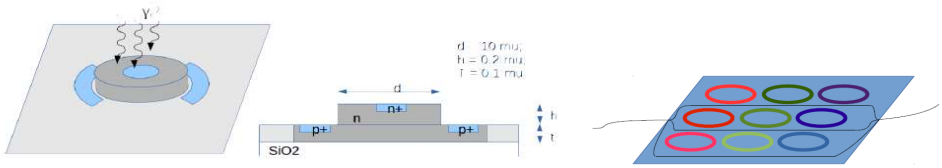


Figure (left and middle)Concept of a diode structure integrated with a ring resonator. (right) Concept of a pixelated sensor with many ring resonators integrated on a single chip: many different sized rings are connected to a single waveguide.

A concept of a pixelated radiation detector has been described which utilized electro-optical effects of free-charge carriers in integrated photonics. The proposed technology may exhibit several advantages over state of the art pixel detectors that utilize microelectronic circuits to collects the free-charge carriers and to process the electric signal. Advantages might be i) the simplicity (and hence costs) of the design, ii) the increased speed of the device as the charge collection speed approximately is limiting in case of optical read-out and iii) no power dissipation at the sensitive part of the detector.

Metamaterials and metasurfaces

Metamaterials and metasurfaces have emerged in the last years as a breakthrough technology for the development of novel optical components, with unprecedented light manipulation capability, extremely low-form factor and ease of integration with sensors. This technology is based on the use of architectures (arrays) of engineered nanoparticles (dielectric or metallic) to create extremely thin membranes able to perform any types of light (and in general electromagnetic waves) manipulation.

During the reporting period, the research activities on metasurfaces, performed in the framework of the professorship of Prof. dr. G. Gerini at the Technology University of Eindhoven (TU/e), have been focused on two main topics:

- Development of new optical components based on metasurfaces consisting of all-dielectric nanoresonators. In particular, a tool for robust designs of metasurface lenses has been developed and used to design an array of microlenses. In particular, this tool can be used to design lenses based on application driven requirements (field of view, optical aberrations etc.) and including also the effects of possible manufacturing tolerances.
- Development of a technology platform and analytical design framework for metasurface based perfect absorbers (with broadband or extremely selective absorption characteristics). The structure designed shows better performances

with respect to the state-of-the-art technology. In particular, this research effort has led to the design, manufacturing and experimental validation of a broadband metasurface perfect absorber.

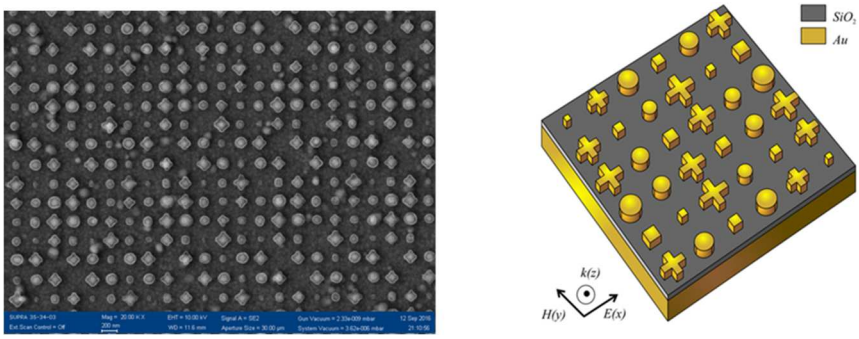


Figure (left) Broadband metasurface absorber demonstrator. (right) Artistic impression of the structure which consists of an array of gold nanoresonators deposited on top of a glass substrate backed by a gold thin substrate.

Optical germ detection

For the production of a medicine X no bacteria are allowed on the working gloves, while the gloves can be contaminated with bacteria due to putting the gloves on or when accidently touching something. Each working glove must therefore be checked for possible bacteria. The analysis takes up to 2 – 3 days, while production continues. After 2 – 3 days the medicine batch is either released for sales or discarded. The 2 – 3 days delay of the medicine is expensive, because of e.g. storage and thereby a discarded batches cost money. TNO has ideas for optical method which allows real-time germ detection and saves the 2 – 3 days analysis time.

Initial results show that there is a potential way of detecting bacteria on a glove with an optical fluorescence method.

Publications

SPIE Advanced Lithography 2016

- S. Kuiper, E. Fritz, T. Liebig, G. Kramer, T. Overtoom, T. Duivenvoorde, R. Rijnbeek, G. Witvoet, W. Crowcombe, E. van Zwet, “Overlay improvement via large dynamic range scanning probe microscope”. published at SPIE Adv. Litho 2016.
- M. H. van Es, “Can AFM scan a full EUV blank with 1 nm resolution in a practical time?” published at SPIE Adv. Litho 2016.
- P. Bussink, J-B. Volatier, P. van der Walle, E. Fritz and J. van der Donck, “Sub 20 nm particle inspection on EUV mask blanks”, published at SPIE Adv. Litho 2016.
- Edwin te Sligte, Norbert Koster, Freek Molkenboer, Alex Deutz, “EBL2, a flexible, controlled EUV exposure and surface analysis facility”, SPIE conference 2016 and in SPIE proceedings.

SPIE Advanced Lithography 2016 – Proceedings

- M. H. van Es; H. Sadeghian, “EUV blank defect and particle inspection with high throughput immersion AFM with 1nm 3D resolution”.
- Edwin te Sligte, Norbert Koster, Freek Molkenboer, Alex Deutz, “EBL2, a flexible, controlled EUV exposure and surface analysis facility”.

- A. Keyvani; M.S. Tamer; M.H. van Es; H. Sadeghian, “Simultaneous AFM nano-patterning and imaging for photomask repair.

AVS 2016
- Jacqueline van Veldhoven, Edwin te Sligte, Jochem Janssen, “A high-flux low-energy hydrogen ion beam using an end-Hall ion source”, published at the AVS 2016.

Professorship Giampiero Gerini
- F. Silvestri, G. Gerini, S.M.B. Bäumer, E.J. van Zwet, “Robust design of dielectric resonator metasurface lenses for maskless lithography”, accepted for publication on Optics Express.
- F. Silvestri, L. Cifola, G. Gerini, “Diamagneto-dielectric Anisotropic Wide Angle Impedance Matching Layers for Active Phased Arrays”, published on Progress in Electromagnetics Research (PIER).
- [3] F. Silvestri, F. Bernal Arango, K.J.A. Vendel, G. Gerini, S.M.B. Baumer, A.F. Koenderink, “Optical Antennas for Far and Near Field Metrology”, European Conference on Antennas and Propagation (EuCAP), Davos, Switzerland, April 2016, (Invited to Convened Session “Optical antennas: scaling electromagnetics to the nanoscale”).
- [4] F. Silvestri, G. Gerini, “Optical metasurfaces for light manipulation in imaging and metrology”, Photonics Event, Veldhoven, June 2016, (Invited talk to Session on Nanophotonics).
- [5] L. P. Stoevelaar, F. Silvestri, A. Nagarajan, G. Gerini, S.M.B. Bäumer, “Millimeter-range phase-only super-oscillatory lens with side-lobes reduction imaging algorithm”, European Optical Society Bi-Annual Meeting (EOSAM 2016), Berlin, Germany , September 2016.

10.2 Roadmap Smart Industry

10.2.1 Summary

The European manufacturing industry, and the Dutch high-tech industry in particular, is specialized in agile production in low volume. To maintain economic growth and employment, the EU is investing in the next economy, digitization and innovation of the manufacturing industry. To stimulate these essential innovations, several initiatives are started such as Digital Production (Manufacture/EFFRA), Industrie 4.0 (DE) and Smart Industry (NL).

TNO Industry aims at reinforcing the innovative power of (Dutch) manufacturing and process industry. One major trend in this regard is Smart Industry [www.smartindustry.nl]. The effects of ICT and internet on society in general and on manufacturing industry are enormous, to the effect that it is called the fourth industrial revolution. Dutch industry needs to quickly embrace this development in order to improve its international competitive edge. Reinforcing the current activities and reshoring of production can, in fact should, lead to renaissance of Dutch manufacturing industry.

Three major aspects of Smart Industry are:
1. Smart products that incorporate ‘intelligence’: sensors, data acquisition and processing, communication to ‘headquarters’.
2. Smart production that is automated, flexible and optimized by communication

between production units and along the production chain.
3. Smart business model and other social innovations as a consequence of (the opportunities presented by) the above developments.

The Industrial Instrumentation program is primarily focusing on the development and implementation of smart sensors/measurement systems (aspect 1 & 2 of Smart Industry). This means integration of sensors, actuators, design- and process-knowledge, and Big-Data.

10.2.2 Short description

This program as well as TNO's position in this market is relatively new. In the past, TNO developed multiple technologies, often based on its experience in high-tech sectors like the semiconductor industry or space technologies, that could in retrospect have been labelled Industrial Instrumentation or Smart Industry. But it is now considered as a renewed program, with a long term vision. In 2016 TNO has worked on this vision, which is called a Roadmap for Industrial Instrumentation. Choices have been made on the technologies, applications, and business models that shall be part of this program. Proper alignment with the objectives of EFFRA (EU), Industrie 4.0 (D) and Smart Industry (NL) and a strong focus are essential. To ensure alignment with Smart Industry, one of the core team members, Gregor van Baars, is closely involved in the Topsector team, led by Jan Post (Philips Consumer Lifestyle/RUG)**.**

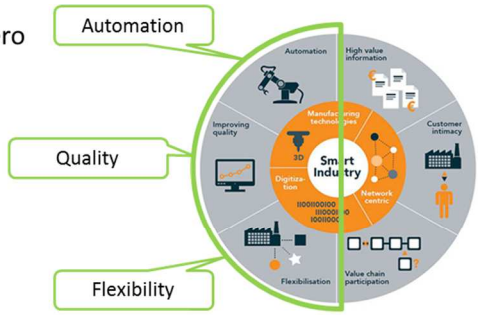
The program is currently a mixture of European and national projects, business-to-business projects, TKI- and/or SMO funded projects, and participations to Fieldlabs. This mixture represents the current state of the program, with the following characteristics.

1. TNO has many relevant technologies and disciplines in house, but still has to build up a track record and find its position in this market relative to other parties (both institutions and companies).
2. Many companies show interest in the potential of the proposed innovations, but cannot fully judge the added value for their position or are hesitant to invest. Projects that are partially funded, or in other ways reduce the risks for companies, are needed as show cases to motivate (more) companies in the Netherlands in invest in such technological and social innovations.
3. Multiple Fieldlabs are being initialized. TNO considers this as a valuable approach of the challenges of the Dutch industry in this phase and participates in several of these Fieldlabs.

With respect to the development of innovative sensing concepts, this program is focusing on zero defect manufacturing and flexible manufacturing (Figure below). Especially for zero defect manufacturing, the prime focus is on the development of dedicated sensors and measurement systems and extracting KPI (Key Performance Indicators). These indicators provide relevant and easily interpretable information of the tooling and products and therefore are of much more value to the operator than raw-data. At this moment, the reliability of process-control and predictive-maintenance during production and during ramp-up is significantly influenced by the number of measurements. Extraction of the right KPI in combination with model based and data driven analysis is essential for HMLV (High Mix Low Volume) production. Especially for process control, adaptive actuation is a prime focus area for Industrial Instrumentation.

Development of instrumentation for enabling automated Zero Defect Manufacturing (ZDM) and Flex Manufacturing (FLEX)

- High precision production
- Improve OEE, yield, quality and uniformity
- Enhance quality, yield and efficiency for HMLV
- 1st time right production
- Zero programming
- Improve ramp-up & change-over efficiency



Nearly all SMO budgets for the Industrial Instrumentation program is used for contra-financing mixed funding projects. The remaining budget is mainly used to stimulate PPP and new initiatives. The following mixed funding projects are part of the program:

EU projects, running in 2016
- Actphast (FP7)
- Plat4M (Photonics)
- HORSE (I4MS)

EU projects, granted in 2016
- TakeMi5 (Excel)
- Productive 4.0(Excel)
- I-Mech (Excel)

NL projects, running in 2016
- IOP-iOCT
- IOP-Raskin
- STW HiReamp

NL projects, granted in 2016
- ROSF (NOM)
- SI Fieldlab ACM
- SI Fieldlab Freshteq
- TKI flexible manufacturing zuid

10.2.3 *Highlights*

Stimulate PPP

A total of 7 new mixed funding projects are granted in 2016. All new projects are fully in line with the new Roadmap of the industrial instrumentation program. The Smart Industry Fieldlabs Freshteq and ACM showed significant delay in finalizing the consortium agreements.

Adaptive control

Robo House is an initiative for a Smart Industry Fieldlab in the region Zuid-Holland with main topic automated manufacturing by means of intelligent robot systems. Besides TNO, the prime coordinators are Delft University of Technology, de Haagse Hogeschool (HHS), Exact, and Festo. In this initiative, the collaboration with HHS resulted in two Proof of Concepts realized together with Batchelor students: An end-

effector is integrated on a robot system and together with a machine vision system applied in an environment to demonstrate complex automated bin-picking. Adequate bin-picking is essential in warehouses for companies like Amazon, Bol, Hellofresh, and technology providers such as Vanderlande. The second Proof of Concept is realized to automatically adjust the orientation of an optical inspection tool for high quality inspection systems. Both projects will be continued in 2017.

Smart sensors/new sensors
A first study is explored to identify different types of aluminium based on LIBS. About one third of the aluminium used in developed countries comes from recycled aluminium because re-melting of aluminium requires less energy (about 95% less) and it is therefore economically more favourable than creating new aluminium. Nevertheless, there are different types of aluminium alloys with different purities and characteristics.

With our in-house LIBS setup, 4 types of known Aluminium samples (specifically: 5083, 6061, 6082 and 7075) were measured. With these measurements we were able to create a database with the strongest spectral emission lines that would allow us to classify the different alloys.

10.3 Roadmap Nanotechnology (QuTech)

10.3.1 Summary

Quantum science has entered a transformational phase from university based research to engineering driven technologies. Seemingly fundamental limitations of quantum systems have recently been overcome. Although significant challenges remain available to create further scientific breakthroughs, we have also reached the point where quantum science is ready for engineering.
The Netherlands has an innovative ecosystem in the high-tech industry supply chain. In The Netherlands a well-trained and talented human capital pool is already present and can be further expanded towards this future technology. The very first quantum technology startups and SMEs addressing these markets are already sprouting.

Quantum research in Delft is at the forefront of new developments with seminal discoveries in superconductor- and semiconductor-based qubits, the discovery of the Majorana fermion, and the recent demonstration of teleportation between two chips separated by 3 meters. In order to enable the existing and future European high-tech industry to gain a sizeable portion of the future quantum sector, TU Delft and TNO have established joint a center of know-how with Industrial partners. The envisioned developments cover many TRL's, multiple disciplines, and thereby about 15 years. This will result in a different approach during the subsequent phases of the development.
The first phase (2014 – 2017; Proof of Principle) will be dominated by solving the current bottlenecks to accelerate the research, and by making the transition towards the mission-based way of working. The latter includes, amongst others, a better defined goal of the project, working out the project plan, system architectural considerations, and involving third parties.
The second phase (2018 – 2022; Proof of Concept) will be used to demonstrate progress on key technologies (critical milestones), benchmarking, defining the requirements and system architecture, and updating the project plan including contributions by third parties and potential spin-off. Also a relevant and

mathematical challenge shall be selected for the demonstration. This challenge shall be mapped to the electronic hardware.
During the third phase of the project (2023 – 2029; working demonstrator) all technologies shall be developed to the level of a working demonstrator. A convincing demonstration shall be executed. Positioning the Dutch industry (by knowledge transfer) is critical during this phase.

10.3.2 Short description

QuTech works according to Roadmaps. The most critical enabling technologies that will be developed during the coming years are incorporated in the most relevant Roadmap. The state of the art, knowledge gaps, and planned developments will be described per Roadmap.

10.3.3 Highlights

Topologically protected quantum computing Roadmap

In 2015 a new and very advanced system for material deposition was installed in the cleanroom in Delft. The unique MBE/ALD setup for growth of semiconductor nanowires has been installed and tested in the VLL. As first Proof of Concept, InAs nanowires have been successfully grown in the MBE in 2016. Such nanowires form a critical component to quantum computers based on Majorana quasi particles.

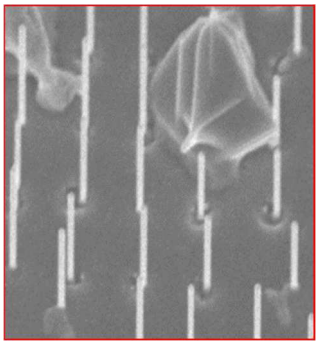


Figure 1. First nanowires at VLL.

Two other colleagues have continued the work on devices for mobility measurements. They have grown devices with perfectly flat (<1nm rms) dielectrics with conductive gates underneath. Colleagues of TU Delft will perform mobility measurements on nanowires laid on top of these devices.
One colleague has focused on 3D lithography to enable growth of nanowire crosses. Two colleagues have simulated the effects of stress, induced in nanowires upon cooling down from room temperature to 15 mK, on electron mobility.

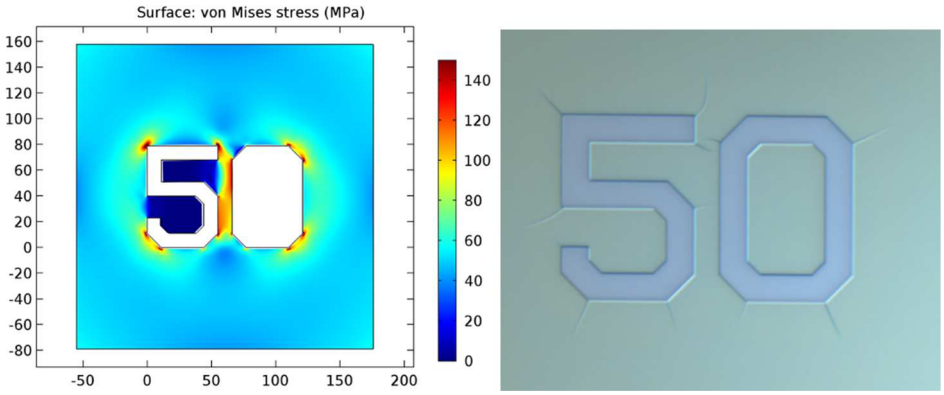


Figure 2. Stress Calculation results vs crack observations.

Two more colleagues have focused on nanowire characterization and process control for extremely well defined thin layers of superconductive material (NbTiN). One colleague has supervised these activities and work on the long term strategy: the requirements and design of the device ultimately to be used for braiding, in which all these technologies have to work together.

QuTech is still growing. New scientists and engineers are participating every month. This Roadmap has some specific dynamics due to the fact that it's Roadmap Leader (Leo Kouwenhoven) has moved to Microsoft. Furthermore, one other professor (Erik Bakkers) has decided to focus his activities to the TU/e. Unclear at this point of time is what the consequences will be for the Roadmap.

Fault - tolerant quantum computing Roadmap
Several colleagues have worked on the challenges related to the 17 or 49 transom qubits devices: the next generation of the successful vector switch matrix will be designed and built to be used for qubit control by frequency re-use. The FPGA-based feedback loop electronics, designed and built in 2015, have been tested, implemented, and used in quantum measurements. The feasibility of (coax) connections from the third dimension to the 2x7mm small device have been investigated.
For the first small size demonstrator of the quantum computer (17 and 49 qubits) the functional architecture has been defined to support full use of this system. This includes error correction functionality and automated control of simple qubit algorithms. Support has been given to the development of a quantum emulator, aimed at emulating small scale quantum systems at a very detailed level, up to 40 qubits.
Support has been given to the development of a cryo CMOS control system for spin qubits. This system is essential to allow upscaling of quantum computers to larger numbers of qubits (>50 qubits).
The successful computer-assisted tuning of double spin qubits will be extended for tuning of devices with larger numbers of qubits.

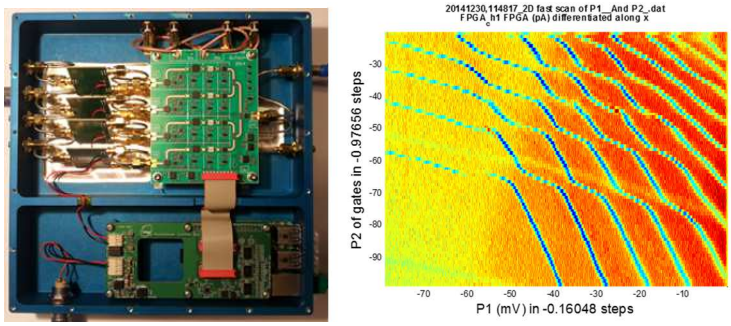


Figure 3. Vector Switch Matrix & automated qubit tuning.

A consortium of TU Delft, TNO, ETH, and ZI was granted a funding from IARPA for the development of the first logical qubit. TNO engineers delivered or contributed to:

- Sample holder design and production for surface-7 quantum chip, BGA (ball grid array) style.
- Quantum Wave Generator (QWG) for RF control of SC and spin qubits.
- Single SideBand (SSB) mixer prototype and first series production.
- Flip-chip process for spin qubits.
- Video-mode tuning: real-time feedback of the status of the quantum dots.
- Development of QCoDes, data acquisition modules.
- Automated tuning, continued from 2015: Develop algorithms to automate the tuning of the spin qubits, e.g. the tunneling rate.
- Database for fabrication (processes flow written down, common library of processes, fast and easy way to share info, continuity facilitated, process monitoring).
- Fast turnover fabrication introducing the EKL capabilities.

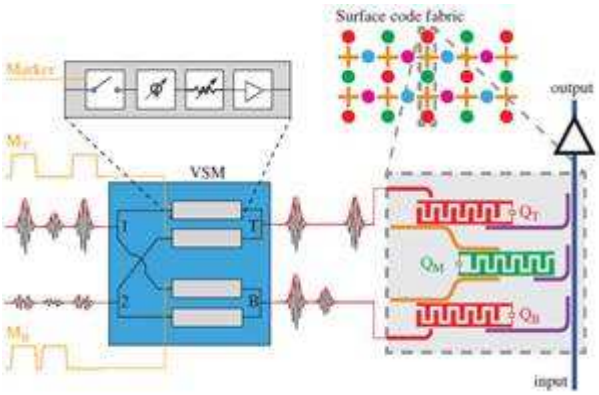


Figure 4. The electronics to broadcast microwave signals to multiple qubits as developed by TNO in 2015, has been used by scientific experiments by QuTech/TU Delft on transmon qubits in 2016. The results were published in a joint paper.

With the start of the IARPA and the Intel projects, this Roadmap has gained extra momentum. This has led to an increased involvement of TNO.

Quantum Internet and Network Computing Roadmap

Wavelength conversion, as demonstrated in 2015, has been extended to the single-photon level. Difference frequency generation (DFG) setup upgraded with new crystal and very narrow-frequency pump laser, and improved overall conversion efficiency. Design and assembly of extremely stable unbalanced (with large Optical Path Difference) fibre interferometer system for the telecom (1588nm) wavelength, with an option of active piezo-stretcher assisted stabilization of the Optical Path

Difference (OPD). Assembly of unbalanced interferometer for the visible (637nm) wavelength. Contributed to demonstrating frequency conversion of single photons from an NV-center to telecommunication wavelength. Contributed to experiments showing that the single-photon nature of the converted photons is preserved. Achieved better than 2% phase stabilization with the unbalanced fibre interferometer with an in-fibre OPD of ~40 m by accurate compensation for both thermal and mechanical instabilities, with a piezo-based feedback loop. This interferometer is a crucial component for the planned experimental demonstration of spin-photon entanglement.

10.3.4 Dynamics

The Roadmap has been steadily growing in 2016. The move of Leo Kouwenhoven to Microsoft has resulted in the promotion of Ronald Hanson as Scientific Director of QuTech. This will have an effect of his availability as QINC Roadmap leader.

Shared Development Roadmap
TNO scientist and engineers established a new concept to reach Fault Tolerance in quantum computers and new applications of quantum technologies. TNO submitted to ESA a proposal for a scientific experiment on quantum technologies a low gravitational fields, together with TU Delft, Leiden University, and satellite manufacturer OHB. TNO scientists contributed to new RVO research proposal, Roadmap Human Effectiveness, on quantum effects and a new KI research proposal, Roadmap Networked Information on Quantum Computing, on Quantum Communication and (post-) Quantum cryptography.

The organization development of QuTech continued in 2016. The interaction between the QuTech partners has been improved. New TNO personnel on management level (Jorrit van Wakeren, Garrelt Alberts) was introduced to facilitate a better interaction between TNO and TU Delft and to professionalize the interaction with B2B partners.

Overview cooperation
TNO contributed to the following papers form various Roadmaps:

- S. Asaad, C. Dickel, N. K. Langford, S. Poletto, A. Bruno, M. A. Rol, D. Deurloo and L. DiCarlo - Independent, extensible control of same-frequency superconducting qubits by selective broadcasting, NPJ Quantum Information (2), 16029 (2016).
- M.A. Rol, C.C. Bultink, T.E. O'Brien, S.R. de Jong, L.S. Theis, X.Fu, F.Luthi, R.F.L. Vermeulen, J.C. de Sterke, A. Bruno, D. Deurloo, R.N. Schouten, F.K. Wilhelm, L. DiCarlo - Restless Tuneup of High-Fidelity Qubit Gates, arXiv:1611.04815 [quant-ph].
- D. Deurloo - Microgolf-router maakt kwantumcomputer schaalbaar, Bits & Chips (Oct 2016).
- X. Fu, L. Riesebos, C.G. Almudever L. Lao, F. Sebastiano, R. Versluis, E. Charbon, K. Bertels - A heterogeneous quantum computer architecture, Proc. of the ACM International Conference on Computing Frontiers (2016).

TNO contributed to the following patents form various Roadmaps:

- TNO/ TU Delft patent filed on a new concept to reach Fault Tolerancy.
- TNO/TU Delft patent on VSM (EU filing in 2015) extended to JP,US.

TNO Scientists and engineers gave presentations at the following technology events (and various QuTech internal presentations):

- Dutch RF-Conference: D. Deurloo - Microwaves for quantum.
- QCIT Workshop: D. Deurloo – Sample holder design.
- APS March meeting: W. Vlothuizen - Flexible, low-latency architecture for qubit control and measurement in circuit QED.

11 VP Flexible and Freeform Products (3F)

11.1 Roadmap Components and Circuits (Holst)

11.1.1 Summary

Our ambition is to develop and use smart- and low-cost methods to make simple electronic circuits that bring intelligence and interactivity on everyday objects that then become ‘smart’ in line with the vision of Internet of Things.

11.1.2 Short description

TNO-Holst Centre develops microelectronic components and circuits on unusual substrates such as plastics, rubbers, textile and paper. Using these substrates rather than the conventional silicon or glass makes the final electronics bendable, flexible and even stretchable. It open up all sorts of new applications. For example, displays that you can fold up and put in your pocket. Or, flexible body patches that help us understand what is happening inside our bodies. Furthermore, flexible electronics might cost less to make. Because of the multidisciplinary character of the technology challenges, this ambition is realized in close collaboration with industrial partners along the entire value chain: material suppliers, equipment builders, technology integrators and end-users working together in Shared Research Programs.

11.1.3 Highlights

- In recent years, there has been a growing interest of the automotive industry to deploy printed electronics technologies for various interior and exterior car parts. In 2016 this resulted in the partnerships of Faurecia and Enmech in Holst Centre’s printed electronics program. Faurecia a world leading automotive interior manufacturer. It would like to use printed electronics technologies to ‘augment’ the interior. For example adding touch functionality to a large part of the car dashboard. But also for adding ‘mood’ and safety lighting functionality to door panels. Enmech is an automotive supplier manufacturer that is already using printed electronics technologies. For example to realize printed heaters, LED strips for side view mirrors etc. A demonstrator that was made in the field of automotive interiors in 2016 is shown in the Figure below.

Photograph of automotive interior demonstrator made at Holst Centre.

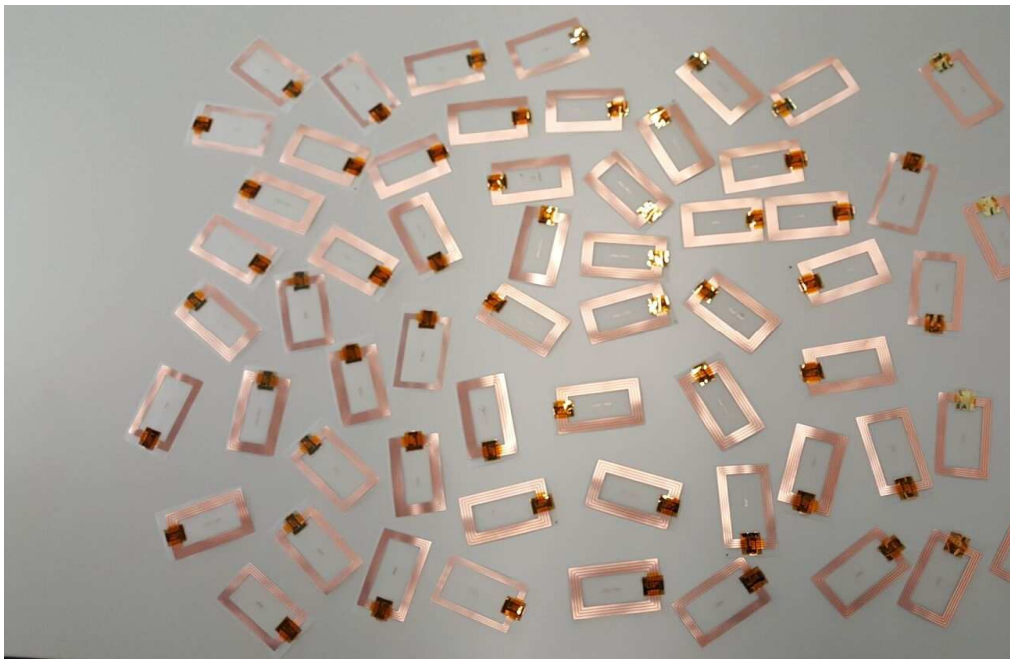
- Holst Centre already works for a number of years on health patches. In 2016, the functionality of the patch has been expanded with bio impedance. Moreover, for the first time, a significant number (250) of health patches have been fabricated at the Holst Centre pilot facilities. These health patches were also used for first clinical studies. The Figure below shows the most recent embodiment.

Photograph of the most recent health patch (measuring ECG and bioimpedance) made at Holst Centre. This patch has been made in a small series (250 pieces).

- A major car manufacturer joined the batteries program to conduct a feasibility study on 3D solid-state batteries suitability for automotive applications. The technical progress has been on the modelling of energy density, reproducible patterning of the pillar bases and deposition of the Lithium anode on Ni pillars. One of the work packages making high-aspect ratio structures has also been

appealing to Philips Healthcare for an application in a fully different field: a nice example of cross-fertilization.

- High-resolution transistor backplanes were made using new materials, processes and transistor architecture (with smaller footprint). Prototype displays were demonstrated at premier display events, such as SID, IMID, IDW and Touch Taiwan. The same backplane technology was used to realize curved photodetectors, as well as wireless identification tags. together with the Flemish company Cartamundi, Holst Centre and imec were awarded the Best Product Award from Printed Electronics Europe for the work on RFID tags integrated in paper cards.



Photograph of 60 flexible, ultrathin RF ID tags that can be integrated in a playing card and used in new electronic and interactive games.

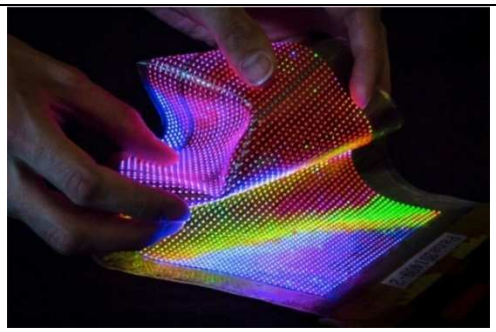
11.1.4 Dynamics

No major change in direction is foreseen. Wearable electronics and IoT (integration of electronics in everyday objects, like automotive interiors) continue to be key drivers for our technology development. Three important trends continue: (i) a stronger focus to bring technologies to a higher TRL level, and (ii) combine the technologies to enable new product categories, (iii) small pilot line production for early market development studies. Our activities take place in the frame of the PPS programs executed by Holst Centre. The multi-year Roadmaps of the programs are also in line with the HTSM Roadmap Component and circuits. Holst Centre has an active role in shaping the Roadmaps of international fora such as the Organic Electronics Association (OE-A), Photonics 21 and INEMI. These activities (amongst other things) have also in 2016 led to a well above average success rate for Holst Centre in competitive funded projects such as H2020 and Ecsel. European project that have started in 2016 or will start in 2017 are: InScope, CAPID and PYCSEL.

11.2 Roadmap Lighting (Holst)

11.2.1 Summary

Energy efficient solid state lighting is set to replace traditional light sources, bringing huge reductions in global energy consumption. It is expected that by 2020 solid state lighting will account for around 60% of the 100 B€ global lighting market value. There are two solid state lighting technologies: LEDs (point source) and OLEDs (large area patternable source). As solid state lighting is becoming the dominant lighting technology, the market focus is shifting from energy efficiency to smart lighting, based on integration of LEDs and OLEDs into larger systems and the additional features and functionalities that these devices can offer. Holst Centre/TNO's vision is to realize the potential to create next generation free form , robust, ultrathin (<0.2 mm) films of OLEDs and LEDs with customized designs. Examples of such OLED (here semi-transparent) and LED (here a stretchable matrix) lighting films are shown in the left and right hand side of the Figure below respectively.



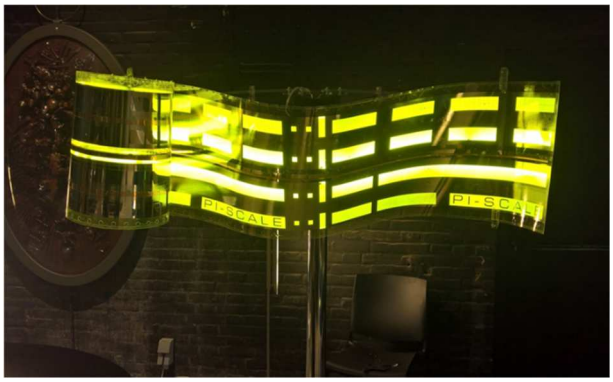
During the past 5-10 years, Holst Centre has developed key expertise in the areas of: 1) high performance moisture barrier technology that prevents degradation of the flexible OLED devices, 2) large area deposition of OLED materials by R2R solution processes, and 3) fabrication of stretchable matrices of ultrathin LED devices and other components.
For 2017 the goal of Holst Centre/TNO is to fabricate customized lighting films, and to help companies from diverse application areas seamlessly integrate these into novel products that are only made possible by having such free form, ultrathin layers of light. The European flexible OLED pilot line service, established in 2016 and funded by the EU for the first 3 years (PI-SCALE), will also be able to accept new customers from mid 2017 and will offer upscaled prototyping services with a capacity of up to 5000m^2/OLEDs/year. The intention is that after using the pilot line companies will have fixed their flexible OLED product design and be ready to go to a mass manufacturer. This pilot line combines the knowhow and infrastructure of Holst Centre, Fraunhofer FEP, VTT and CPI, and is intended to increase access to, and awareness of, flexible OLED technology. Holst Centre/TNO will also continue to work on lowering the manufacturing costs of flexible OLEDs, by further optimizing moisture barrier technology and establishing a stable, multilayer solution coating (not in vacuum) process for deposition of OLED layers.
In 2017, the work on LED light sources will focus on further increasing the resolution of the information display, and on manufacturing and product integration processes. In particular, work will focus on form factor: large area LED based systems that are either stretchable or formable so they for example be integrated into automotive interiors or clothing.

11.2.2 Short description

The technical ambition of the OLED lighting program at Holst Centre /TNO is to develop a production process for customized flexible OLEDs at a cost of less than 100 €/m^2 (or <10 €/klm) (a reduction by a factor of 20 compared to commercially available rigid glass-based devices), with an efficacy comparable to glass-based OLED devices (at least greater than 50 lm/W) and a resistance to degradation by water which allows device lifetimes of at least 5 years by 2018. It is also the intention that other application specific device requirements are met and product integration issues (for example lamination, and combination with other ultrathin electronics) are addressed. For LEDs the ambition is to develop the enabling technologies for realizing stretchable and formable matrices of LEDs that can be individually addressed. Such matrices are useful for signage applications but also for mood lighting luminaires (e.g. Philips Hue). Key to its shared innovation model, Holst Centre/TNO has the ambition to bring together value chains and ecosystems of companies for the fabrication, integration and commercialization of flexible OLED devices and to stimulate and educate industry around design and integration of flexible OLEDs and LEDs into novel products for diverse application areas. Through all of this we hope to enable secured and reinforced industrial technology leadership of Europe in the global lighting market.

11.2.3 Highlights

During 2016 there were a number of key achievements in the development of flexible OLED production processes at Holst Centre/TNO which have implications for the targeted results for 2017. Firstly, the roll-to-roll moisture barrier tool is now able to produce very high performance single SiN moisture barrier layers with WVTR of 10^{-6} g/m^2/day and very low defect densities of <0.03/cm^2 on km length scales. Secondly, Holst Centre's state of the art multilayer solution coating tool has been used to continuously coat two OLED layers on top of each other and working devices were made from this, demonstrating the feasibility of continuous multilayer solution coating for fabrication of OLEDs. Thirdly, flexible OLED devices with optical transparencies of 80% were fabricated by using novel electrodes. This is significantly better than the transparencies of standard worldwide OLED technology, which is typically only 50-60%. In addition the EU funded PI-SCALE flexible OLED pilot line project began, and saw process flows with devices made on combinations of the tools at Holst Centre, Fraunhofer FEP, VTT and CPI. Successful sheet-to-sheet and roll-to-roll flexible OLED device fabrication runs were performed, demonstrating the distributed pilot line concept can work (see Figure showing patterned R2R OLED of 30 cm width, 1.8 m length cut from a roll of 15 meters length). These process flows also include deposition of flexible electrodes in R2R processes. In addition, Holst Centre/TNO worked on several flexible OLED integration projects, for example for partners in the automotive industry. An example of OLED devices (blue/green light emission) within a console made by thermoforming various thin film flexible electronics components is shown in the Figure below.



In previous years, work has been done on integrating LEDs on foil to realize flexible lighting modules. Clothing industry has been one of the end user customers interested in this technology. In 2016, a concrete prototype of a ‘nighttime visibility running shirt’ went into mass production. A photograph of the final product is shown in the Figure below.

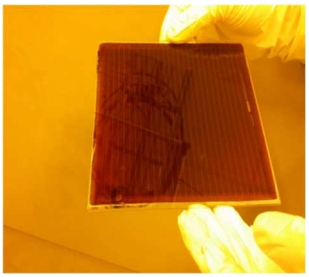
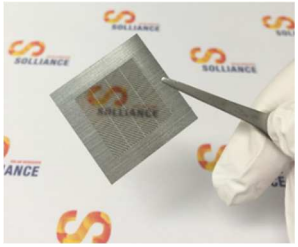
11.2.4 Dynamics

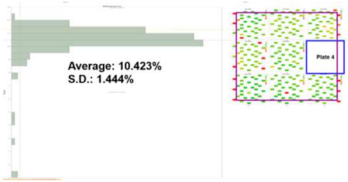
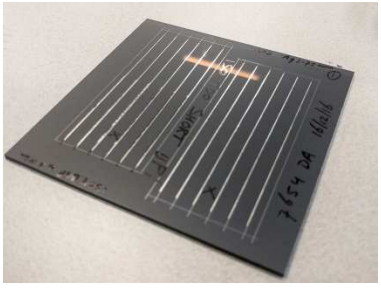
2016 has seen the first commercially available flexible OLEDs for lighting from LG enter the market. The first (rigid glass) OLEDs for car taillights were also released in the AUDI TT in the summer of 2016. This is a very important proof of the viability of (flexible) OLEDs for various lighting applications. As a result we see a shift away from the need for Holst Centre/ TNO and its partners to demonstrate feasibility of the first generation of flexible OLEDs. We can now work on helping companies develop application specific customized flexible OLED designs and on solving product integration issues. We are helping increasing numbers of companies that don’t have a background in OLED technology, but would like to use it in their product, and who are not yet ready to go to a mass producer. The needs of these diverse application areas for customized flexible OLED lighting (which now extend far beyond general lighting) are driving our development of the next generation of functionalities for this technology. For example cost performance targets related to moisture barriers, optical transparency of devices, device structures that will survive specific product integration processes, thinner and more flexible device, and integration of OLED or large area LED devices with various other thin film electronics at system-level.

11.3 Roadmap Solar (Solliance)

11.3.1 Summary

In 2016 good progress has been made in the Solliance programs (Perovskite based PV, CIGS and thin film PV integration). Key achievements were realization of large-area upscaled Perovskite PV modules, an operational back-end tool and working back-end interconnection process for CIGS and successful integration of flexible CIGS modules in the SolarRoad. Some pictures of these realizations are shown below.

			
10% PSC glass module (168 cm^2)	6% PSC flexible module (168 cm^2)	14% cSI/PSC tandem module (64 cm^2)	Translucent PSC mini-module (4 cm^2)

		
Performance homogeneity of 30x30 cm^2 ECD produced CIGS wafers	First-ever in-line (BEEP) processed back-end interconnected CIGS module	Operational and fully installed BEEP tool

		
Flexible CIGS modules integrated in SolarRoad	Solar powered street lighting element with integrated flexile CIGS modules	Greenhouse equipped with integrated flexible CIGS screen

11.3.2 Short description

Crystalline Silicon PV modules dominate the rapidly growing PV market, but also the market volume of thin film PV devices is expected to increase dramatically in the coming decade. This will be especially the case in integrated applications,

where thin film PV offers more freedom to adapt to demands on size, shape, appearance and electrical properties.

Ambition of the Solliance Shared Research Programs is therefore not only to provide process and equipment solutions for low-cost high volume production, but more importantly also for integrated products and (building) components, through custom designed free form PV module formation ("Smart Industry for PV") followed by adaptable automated integration processes.
In addition, it is generally expected that the next leap in efficiency improvement of PV modules will be enabled by combining crystalline Silicon and thin film technologies in tandem structures. Ambition is here to develop device solutions where high band gap thin film absorbers are combined with transparent electrodes, to be used in tandem with crystalline Silicon.

As defined and set up in 2015, the overall Solliance approach currently still considers 3 main steps:

1. Technology scouting and development, i.e. Research & Development projects for New Materials, Processes and equipment (NMP) to be implemented for CIGS and/or Perovskite based PV (PSC) up-scaling purposes.
2. Platform development and implementation, i.e. released combination of processes, materials and equipment with reproducible results for demonstrating manufacturability of high efficient and stable CIGS and PSC modules.
3. Integration of thin film PV for the following applications: Infrastructure Integrated PV (IIPV), Building Integrated PV (BIPV) and Vehicle Integrated PV (VIPV).

The first two steps are performed in both the CIGS and Perovskite programs. These programs are guided by the industrial partners of the respective programs as well as by market driven interests for specific integrated PV applications. Main goal is to develop and demonstrate high performing CIGS and PSC PV modules produced with (possibly novel) scalable and cost effective tools and processes.

The third step aims to demonstrate thin film PV integrated prototype products and demonstrators, either based on Solliance's own CIGS or PSC PV modules or based on third party thin film PV modules. In a next step, cost effective tools and processes (possibly novel) need to be developed for future production of these integrated thin film PV products. These which can be cost effective manufacturing processes. These integration processes are defined and developed in the integration program and can also guide the most desired semi-finished module product lay-out as developed in the CIGS and PSC program.

The intention is to initiate new industrial activities on thin film PV integrated product manufacturing and potentially on setting up new thin film PV production plants in the Netherlands, as it is believed that manufacturing of integrated thin film PV products will be economically more relevant as this is done locally at the place of implementation.

The programs consist of a list of clearly described deliverables (as defined by the R&D partners of Solliance together with the industrial partners) that pave the way towards the overall program end goals for in about three years.

11.3.3 Highlights

Perovskite Solar Cells (PSC) Program

- Two additional industrial partners (apart from DyeSol and Solartek that became already partner in 2015) entered the program: Panasonic and Heraeus.

- 10% efficient upscaled and packaged modules on glass/ITO of 15x15 cm^2 were produced. At that time (March 2016) it was a world record.
- 6% efficient upscaled and packaged flexible modules on PET/Ti of 15x15 cm^2 were produced. At that time (October 2016) it was a world record.
- A 14% efficient large area (64 cm^2) fully integrated 4 terminal cSi/PSC tandem module was produced. At that time (March 2016) it was a world record.
- A 14,7% efficient semi-transparent PSC cell was produced and combined in a four terminal tandem configuration with a cSi solar cell which yielded an unprecedented 21% tandem efficiency or an absolute efficiency increase of 2,4% compared to standalone c-Si cell with an efficiency of 18,6%.
- A world record of 16,5% cell efficiency of a PSC solar cell on plastic (PET) was realized.
- The two first photo-active layers of this stack have been successfully processed on the R2R slot die coating line. Already over 500 meters of perovskite material was processed on PET foil so far.
- A new stable high efficient baseline (19,5% cell efficiency) on glass was developed for future upscaling.
- First ever almost colorless translucent PSC mini-modules where produced with bias-able transparencies (between 25 and 80%) with a linear dependency of the module efficiency. This could be very important for future windows applications (buildings, vehicles).
- The water sensitivity of the PSC stack could be drastically reduced by applying a very thin spatial ALD layer on top of the Perovskite, while on the same time the absolute efficiency increased with 2-3%.
- The thermal stability could be substantially improved by applying very dense layers (either by (s)ALD or evaporation) on top of the perovskite layer (transport layer and/or electrode and/or additional top layer and by modifying the perovskite composition by using larger cations and smaller anions.
- The observed hysteresis during the IV measurements could be substantially reduced by optimizing interlayer composition and deposition and by optimizing further the perovskite composition.
- The program attracted many attention which resulted in several press releases, a large number of invited presentations, a lot of industrial visits to the Solliance premises and several new collaboration proposals under negotiation (so called “hot leads”).

CIGS Program

- ADPV became partner of the CIGS Program.
- For this, a baseline manufacturing process, based on electro-deposition of the CIGS precursor was set up to enable the production of 30x30 cm^2 CIGS wafers with an average efficiency of 10,5%, homogeneously on the wafer. This could be realized in only 3 months. Goal is to demonstrate minimum 15% efficiency end of May 2017.
- The back-end interconnection process, that will allow fully digital production of free form modules for any thin film PV technology was further optimized for CIGS. At the same time the back-end enabler processor tool (BEEP) was further integrated. At the end of 2016, the first-ever in-line processed CIGS module was demonstrated on the BEEP with a 6,6% efficiency. Further improvements should result in at least 12% efficient 30x30 cm^2 modules by Q2 2017.

- As part of this, an innovative solution was developed to enable shunt-free laser scribing of the CIGS layer stack down to the back electrode. This attracted interest of leading CIGS manufacturers, and it was shown that this solution also worked on different kinds of industrial test samples.
- World's first spatial ALD of aluminum oxide layers on 30x30 cm rigid glass plates was successfully demonstrated on the large area ALD tool that became operational mid-2016. These layers will be applied as barrier- and passivation layers for CIGS.
- On smaller scale, successful combination of an aluminum backreflector with an ALD barrier/passivation layer was demonstrated for CZTS cell formation.
- CIGS deposition on light reflecting textured back surfaces, obtained by nano imprint, was demonstrated with improved conformality.
- Solliance was one of the co-authors of the international CIGS white paper (http://cigs-pv.net/cigs-white-paper-initiative/).

Integration Program

- End of 2016, flexible CIGS modules were successfully integrated in the SolarRoad (next to further optimized cSi PV panels). Using flexible PV modules will allow to move towards a much more efficient integration of PV into roads.
- A working greenhouse screen demonstrator has been produced based on flexible CIGS mini-modules.
- First steps were set to integrate flexible CIGS modules in façade panels.
- It was shown that semi-fabricate CIGS modules can be formed in any shape and size (including transparency).

Materials Transition Program

Within the Thin Layer Manufacturing part of the Materials Transition Program progress has been made with the atmospheric plasma spatial ALD technology. It became possible to create more variation in material selection in order to deposit and built gradual structured layers with nanometer resolution. This had led to the realization of two new spatial ALD prototype machines at semi-industrial scale, a sheet-to-sheet spatial ALD reactor to be used for display applications and a rotational ALD tool to be used for thin film battery processing.

11.3.4 Dynamics

PSC Program

For 2016, 45 technical deliverables were agreed and defined together with the program partners, in order to have a clear stepping plan for the development of the PSC platforms. Al this is described in the Technical Annex. At least 41 deliverables have been reached and of each deliverable a technical report has been written in order to safeguard the developed know-how for the future.

For 2017, the three different PSC platforms aim to reach the following module performances:

1. Rigid non-transparent platform: 15% efficiency for an upscaled module on glass of 15x15cm^2 with a stability of ≤ -20% efficiency loss @ 85^{0}C/85%RH/1kh.
2. Flexible non-transparent platform: 10% efficiency for an upscaled module on foil of 15x15cm^2 with a stability assessment (losses determined @ 65^{0}C/85%RH/1kh.
3. Rigid transparent platform: 12% efficiency for an upscaled module on glass of 15x15cm^2 with a stability of ≤ -20% efficiency loss @ 85^{0}C/85%RH/1kh.

In order to reach these ambitious goals, a set of intermediate deliverables has been defined and described in the Technical Annex 2017 and pre-defined sub-teams will work on these for realizing these.

CIGS Program
The Shared Research Program for CIGS/CZTS comprises 6 main activities, with the following milestones/results, as described in the Technical Annex.

Short term:
1. Development of a CIGS module production process based on electroplating. Solliance is one of the few institutes in the world with this capability, and the work is performed together with industrial residents of participating companies and external advisors. The first milestone for this activity is to achieve a cell efficiency of 15% by mid 2017, resulting in a module efficiency of 12%.
2. Development of process and equipment for back-end interconnection of CIGS modules. Many CIGS manufacturers wish to process their modules with a back-end process but so far no commercial solution is available. Solliance is world-wide unique with a laser technique to make shunt-free back-end interconnections. The target is to prove on industrial CIGS materials that such a back-end interconnected module works as good as the traditional in-line interconnected module. Target is demonstration of an interconnected module with 1,5% (absolute) better efficiency than a traditional in-line interconnected module by mid 2017.

Mid term:
3. Improve CIGS module efficiency by application of passivation layers at the absorber interfaces. Focus is on deposition of such passivation layers by fast Atomic Layer Deposition, and creating contact holes by nano imprint technology.
4. Evaluation, prediction and improvement of the performance reliability of CIGS modules. Facilities for accelerated lifetime testing in combination with real time performance measurement have been developed with Dutch equipment partners, and are used to detect life time limiting factors in the CIGS device. Based on this knowledge, improvements towards extended lifetime are developed. Current focus is on encapsulation, transparent conductors with improved corrosion resistance, and influence of alkalis (Na, K) in the absorber.

Long term:
5. Development of CIGS on flexible foil. The feasibility is studied of using the (HyET) temporary substrate method for low-cost fabrication of light weight flexible CIGS with polymer encapsulation. Together with external partners, also specific process steps for the manufacturing of CIGS on flexible metal substrates are addressed.
6. Study the feasibility of a high-bandgap absorber based on modifications of CIGS/CZTS (15% efficiency), aimed at realization of high efficiency tandem concepts in combination with crystalline Silicon. Material development is performed by Solliance partners, while TNO participates in process development and evaluation.

Integration Program
Smart production for on demand custom fit thin film PV modules will be made possible through the concept of end-of line (“back end”) monolithic interconnection. Aim of the program is to create business cases for automated manufacturing of PV integrated (building) components and flexible/colored/transparent/free form modules for optimized integration in products. New production concepts, where thin film PV is first mass produced at low-cost, and then in a second stage (locally) tailored for customer specific module designs will be made possible. A very important factor will be the aesthetics of integrated PV, as the desired introduction of much larger scale application of PV energy generation would be greatly enhanced if the current public

acceptance of PV technology can be maintained: this will require aesthetic and cost-efficient integration of PV in the (built) environment. Since the COP21 agreement in Paris end of last year, the interest in integrated PV products has been increased exponentially. Hence, we believe that Solliance has an unique position to enable launching new integrated thin film PV product, together with industrial partners, in the near future.

This year a new technical annex will be set up. The program is envisaged to target three main application areas being building integrated PV (BIPV), Infra structure and transport. The former two topics are backed with ongoing projects, the transport topic will be further explored and medio 2017 a decision will be made what the activities in this area will be. The program will have four work packages covering the generic technology developments:

- **Electrical Integration** of cells and submodules (semi fabricates) into modules which is dealing with shaping, contacting, soldering, routing issues. Also the electrical back-end systems are part of this work package.
- **Encapsulation**, compatibility and integration with **manufacturing technology**. Dealing with material science related issues such as heat, stress, pressure resistance, of semi fabricates. Making logical combinations of functionalities.
- **Innovative Module Architectures** deals with shadow tolerance, application specific architectures, reliability manufacturability of complex architectures, and application specific electronics.
- **Demonstration and prototyping** deals with the Design, validation and manufacturing of prototype demonstrators up to TRL 6. Were possible in cooperation with industrial parties.

11.4 Roadmap Printing

11.4.1 Summary

Additive manufacturing will play an important role in specific manufacturing chains, based on the benefits of customization and personalization, freedom of design and cost effective small-scale and on-demand manufacturing. TNO focusses on the development of next generation additive manufacturing equipment and technology for manufacturing chains for free form electronics, 3D pharma, 3D food and high-tech application domains. For this, TNO builds strategic alliances with complementary (inter)national R&D partners and strongly engages its large (inter)national network of material companies, equipment manufacturers and end users in shared and bilateral (B2B) innovation programs. These innovation programs are designed to develop world-class, next generation, additive manufacturing technology to enable or accelerate additive manufacturing innovations by companies along the additive manufacturing value chain.

To address the identified needs related to product quality, capabilities, productivity, and integration in production chains, TNO co-founded two initiatives. The materials challenges are addressed in the ‘Materials for AM’ program, which is part of the Brightlands Materials Center (established in 2015). The equipment and system challenges are addressed in the AMSYSTEMS Center, a new research center established together with the High-Tech Systems Center – TU/e in 2016.

The ‘Materials for AM’ program focuses on improved material performance (mechanical as well as geometrical quality) and new material functionality. In 2016, the PhD program on improved material performance was established. A number of

PhD projects is defined to improve the mechanical integrity of photopolymers and thermoplastic materials. In addition, a number of PhD projects was defined to address bio-medical 3D print challenges, including the development of scaffold technology. Also, a study into photopolymers for thermal management was executed, targeting at improved heat transfer capability for 3D print applications.

The AMSYSTEMS Center focuses on the development of new multi-material/multi-technology Additive Manufacturing equipment concepts. AMSYSTEMS targets high-tech, 3D printed electronics, 3D food and 3D pharma markets with spin-off to other markets that require personalized, customized, on-demand manufacturing. AMSYSTEMS focuses on the integration of multi-material AM technologies in mass-customization production equipment, making it an integral part of a 'next generation industry' approach. AMSYSTEMS Center has a strong link with the Dutch Smart Industry action agenda and established the Fieldlab MultiM3D. Furthermore, TNO and HTSC-TU/e successfully applied for a grant from the Toekomstfonds to invest in the Printvalley2020 pilot line. In addition, a PhD program with ~10 PhD projects started and several Public Private collaborations and B2B projects were acquired, including the strategic collaboration with BigRep to develop an industrial AM printer for spare part manufacturing.

11.4.2 Short description

Based on the trends of digitization of the manufacturing industry, decentralized manufacturing (reshoring of the industry) and the increasing need for personalized and customized smart products, we envision a future smart factory in the personalized centric world, with an extensive ICT infrastructure in combination with flexible, single product manufacturing cells, allowing small-series customization at large-series manufacturing cost level.

Additive Manufacturing (AM) is an enabling technology for such a future factory, and has numerous advantages compared to conventional subtractive manufacturing. It enables the manufacturing of complex, personalized and customized products at low-cost. AM also offers the possibility to introduce multi-material products or parts with material gradients. Integration with design tools and CAD software will enable AM to create significant impact on both time and cost savings, as well as inventory, tooling, supply chain management, assembly, weight, and maintenance. By utilizing numerous state of the art technologies such as pick and place, dispensing of viscous materials, sintering etc., Additive Manufacturing can leap itself from merely producing bespoke dump parts to building smart objects. Such advanced manufacturing will be an enabling technology for many applications, such as embedded and smart integrated electronics (Internet of Things, smart conformal and personalized electronics), complex high-tech (sub-)modules, human centric products (like dentures, prostheses, implants), etc.

To address the identified needs related to product quality, capabilities, productivity, and integration in production chains, TNO co-founded two initiatives. The materials challenges are addressed in the 'Materials for AM' program, which is part of the Brightlands Materials Center (established in 2015). The equipment and system challenges are addressed in the AMSYSTEMS Center, a new research center established together with the High-Tech Systems Center – TU/e in 2016.

11.4.3 Highlights

The 'Materials for AM' program (part of the Brightlands Materials Center, BMC) aims to develop functional polymer-based materials suitable for state of the art as

well as new AM technologies, in order to obtain functional products with good long-term performance. In particular, improving strength and durability is an important goal to expand the applicability of AM materials for different applications, but also customizing optical, electrical and other functional properties. Focus will be on photocurable and other thermoset polymers and polymeric composites, in particular those processable by vat photo-polymerization and large-scale patterned illumination. Since material performance is strongly dependent on the process settings and conditions, models are used to find the optimal process settings and the sensitivity of the process. Also, enabling multi-material AM processing is an important driver. Target applications include human centric products (such as dental products, medical microfluidic devices, or organs-on-a-chip) as well as optoelectronic products. For human centric products, biocompatibility of the developed materials is an important requirement.

In 2016, the PhD program on improved material performance was established within BMC. A number of PhD projects is defined to improve the mechanical integrity of photopolymers and thermoplastic materials, including computational modelling of viscoelastic non-isothermal sintering processes, experimental characterization of the sintering process, and the study into structure and mechanical properties of sintered PA12, mechanical properties for photocurables, modelling the 3D printing of electromagnetically active components (Konstantinos), multiphysics modelling of 3D printed STL process. Also a number of biomedical projects was started, including a study in memory shaped mechanically instructive scaffolds, 3D scaffolds for specific tissue regeneration, improved thermoplastic polymers with enhanced bioactivity, reversible networks for 3D printing materials, standardizable products based on thermoplastic polymers or hydrogels, 3D (bio)printed scaffolds for cardiovascular regeneration and 3D bio-printed cell-laden hydrogels for internal organ regeneration, 3D manufacturing of plastic products by melt jetting. In addition, a study into AM Photopolymers for thermal management was executed. For thermal management in 3D printed molds, integrated cooling channels and 3D printed structural electronics applications, materials with sufficient thermal conductivity are needed. While the thermal conductivity of photopolymers is typically around 0.2 W/m.K, values of at least 1 – 5 W/m.K are required for the identified applications.

The AMSYSTEMS Center focusses on development of new multi-material/multi-technology AM concepts and the integration of these technologies in mass-customization production chains, making it an integral part of a ‘next generation industry’ approach, and aimed at stimulating the competitiveness and growth of the Dutch industry. AMSYSTEMS Center offers a mix of shared research and contract research, to serve the needs of the industry. The AMSYSTEMS Center has a strong link with the Dutch Smart Industry action agenda, has established the Smart Industry Fieldlab MultiM3D and received an investment grant for a pilot line additive manufacturing (PrintValley2020). The center brings AM concepts from prototyping to industrialization with emphasis on new functionality and cost effective manufacturing while maintaining system flexibility, stability & reliability. The center activities focus on the development of: 1) new concepts for multi-material/multi-technology digital manufacturing, 2) high-speed and continuous AM technology, 3) in-line metrology technologies, and 4) novel integration and ICT architectures. Thermo-mechanical models are developed to support the development of high-speed single pass SLS processes and to support one-time right manufacturing concept development. Models are also used to increase the manufacturing accuracy by adjusting the design for aspects as internal stress and shrinkage. The AMSYSTEMS Center targets high-tech, 3D printed electronics, 3D food and 3D pharma markets with spin-off to other markets that require personalized, customized, on-demand manufacturing.

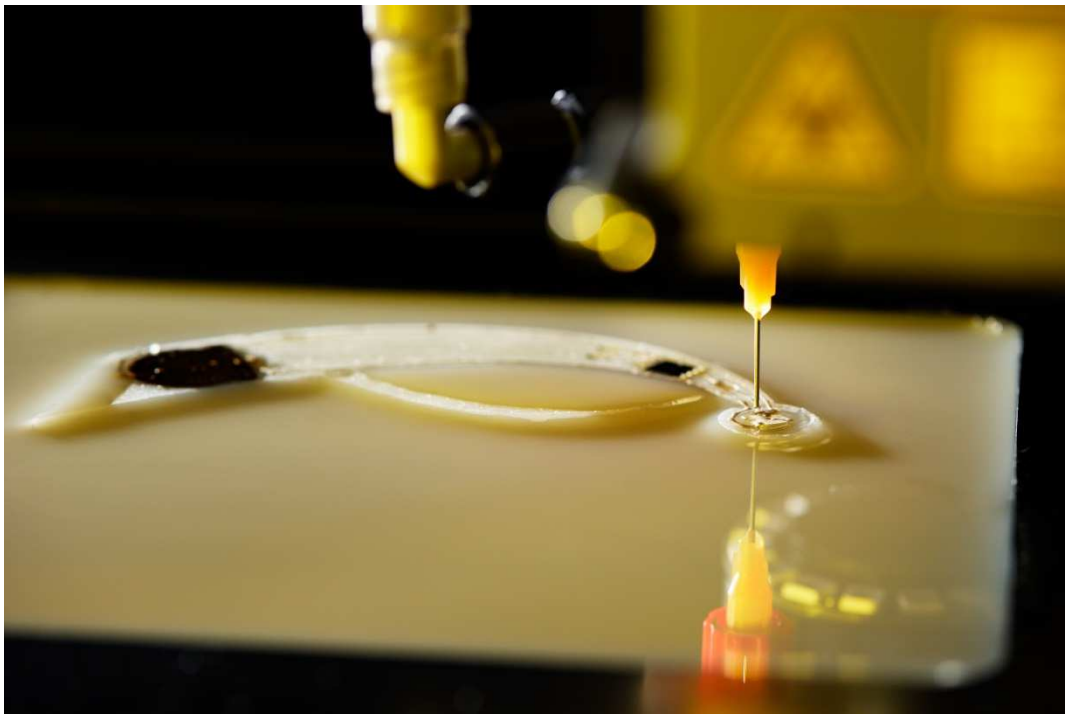
In 2016, the Dutch Smart Industry Fieldlab MultiM3D was established, with +15 partners collaborating on multi-material AM use cases, such as 3D printed electronics, ceramics and multi-color dental. Furthermore, TNO and HTSC-TU/e successfully applied for a grant from the Toekomstfonds to invest in the Printvalley2020 pilot line for continuous, multi-material hybrid manufacturing. The PV2020 will be located in the MultM3D. In addition, a PhD program with ~10 PhD projects started on the topics of large-scale ceramics, 3D food texture and 3D printed electronics. Also, several Public Private collaborations on hybrid integration were established, among other the collaboration to develop post-processing technology for AM parts, and the strategic collaboration with BigRep to develop an industrial AM printer for spare part manufacturing.

One of the key objectives of AMSYSTEMS Center is the development of laser-array based technology for in-line SLS (thermal sintering) and SLA photo-polymerization) for mass-customization application. For this, high-speed polymer material deposition (~10cm*10cm area), high-speed laser-array laser photo-polymerization and sintering (target 1 m/s) and system integration need to be developed. The patented laser-array based additive manufacturing systems were further developed in 2016. The field of application includes, among others, hybrid manufacturing (Printvalley2020), insoles and spare parts. A concept system was developed, based on 8 carriers, for continuous manufacturing of footwear parts, including midsoles and insoles. The technology will be commercialized by a TNO supported startup initiative. Future exploitation of the continuous hybrid AM technology and in-line technology is foreseen in other markets as well (like the post-processing @ AM parts, smart manufacturing of watches, Neuchatel).

Close up of a laser engine for single-pass high-speed selective laser-sintering.

For SLS, the thermal history during build of a product is one of the key parameters that determine material performance and accuracy of the part. A virtual selective laser sintering simulation tool was developed for product modelling to be used for design optimization and machine planning. For this purpose the tool was optimized for speed. To guarantee the required accuracy, the model was fitted and validated based on a test methodology using the final AM equipment.

Another development is the further advancement of multi-material AM technology, including design, materials, processes and deposition concepts (mainly polymer-based, composites, ceramics). Within the MultiM3D, a project on 3D printed large SiC/SiN ceramic parts for high-tech applications started. The program '3D Printed Electronics' started in 2016 as well. The combination of Additive Manufacturing and structural electronics will unlock new areas of "intelligent/smart" 3D printed products. In 2016, technology building blocks for conductive track deposition and hybrid integration of components were developed and integrated in the high-speed multi-laser SLA platform. First demonstrators were made in 2016, showcasing the potential of electronics integrated in 3D printed parts. The multi-laser array technology, used for high-resolution, high speed photo-polymerization, was further improved to demonstrate high-quality polymer manufacturing, with resolution down to 30 micron, and sizes beyond 10 cm.



Close up of the high-speed stereo-lithography printer with integrated conductive track printing for 3D printed electronics applications.

Collaborations with industry and academic partners were established to develop models for thermal additive manufacturing, including a multi-year collaboration with NLR, M2i, UTwente and TU Delft on thermo-mechanical modelling and topology optimization (2 PhD projects), and representation in a number of EU projects. A thermo-mechanical design tool for SLM processes was developed and validated. Also a number of use cases was validated with the developed model. New opportunities in the field of models for multi-material AM will be considered, among others via new EU projects or via a new PPS program.

Materials Transition Program

The Materials Transition Program together with NLR and M2i in the field of thermal models was successfully continued. Collaborations with industry and academic partners (TU Delft, UTwente) were established to develop models for thermal additive manufacturing, including projects on thermo-mechanical modelling and topology optimization (2 PhD projects). A thermo-mechanical design tool for SLM

processes was developed and will be further detailed and validated in 2017. Also a number of use cases, addressing manufacturing challenges, will be validated, in particular challenges related to material properties induced by temperature variation and process conditions.

11.4.4 Dynamics

The existing activities in the field of vat technology @ dental applications will be continued via the 'Materials for AM' program. Focus will be on improved material performance (high-tech polymers), multi-material and multi-technology AM (polymer composites, crowns & bridges with good mechanical and esthetical properties).

The MultiM3D Fieldlab is designed as a network organization and collaboration platform to orchestrate and facilitate co-creation along human-centric and high-tech customization applications with industrial and academic partners. Within the Fieldlab, multi-material/multi-technology research projects on ceramics, multi-color and 3D printed electronics are executed, the developed knowledge to be transferred to industry and other application Fieldlabs. Fieldlab projects synergize with other PPS programs e.g. ceramics and free form electronics. Within this Fieldlab, a collaboration with ECN on ceramic technology and applications is established. Also, the PV2020 will be located in the MultiM3D Fieldlab.

11.5 Roadmap Healthcare

11.5.1 Summary

This year we developed a miniature selective ion sensor for dialysis, we developed a hand-held fundus camera for diagnosing eye diseases in primary care and we developed and tested an optical device for cancer screening.

- We develop a miniature selective ion sensor (Na, K, Ca) to enable personalized haemodialysis and the reuse of dialysate in portable artificial kidneys. We have demonstrated that a low-cost compact laser with a pulse energy of only 170µJ is able to create a stable plasma in dialysate. A new optical design of the laser-induced breakdown spectroscopy setup has been made to reduce the number of components, cost and volume. To keep the setup compact, all components are integrated into a single system. This simplification, enabled by the smaller diameter plasma, will also result in lower cost price of the setup.
- Within the field of diagnosing eye-related diseases there is a need for easy to use, low-cost point of care retinal imaging devices. We have developed a prototype hand-held fundus camera capable of imaging the human fundus and documenting retinal pathology. The fundus camera is easy to use and combines a high quality full-color image with sufficient resolution and field-of-view at affordable costs in a small, hand-held footprint.
- Screening of the general population for early signs of cancer is the key to reduction of cancer-related death. We have developed an optical device to measure light scattering-related biomarkers of field carcinogenesis, and have demonstrated the feasibility of the approach on patients with head and neck (H&N) cancer. The optical technology is non-invasive, safe, fast, easy-to-use and can be developed using low-cost components; key aspects that will promote future wide-spread utilization of this technology in cancer screening programs. We were able to discriminate H&N cancer patients from controls with a sensitivity and specificity of >85%, which is promising. Next steps are to

include more patients for clinical validation of the method and to explore use case scenario's and build a strong business case for further development of this technology.

11.5.2 Short description

Medical technology development related to the HTSM Healthcare Roadmap is embedded in the Van 't Hoff program. The Van 't Hoff program is a Shared Research and Innovation Program, initiated by TNO, in the field of biomedical optics. The Van 't Hoff program forms an ecosystem where industry, university hospitals, research institutes and health foundations collaborate in order to accelerate medical and technological innovations and their implementation in health care.
Within the program we develop biophotonics technologies to enable better and faster diagnosis and monitoring of diseases in (a)symptomatic stages; better and/or personalized treatment for patients; and less invasive surgical procedures leading to improved health outcomes, reduced healthcare costs and a sustainable health care system.
Five different technology platforms are used as underlying technologies for our developments:

- A fluid characterization platform
- A nano-photonic biosensing platform
- An ophthalmic imaging platform
- A tissue characterization platform
- A fiber-optic sensor platform

11.5.3 Highlights

Fluid characterization platform

We develop a miniature selective ion sensor (Na, K, Ca) to enable personalized haemodialysis and the reuse of dialysate in portable artificial kidneys. An important step that was taken in 2016 is the integration of a compact and low-cost laser in the setup. We have demonstrated that a newly purchased low-cost compact laser with a pulse energy of only 170μJ was able to create a stable plasma in the dialysate. Additional advantage of this novel laser is that its beam quality is better, resulting in a smaller focus within the dialysate which makes the energy density higher and the plasma smaller, which is optically advantageous on the detection side.
A new optical design of the LIBS setup has been made to reduce the number of components, cost and volume. To create a very small focus (beam radius in focus ~3μm) in dialysate, 3 lenses were used. The total length of the optical path is only 30 mm. To guide the light emitted from the plasma to the spectrometer 2 additional lenses are used, with a total optical path of only 15 mm. To keep the setup compact all components are integrated into a single system. A next generation spectrometer that is thinner and optically more simple than the first generation was designed and produced. This simplification, enabled by the smaller diameter plasma, will also result in lower cost price of the setup. Finally, the 2D detector chip has been replaced by a low-cost 1D line array chip. The new laser, optical components, spectrometer and detector have been combined in a new compact LIBS setup. The size of the entire system is now 30x20x10cm.

Ophthalmic imaging platform

To enable a transition from secondary to primary care for earlier diagnosis of eye diseases, we have developed a prototype low-cost hand-held fundus camera for use in primary care. The final product will combine a high quality full-color image with sufficient resolution and field-of-view at affordable costs in a small (portable)

footprint. It should also to be easy to operate by a first line care professional (GP, GP assistant, nursing home physician, etc.) and limit the burden of a measurement to the patient (non-mydriatic). In 2017 a next generation of this hand-held fundus camera will be designed and developed with a particular emphasis on design for large scale fabrication and usability.

Fiber-optic sensor platform
Screening of the general population for early signs of cancer is the key to reduction of cancer-related death. A critical issue in screening programs is the need for a simple and reliable risk stratification of the general population: only high-risk patients should be selected to undergo a full range of tests using expensive hospital-based cancer detection technologies. In the case of risk stratification for head and neck (H&N), lung and esophageal cancer, an initial simple screening test would involve interrogation of the buccal mucosa as an easily accessible location for determining the risk of having distant cancer. We have developed an optical device to measure light scattering-related biomarkers of field carcinogenesis, and have demonstrated the feasibility of the approach on patients with H&N cancer. We have performed optical measurements in the buccal mucosa of 24 patients with H&N cancer and 24 age matched controls (patients free of cancer in these organs). Optical measurements have been performed in the outpatients clinic of the Erasmus MC. Measured spectra were fitted to recover parameters related to the structural, functional and biochemical differences in tissue. Based on these differences, we were able to discriminate H&N cancer patients from controls with a sensitivity and specificity of >85%, which is promising. Next steps are to include more patients for clinical validation of the method and to explore use case scenario's and build a strong business case for further development of this technology.

11.5.4 Dynamics

Besides all technological advancements, in the course of 2016 the Van 't Hoff program has been evaluated, resulting in a stronger focus on transfer to industry of high TRL technology platforms combined with (partly) public-funded maturation of low TRL technology platforms:

- A functioning model of the developed miniature selective ion sensor based on our **fluid characterization platform** will be transferred to industry. Spin-offs of this relatively mature technology in other application areas are emerging and will be pursued in 2017 in preferably bilateral settings.
- Discussions are taking place to exploit TNO's high TRL **nano-photonic biosensing platform** jointly with industry. The industrial and developmental activities with respect to this technology are increasingly funded in bilateral settings.
- Together with an industrial partner TNO has developed a prototype low-cost hand-held fundus camera for use in primary care. Additionally the EU has approved a grant application ("Moon") where TNO designs and builds a fluorescent fundus camera for curcumin imaging, which binds to protein (senile) plaques in the retina and can be visualized using fluorescence imaging. Meanwhile, a novel (low TRL) **ophthalmic imaging platform** is under development that involves looking into the eye with a camera and quantifying light scattering, absorption and fluorescence from the retinal images thus made. Quantification of tissue structure, physiology and biochemistry from these optical properties uniquely allows longitudinal monitoring of disease progression, therapeutic efficacy and potentially earlier detection of diseases. We expect the approach to be applicable to a range of diseases, also others

than eye diseases (e.g. neurodegenerative, cardiovascular, metabolic). This topic will be central to the Van ‘t Hoff program in 2017 and onwards.

- “non- invasive glucose sensor”: after extensive clinical testing of the **tissue characterization platform**, a partnership for further exploration with industry is now in preparation.
- With financial support of KWF we were able to show in initial clinical tests that certain cancer types can be detected non-invasively at an easily accessible, distant location based on the field-effect using our **fiber-optic sensor platform**. KWF support will continue in 2017, after which we aim to proceed with clinical and industrial involvement.

In briefest summary, the outcome of the program evaluation is that Retinal Imaging is foreseen to be the key topic for continuation of our (partly) public funded activities in the frame of the HTSM Roadmap Healthcare.

12 VP ESI

12.1 Roadmap Embedded Systems

12.1.1 Summary

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

The applications of embedded systems technology in the various industrial and societal fields, all rely on comparable technology building-blocks, methods and techniques. As a result, it is of utmost importance that new knowledge is not only generated for individual products or applications, but that opportunities for synergy, knowledge sharing and knowledge exchange are fostered. Such a coherent approach leads to a faster and more efficient build-up of knowledge, with sharing of solution strategies, architectures, platforms, best practices, education, etc.

The TNO-ESI program is growing steadily and its research budget is growing with 7,5% each year. This growth is enabled by the entry of new industrial research partners and the growth in both research volume and research topics with the individual industrial partners. TNO-ESI has strengthened its unique position and the interest in the TNO-ESI results is growing nationally and internationally. A good example of the latter is the signing of an MoU with the Fraunhofer Institute for Experimental Software Engineering (IESE, Kaiserlautern) in Spring 2016.

In addition to its research program, TNO-ESI has paid special attention to further generalization, consolidation and dissemination of the research findings, in order to maximize the knowledge and investment multiplier, both towards industrial and academic stakeholders. A successful dissemination example was the 2016 TNO-ESI symposium. This full-day symposium attracted a wide audience of 400 subscriptions whom received a program of presentations, academic and industrial key-notes, workshops, demonstrations and discussions. The symposium was very well received and in 2017 a next symposium is being scheduled. Other successful dissemination examples are the growing number of networking events in which interested parties share their insights and experiences in latest applications in embedded systems.

The knowledge base of TNO-ESI is expanding and research results are integrated into this knowledge base. TNO-ESI has proven to be capable of building such a knowledge base that is of interest for both academic and industrial partners. This knowledge base is also the enabler for a successful competence development program as provided to our industrial partners. TNO-ESI is putting its efforts to integrate this competence development program in company specific system architect trainings and in 2016 such training programs were organized world-wide for Philips, Thales and NXP. To cater with the required flexibility of location and teacher, first steps were made in blended learning in which MOOCs were produced for the Architecting for Business Value training and for the System Performance training. The development of these MOOCs were enabled with a cooperation with EIT Digital, iMinds (Belgium) and Fraunhofer.

12.1.2 Short description

The TNO-ESI research and development results are expressed in terms of methods, techniques and, if necessary, supporting SW-tools for designing high-tech systems. Application of TNO-ESI results requires these methods to be incorporated into industrial development processes, including the adequate training of personnel. Research is organized in four programs, each program having its own set of objectives.

- *System performance.* The long-term goal is to realize multidisciplinary design approaches that realize full 'performance-by-construction'. Focus for 2016 and 2017 is on performance modeling and analysis and system robustness.
- *System quality and reliability*. The target results are methods and techniques for early system validation and certification, such as model-based methods for integration and test. For 2016 and 2017, the focus is on model-based testing.
- *Future-proof systems.* The target results are methods and techniques for re-use of design assets, (model-based) virtual product development, techniques to migrate legacy systems into a model-based environment, system modularization, component and object-based architectures, run-time techniques, and methods for system configuration, maintenance and upgrade. For 2016 and 2017, the focus is on software refactoring/legacy systems and on virtual product development.
- *Systems in context.* The target results are information-centric architectures in which embedded intelligence reflects and reasons on the system's own operations and the interaction with its environment. The focus for 2016 and 2017 is on system diagnostics and health monitoring and on system architecting systematics.

TNO-ESI works with a restricted but highly loyal set of stakeholders mainly from high-tech OEM industry and their (SME) suppliers. These customers span a wide range of markets and applications. The research comprise long-term programs (typically three to four years) with a go/no-go review typically on a single year basis.

Through its innovation support activities, TNO-ESI supports a much wider range of stakeholders in the embedded systems ecosystem, categorized as follows:

1. *OEM companies*. These are the industrial OEM's, including large international companies. In 2016, this included ASML, NXP, Océ, Philips Healthcare, Philips Lighting, and Thales. During the course of 2016, this list has been extended with DAF, FEI (currently Thermo Fischer Scientific) and Barco.
2. *Industrial suppliers*. These are the partners and suppliers of the larger OEM's such as VDL ETG.
3. *International research institutes*. These are the international research institutes that have a reputation for software-intensive systems for industrial applications and having an interest in jointly pursuing areas of mutual interest. In 2016, TNO-ESI has signed an MoU with Fraunhofer Institute for Experimental Software Engineering (IESE) and has set-up a close cooperation with Fraunhofer Academy, Fraunhofer IESE and iMinds (Belgium) in the area of blended learning.
4. *Tool vendors and process integrators*. These are the potential partners that professionalize the TNO-ESI tooling and integrate such tooling in the industrial development processes. Examples are Axini and Siemens PLM as tool provider and Altran as integrator.
5. *Academia*. These are the universities that are involved in research and teaching in topics relevant to the embedded systems domain, such as TU Delft, TU/e, UT, RU, VU and UvA.

12.1.3 Highlights

In 2016, a large number of Public Private Partnership research projects were part of the TNO-ESI portfolio. In total, five European projects and more than ten large scale national research projects were executed. We mention a few highlights.

Concerto. A joint research project with ASML. The system-level design criteria of high-tech systems, and in particular system performance, are strongly influenced by system controllers. System controllers are key system component that act as a conductors of an orchestra. They coordinate all timed and relational behavior of the sub-systems that handle the movement, measurement and processing steps of wafers, thereby directly impacting system accuracy and productivity.

Designing system control behavior that is *performant* (e.g. optimizing throughput while satisfying timeliness requirements) and *robust* (e.g. able to cope with varying client scenarios) is an increasingly challenging task. Although these days sophisticated techniques are applied by mechatronic engineering for low-level (loop) control design, established and scalable approaches that effectively cope with system control complexity are still lacking.

The goal of the Concerto project is to develop a model-based methodology to diagnose, predict and optimize system timing and throughput and to keep computational tasks out of the critical (throughput) path as much as possible. The Concerto project started in 2016 and is planned for a period of four years.

Octo+ 2016. A joint project with Océ Technologies that addresses a range of model-based techniques for optimization of design trade-offs. The objective is to develop an approach in which physical systems are represented by virtual models in such a way that they can be used to analyze the system's functional and non-functional characteristics at earliest possible design stages. The models can be used to eliminate the need for costly physical prototype and to predict the impact of system variations an design alternatives. Tools and techniques have been developed for modeling and analysis of high-tech systems using actual examples of Océ printers as study case. Another excellent result is the development of the "Design Framework". The Design Framework is an approach and a tool that helps to link all design activities to concrete design artifacts and to track consistency of these artefacts in a multi-disciplinary environment.

Vivace. A joint project with Philips Healthcare. Design faults are often found during final system integration and test. The root cause of many of these faults can be traced back to component/sub-system interface mismatches which may be the result of ambiguous specification, undocumented usage or unintended changes to functionality and/or system-level timing. Reducing the number of faults found during final system integration and test can have a significant economic benefit by reducing the amount of redesign and test cycles and therefore bringing robust products faster to market. To help overcome such problems being experienced by high-tech industry new methods are required to specify, design and test interfaces together with methods to understand and modify existing legacy designs. The Vivace project therefore has two complimentary goals: (i) methods to formally define interfaces and be able to test for interface compliance, (ii) methods to extract the structure and key business logic from existing software components. The Vivace project started in 2016 and is expected to run for three to four years.

EcoTwin II/EcoTwin III. A joint series of projects with TNO Automotive, DAF, NXP and Ricardo. The EcoTwin II project participated in the European Truck Platooning Challenge organized by the Dutch Ministry of Infrastructure and the Environment on Wednesday April 6th. The objective of the Challenge was to obtain permission from governments to perform large-scale, pan-European testing of truck combinations that are linked wirelessly ('platoons'). This enables truck combinations to drive very close to each other, which presents benefits in terms of fuel consumption and therefore CO_2 emissions, safety and the flow of traffic.

Truck Platooning involves trucks driving a short distance apart using automated driving technology. The Truck Platooning Challenge demonstrated that a second vehicle is technically capable of automatically following the combination ahead using Wifi-P, radar and cameras.

The EcoTwin III project is taking a next step in automated driving, further reduce the following distance and make a step from 2 trucks to 3 trucks.

Prognosis. A joint project with Thales. The long-term goal is to establish in industrial practice a model-based product development process removing the need to build multiple costly physical prototypes. A shift from a fixed product design way of working to the creation of flexible platforms can maximize reuse and avoid duplication of efforts. Virtual prototypes are used to replace traditional physical prototypes and have the advantage that they can be easily and quickly updated and replicated to fulfill the needs of various stakeholders. The creation of virtual prototypes requires a framework to support the dynamic interworking of models from different technical disciplines. Essential characteristics of virtual prototypes are the ability to run scenarios, to visualize the behavior and to probe the internal workings of the proposed solution. The methods developed and tooling used can be applied to most industrial organizations developing high-end electromechanical products with a high software content.

Prisma. A joint project with Philips Lighting. The Prisma project develops techniques to (i) analyze a system's robustness and reliability, (ii) concepts and architectural guidelines for robustness and reliability and (iii) concepts to reduce risk and integration effort at the on-site commissioning These techniques should be applicable to large scale distributed systems-of-systems (so applicable in the 'Internet of Things' context) with proven applicability for intelligent lighting systems for the office and retail market.

Juventas. A joint project with Thermo Fischer Scientific (previously FEI). The main goal of the Juventas project is to enable in industrial practice the efficient migration of embedded legacy software to a modern design. The method developed to migrate legacy code should require 60% less effort as compared to manual migration, and result in a code base at least 40% smaller case resulting in less recurring maintenance efforts.

Reflexion. An Itea project with the goal to optimize the full end-to-end product development lifecycle and maintenance process, bringing in analytics to automate and complement expert knowledge, and enabling predictive maintenance on a broader industrial scale and shortening product evolution development iterations. The project's focus is on exploiting operational data, for example continuous logs of sensor readings, leading to more efficient development and validation of systems individualized to customer needs and fully integrated in the customer's operating workflow. Prime partners are Philips Healthcare and Océ Technologies.

For each of these research projects, new methods and techniques have been developed that were tested up to Proof of Concept, using real industrial cases. In most cases the respective industrial research partner(s) have adopted and integrated these results into their own operational practice. In addition to this, TNO-ESI has paid special attention to further generalization, consolidation and dissemination of the research finding, in order to maximize the knowledge and investment multiplier, both towards industrial and academic stakeholders.

12.1.4 Dynamics

The TNO-ESI program is rather stable. The long-term direction is in-line with the HTSM Embedded Systems Roadmap that obtains an update every two years. The next update of the HTSM Embedded Systems Roadmap is expected end of 2017. The short-term (yearly) priorities are discussed and set with the TNO-ESI Partner Board (PB). The TNO-ESI PB consists of senior representatives from academia and industry. This board has responsibility for overall strategic direction and value proposition, including supervision of program objectives, embedding in the academic and industrial network and the general alignment of the TNO-ESI program with the Topsector HTSM.

Next to a gradual growth in industrial research partners, a slight shift in attention in the four program lines is observed. We earmarked them as ‘paradigm shifts’. These paradigm shifts were presented and discussed in the successful TNO-ESI Symposium held in April 2016 with nearly 400 participants. These paradigm shifts are the following.

- From prototype to virtual product development
- From stand-alone to collaborative systems
- From fixed product to flexible platform
- From manual coding to model-based

The latter topic has resulted in a possibility to exploit the synergy between the ICT Roadmap and the HTSM Embedded Systems Roadmap in the area of software legacy.

Next to these paradigm shifts we also observe an extension of industrial interest. Originally, the interest of our industrial customers was on the design and engineering of their high-tech systems. In 2016 and 2017 we expand this interest towards the total product life cycle including servicing and condition-based maintenance aspects.

13 Ondertekening

Eindhoven, 28 februari 2017 TNO

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