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TNO-rapport

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Meerjarenprogramma 2015-2018 Topsector High-Tech Systemen en Materialen Bijstelling 2017

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Inhoudsopgave

1 Introduction

This report describes the 2017 update of TNO's 'Speurwerkprogramma 2015-2018: Thema High-Tech Systemen en Materialen'. The report shows the contributions of TNO's Demand Driven Programs (VP, Vraaggestuurd Programma) to the different Roadmaps of HTSM.

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 (SI). The research line Industrial Instrumentation, for practical reasons part of VP High-Tech Semicon, also contributes to Smart Industry. However, SI activities are performed within other HTSM Roadmaps as well, for instance the Additive Manufacturing Fieldlab described in the Roadmap Printing. SI activities within the Roadmap ICT are described in the separate 2017 update report of the Demand Driven Program ICT.
Two new VP's were added in 2016 that will contribute to the HTSM High-Tech Materials Roadmap:

- VP Environmental Technology, focusing on the development and validation of new material solutions for environmental sensing and circular products.
- HTSM Building Innovation, focusing on construction materials, asphalt and responsive materials for the construction sector.

TNO is contributing to the HTSM Embedded Systems Roadmap. The related Demand Driven Program (VP ESI) was described in TNO's 'Speurwerkprogramma 2015-2018 Thema ICT'. The 2017 update of VP ESI is included in this report.
The table below shows the relations between TNO's Demand Driven Programs and the HTSM Roadmaps. The QuTech initiative and the Embedded Systems Institute (ESI) are indicated. 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 Security

Contactpersoon TNO: Bert Don

2.1.1 Samenvatting

De steeds grotere invloed van ICT op de bedrijfsvoering bij bedrijven en overheden vergroot het belang van cyberresilience en de bestrijding van cybercrime. De dreigingen voor eigenaren van ICT systemen zijn complex en veranderen bovendien snel. De schade door chantage na blokkade van computers en informatiebestanden met zgn. *ransomware* stijgt voortdurend. Ook de klassiekere cyberaanvallen, zoals *phishing* en bedrijfsspionage, tonen nog steeds een toename. Daarbij speelt dat criminelen business ontwikkelen met het o.a. op *dark web* aanbieden van kant-en-klare tools voor cyberaanvallen.
Voor bedrijven en branches met potentieel hoge schade door cyberdreigingen is kosteneffectieve beheersing van cyberrisico's essentieel. Op maat beschermen en adequaat reageren bij een daadwerkelijke cyberaanval vragen om een gebalanceerde mix aan maatregelen en samenwerking met ketenpartners uit bedrijfsleven en overheid. Organisaties met gegevens van vele personen en instellingen vereisen een efficiënte, privacy compliant bedrijfsvoering. Leveranciers van IT-componenten, -systemen en -diensten spelen hierop in met nieuwe producten en services.
Gezien de toenemende impact van cyberdreigingen heeft TNO het onderzoek naar Cyber Risk Management en System Resilience in 2016 sterk geïntensiveerd. In een apart Vraaggestuurd Programma worden nieuwe concepten en tools ontwikkeld voor bedrijven en overheden en hun IT-gerelateerde toeleveranciers. De zwaartepunten voor 2017 zijn:

- Cyber Threat Intelligence sharing (in samenwerking met banken en andere instellingen)
  Het uitwisselen van actuele dreigingen binnen en tussen grote organisaties kan de alertering en respons substantieel versterken. Dit vraagt ontwikkeling van veilige standaarden voor het communiceren van deze uiterst gevoelige informatie.
- Human factors (in samenwerking met grote instellingen uit bedrijfsleven en overheid)
  Een kwart van alle schade bij grote organisaties als gevolg van cyberincidenten is te wijten aan menselijk falen. Profilering van taken èn medewerkers op potentiele bijdrage aan cyberrisico's biedt een basis voor op maat ontworpen maatregelen in de bedrijfsvoering. Ook het beleven en oefenen van de response op een cyberaanval in een nieuw te ontwikkelen faciliteit dient om de competenties van cruciale medewerkers te versterken.
- Blockchain security
  Met de snel opkomende blockchain-technologie kunnen twee partijen die elkaar niet kennen, zonder tussenkomst van een derde partij, een betrouwbaar uitgevoerde transactie aangaan, anoniem en zonder hoge kosten. Vanuit dit VP zal een PPS-initiatief ontwikkeld worden om fraude met gebruikmaking van deze technologie te bestrijden.
- Veilige hard- en software: validatie van security technologie
  Na tal van incidenten is er over het algemeen bij (vitale) organisaties het bewustzijn dat meer technische cybersecurity maatregelen nodig zijn. Het

ontbreekt echter aan goed inzicht in de kwaliteit en security van dergelijke technologie. Hoe goed werkt het? Wat is kosteneffectief als oplossing aan te schaffen? Testen en validatie, eventueel met certificering, bevordert dit inzicht sterk voor afnemers. Europese samenwerking biedt daarnaast grote voordelen. (http://europa.eu/rapid/press-release_MEMO-16-2322_en.htm).

2.1.2 Korte omschrijving

Het VP Cyber Risk Management & System Resilience sluit aan op de HTSM Roadmap Security (zie: http://www.hollandhightech.nl/nationaal/innovatie/roadmaps/security). Door het steeds verder doordringen van ICT in onze samenleving is het waarborgen van de veiligheid in de virtuele wereld inmiddels net zo belangrijk als veiligheid in de fysieke wereld. Met dit VP wil TNO bijdragen aan de innovatiekracht van Nederland op het gebied van digitale veiligheid en weerbaarheid. Enerzijds is de uitdaging om de economische en maatschappelijke kansen van digitalisering te verzilveren en anderzijds is het zaak om nieuwe dreigingen en kwetsbaarheden het hoofd te bieden.

De dynamiek van het digitale domein vereist structurele samenwerking van bedrijfsleven, overheid en kennisinstellingen. De overheid heeft daarbij niet alleen een beleidsbetrokkenheid maar ook uitvoerende taken in bedrijfsmatig gerunde organisaties die zich adequaat moeten beschermen tegen cyberdreigingen; te denken valt aan de belastingdienst, UWV en gemeenten, maar ook aan politie en defensie.

Voor het realiseren van de beoogde situatie bij het beëindigen van dit van 2015 – 2018 lopende onderzoekprogramma zijn nodig:

- Fundamentelere, generieke ontwikkelingen voor specifieke aspecten:
  - In 2015: ontwikkeling van een Advanced Risk Management Methode en tools voor detectie van ICT-misbruik.
  - In 2016: platforms/tools voor het kunnen delen van Threat Intelligence tussen organisaties en vermindering van cyberincidenten door menselijk falen.
  - In 2017: onderkennen en bestrijden fraude door misbruik van blockchain technologie.
- Innovaties voor specifieke sectoren of gebruikerscategorieën in Publiek Private Partnerships:
  - In 2015:ontwikkelen technologieën en methodieken voor grote banken in gezamenlijk gefinancierd meerjarenonderzoeksprogramma.
  - In 2016: ontwikkeling van methode voor onderkennen van kwetsbare functies/posities en medewerkers voor benadering door cybercriminelen en ontwikkelen van response daarop; opstart van onderzoekprogramma voor consortium van bedrijven met mega IT- en databestanden.
  - In 2017: nationaal initiatief voor blockchain ontwikkelingen.

De onderdelen van het VP CRM&SR sluiten aan op parallel in uitvoering zijnde kennisontwikkelingsprogramma's onder regie van de Ministeries VenJ en Defensie.

2.1.3 Doelstellingen

Voor 2017 zijn de volgende werkpakketten voorzien:

1. Cyber Threat Intelligence Sharing
   Het vergroten van de digitale weerbaarheid van organisaties door het

verzamelen, bewerken, analyseren en delen van cyber threat intelligence. Daarbij wordt zowel informatie uit open en gesloten bronnen en het dark web in één analyseplatform bijeen gebracht en gecorreleerd. De focus ligt op het toepassen van big data analytics voor het grip krijgen op cyberdreigingen; zo nodig zal ook onderzoek gedaan worden naar standaard technische protocollen, visualisatie voor besluitvorming en het uitwisseling van intelligence. Voor effectief beleid en slagkracht bij incidenten is het van belang om te beschikken over de juiste uitgangspunten en getallen. Het gaat dan om de *juiste bronnen* te ontsluiten voor het analyseren van specifieke cyber security metrieken en de *juiste indicatoren* te ontwikkelen voor het nemen van de juiste beslissingen en maatregelen. Daarbij moet niet geredeneerd vanuit de beschikbare informatie en expertopinies, maar vanuit de informatie en intelligence die echt van belang zijn.
De tot nu toe toegepaste, meer subjectieve en kwalitatieve analyses vragen om aanvulling met objectieve en kwantitatieve indicatoren. Deze dienen zowel gericht te zijn op de impact van verschillende type dreigingen, als een beeld te geven dat representatief is voor Nederland. De basis hiervoor ligt voor een belangrijk deel bij de Nederlandse organisaties die belang hebben bij de indicatoren. Uiteindelijk kan dit leiden tot een real-time Cyber Trend Watch en Threat Intelligence platform, waarmee verschillende organisaties cyber intelligence kunnen delen, verrijken en filteren, om vervolgens een actueel, gepersonaliseerd en actionable cyber intelligence beeld gepresenteerd te krijgen. Dit kan gaan over:

- hun eigen organisatie (hoe goed doe ik het, wat zijn mijn dreigingen, wat zie ik richting mijn organisatie gebeuren);
- hun organisatie als onderdeel van de sector (hoe goed doe ik het ten opzichte van anderen, wat gebeurt er bij anderen en hoe vatbaar ben ik hiervoor, op welke dreigingen zou ik me moeten richten);
- hun organisatie als schakel in een keten of netwerk (welke dreigingen zijn er op mijn toeleveranciers, ketenpartners en partijen waar ik zaken mee doe, welke trends zijn bij hen zichtbaar en in hoeverre zijn deze van toepassing op mij).

Een dergelijk platform lijkt des te meer nodig voor de nieuwe rol, die in opkomst is op het gebied van cybersecurity: de “Cyber Threat Intelligence Officer”. Deze heeft als verantwoordelijkheid om verschillende informatiestromen omtrent cybersecurity te verwerken en te vertalen richting meer operationele teams die zich bezighouden met incident response (CERT) en security operations (SOC).
Doel van het onderzoek in 2017 is om een proof-of-concept (demonstrator) van een cyber security intelligence omgeving te realiseren. Hiertoe wordt het Cyber Threat Intelligence Laboratium (CTI Lab) op de HSD te Den Haag als uitgangspunt gebruikt. Daarnaast zal de stap gemaakt worden van analyse van statische datasets naar real-time analyse binnen een CTI workflow. Verder zullen de databronnen worden uitgebreid en analysemethoden worden verfijnd.

Resultaat 2017:
Ontwikkelen van een proof-of-concept waarin informatie vanuit Clear Web (open en gesloten bronnen) en Dark Web bij elkaar wordt gebracht, gecorreleerd en verspreid naar stakeholders. Het produceren van bruikbare metrics om het dreigingsniveau op cybersecurity gebied voor specifieke organisaties en sectoren te bepalen. Tevens wordt een model ontwikkeld om intelligence met elkaar te delen.

Met partners zoals: banken, multinationals, MKB en 1 of meer IT-bedrijven.

2. Human factors in cyber
   Om organisaties cyberresilient te maken en te houden, speelt de menselijke factor een cruciale rol naast de organisatorische en technologische factor. Op dit moment ontbreekt bij organisaties de kennis en methodieken om hun personeel functie- en persoons specifiek te trainen, de cyberresilience van de organisatie te bepalen en te vergroten. Als vervolg op het onderzoek in 2015/2016 is nu een consortium in voorbereiding voor het kunnen vinden en versterken van zwakke menselijke plekken in een organisatie (zie werkpakket 6).
   In dit werkpakket 2 vindt verdere verdieping plaats naar de ontwikkeling van effectieve maatregelen om medewerkers te beïnvloeden om zich veiliger te gedragen. Onderzoeksvragen zijn onder andere:
   - Wanneer is iemand gemotiveerd zich cyberveilig te gedragen?
   - Correleren veílig gedrag en gepercipieerde waarde van data met elkaar? Hun organisatie als schakel in een keten of netwerk (welke dreigingen zijn er op mijn toeleveranciers, ketenpartners en partijen waar ik zaken mee doe, welke trends zijn bij hen zichtbaar en in hoeverre zijn deze van toepassing op mij).

   Voorgaand onderzoek naar de correlatie tussen attitudes en gedrag op het gebied van privacy heeft aangetoond dat - hoewel de meeste mensen aangeven hun privacy belangrijk te vinden - dit niet correspondeert met hun werkelijke gedrag, de zogenaamde privacy paradox. Er zijn verschillende verklaringen voor dit resultaat. Onderzoek naar het kwantificeren van de waarde van data in relatie tot privacy heeft bijvoorbeeld aangetoond dat mensen het lastig vinden om in te schatten wat de kosten en mogelijke gevolgen van gecompromitteerde privacy data zullen zijn. Het nemen van een rationele, geïnformeerde beslissing is ook lastig omdat de informatiedeling over het gebruik van privacygevoelige, persoonlijke data in de digitale economie vaak tekortschiet. Daarnaast beïnvloedt de manier waarop informatie wordt aangeboden, zoals de default setting en de volgorde waarin informatie wordt aangeboden de mate van privacy gerichtheid bij het maken van keuzes. Echter, wanneer negatieve consequenties van een keuze expliciet duidelijk worden gemaakt en er handelingsperspectief wordt geboden, zijn mensen eerder geneigd een veilige keuze te maken. De waarde van data, betrouwbare en duidelijke informatie, en handelingsperspectief hebben dus invloed op veilig gedrag. Verder inzicht in factoren die veilig gedrag stimuleren en die de motivatie en de moeite die iemand wil doen om veilig te werken vergroten biedt mogelijkheden om dit gedrag positief te beïnvloeden. Als de gevolgen van persoonlijke informatiedelen negatieve consequenties kunnen hebben voor een ander, zoals het bedrijf waar iemand werkt, zou dit de waarde van de informatie en/of de motivatie om veilig te werken bijvoorbeeld kunnen vergroten.

Resultaat 2017: Inzicht in de relatie tussen gepercipieerde waarde van data en motivatie om veilig te handelen en het ontwikkelen van effectieve interventies. Doorontwikkeling in samenwerking met belanghebbende private en publieke organisaties.

3. Ontwikkeling en validatie van cyber resilient systemen met innovatieve hard- en software
   Het onderzoek naar de verbetering van de cyber resilience van remote

aangestuurde apparaten en infrastructuren hebben geleid tot een door de waterschappen gefinancierd vervolgproject met deelname van een tweetal industriële toeleveranciers. In principe zijn de resultaten daarvan confidentieel. Uit de hierbij opgedane inzichten is een bredere vraagstelling geïdentificeerd: Hoe goed is technologie voor cybersecurity? Bijv. detectie, firewalls, datadiodes enz. leveren dergelijke oplossingen met geavanceerde hard- en software-componenten na implementatie op het netwerk van een organisatie wel de veiligheid die ze zouden moeten? De meeste security technologie is voor de afnemers een 'black box' waar geen inzage in is, als afnemers zelf al de capaciteiten hebben om zelf de performance van de oplossing te testen. Zowel in de Topsectoren als bij overheden leidt dit geregeld tot onzekerheid over de kwaliteit van de aan te trekken oplossing (ook t.o.v. de te maken kosten in tijd en geld).
De Europese Commissie stuurt gezien deze problematiek aan op certificering van security oplossingen, mede omdat de meeste oplossingen van buiten de EU afkomstig zijn (zie factsheet 'Commission boosts cybersecurity industry and steps up efforts to tackle cyber-threats'[1], 5 juli 2016). Achterliggend doel is ook de Europese cyber security industrie een steun in de rug te geven door een keurmerk te propageren.
Het VP beoogt in concreto een bijdrage te leveren aan beter inzicht van afnemende bedrijven in de werking van security oplossingen. Deze bijdrage bestaat uit het verder ontwikkelen van een test- en validatiemethodiek, zodat het ook voor benchmarking geschikt is (verdieping kennis, zie hierna) en voor verschillende soorten security technologie (verbreding kennis). Tevens is kennisopbouw nodig over het simuleren van cyberaanvallen in een gesimuleerde omgeving voor het realistisch testen en valideren zonder schade aan derden.
In het kader van de Europese ontwikkelingen heeft het Ministerie EZ ook aan TNO gevraagd om - met additioneel budget - aandacht te besteden aan de consequenties van de in juli 2016 gepubliceerde Richtlijn Netwerk- & Informatiebeveiliging (NIB). Deze moet in nationale wetgeving worden geïmplementeerd en in mei 2018 in werking treden. De Richtlijn NIB verplicht aanbieders van essentiële diensten (bijv. drinkwater & energiebedrijven) en zogeheten Digital Service Providers (DSP's) een NIB-incident te melden bij een CSIRT (Computer Security Incident Response Teams). Onder de Digital Service Providers worden de "online marketplaces", "online zoekmachines" en "cloudcomputing diensten" verstaan. De kernvraag aan TNO betreft het beleggen van de CSIRT-functie, voorzover deze niet door het NCSC wordt afgedekt. Er zullen verschillende alternatieven in kaart gebracht moeten worden met de voor- en nadelen (organisatorisch, financieel, opbouw benodigde kennisexpertise etc.). Hierop aansluitend vindt een verkenning plaats voor cybersecurity informatiedeling voor de Topsectoren. Op basis van de behoefte en noodzaak voor het delen van informatie over cyberdreigingen binnen de topsectoren (zowel *face-to-face* als via een technisch platform), zal een ontwikkelplan voor Information Sharing Analysis Centers (ISAC's) of een andere vorm van informatiedeling voor de Topsectoren worden opgesteld. Hiermee wordt invulling gegeven aan zowel de afspraken die zijn gemaakt tijdens de strategische sessies 'Ministerie EZ – Cyber Security' in december 2015 en januari 2016 jl. als het thema Cyber-innovatie in het Deltaplan Cyber Security.

4. Blockchain en Security
   Binnen TNO wordt een brede samenwerking opgezet voor de snel opkomende Blockchain technologie. Daarbij participeert TNO in de Topsector ICT/Dutch

[1] http://europa.eu/rapid/press-release_MEMO-16-2322_en.htm

Digital Delta en een Nationale Blockchain Coalitie - waarin NWO, TNO en enkele brancheorganisaties samenwerken; de focus daarbij is benutten van blockchain technologie voor legale toepassingen van bedrijfsleven en overheden. Vanuit dit VP is er een samenwerkingsrelatie in opbouw met het Publiek Private Samenwerkingsverband IFFC. Beoogd wordt vanuit dit VP onderzoek te initiëren naar het opsporen en tegengaan van fraude met behulp van blockchain technologie. In de komende maanden wordt dit verder uitgewerkt in een plan voor activiteiten in 2017.

5. Cybersecurity in de financiële sector
   Het Strategische Research Programma in samenwerking met de Nederlandse banken zal ook in 2017 worden voortgezet. Dit in januari 2015 opgestarte initiatief richt zich op het ontwikkelen van technologieën en methodieken die in staat stellen tot:
   - betere weerbaarheid tegen cyber aanvallen;
   - snellere en betere detectie van cyber security incidenten;
   - sneller herstel van cyber security incidenten;
   - betere beveiliging van elektronische transacties;
   - effectievere besteding van geld voor cyber security maatregelen;
   - verbeteren van opsporingsmogelijkheden.

6. Cyberresilience van organisaties en competenties en gedrag van medewerkers
   Als vervolg op het onderzoek naar Human Factors in cybersecurity is een onderzoeksprogramma ontwikkeld dat zich richt op het verhogen van de cyberresilience van organisaties, met als focus de mens. Dit programma heeft inmiddels support verkregen van enkele grote informatie-intensieve bedrijven en adviesbureaus en een IT-trainingsbedrijf. Verwacht wordt dat het programma kan starten in het vierde kwartaal van 2016.
   Een organisatie is pas cyberresilient wanneer de drie assen van mens, techniek en organisatie (en de interacties tussen deze assen) resilient zijn. CRONTAB heeft als doel het verhogen van de cyberresilience van medewerkers. Hiertoe wordt onderzocht welke verschillende typen medewerkers onderscheiden kunnen worden als het gaat om cyber(on)veilig gedrag. Vervolgens worden op basis van deze prototypische profielen specifieke trainingsmodules ontwikkeld die erop gericht zijn de awareness van de medewerker op zijn of haar specifieke kwetsbaarheden te verhogen, alsmede handelingsperspectief te bieden. Daarna zal een toolkit ontwikkeld worden die erop gericht is awareness ook daadwerkelijk om te zetten naar cyberveilig gedrag. Ten slotte wordt een analyse gemaakt van potentiële toekomstige cyberdreigingen en hoe medewerkers daar snel (eventueel geanticipeerd) op kunnen worden voorbereid.

2.1.4 Dynamiek

Ten opzichte van het oorspronkelijke plan 2015-2018 is de omvang van het cybersecurity-onderzoek in het VP Security voor de jaren 2016-2018 meer dan verdubbeld ten opzichte van 2015. Dit was reden om dit onderzoek onder te brengen in een apart VP.

Het onderzoek is gedurende 2016 scherper gefocusseerd op threat intelligence en de human factor. De separate lijn voor dark web monitoring is versterkt, maar ook in het speerpunt threat intelligence opgenomen omdat juist het bijeenbrengen van signalen uit *Clear web* (open en gesloten bronnen) en *Dark web* een effectieve

versterking van resilience en respons op incidenten mogelijk maakt. Het onderwerp Security van Remote controlled systems zal worden verbreed naar Cyber resilient systemen met innovatieve hard- en software. Als nieuw onderwerp zal in 2017 worden gewerkt aan blockchain technologie, waar aansluitend op nationale samenwerkingsverbanden voor het legaal gebruik van deze technologie voor bedrijven en overheden in dit VP het onderkennen en bestrijden van *crimineel* gebruik van deze technologie centraal staat.

Onderwerp in 2016	**Onderwerp in 2017**	**(Beoogde) Partners**
Threat Intelligence sharing Dark web tooling	Threat Intelligence	• Lopend SRP met banken (1 M€/jaar) • Initiatief i.s.m. Groep Multinationals • Clusterontwikkeling rond Cyber Threat Intell Lab in HSD/Den Haag
Security of Remote controlled systems	Ontwikkeling en validatie van cyber resilient systemen met innovatieve hard- en software	• Spin-off opdracht voor waterschappen i.s.m. 2 IT-bedrijven (0,5 M€) • Studie CSIRT/EU-richtlijn voor EZ • Verkenning MKB initiatief
Human factor in cyber security	Human factor in cyber security	• Sponsorproject *Cyberresilience van organisaties en hun medewerkers* ism consortium bedrijven (start Q4 2016)
-	Blockchain	Aansluiting bij nationale samenwerkingsverbanden ontwikkelen (o.a. IFFC en Dutch Digital Data)

De dynamiek wordt samengevat in bovenstaande tabel, waarbij ook de huidige partners en beoogde partners summier zijn aangegeven. De ontwikkeling van PPS consortia voor strategische innovatietrajecten heeft zich in 2016 gunstig ontwikkeld.

De cybersecurity industrie in Nederland heeft internationaal een vooraanstaande positie. De Gemeente Den Haag vervult een voortrekkersrol in de ontwikkeling van een sterk industrieel cluster op dit gebied. TNO heeft geholpen om Den Haag samen met Rotterdam te positioneren in het mondiale Rockefeller-initiatief voor City resilience. Via commerciële activiteiten van TNO in Singapore is aansluiting gecreëerd met voortrekkers uit de Zuid-Oost Aziatische ICT-hub; als spin-off daarvan zijn in Brussel dark web trainingen georganiseerd met enkele honderden deelnemers. In juni bracht een delegatie van permanente vertegenwoordigers van de EU een bezoek aan Den Haag en kreeg een demonstratie van de door TNO opgezette cyberfaciliteiten in HSD.

Het VP CRM & SR wordt begeleid door het door de Topsector benoemde Roadmapteam Security, bestaande uit Thales als industrieel boegbeeld, VenJ, Defensie, NLR, STW/NWO en TNO. Het Roadmapteam heeft hieraan als leden toegevoegd: NIDV, Gemeente Den Haag, de Nationale politie en het IFV. Ook het Ministerie EZ is in het Roadmapteam vertegenwoordigd. In oktober/november zal voor cybersecurity een bijeenkomst met een bredere groep bedrijven worden georganiseerd.

3 VP Radar & Sensorsystemen

3.1 Roadmap Components and Circuits

Responsible TNO: Frank van den Bogaart

3.1.1 Summary

The TNO applied research carried out in VP Radar and Sensor Systems is reported in:

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

The impact of the VP in the Roadmap Security is aimed at strengthening the global leadership and competitiveness of our national defence and security industry and associated technology suppliers. 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. One of the major goals is to accelerate the speed of innovation. We do this by consistency in joint Roadmaps, an open exchange of knowledge and by increasing the 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[2] between knowledge institutions, industries and supplying technology companies and military stakeholders (both national and European level), whereby all together at an early stage can be aligned for the development of an optimal knowledge base that innovative, trend-setting and leading the way 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*.

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

3.1.2 Short description

The program in 2017 will be characterized by programs and projects that are always carried out within a national or international consortium. It will be a flavour of the continuation of already running programs and new programs that ramp up in 2017 or which are currently in development.

The program focusses on projects that contribute to the national *Roadmap Radar en Geïntegreerde Sensorsuites* and in particular to the sensor suite for the next

[2] 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.

generation of frigates of the Royal Netherlands Navy. National projects have been implemented together with Thales Netherlands and supply chain partners and universities. Projects at an international level are carried out in different consortia.

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. In the ecosystem that is emerging around D-RACE we see as increasingly important parties NXP, the Centre or Array Technology (CAT) of the University of Twente and Delft University of Technology. 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 mm2 integrated circuit. The technology base for the S-band was chosen to be SiGe BiCMOS because of the robustness and linearity and because of the integration perspectives: a complete radar receiver, including the limiter and the IF-chain, can in principle be integrated in this technology (SiLC).

In the context of DAISY, another great national project funded in this Roadmap by regional structural funds, we work together with NXP, Thales Netherlands, various technical universities and SMEs. DAISY focuses on the next generation miniaturized but also affordable sensor modules. DAISY is a good example of the social relevance of this VP. The knowledge becomes through the participating of SMEs also available in other sectors on the market. Within DAISY integrated SiGe transceivers are developed and manufactured.

We 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; most often is the cooperation in the Roadmap than in the form of regular STW projects, or through the special STW HTSM calls. 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.

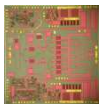
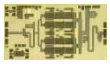
At international level we do see an increasing role of UMS in France, especially for GaN an SiGe applications.

In the framework of the European Defence Agency, the European JTI's PENTA and ECSEL and the H2020 Framework programme 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 Nederland 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 100W output power at chip level.

3.1.3 Goals

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)
	Lower cost GaN circuits		GaN on Silicon substrate (i.e.: PENTA project GaNSi)
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)
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

3.1.4 Dynamics

A number of projects launched in 2014, 2015 and 2016 will be continued in 2017. These are the European projects SWAP-C and EAST, the national project PHSDRVPOC on an MMIC Phase driver, the binational projects SiGe supply chain and the TKI Toeslag project on the Power Fundamentals for Radar.

- 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.

Projects in development envisaged to start in 2017 is GaNSi:

- DAISY2 (Daring Applications & Innovations in Sensor Systems) is a development in the context of regional business support. Intended participating companies NXP and Thales Netherlands and TNO, besides a large number of SMEs and universities. DAISY2 focuses on the next generation of highly miniaturized sensor modules that can also be produced cheaply. With the participation of many SMEs the knowledge developed is also available in other economic sectors.
- GaNSI is on the development of low-cost GaN power technologies, aiming at the performance of GaN power amplifiers and linear pre-amplifiers without the GaN on SiC cost structure. The programme will be carried out together with OMMIC, AMPLEON and other European partners.

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 forces and Royal Dutch Marechaussee
	(in development: *Mission Critical Systems* with stakeholders Dutch Maritime Defence industries and Royal Dutch Navy)

3.2 Roadmap Security

Responsible TNO: Frank van den Bogaart

3.2.1 Summary

See summary Roadmap Components and Circuits.

3.2.2 Short description

Figure 1: Artist impression of possible next generation frigate.

The program for the HTSM Roadmap Security focusses in 2017 on projects that contribute to the national Roadmap *Radar en Geïntegreerde Sensorsuites* and in particular to the sensor suite for the next 2 generations of frigates of the Royal Netherlands Navy. 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. In addition, an extension of the knowledge portfolio is implemented to support the national defence-related, 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*. The first examples of this extension are already visible in the project portfolio.

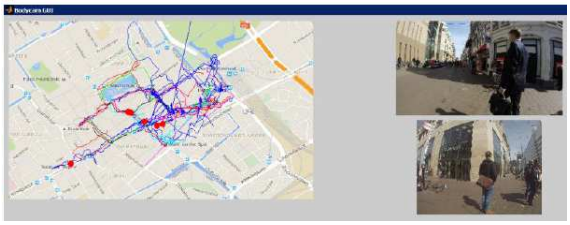


Figure 2: Video analytics on bodycam data.

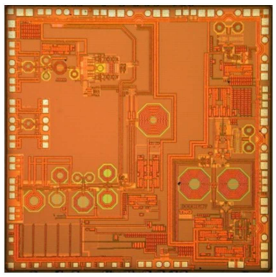


Figure 3: Typical MMIC developed in this VP.

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 2017 in the HTSM Roadmap Components and Circuits are 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 these systems.

3.2.3 Goals

The basic objective is to generate impact on export opportunities and employment, based on industrially relevant R & D and speed of innovation. To that end, also in het Platform Nederland Radarland, programs and ideas are developed to serve the national OEMs, SMEs and their supply chain partners in the field of sensor technology. 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 command and control systems for navies. Radar is ideally suited for detecting and recognizing objects of so-called non-cooperative objects.

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 typically be. Market research shows significant global market potential.

Radar sensors are challenged to operate in a broader application range, for example, objects that pose a threat through the high atmosphere or space, or objects such as (improvised) mini-UAV's which in terms of reflective properties are very difficult to distinguish from the natural background environment. New challenges also lie in the use of radar in a highly asymmetrical operating environment, supporting flexible defence systems or where free propagation is limited, such as in an urban environment. Radar sensors will increasingly form the basis of heterogeneous sensor suites including multi-spectral observation.

The program in 2017 focusses on projects that contribute to the national *Roadmap Radar en Geïntegreerde Sensorsuites* and in particular to the sensor suite for the next generation of frigates of the Royal Netherlands Navy. National projects have been implemented together with Thales Netherlands and supply chain partners and universities. Projects at an international level are carried out in different consortia. Related projects in the field of RF components are reported in the HTSM Roadmap Components and Circuits in the next chapter.

The year 2017 is characterized by further implementation – in national and international context – of the *Roadmap Radar and integrated Sensor suites*.

In addition, an extension of the knowledge portfolio will be implemented to support the national defence and security industry and their supply chains on a wider scope, in particular in the field of other (passive) *Sensors and Systems for Security*, *Technology for Passive Sensors* and *Mission Critical* Systems. The first examples of this extension are already visible in the project portfolio.

The overall target of the programme line Sensors and Systems for Security is to support risk-based implementation of security tasks. To this end, (high) technology (sensor) systems are developed together with the Dutch industry in accordance with the HTSM Roadmap Security. Risk-Based action requires accurate and timely information about assets, threats and vulnerabilities. The focus is on two main substantive priorities: "Systems for Analysis of full body behaviours for recognition of intentions, including lie detection" and "systems for exploiting the huge image flow of bodycams/wearable sensors for safety tasks systems." In addition, tools to share information between users in risk-driven action (in accordance with "0 + 0 = 1") will also be continuously developed. The involvement of suppliers and their private customers (for example Critical infrastructure) will be intensified; international harmonization will get substantial attention.

The target for the program line *Technology for Passive Sensors* is aimed at supporting Dutch SMEs in the field of electro-optical systems.
The overall objective of Mission Critical Systems (MCS) is to design and develop adaptive autonomous systems for combat management, platform management, bridge management and mission management in the military and civil maritime domain. By combining the scientific areas of general artificial intelligence and complex adaptive systems design, MCS can make decisions that are critical to maintain the mission goal under varying circumstances and for varying availability of resources. Key to the success of MCS is to model the complex relations between sensors, weapons, propulsion, and energy systems, as well as their interaction with the human operator.

3.2.4 Dynamics

A number of projects launched in 2014, 2015 and 2016 will be continued in 2017. These are the European projects MIDNET, ACACIA, EXIST and the project Sensors and Systems for Security:

- ACACIA, a project in the scope of EDA (European Defence Agency) that provides research on applications of micro-doppler and compression sensing for detection, identification and classification of mini-UAVs and is carried out with Thales, Saab and FOI.
- MIDNET is also a project in the scope of EDA on robust routing-concepts for distribution of data/information on military radio networks, in a mobile, wireless disruptive environment to improve network performance.
- EXIST is an ECSEL project on research into new technologies for CMOS image sensors that are needed in the next generation of the various applications and is carried out amongst others with Dutch SME.
- Sensors and Systems for Security is to support risk-based implementation of security tasks together with Dutch industries.

Projects in development envisaged to start in 2017 are WINLAS, ALFA, DAISY2, SA3 and EDM:

- WINLAS is in the scope of EDA and researches sensor, energy, and information management in large-scale soldier modernization systems and is carried out with national and international defence industries and research organizations.
- ALFA is a H2020 proposal in the area of border security and focuses on the detection and identification of small UAV's that are used for drug transport, international partners are police forces and will be carried out together with research institutes and European defence industry.
- SA3 (Situational Awareness by Distributed Sensor Analytics in Smart Areas) is an ECSEL project with about 30 international partners and will provide novel ways to analyse and integrate distributed sensor streams into an true situational understanding of activities in a (dynamic) smart area. Based upon this understanding it will provide real-time services to improve effective operations of city agencies and to increase the quality of life of its citizens.
- EDM (Evolution Design Model) focuses on the development of a test bed for the benefit of the next generation of functionally integrated sensor suites for the Royal Netherlands Navy and is carried out with Thales and the Royal Navy with in-kind support of others.

The program line *Technology for Passive Sensors* will be further developed in 2017*;* we envisage the start of the following activities:

- A new sensor head for the MoD FENNEK reconnaissance vehicle, the effort consists of 2 phases, from which the first is a requirements study, performed together with industry and JIVC. In the second phase, a demonstrator is built by the industry, supported by TNO. The second phase is expected to start in 2018. Industries are (depends on the foreseen functionality): Nedinsco, AdIMEC, Photonis, Microflown.
- Advanced Image Processing with AdIMEC. TNO obtained a contract from AdIMEC. Based on the license agreement, more precise the anti-shelving clause, TNO can development new technology.

- Cooperation, based on the common grounds for camera signal conditioning and behaviour recognition. Foreseen sponsoring companies: Photonis, AdIMEC, Nedinsco.

4 VP Sociale Innovatie

4.1 Roadmap Smart Industry

Contactpersoon TNO: Steven Dhondt

4.1.1 Samenvatting

In het nieuwe programma 2017 wordt ingezet op de volgende thema's:

- *Human Factors Engineering*: het doel is om onze kennis over samenwerking van mens en technologie toe te passen en verder te ontwikkelen op drie nieuwe technologiegebieden: cobots, wearable robots en (cognitieve) operator support systemen voor flexibel en foutloos produceren. In 2016 is het Joint Innovation Centre iBotics opgericht, is een TKI voorstel en een H2020 voorstel exoskeletons in voorbereiding. In het kader van iBotics is gestart met een Kiem-ERP project en is een TKI project (LSH) voorbereid. Het (thema overschrijdend) TKI project Flexibele Manufacturing dat zich o.a. richt op flexibele support systemen en cobots is goedgekeurd; In 2016 is tevens het RAAK MKB project "(G)een moer aan" gehonoreerd dat zich richt op gebruiksvriendelijke mens-robot-interactie bij MKB bedrijven. Daarnaast loopt het gezamenlijke thema overschrijdend EU project "Horse" op het gebied van mens-robot-samenwerking. Tot slot zijn in 2016 diverse fieldlabvoorstellen voor Smart Industry in voorbereiding, met name Flexible Manufacturing (Zuid Nederland en Zuid Holland), die zich o.a. richten op flexibele support systemen.
- *Skills for the future*: het verkrijgen van inzicht over cohort-specifieke ontwikkelingen van kennis in de industrie; over taken van de toekomst en cognitive support systems; over hoe medewerkers in en voor Smart Working-settings te motiveren (o.a. Intrapreneurship en Staymobil). Regionaal werken en flexwerken behoren ook tot deze thema's. In 2016 is een cohorte-analyse uitgevoerd voor de logistieke sectoren. Ook is het TKI Dinalog voorstel Infus@ gestart waarin TNO de technologische toekomst van de logistiek onder de loep neemt. Initiatieven zijn er genomen om een nieuw skills-strategie en –tooling te ontwikkelen. Op Europees niveau is een voorstel in voorbereiding over skills-ecosystemen (ECOSYSTEMS).
- *Flexible and Innovative Organizations*: het ontwikkelen van kennis over hoe 'data driven organizations' binnen Smart Industry feitelijk functioneren en hoe zij in hun operatie kunnen worden geoptimaliseerd. Dat houdt in strategisch advies, nieuwe socio-technische ontwerpen en 24/7 roostersystemen, maar ook Collective Awareness Platforms ter ondersteuning van multi-actor netwerken. In 2016 is met Centric het initiatief genomen om een CAP op basis van Blockchain technologie te gaan ontwikkelen. In samenwerking met Europese instellingen is een brede analyse van Platform Economie en gevolgen voor werk uitgevoerd. Hier wordt verder op ingezet. Met Smart Industry wordt gekeken hoe de Smart Working-kennis bruikbaar is voor andere projecten.

De ambitie is op deze drie onderwerpen met bedrijven, branches en sociale partners nieuwe initiatieven te realiseren. Het Fieldlab Sociale Innovatie en ook andere Fieldlabs, zoals het Fieldlab Flexible Manufacturing, en het Joint Innovation Centre iBotics zullen belangrijk instrumenten hierin zijn.

Doelstellingen in 2017 op hoofdlijnen

- Robotics-initiatieven ter ondersteuning van Smart Working realiseren met name op het gebied van Operator Support en Wearables/Exo-skeletten. Samenwerking met Fieldlab Sociale Innovatie opzetten en de projecten op 'zelf-organisatie', met name gericht op technologie, binnen halen en uitvoeren.
- Voor Skills for the future zullen we (mee) investeren in Beamer Projectie als instrument om skills ontwikkeling te stimuleren. In het InFus@-project wordt de toekomstige skillsontwikkeling in de logistiek uitgewerkt. De samenwerking met Fieldlabs Smart Industry zoals Flexibel Manufacturing initiëren en uitbouwen op het gebied van mens robot samenwerking en operator support systemen.
- Voor Flexible and Innovative Organizations gaan we verder met toepassingen met Blockchain technologie realiseren in de sfeer van werk en organisatie. Een koppeling met leeromgevingen voor elkaar krijgen. Voor Platformeconomie; platformen voor werk en organisatie opzetten en uitbouwen.

4.1.2 Korte omschrijving

Wat is het doel van het VP in de periode 2015-2018?
Het overall doel is het bevorderen van duurzame innovaties in Smart Working door voldoende inzicht te verkrijgen in de mogelijkheden voor betere interactie tussen slimme technologie (o.a. robotsystemen en digitalisering) en medewerkers, in de mogelijkheden om kennisontwikkeling te stimuleren en beter te standaardiseren zodat kennisdeling wordt vergroot. In 2016 zijn hiervoor de eerste initiatieven genomen en in 2017 wordt hier verder op ingezet. Daarnaast zullen verschillende initiatieven die in 2015 zijn opgestart worden doorgezet en afgerond.

Wat is nodig om daar te komen?

- Samenwerking met Fieldlab Sociale Innovatie voor projecten over robotisering en mens.
- Samenwerking met Human Capital Tafels Topsectoren gericht op inbreng expertise TNO in projecten.
- Inzetten op inbreng in meerdere Fieldlabs op mens-machine interactie (o.a. Flexible Manufacturing).
- Inzetten op Horizon2020 en Penta call op de genoemde onderwerpen.
- Inzetten op TNO-brede verbanden: Joint Innovation Centre iBotics; Blockchain.
- Samenwerking over thema's heen met Networked Information en Semiconductor Equipment binnen Smart Industry.
- Samenwerking met DG GROW en DG Connekt voor Platformeconomie realiseren.

4.1.3 Doelstellingen

Beoogde resultaten voor 2017

- Robotics-initiatieven ter ondersteuning van Smart Working realiseren zoals het Joint Innovation Centre iBotics.
- Samenwerking met Fieldlab Sociale Innovatie opzetten en de projecten op 'zelf-organisatie', met name gericht op technologie, binnen halen en uitvoeren.
- Toepassingen met blockchain technologie realiseren in de sfeer van werk en organisatie. Een koppeling met leeromgevingen voor elkaar krijgen.
- Voor Platformeconomie: platformen voor werk en organisatie opzetten en uitbouwen in samenwerking met DG GROW en DG Connekt.

- Samenwerking met Fieldlabs Smart Industry zoals Flexibel Manufacturing initiëren en uitbouwen op het gebied van mens robot samenwerking en operator support systemen.
- Lopende initiatieven verder zetten.

Welke partijen zijn of worden betrokken?

- In dit programma wordt samengewerkt met een breed aantal kennisinstituten op het gebied van sociale innovatie, cobotisering, intrapreneurship: Universiteit Utrecht, INSCOPE, Vrije Universiteit Amsterdam, KU Leuven, Hogeschool Utrecht, Hogeschool Windesheim, Fontys Hogeschool, TU Eindhoven, Universiteit Twente, Brainport Industries. Ook zijn bedrijven aangesloten zoals Philips, Centric, Bronkhorst, Omron, TE connectivity, Bosch Rexroth. Geodis, Boskalis, Shell en DHL en Vanderlande Industries, maar ook Topsectoren zoals HTSM en Logistiek en Life Sciences and Health.
- Netwerk robotics partijen ('system integrators'): ABB, UR/Gibas, Smart Robotics, Yaskawa, Blue Ocean Robotics maar ook het netwerk "Roboned".
- Netwerk blockchain bedrijven startend met Centric.
- Europese netwerk workplace innovation: vorig jaar is een AIO van start gegaan bij de Universiteit Utrecht op het gebied van intrapreneurship (Prof. Erik Stam). Alle activiteiten zijn internationaal verankerd doormiddel van samenwerkingsverbanden met partners binnen het European Workplace Innovation Network (van DG GROW).
- Fieldlab Sociale Innovatie.
- Fieldlab Flexibele Manufacturing.
- De ontwikkelde kennis op het gebied van Smart Working in de verschillende terreinen wordt geïmplementeerd in praktische tools voor het MKB. Daarvoor zal nauw worden samengewerkt met het TNO MKB programma.

4.1.4 Dynamiek

Het programma Sociale Innovatie 2015-2016 was tot op heden gericht op de volgende onderwerpen: Samenwerking van mens en technologie ('Human in Automation'); Ontwerp van werkplekken ('Hightech support for human work'); Aanboren talent en ondernemerschap; Nieuwe dashboards voor bedrijven; Ontwikkeling van inclusief beleid door overheid. In het nieuwe programma 2017 en later is sprake van continuïteit en een lichte verschuiving naar nieuwe thema's:

- Het programma Smart Working is een voortzetting van het Speurwerkprogramma Sociale Innovatie (P207), onderdeel van de Roadmap Prevention, Work & Health. Zoals aangegeven, krijgt het programma een nieuwe focus die het toelaat aan te sluiten op technologieën ontwikkeld binnen Smart Industries. Deze ontwikkeling zal geleidelijk aan doorzetten.
- Op dit moment wordt verder ingezet op het succes van het programma van de afgelopen jaren. De helft van het budget in 2017 ligt vast in gemaakte SMO afspraken. De rest van het programma is nog vrij inzetbaar om in PPSen te worden ingezet. De marktontwikkeling is erop gericht om de gevraagde multiplicator te halen.
- In de laatste paragraaf is een overzicht gegeven van de doorlopende verplichtingen. Voor het programma is van belang gebruik te maken van TKI Toeslag uit HTSM.
- Voor 2017 wordt geprobeerd 'cross-over' projecten voor elkaar te krijgen. Op dit moment zijn er de exoskeletten/telerobotica-projecten: voor de Topsector LSH bereiden we een TKI voorstel voor waarin we met partijen als Shell, Boskalis en

Geodis technologie een industrie scan maken. Een crossover met HTSM ligt voor de hand.

Wens stakeholders/ministerie/kennisarena/partnerraad?
- Overleg tussen de Ministeries EZ en SZW
- Overleg Fieldlab Sociale Innovatie
- Overleg logistieke sector

Wat is het gevolg?
Omdat de 'vrije' SMO ruimte in het programma voor 2017 nog beperkt is (50%) is er een continuïteit in het werk. De inhoudelijke verschuiving zorgt wel voor een verdere optimalisering van onze kennisbasis (experts, netwerken), maar vooral een verdere verdieping en versteviging van onze netwerken in de HTSM en in de Logistiek.

In de volgende tabel zijn de geplande initiatieven voor 2017 aangegeven.

	PPS-Initiatieven voor 2017
Human Factors Engineering	iBotics: JIC for interaction robotics FOF10 H2020 Horse RAAK MKB "(G)een moer aan" Fieldlab Flexible Manufacturing Fieldlab Human Machine Interactie NV Oost Brainport Innovation Campus (BIC) Hoogleraarschap Prof.de Looze
Skills for the Future	Fieldlab Sociale Innovatie StayMobil Intrapreneurship Beamer Projectie als operator support system Lectoraat Dr. Klaas ten Have
Flexible and Innovative Organizations	USI NWO Accelerator Logistiek CAPS 2017 Co-Creation-07-2017: ECOSYSTEMS InFuS@ (TKI Dinalog) Hoogleraarschap Prof. Dhondt

Annex: Lopende initiatieven uit projecten 2015
- CORTEXS: 2017 is het afsluitende jaar voor het project over geïntegreerde zorg. In het project wordt wel de aandacht gericht op database gestuurde organisaties.
- SI-DRIVE: 2017 is het afsluitende jaar voor het project over sociale innovaties in zeven beleidsterreinen (werk en technologie; energie; gezondheid; armoede etc.).
- USE-IT-WISELY: 2017 is afsluitend jaar voor project over IT in werkplekken.
- ROBOMATE: 2017 is afsluitend jaar over exoskeletons.

5 VP Automotive Mobility Systems

5.1 Roadmap Automotive

Contactpersoon TNO: Riné Pelders

5.1.1 Samenvatting

Het Vraaggestuurde Programma 'Automotive Mobility Systems' (VP AMS) sluit aan bij de Topsector HTSM, Roadmap Automotive en richt zich op het versterken van de competitieve positie van de Nederlandse automotive en mobiliteitsindustrie. Het VP AMS valt binnen TNO binnen het thema 'Leefomgeving', Roadmap 'Mobiliteit en Logistiek'. Op dit kruispunt van interesses wordt een kennisontwikkelings-programma uitgevoerd dat zich richt op nieuwe innovaties op het gebied van automotive en mobiliteit die op middellange termijn een bijdrage leveren aan de versterking van de Nederlandse industrie en daarnaast oplossing bieden voor het verbeteren van de vitaliteit en ontwikkeling van onze leefomgeving.
Binnen het thema 'Leefomgeving' wordt daarbij naar synergie gezocht met andere Roadmaps van dit thema (Smart City, Environment and Sustainability en Buildings and Infrastructure).
Het VP AMS heeft haar activiteiten verdeeld over twee deelprogramma's:

1. Automated Driving
   het ontwikkelen van controle oplossingen en methodologie voor het automatiseren van voertuigfuncties.
2. Low Carbon HD Transport
   het ontwikkelen van oplossingen voor significante broeikasgas reductie in het Heavy Duty transport (trucks en bussen).

De activiteiten op het gebied van Cooperative & Connected Mobility worden (sinds begint 2015) binnen het Vraaggestuurde Programma Betrouwbare Mobiliteitssystemen verder doorgezet.

5.1.2 Korte omschrijving

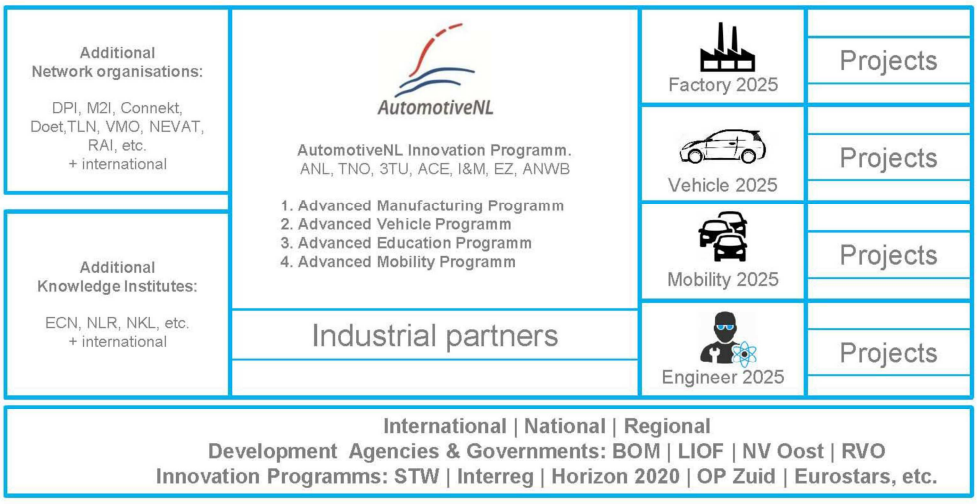
Samenwerking

Het dominante partnershipmodel voor dit VP blijft samenwerking met de automotive sector in Nederland binnen Publiek Private Partnerships. Hiervoor worden in de deelprogramma's specifieke initiatieven genomen.
Daarnaast is AutomotiveNL voor TNO de belangrijkste vertegenwoordiger van de sector in Nederland en TNO zal haar inspanningen blijven continueren om AutomotiveNL hier zo goed mogelijk in te ondersteunen.
Het TKI HTSM Roadmap Automotive wordt steeds belangrijker voor TNO als partnership om ontwikkelprojecten uit te voeren. TNO zal in 2017 wederom in staat zijn (dankzij haar significante internationale B2B portefeuille) om een grote bijdrage aan TNO toeslag te genereren.
Op Europees niveau blijft TNO actief in samenwerkingsverbanden als EARPA, ERTRAC, ERTICO, etc., maar ook in directe samenwerking met de EC, zoals o.a. in STRIA en GEAR2030.

Interactie, vraagsturing

Zoals hierboven aangegeven is de Nederlandse Automotive sector de belangrijkste stakeholder voor dit VP. AutomotiveNL is voor TNO het aanspreekpunt m.b.t. organiseren van vraagsturing en interactie met de sector. TNO ondersteunt

AutomotiveNL actief om de interactie binnen en met de sector zo optimaal mogelijk te laten verlopen.
Er zijn een aantal samenwerkingsverbanden, waarbinnen gezamenlijk onderzoek met bedrijven uit de sector wordt geagendeerd en uitgevoerd, waarin TNO actief participeert.
Het TKI HTSM Roadmap Automotive heeft een Roadmapteam dat verantwoordelijk is voor het beheer en onderhoud van de gezamenlijke onderzoeksroadmap en voor beoordeling (en eventueel initiatie) van onderzoeksprojecten. De vraagsturing wordt het meest concreet in deze TKI Roadmap en in de interactie m.b.t. TKI voorstellen ingevuld. In het voorjaar 2015 is de Automotive Roadmap van het TKI vernieuwd (http://www.automotivenl.com/images/HTSM_Roadmap_Automotive_2016.pdf). Deze Roadmap is richtinggevend voor de inhoud van het TNO programma binnen VP AMS.



Figuur 1: AutomotiveNL Innovation Program.

Samen met DAF, NXP en Ricardo werkt TNO aan de ontwikkeling van truck platooning. Ten tijde van het schrijven van deze bijstelling is er een TKI plan ingediend waarbij de volgende stappen worden gezet in functionaliteit en betrouwbaarheid van truck platooning. De technologie wordt verder ontwikkeld met als doel om voor 2020 het, zowel technisch als wettelijk, mogelijk te maken om met truck platooning op de Nederlandse weg te kunnen rijden. Op deelgebieden wordt ook samengewerkt in de context van truck platooning met o.a. de TU Eindhoven en TU Delft.

Naast samenwerking met de industrie en de universiteiten worden ook voorbereidingen getroffen om samen met overheden en logistieke partners in 2017 de eerste truck platooning pilots op de openbare weg te gaan starten.

Samen met DAF, TU Eindhoven en de BOM werkt TNO aan een samenwerkingsprogramma op het gebied van geavanceerde verbranding. Ten tijde van het schrijven van deze bijstelling ligt er een voorstel bij de Provincie Noord-Brabant voor ondersteuning van de eerste fase van deze samenwerking waarin wordt geïnvesteerd in de infrastructuur (mensen en middelen) voor het fundamenteel onderzoek op dit gebied aan de TU Eindhoven. TNO draagt hier ook aan bij. In de loop van 2017 zal het samenwerkingsprogramma worden uitgebreid tot een onderzoeks- en ontwikkelingsprogramma op het gebied van geavanceerde verbrandingsconcepten en toepassing van nieuwe duurzame brandstoffen.

5.1.3 Doelstellingen

Visie

In het Speurwerkprogramma 2015-2018 wordt ingezet op het verbeteren van verkeersveiligheid, gezondheidseffecten van vervoer naar nihil, verlagen van de invloed op klimaatverandering en verbetering van de transport efficiëntie.
Dit wordt in de deelprogramma's verder vertaald naar een aantal concrete doelen.

Automated Driving

De focus binnen automatisch rijden richt zich op vier applicatiegebieden, c.q. domeinen: private transport (cars), commercial transport (trucks), public transport (busses, PRTs) en terminal transport (AGVs). Binnen al deze domeinen is het doel om middels het automatiseren van voertuigfuncties i.c.m. draadloze communicatie tussen de voertuigen, deze veiliger, efficiënter en effectiever te laten functioneren. Ook richten we ons op het wettelijk toelaatbaar krijgen van automatisch rijdende voertuigen op de openbare weg. Dit in een complexe omgeving zoals een snelweg of stedelijke omgeving, met verschillende weggebruikers in uiteenlopende omstandigheden.
Belangrijkste doel is om de toepassing mogelijk te maken in de context van de openbare weg en te versnellen. Dit door zowel de onderliggende technologieën te ontwikkelen, als de methodologie om efficiënt (tijd en kosten) te ontwikkelen en te valideren.

Low Carbon HD Transport

Nederland heeft een sterke automotive en logistieke sector, met name in het zware transport segment. De technologische uitdagingen voor verlaging van uitstoot van broeikasgassen zijn in dit segment het grootst.
TNO kiest ervoor om naar het hele transportsysteem te kijken om te analyseren welke maatregelen het meest kosteneffectief zijn. Hiervoor zullen analysemethoden worden ontwikkeld welke ingezet worden door zowel de industrie als overheden in hun strategische beslissingen.
Daarnaast zullen, samen met partners, op een aantal specifieke onderwerpen technologische oplossingen worden ontwikkeld om doorbraken mogelijk te maken. Deze concepten zullen in de praktijk worden gedemonstreerd in pilots of living labs.

Ambitie

Om deze visie te realiseren zijn de volgende activiteiten gepland voor het komende jaar.

Automated Driving

In 2016 bouwt TNO voort op de ingeslagen weg t.a.v. methodeontwikkeling voor ontwikkelen, testen en valideren (mogelijk certificeren) van automated driving systemen. Na een focus in 2015 op het identificeren en kwalificeren van scenario's, waarbinnen automated driving systemen moeten opereren, wordt in 2017 net als in 2016 gefocusseerd op het modelleren en virtualiseren van de applicaties. In 2017 zal er nog meer focus komen dan in 2016 op toepassingen en functies voor het stedelijk gebied en het gebied vanuit het hoofdwegennet van/naar het stedelijk gebied. Ongeacht de omgeving, voor alle typen toepassingen en functies kan een scenario gebaseerde aanpak worden toegepast, met als concreet doel het toepassen en tegelijkertijd aantonen dat een dergelijke aanpak versnellend werkt op ontwikkeltijd van coöperatieve control oplossingen.
Dit zal o.a. ook in 2016/2017 in een TKI project met industriële partners worden opgepakt, in kader van de Next Milestone '2-truck platooning' maar ook in EU of bijv. STW projecten.

Low Carbon HD Transport
In 2017 wordt een verder focussering van het programma doorgevoerd naar twee focusgebieden: ‘Urban Transport system Optimization’ en ‘flex fuel control’.
Het focusgebied Urban Transport system Optimization richt zich op de optimalisatie van complete voertuigvloten in een stedelijke omgeving in de transitie naar volledige elektrificering. In 2017 zullen instrumenten worden ontwikkeld en toegepast in vloten (elektrische bussen en (hybride) distributie trucks) die door multi-criteria optimalisatie zullen leiden tot verlaging van energieverbruik en (operationele) kosten.
Het focusgebied flex fuel control richt zich op het verbeteren van het verbrandingsrendement van motoren in de transitie naar nieuwe volledig duurzame brandstoffen. In 2017 zal gefocusseerd worden op verhoging van het lastbereik, verlaging van de methaanslip en robuustheid voor toepassing van andere brandstoffen.

5.1.4 Dynamiek

Binnen de twee deelprogramma’s ligt de focus op het ontwikkelen van een samenhangend onderzoeksprogramma in Publiek Private Samenwerking. In elk deelprogramma wordt dit op eigen wijze ingericht. Het doel is om het onderzoeksprogramma zoveel mogelijk relevant te laten zijn voor de betrokken bedrijven en bij te dragen aan hun concurrerend vermogen middels gezamenlijke nieuwe innovatie en tegelijkertijd zoveel mogelijk bij te dragen aan de maatschappelijke doelstellingen.

Impact van vraagsturing
Uit interactie met onze stakeholders komen specifieke wensen, aandachtsgebieden naar voren.

Automated Driving
Momenteel worden door verschillende partijen in de automotive maar ook in de transport/logistiek Automated Driving applicaties ontwikkeld. Met de toename aan functionaliteit en complexiteit van de omgeving, wordt de ontwikkelinspanning, maar ook de validatie inspanning steeds groter. We zien die situatie bij de bedrijven langzaam ontstaan, waardoor onze methodologisch (scenario-gebaseerde) aanpak steeds meer gehoord en gezien gaat worden.

Low Carbon HD Transport
In dit programma wordt gezocht naar oplossingen die nu al economisch attractief zijn zonder dat wetgeving voor CO_2 emissiereductie noodzakelijk is. Dit betekent aansluiten bij eisen als zero-emission stadsbussen, geluids- en milieueisen voor stadsdistributie, inzet van low-carbon brandstoffen en CO_2 declaratie voor trucks. Binnen deze randvoorwaarden moeten de oplossingen de laagst mogelijke Total Cost of Ownership bieden, wat het leidende koopmotief is in het commerciële transport. Analyse van de kosteneffectiviteit van maatregelen is in de modellen voor multilevel systeem analyse een beslissend criterium.

Aansluiting innovatie contract HTSM en Roadmap
Het TNO onderzoeksprogramma in dit VP draagt bij aan en past volledig binnen de scope van de Smart Mobility (Automated Driving) en de Green Mobility (Low Carbon HD Transport) agenda van de HTSM Automotive Roadmap.
TNO werkt samen met haar partners in diverse soorten projecten:

- Samenwerkingsprojecten binnen Nederlandse of Europese onderzoeksprogramma’s.
  In deze projecten met gemengde financiering werkt TNO samen met

Nederlandse bedrijven, kennisinstellingen en andere stakeholders. TNO borgt dat de kennis die wordt opgebouwd relevant is voor de Nederlandse partners binnen deze projecten en dat de kennis vernieuwend is voor de TNO programma's (en daarmee HTSM Automotive Roadmap).

- Nieuwe kennisontwikkeling binnen contractonderzoeksopdrachten.
  Opdrachten voor contractonderzoek bij TNO hebben soms toepassing of hergebruik van bestaande kennis als scope. Veel vaker gaat het echter om de ontwikkeling van nieuwe kennis.
  TNO borgt dat nieuwe kennisontwikkeling binnen contractonderzoek altijd past binnen haar programma's (en daarmee HTSM Automotive Roadmap).
- TKI projecten.
  Met de TKI Toeslag die is gegenereerd in bovenstaande opdrachten worden TKI projecten uitgevoerd. Deze projecten passen per definitie binnen de HTSM Automotive Roadmap en worden met het TKI Roadmapteam afgestemd.
- Nieuwe kennisontwikkeling gefinancierd uit Rijksbijdrage
  Een deel van het programma bevat speurwerkonderzoek om nieuwe achtergrondkennis te verwerven. Het betreft hier vaak verkenning van nieuwe kennisgebieden of verdieping van kennis die niet direct past binnen andere samenwerkingsprojecten.
  In deze projecten wordt altijd de verbinding gezocht met praktische use-cases en ondersteuning van bedrijven. TNO borgt dat de kennis past binnen haar programma's (en daarmee vernieuwing en verdieping van de HTSM Automotive Roadmap).

Binnen elk van de twee deelprogramma's wordt er een portefeuille van projecten uitgevoerd die bestaat uit een mix van bovenstaande typen samenwerkingsprojecten. De deelprogramma's proberen synergie te bereiken tussen deze projecten en daarmee hun Roadmap te versnellen.
Met betrekking tot de twee deelprogramma's kan daarover nog aanvullend worden opgemerkt:

Automated Driving
TKI is ook voor Automated Driving een belangrijke samenwerkingsvorm, met focus op o.a. methodeontwikkeling in het truckdomein. In EU verband gebeurt dit ook voor het domein personenauto's.
De volgende stap is om de methodologische aanpak voor alle 4 de applicatiedomeinen op te pakken. De insteek is om binnen iedere applicatiedomein in een PPS achtige constructie met partijen samen te werken. Ook de interactie met de overheid (coöperatief automatisch rijden) is daar een onderdeel van.
In 2017 zal doorgegaan worden met de ingeslagen wegen om de PPS samenwerkingen verder door te zetten en uit te breiden.

Low Carbon HD Transport
Samenwerking in PPS verband blijft het dominante samenwerkingsmodel.
In 2017 wordt in partnership samengewerkt in de nieuw opgezette samenwerking op het gebied van 'advanced combustion' (met DAF en TU Eindhoven) en wordt internationaal samengewerkt in onderzoek binnen de Forschungsvereinigung Verbrennungskraftmaschinen (FVV) in Duitsland. Indien mogelijk zullen voor deze samenwerkingsprogramma's TKI gelden worden ingezet om de TNO activiteiten te financieren.
Dankzij de significante omzet in experimenteel Powertrain onderzoek wordt een constante TKI financieringsstroom gevoed en worden TKI projecten geïnitieerd.
Daarnaast bieden de projecten in het H2020 Green Vehicles Initiative andere mogelijkheden om in bredere (internationale) consortia samen te werken.

TKI programma's
TKI projecten bieden voor bedrijven een aantrekkelijke manier om met TNO samen onderzoek uit te voeren. Het onderzoek kan (gefaseerd) fundamenteel, industrieel of experimenteel van karakter zijn.
De voorkeur van TNO gaat uit om in TKI projecten vooral nieuwe conceptontwikkeling en technologieverkenning uit te voeren (fundamenteel onderzoek) en deze concepten in de praktijk te valideren en geschikt te maken voor industrialisatie (industrieel onderzoek). Projecten zullen dus vaak enkele werkpakketten met een fundamenteel karakter hebben en enkele werkpakketten met een industrieel karakter waardoor de bijdrage van bedrijven typisch tussen de 25% en 40% in zal liggen.
TKI projecten laten ook buitenlandse bedrijven toe en TNO zal zich in 2017 richten op het verder internationaliseren van haar TKI projecten. Het TKI Roadmapteam toetst of participatie van buitenlandse of niet automotive bedrijven in TNO TKI projecten gewenst is.
Initiatieven voor TKI projectenvoorstellen kunnen door TNO zelf worden ontwikkeld, maar kunnen ook via bedrijven of het TKI Roadmapteam bij TNO worden voorgesteld. Het TKI HTSM Automotive Roadmapteam adviseert de Roadmaptrekker over het toekennen van TKI Toeslag aan een TKI project.

TNO TKI projecten in 2017
Advanced safety for automated driving vehicles
De truck-platooning activiteiten zullen in2016 worden uitgebreid met een TKI project met meerdere partners in de ontwikkelingsketen (industriële partners op het gebied van sensor- en communicatie systeem ontwikkeling en certificering) dat tot medio 2017 loopt. Na een succesvolle demonstrator die mee heeft gedaan aan de truck platooning challenge van RWS/I&M/RDW in april 2016, wordt de ontwikkeling voortgezet naar een hogere automatiseringsgraad, hogere eisen aan (functionele) veiligheid en meer functionaliteit gericht op toepassing op de openbare weg (o.a. heterogeniteit van platooning). Insteek is dat per jaar TKI samenwerking verder uitgebreid wordt met meerdere partijen die nodig zijn richting ontwikkeling van het einddoel: automated truck platooning concept technologisch en wetgeving-technisch toegelaten op NL wegennet voor 2020.

Intelligent Intersection
Dit project wordt de tweede helft van 2016 opgezet en zal eind 2016 starten. Doel van dit project is om op basis van het combineren van de situational awareness uit voertuigen en wegkantsystemen een compleet en real time verkeersbeeld op een kruising op te bouwen om zo de veiligheid, doorstroming en milieubelasting te verbeteren. Use cases:

- Anticiperen op/voorkomen van botsingen tussen voertuigen en kwetsbare verkeersdeelnemers.
- Optimaliseren van multimodale verkeersdoorstroming (voertuigen, fietsers, voetgangers).
- Anticiperen op groene golf.

Advanced Combustion Control for High Efficient Engines
Dit TKI project is in september 2015 gestart en zal tot eind 2016 doorlopen. In 2017 zal dit project verder uitgebreid worden met een deelproject binnen het onderzoeksprogramma van de FVV en met een nieuw TKI voorstel dat in lijn ligt met de agenda van het samenwerkingsverband 'advanced Combustion' (DAF, TU Eindhoven).

E4Bus
In 2016 is het project E3Bus afgrond dat zich richtte op verbetering van het energiemanagement van elektrische bussen, met focus op de rol van het klimaatsysteem.
In 2017 zal in een vervolgproject verder onderzocht worden hoe het energieverbruik van een vloot van elektrische bussen kan worden verbeterd met een energiemanagement op vloot niveau met focus op de laadstrategie van de bussen.

Voortzetting bestaande programma's
In 2017 zal het programma worden voortgezet met focus in 2 deelprogramma's. Deze activiteiten worden samen met bedrijven en instellingen uitgevoerd, vaak in contract onderzoek, Europese projecten of met informele ondersteuning.

Automated Driving
Binnen de verschillende expertisegebieden van AD zijn de eerste plannen en focusgebieden voor 2017 aangegeven. Deze zullen de komende periode verder uitgewerkt worden.

- Voortzetten van realisatie richting/op weg naar een SAE level 4 voertuig (longitudinale en laterale) automatisering, gebruik makend van coöperatieve technologie, met focus op het op korte-afstand volgen van voertuigen en manoeuvreren.
  - Situational awareness
  - Sensor fusion & object tracking
  - Control for manoeuvring
  - Functional and technical safety
  - Fault-tolerance & fail-safety concept and algorithm design (level4)
- Methodologieontwikkeling (real life safety assessment methodologie).
  - Scenario data processing
  - Detectie van events en scenario's (detectie en predictie van rijstrook wisselingen van ander verkeer, inclusief cut-in)
  - Re-generatie van events en scenario's
    Methodologieontwikkeling is gebaseerd op combinatie van fysische en virtuele testen. Focus in 2017 ligt o.a. op zowel software- als hardware –in-the-loop ontwikkel- en testfaciliteiten op basis van real life data.
- Technologieën voor het vergroten van de veiligheid van inzittenden als ook kwetsbare verkeersdeelnemers.
  - Bestuurdersmodellen voor adaptive ADAS (adaptie C-ACC controller gebaseerd op bestuurderstype) binnen ERP
  - Gedragsmodellen van andere weggebruikers (detectie en voorspellen rijstrookwisseling van andere weggebruikers, incl. cut-in)
  - Adapteren AD/ADAS functions naar de bestuurder en omliggend verkeer\Ontwikkeling tooling en algoritmiek voor gedragsherkenning van verschillende weggebruikers (waaronder fietsers)
- Het observeren, controleren, behouden en veiligstellen van voertuig operatie onder alle omstandigheden.
  - Bepalen van en controle van vehicle performance envelope
  - Vehicle state estimation technieken (als input naar safety checker)
  - Collision accident avoidance (voertuig automatisch in veilige staat brengen)

Low Carbon HD Transport
De focus ligt op verlaging van uitstoot van broeikasgassen in het Heavy Duty transport. Hiervoor wordt op twee proposities ingezet:

- Urban Transport system Optimization
  Verlagen van het energieverbruik en de totale (operationele) kosten van een voertuigvloot in een stedelijke omgeving. Dit wordt bereikt door het modelleren van het transportsysteem en toepassing van multi-criteria optimalisatie technieken. Hiermee worden gereedschappen ontwikkeld waarmee een optimaal systeem kan worden ontworpen en waarmee de voertuigen in de operatie zichzelf kunnen optimaliseren.
  Investering zullen zijn op het gebied van systeem modellering en optimalisatie en het ontwikkelen van ontwerpgereedschappen en control algoritmes voor voertuigoptimalisatie.
- Flex Fuel Control
  Geavanceerde engine control strategieën die motoren meer robuust maken voor toekomstige duurzame brandstoffen en spreiding in kwaliteit. Dit wordt gecombineerd met verbetering van het verbrandingsrendement (BTE) van de motoren. Voor aardgas (als een low-carbon transitie brandstof) zal gezocht worden naar een oplossing voor verlaging van methaan slip, daarnaast zal steeds meer aandacht worden besteed aan toekomstige duurzame brandstoffen.

6 VP Human Health RM Nano

6.1 Roadmap Nanotechnology

Responsible TNO: Wouter Fransman

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 (MN) 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. 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.

6.1.2 Short description

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 the following:

1) 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.
2) Quantitative models for human risk assessment. To reach this goal, sufficient toxicological and measurement data for nanomaterials should be collected in a harmonized way.
3) Accurate, fast and low costs sensors and measurement methods/instruments to detect nanomaterials in air and other environmental media.
4) Risk management measures to reduce human health risks caused by exposure to nanomaterials.

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. This will be an enabler for safe innovation.

6.1.3 Goals

Horizon 2020

TNO has a strong position in currently running FP7 calls and Horizon 2020 calls in the field of nanosafety and has a leading position in the field of exposure assessment, risk assessment and modeling, and tool development. At this moment TNO participates in the projects given in Table 1.

Table 1: EU projects in the field of risks of nanomaterials in which TNO participates.

EU project	Period	Short description	Role TNO
NANoREG 2	Sep 2015 - Aug 2018	Follow up of NANoREG 1 to support the reduction of differences in pace between innovation and the development of supporting regulatory safety requirements. This method is based on the Stage Gate® Idea-to-Launch model (Cooper) which is often used in innovating organizations.	TNO will expand further the concepts of NANoREG1 to consistently combine the safety aspect along the entire value chain and the industrial innovation processes.
GUIDEnano	Nov 2013 - April 2017	Development of innovative methodologies to evaluate and manage human and environmental health risks of nano-enabled products, considering the whole product life cycle. These developments will be incorporated into an web-based Guidance Tool, which will guide the nano-enabled product developers (industry) into the design and application of the most appropriate risk assessment & mitigation strategy for a specific product.	(1) Development of a quantitative exposure assessment strategy, (2) development of a risk assessment strategy including sensitivity analysis, (3) Contribution to the risk measurement strategies for the GUIDEnano tool, and (4) development of GUIDEnano tool.
SUN	Nov 2013 - Oct 2017	Sustainable Nanotechnologies. SUN research process integrates the bottom-up generation of nano-EHS data and methods with the top-down design of a Decision Support System (DSS) for practical use by industries and regulators.	Development of exposure assessment strategy. Performance of a life cycle assessment for relevant case studies.
FutureNanoNeeds	Jan 2014 - Dec 2018	Development of a novel framework to enable naming, classification, hazard and environmental impact assessment of the next generation nanomaterials prior to their widespread industrial use.	Development of an exposure assessment framework for the next generations of nanomaterials based on the input from the value chains.
NanoSolutions	Apr 2013 - Mar 2017	Development of a safety classification for engineered nanomaterials (ENM) based on an understanding of their	Inclusion of human health risks of nanomaterials in a life cycle assessment. Performance of a case study on quantum dots.

		interactions with living organisms at molecular, cellular and organism levels.	
NanoFASE	Sep 2015 - Aug 2019	Refinement of current understanding of the combination of properties and processes that determine the movement of Nano Materials (NMs) from their release points across the full product value chain into the environment, through their transformation and ultimate fate within and between specific environment compartments, along with their biotic uptake potential throughout their environment transport and transformation.	TNO will (1) contribute on release estimation and modelling and forms, (2) contribute on transformations and transport in air (modelling and measurement) (3) support connection of Air modular model and (4) lead/support on case study on car tires.
NanoSTReeM	Jan 2016 - Dec 2018	Support and coordination of activities in relation to research and development of novel nanoscale or nano functionalized materials enabling further increase of semiconductor manufacturers' productivity and innovation.	Translate current risk assessment strategies to semi-conductor industry.
CaLIBRAte	July 2016 - June 2019	Develop a framework for the risk governance of nanomaterials entering the market by developing and calibrating tools for risk appraisal, risk transfer and guidance for risk communication.	Further development of the STM-nano Hazard/risk banding model and Benchmarking of hazard banding by Omics data interpretation/systems biology, and offer the Diamonds infrastructure by data gap analysis of hazard data and hosting the database.
EC4SafeNano	March 2016 – Feb 2019	Define and validate operating principles, governance strategy and sustainability model for an independent science-based Centre of European organizations for Risk Management and Safe Innovation for Nanomaterials & Nanotechnologies to support industry, safety service providers, regulators and public stakeholders.	Inventory and matching of demands and resources from authorities and private stakeholders regarding nanosafety. Lead in the industry focus network and the network on national Nanocentres.

Various opportunities exist for participation in new Horizon 2020 projects, which are being explored and elaborated to be reviewed on a case-by-case basis on fit in the Roadmap.

By participation in EU projects, TNO has a strong international network. In addition TNO actively participates in the NanoSafetyCluster and chairs the working group on exposure.

Universities, TO2 and RIVM
Within NanoNextNL, strong collaboration was set up with Utrecht University (with graduation of a Ph.D. student on the topic of exposure assessment and modelling of nanomaterials in 2016), Delft University, RIKILT and RIVM. These collaborations are continued and intensified in various FP7 and Horizon 2020 projects.
In addition, TNO has intensified their collaboration with the University of Maastricht to match the database of physical/chemical properties, system biologic effects and the toxicity of NM with the methodologies developed within the project eNanoMapper. Within the project eNanoMapper an Ontology Framework for Nanomaterials is developed which is led by University of Maastricht.

Companies
The methodologies and tools currently under development in the EU projects are relevant for large industry and SMEs on the Dutch market. Interest of these companies is already shown by taking part in FP7 and Horizon 2020 projects, i.e DSM in NANoREG 1 and NANoREG2, Nanoservices in GUIDEnano. Furthermore, TNO observed an increased interest from companies to invest in characterizing and minimizing the risks for the production and use of solar panels, semiconductor industry, chemical industry, and printing industry. There is a lot of interest in the risk assessment of nanomaterials from the surface treatment industry and applicators. In NanoNextNL there is a strong participation with SME companies and larger industries. It is expected that these companies will benefit from the knowledge of TNO and will contact TNO for consultation on the safety questions on their products.

6.1.4 Dynamics

TNO will continue the program started in 2015. In 2016, 2 new Horizon 2020 projects will start, i.e Calibrate and EC4SafeNano. These projects have a strong interaction with industry and will focus on relevant value chains and dissemination of information on nanosafety. The role of TNO in these projects is described in Table 1.
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. In the letter of September 23rd, 2011 the Ministry of EL&I highlighted again the importance it attaches to the development of nanotechnology because of the opportunities for economic growth and social issues. 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. A strong foundation was made within NanoNextNL, a Public Private Partnership of more than 100 companies. Within NanoNextNL, the program Risk Assessment and Technology Assessment (RATA) laid an essential base for obtaining insight into the risks of nanomaterials.

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 enters 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 costs 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.

In September 2012, OECD, after 6 years of work, concluded that the methods used to determine the safety of traditional chemicals can also be used to determine the safety of nanomaterials. In some cases it is necessary to adapt the methods of sample preparation and dosimetry but it will not be necessary to develop a completely new approach for nanomaterials.

Since 2007, the European Registration, Evaluation, Authorization and restriction of Chemicals (REACH) regulation in force. Already in 2008 it was concluded that REACH focuses on substances in any size, shape or physical state. Nanomaterials are already included in the REACH regulations as no distinction is made according to size. At ECHA there is a growing attention for the registration of nanomaterials under REACH. In 2012, ECHA (via Appendices) produced a guidance for nanomaterials, in 2013 ECHA published REACH Annexes specifically for nanomaterials. Based on these governmental developments, there is an increasing awareness to perform a proper risk assessment for nanomaterials and to comply with the regulations.

Scientifically there are still many challenges to assess the risks of nanomaterials. According to the Nanosafety in Europe 2015-2025 it is concluded 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; undertaking this may require the development of novel risk assessment strategies, sensors and measurement methods together with companies that will replace the current ones, being equally reliable, affordable but faster. 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.

6.1.5 Stakeholders and connection with the Roadmap Nanotechnology

NanoNextNL and Roadmap Nanotechnology

This VP aligns well with the Risk Assessment and Technology Assessment (RATA) program of NanoNextNL which focus on the exposure, toxicity and the prediction of the risks of nanomaterials. In addition in the roadmap nanotechnology, the need for standardization and regulation is described in the area of management of potential risks of “nano inside” a next step must be taken, especially in the area of engineered nano materials and nano particles. Also on European level there is much attention on the standardization. At European level CEN is responsible for the standardization of methods. In 2016 TNO worked on the following standardization

documents:

- WI 137052 Workplace exposure – Characterization of ultrafine aerosols/nanoaerosols – Determination of number concentration using condensation particle counters
- WI 137053 Workplace exposure – Assessment of inhalation exposure to nano-objects and their aggregates and agglomerates
- WI 137056 Workplace exposure – Metrics to be used for the measurement of inhalation exposure to nano-objects and their aggregates and agglomerates such as number concentration, surface area concentration and mass concentration
- WI 137057-061 Workplace exposure - Measurement of dustiness of bulk nanomaterials - Part 1-5

In the next years, TNO will continue to translate their knowledge to support standardization.

Nanocentre

Nanocentre (www.nanocentre.nl) aims to support SMEs and other relevant stakeholders to ensure safe innovation of products or processes that utilize nanomaterials. Nanocentre will be used to inform companies about the progress of knowledge and the available tools. This Dutch initiative will be elaborated by the project EC4SafeNano, which started in 2016 and in which TNO collaborates to create an independent science-based Centre of European organizations for Risk Management and Safe Innovation for Nanomaterials & Nanotechnologies to support industry, safety service providers, regulators and public stakeholders.

Dutch Government

Another stakeholder of the results will be the Ministry of Social Affairs and Employment (SZW) and Infrastructure and Environment (I&M). The results of our research will contribute to the protection of workers and consumers that come into contact with nanomaterials and to the protection of the environment.

Risks of Nanotechnology Knowledge and Information Centre (KIR nano)
TNO will continue to collaborate with RIVM and inform KIR nano on the developments and risks of nanotechnology on humans and the environment.

Companies

The development of the knowledge of nanomaterials is done at a European level in FP7 and Horizon 2020 projects. TNO has reached a leading position in the exposure and risk assessment of nanomaterials. In 2016, There was an increasing amount of questions from companies to TNO in this field for instance in the field of coatings, solar panels, chemical production, printers and electronic devices. In the next years it is expected that these questions will increase resulting in an increase of the knowledge development of TNO by participation in FP7 and Horizon 2020 projects and within PPS (Publiek Private Samenwerking) and B2B projects. In this way we assist industry and SME to support safe innovation and compliance with the (REACH) regulations over the complete life cycle in various stages of the development process, and thereby reduce human health risks caused by exposure to nanomaterials.

7 VP Environmental Technology

7.1 Roadmap High-Tech Materials

Responsible TNO: Suzanne de Vos

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 2 research lines (subprograms) Sense4Environment (S4E) and Circular Economy (CE). In Sense4 Environment the goals 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 2 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 a 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. Her 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 Goals

In Sense4 Environment the goals is to continue to develop and validate materials for low-cost, wearable, reliable and highly sensitive sensors for air pollution. In 2016 a benzene-sensor has been developed at proof-of-principle level, based on a methodology generated by Holst. If targets on the required sensitivity and response-times are met, this development will be continued in 2017 - preferably with cooperation of private companies. 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 TNO wants to further develop the hydro-metallurgic technologies to recover scares metals from electronic waste. 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.

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). 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.

8 VP HTSM-Bouw Innovatie

8.1 Roadmap High-Tech Materials

Responsible TNO: Henk Miedema

8.1.1 Summary

Sustainability and cost reduction in construction require reduction of the quantity of building materials used, replacement of raw materials through re-use and use of waste streams and bio-materials, increase of 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 through analytical techniques and advanced modelling, with a focus in 2017 on concrete and asphalt.

Over the past years, a worldwide change is occurring, moving from plain Portland cement to blended cements with more use of fly ash. However, currently there is a strong societal pressure to reduce the number of coal driven power plants. An alternative that can substitute fly ash material is not yet available at a large scale. A possible solution is the utilization of cleaned bottom ashes from waste incineration installations. By understanding fundamentally the silico-aluminate chain build-up the degradation process of these new materials resources in our building materials will be better understood and better estimates will be possible of the service life of constructions in which these materials are applied.

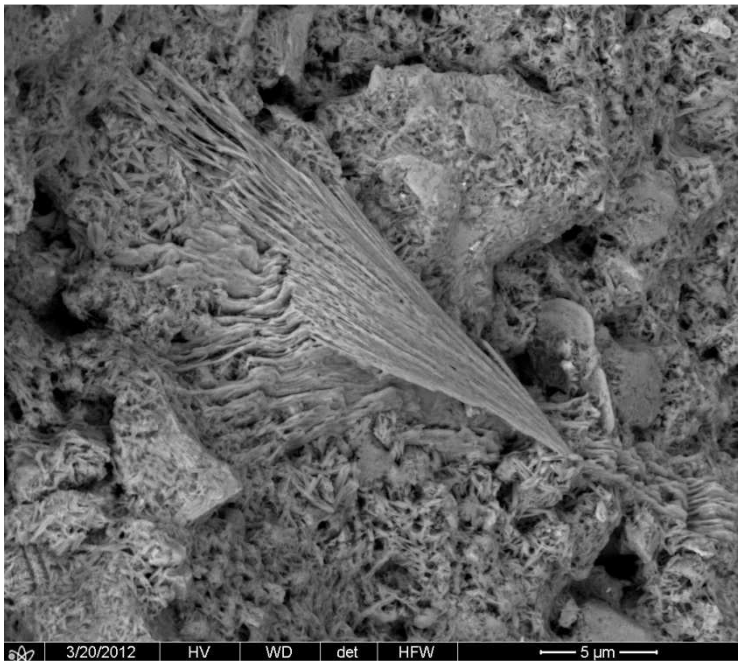


Figure: Better understanding of the microstructure is essential for forecasting and optimizing the performance of sustainable concrete.

8.1.2 Short description

The properties of materials of which infrastructure and buildings consist, together with the geometry of the components and their composition, determine the behavior and performance of the constructions. Therefore, changes in the material properties in time have a direct effect on the performance and service life of a construction.

Societal goals require innovations of building materials because of the necessity of the limitation of the sharply increasing cost of maintenance and renovation, minimizing the time out of use of infrastructure, reduction of energy consumption and increase of comfort, and closing of material chains (circularity) and minimizing environmental impact. At the level of materials this requires reduction of the use of materials, replacement of raw materials through re-use and use of waste streams 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.

This program focuses on the following materials for the construction sector:

- Construction materials
- Asphalt
- Responsive materials

8.1.3 Goals

For the material research for road construction, the goals are:

- Further improving knowledge of aging and material properties into innovative product.
- Tools for the assessment of new mixtures incorporating knowledge of degradation.
- Development of innovative asphalt mixtures that have a reduces sensitivity to ageing.

The Netherlands is frontrunner in the use of cement with a low CO_2 footprint compared to common Portland cement, due to the extensive use of both blast furnace slag and pulverized fly ash. The latter one is obtained from coal driven power plants. All produced fly ash is being used as part of standardized cements e.g. CEM II/B-V 42,5 N. Over the past years, a worldwide change is occurring, moving from plain Portland cement to blended cements with more use of fly ash. However, currently there is a strong societal pressure to reduce and/or close coal driven power plants. An alternative that can substitute fly ash material is not yet available at a large scale.

A possible solution is the utilization of cleaned bottom ashes from waste incineration installations. With the Green Deal Bottom ash, the Dutch government is moving towards 50% use of bottom ash as material source in 2017 and 100% by 2020. Research at TNO is focused at understanding and controlling these new materials as they are now being developed in a wave of new geopolymer initiatives. In 2017 research at TNO will focus at differentiating between reactive and useful silico-aluminate chains and their not reactive and less useful counterparts. By understanding fundamentally the silico-aluminate chain build-up the degradation process of these new materials resources in our building materials will be better understood and better estimates will be possible of the service life of constructions in which these materials are applied.

For the material research for road construction, the goals are as follows:

- Conversion of knowledge of aging and material properties into innovative products.
- Conversion of degradation knowledge into tools for the assessment of new mixture.
- Development of innovative asphalt mixtures that have a reduces sensitivity to ageing.

This translates into the activities:

- Further developing the TNO laboratory aging asphalt procedure for rapid assessment of new mixtures for (open) asphalt surfaces. The current fixed aging protocol is tested for its robustness/sensitivity to variations in the procedure. In addition, it will be investigated how the procedure can be further optimized (accelerated) without compromising the representativeness of the results.

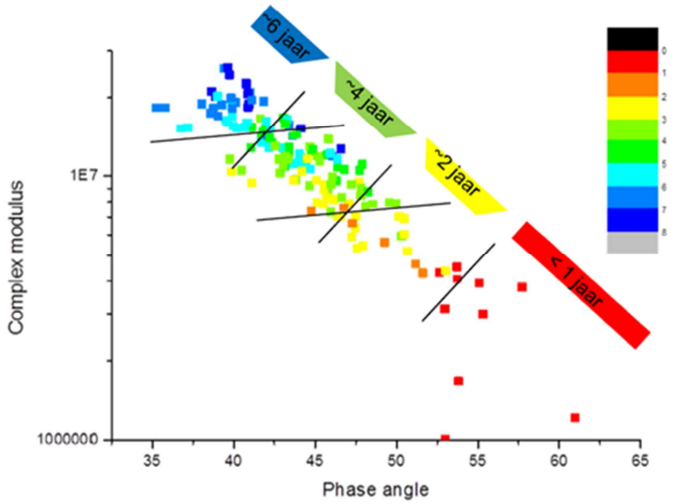


Figure: Development of stiffness and elasticity as a result of aging.

- Validating and verifying the asphalt fraying model on the basis of objective fraying damage scenarios (LCMS) in cooperation with RWS. The current fraying model, incorporating temperature effects and effects of traffic, will be tested and validated on the basis of a large data set (construction data and inspection data). On the basis of the validation, the model is "calibrated ". Also, a probabilistic approach is being developed for the assessment of novel materials.
- Development of innovative asphalt mixtures that have a reduces sensitivity to ageing. Current knowledge on the chemical/physical processes that occur during ageing and the phenomena that ageing displays is used to design a new asphalt composition, reducing the ageing characteristics. The mixtures will be designed, and tested and examined in terms of processing and their performance in service in comparison to existing materials.

8.1.4 Dynamics

- Overall the program will be continued following the original multiannual program.

- There will be a stronger focus on construction materials and asphalt, and limited work on responsive materials.

9 VP Space & Scientific Instrumentation

9.1 Roadmap Space

Responsible TNO: Bart Snijders

9.1.1 Summary

Space technology plays a crucial and unique role in our daily life. Navigation, Telecommunication, Earth Observation and Scientific satellites form the backbone of many integrated applications and services. 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). Being active in the space domain for more than 50 years, it is TNO's ambition to remain one of the core institutes in the Netherlands that is committed to the strong Dutch space heritage. We will do so by strategic collaboration with strong (Dutch) partners (academia, institutes and industry) aiming at a strong international position for the Dutch space ecosystem and healthy business in the areas of world-class instrumentation and demand driven downstream applications.

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 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 major 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 Goals

The space activities of TNO are undertaken in alignment with the HTSM Roadmap Space and several Roadmaps under responsibility of the Netherlands Space Office (NSO). New developments are discussed with NSO in order to align our activities with other national investments. TNO continues to cooperate with partners:

scientific institutes and companies, both national and international, driven by the value chain for Space activities. The main position of TNO in this chain is to develop scientific knowledge, generated by institutes and universities, into prototypes that can be further industrialized by companies. Starting point in these collaborations is added value: we will only contribute where we can make a difference. Of course our partners should use the way of working in order to have a strong joint competitive position.

In particular, together with our partners we will try to obtain a leading role in the market of small satellites, where the Netherlands has all the knowledge and expertise to offer new business models, built upon innovative instruments, small-sat expertise and state-of-the art downstream services. This implies that TNO should become less dependent on the institutional (ESA) market of large satellites and instruments, by venturing in the commercial market that is addressed by small satellites and so-called nanosatellites. The latter class of instruments also fully complies with the desire of the Netherlands Space Office (NSO) for the Netherlands to become more active and successful in the area of commercial space instrumentation. As a result, together with several Dutch companies - all represented in the newly formed Dutch Space Instrument Cluster - and KNMI, TNO is now pursuing this commercial route.

Figure 1: SPECTROLITE breadboard tested in DLR airplane campaign over Berlin.

Recently TNO successfully coordinated an EFRO budget application for the development of a compact Remote Sensing instrument for nanosats (SPECTROLITE), within the framework of the Dutch Optics Centre, a joint R&D centre recently initiated by TNO and TU Delft.

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 will be more opportunities for TNO to propose new instrument concepts successfully. 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 will be 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 a dominant role in developing subsystems of Sentinel 5, in combination with the actual calibration of the instrument.
Other large instruments where TNO has the realistic ambition to play a significant role, together with Dutch industry, include:

- FLEX, calibration.
- 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.

Future *candidate* missions include:

- PACE, an ocean color/aerosol instrument for NASA, which is pursued by Airbus DS NL, SRON and TNO.
- CarbonSat, an improved spatial resolution (2x2 km^2) spectrometer aiming at quantification and monitoring of the distribution of the two most important greenhouse gases in the atmosphere released through human activity: carbon dioxide and methane. Although CarbonSat is not yet selected by ESA for further development, ESA expressed an interest in applying new (TNO-) technologies for this type of a mission.
- FLEX, an imaging spectrometer for vegetation monitoring; SPECTROLITE, a smaller size spectrometer, also having an improved spatial resolution (1x1 km^2), aiming at measuring individual emission sources of air pollutants. Instruments of this type are being considered by ESA for a microsat usage, complementing the TROPOMI and Sentinel missions.

A target market for some of our technologies, identified in recent years, consists of atmospheric observation instruments built for China, and other countries with a growing interest in Space instruments. Currently BISME, a leading space institute in China, with which a joint lab agreement has been signed early 2014, has expressed the need for a CO_2 instrument. It should be stressed that all business with China has to comply with stringent export licenses. Triggered by the strong recent interest for TNO's space activities expressed by NASA, but also due to the venture rich market for microsatellites, we plan to undertake some business development activities in the USA.

The Netherlands has the opportunity to address the full value chain of space mission design and development, in combination with space data utilization (see figure 2). It should be noted that the latter also plays an important role in providing necessary input for the instrument design, and therefore ties between upstream and downstream should be tightened.

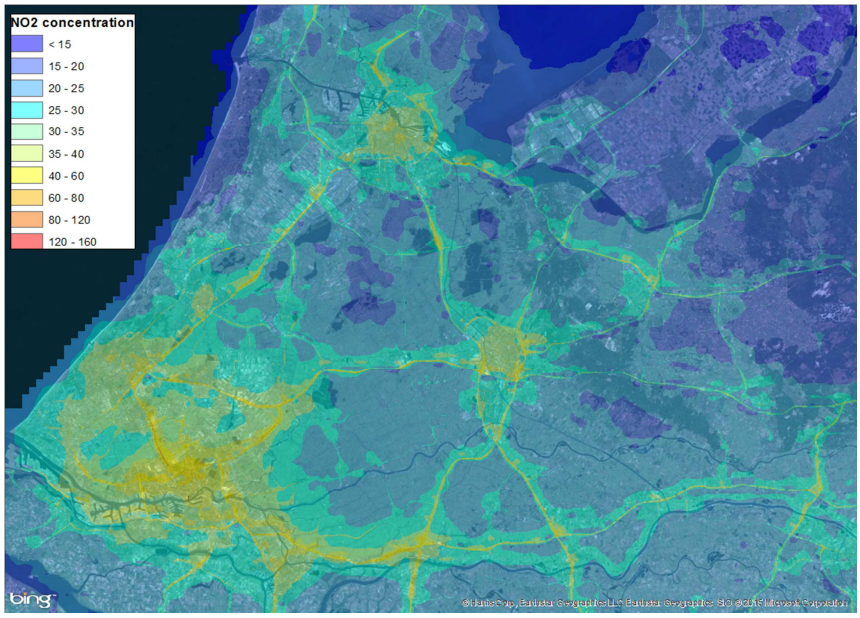


Figure 2: NO_2 emissions over the south-western region of the Netherlands.

Instrumentation for spaceborne astronomy
Instrumentation for spaceborne 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. TNO's research activities in the HTSM Roadmap Space are mainly focused on ESA's Short and Medium-term missions, i.e., having a time frame of 10 years.

Activities in the Netherlands currently focus the SAFARI instrument and Athena. At the moment it looks like TNO will have no or only a very small role in the development of these instruments.

Regarding the Long-term mission eLISA will be of particular importance. TNO was involved in the LISA Pathfinder mission by testing the prototype picometer laser interferometer at the TNO OPD test-bench, which was developed for the GAIA program. In the context of the ESA technology program TNO has developed a prototype of the LISA Point Ahead Angle Mechanism (PAAM). TNO has also developed concepts for the following LISA mechanisms: 1) Fibre Switch Unit; 2) Optical Articulation Mechanism; 3) In Field of View Pointing Mechanism. TNO has been involved in an ESA contract for the development of the metrology needed for the stability measurements of the eLISA telescopes.

Optical satellite communication
A promising possibility for Dutch industry to extend Space activities to commercial markets is to enter the market of optical/laser communication. Since optomechanical sub-systems are the core of the optical communication systems, this will enable Dutch industry to enter a market that needs optomechanical systems on recurring and commercial bases, which is attractive due to its recurring character, broad market segmentation and its growth rate.

Together with Dutch Industry and RUAG (Switzerland), 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.

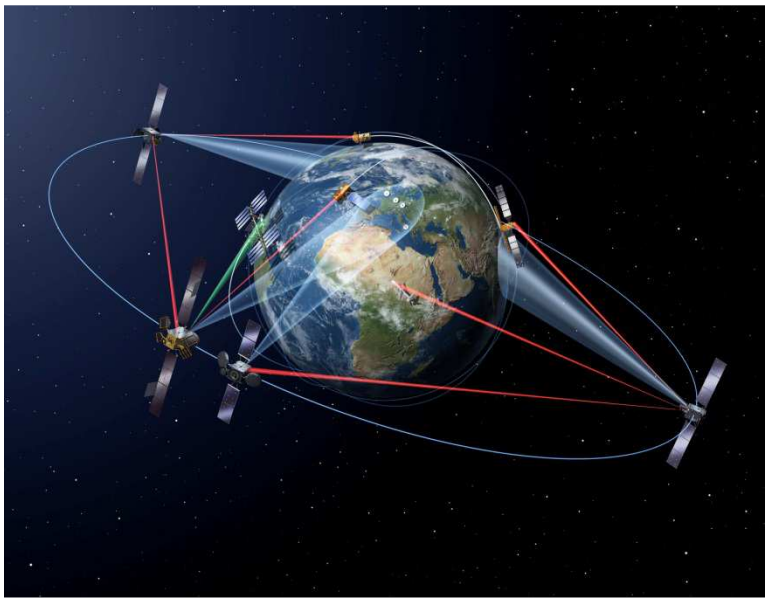


Figure 3: Laser Intersatellite Links (ref.ESA).

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. TNO aims at participating in ESA's ARTES program for optical satellite communication.

Demand driven interaction

TNO aims for intense interaction with both scientific and industrial partners, by jointly developing solutions for institutional and commercial customers. An integrated development approach, where the different partners cooperate from the first conceptual phases of instrumentation development on, is a critical factor for success. This includes concurrent development of hardware and software, optics and detectors, instrument and platform. In these activities TNO and partners will always strive to be at the forefront of technical development.

We work together with almost all players in the Dutch space industry and institutes. The key collaborations occur with:

- SpaceNed. TNO is member of SpaceNed and works together with SpaceNed partners in merely all research lines. Collaboration with Dutch industry includes Airbus Defence and Space NL, ISIS, ATG, S&T, APP, MOOG Bradford, Cosine, Lionix, Technobis, Systematix, Hyperion Technologies.
- SRON. We primarily work together in the research lines Earth Observation Instrumentation and Space Science Instrumentation. Roadmaps are getting more entangled.
- The National Aerospace Laboratory NLR.
- TU Delft (Delft Space Institute). We work together in the area of microsatellites and their applications.
- Important suppliers in the instrument chain are VDL-ETG, Focal and Nedinsco.

In the downstream domain (Space Data Utilization) we have established relationships with:

- KNMI, SRON, TU Delft (DEOS), Universiteit Utrecht (IMAU), WUR, Universiteit Twente (ITC), Vrije Universiteit, Wageningen Universiteit (WUR), Deltares, Alterra, ECN.
- NEVASCO (Nederlands Value Adding Services Collectief).

In regular meetings with many of these partners we define joint interest for future activities, and this information is used to update the priorities within TNO's VP program. TNO has been coordinating the creation of the NSO Antenna Roadmap and the Roadmap on Optical Instrumentation.
In order to coordinate and strengthen collaboration between Dutch parties for doing business in China, TNO initiated the formation of a PIB-consortium called INSET China supported by RVO.

TNO is also pursuing the following:
- Becoming the established center for contamination control for ESA.
- Establishing new Synthetic Aperture Radar (SAR) project with Dutch industry.
- Establishing shared facility center with other knowledge partners (e.g. TU Delft, SRON) and industry.

Activities in PPS programs
TNO and TU Delft recently initiated a joint R&D centre, called the Dutch Optical Centre. Its mission is to strengthen Dutch businesses in optics and optomechatronics by increasing high-end production processes, with the ultimate aim to bring the Dutch business in these areas to an internationally competitive level. Collaboration with other knowledge institutes such as University Twente, TU Eindhoven, SRON, and FOM-institute AMOLF will be pursued. DOC facilitates and initiates development of commercial projects, production of (small) series of optomechatronic instruments, start-up support and co-development projects. DOC is a research centre for optics and optomechatronics where top researchers share facilities, PhD-students are educated and businesses contribute to new knowledge development.

An evaluation by ESA showed the increased need for stimulation of crossovers between Space and other HTSM Roadmaps, supported by programmatic choices for the Dutch contribution to optional ESA programs; TNO is in a very good position to support and coordinate this.

Research program 2017
The technology development programs by TNO within the Space Roadmap will focus on development of critical components (e.g. unconventional optical designs using curved gratings and freeform optics, ultrastable mechanics), innovative modules meant to increase instrument performance (e.g. slit homogenizers and polarization scramblers for spectrometers), and new time-consuming ground support equipment. This will lead to optical instruments with specifications that exceed the already excellent achievements of the past, which is required by e.g., ESA and the big primes like Airbus Defence and Space and Thales Alenia Space. All of this aims at improving the competitive position of the Dutch ecosystem in this area. Also new instrument concepts (different from the current push broom spectrometers and much smaller) will be developed, worked out and demonstrated together with Dutch partners, aiming at the commercial market of microsatellites. In order to better assess the added (commercial) value of these new instruments, Observation System Simulation Experiments will be carried out. In view of the microsatellite business the development of new micro thruster systems will be supported as well. Together with Dutch industry and an international prime we will

continue to invest in the development of optomechatronic systems to be used for laser satellite communication.

TNO has strong heritage regarding microwave chip design (MMIC). These MMIC's have been used in components (also designed by TNO), some of which are being used in space today. TNO is one of the recognized frontrunners in use of new materials like SiGe and GaN. Related to radar technology required for missions like BIOMASS and developments like PanelSAR, TNO will further invest in GaN technology (state of the art material) to not only build components, but a whole subsystem (e.g. a Solid-State Power Amplifier), which has to be space compliant (hermetically sealed and resistant against extreme launch conditions). The challenge is to obtain RF properties that are nearly unchanged after mounting and launch vibrations. The outcome of this research will enable us to enter the RF satellite communication market as well, which will strengthen the case for laser satellite communication (where hybrid systems are being envisioned).

Technologies that are developed in the framework of the Space Roadmap, which are also relevant for the Advanced Instrumentation and the Semicon Roadmap, include Active Optics/Deformable Mirror technology, and the usage of new production technologies like Additive Manufacturing. Active optics will lead to improved optical imaging, which will find applications in (small) satellite instruments and in ground stations of e.g. laser satellite communication systems. This is one of the areas where we co-invest in PhD students (University of Leiden, Technical University Delft). Additive manufacturing allows for structures impossible to make in the traditional way, leading to more compact and lightweight instruments with improved mechanical properties.

9.2 Roadmap Advanced Instrumentation

Responsible TNO: Bart Snijders

9.2.1 Summary

In this program we address the development activities for the ground based astronomy instrumentation and developments for Big Science. Big Science contains the development and upgrade activities for the large European Science facilities, like CERN, ITER, ESRF, and KM3net. It should be mentioned that there is strong synergy with activities outlined in the HTSM Roadmap Space.

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, while TNO has experience in designing and prototyping instrumentation for space and science.

9.2.3 Goals

TNO initiated plans for a partnership with two partners: NWO, and high-tech industry. This cooperation is named “Het Huygens Huis” (HHH), with the objectives to increase industrial return, create spin-off, build a network of hightech partners, strengthen the role of NL-scientists, and trigger extra investments in the knowledge base. These activities are all in line with recommendations from Topsectors and the Kenniscoalitie. The scope of spin-off projects for industry is found to be a factor of 2-3 larger than the turnover for Big Science and/or Space projects, making this a very effective path for innovation and economic growth. A governing body, consisting of representatives of industry, NWO and TNO, will formalize the involvement of the main HHH partner groups. This should lead to a prominent position of Dutch industry, in focused areas of the worldwide field of high-end instrumentation, in combination with a prominent position for Dutch scientists.

9.2.4 Dynamics

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,

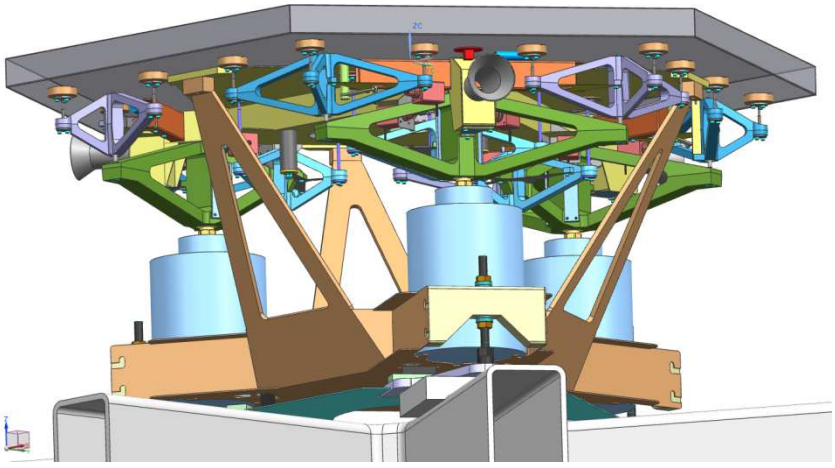


Figure 4: ELT primary mirror support structure and PACT actuators.

- Nuclear fusion facility ITER and particle accelerators. In particular TNO is focusing on diagnostic systems and contamination control for ITER. Preliminary discussions with industry and academia take place about TNO's participation in a project concerning the development of a compact tunable X-ray source.
- KM3NeT, a future European deep-sea research infrastructure hosting a new generation neutrino telescope with a volume of several cubic kilometers that - located at the bottom of the Mediterranean Sea.

Demand driven interaction

TNO operates in close collaboration with industry and scientific world, addressing the needs of industry and academia. Within the framework of ITER, TNO is involved in a joint development with VDL-ETG Hittech and NOVA. Regarding ITER, we are strengthening our collaboration with the institute DIFFER (Dutch Institute For Fundamental Energy Research), while we discuss accelerator and compact X-ray source issues mainly with VDL-ETG, NIKHEF and the TU Eindhoven. Our possible contribution to KM3Net takes place in close collaboration with NIKHEF.

In general TNO participates in ILOnet, the network of Industrial Liaison Officers of scientific institutes; ILOnet aims at providing information to NL-industry about Big Science projects, and vice versa.

Activities in PPS program

TNO and TU Delft initiated a joint R&D centre, called the Dutch Optical Centre. Its mission is to strengthen Dutch businesses in optics and optomechatronics by increasing high-end production processes, with the ultimate aim to bring the Dutch business in these areas to an internationally competitive level. Collaboration with other knowledge institutes such as University Twente, TU Eindhoven, SRON, and FOM-institute AMOLF will be pursued. DOC facilitates and initiates development of commercial projects, production of (small) series of optomechatronic instruments, start-up support and co-development projects. DOC is a research centre for optics and optomechatronics where top researchers share facilities, PhD-students are educated and businesses contribute to new knowledge development.

Research program 2017

In 2017 technology development programs at TNO in the framework of Advanced Instrumentation focus on:

- Highly accurate (<10 nm), yet pricewise competitive, support structures and actuators for the M1 mirror segments of the European Extremely Large Telescope.
- Active optics (actuator design and control systems) for astronomical telescopes (ITER, CHARA, TMT); this research is strongly related to the Roadmap Space.
- Diagnostics for monitoring the nuclear fusion plasma (ITER).
- Concept development for an acoustic fiber array augmenting the current optical detectors of KM3NeT.

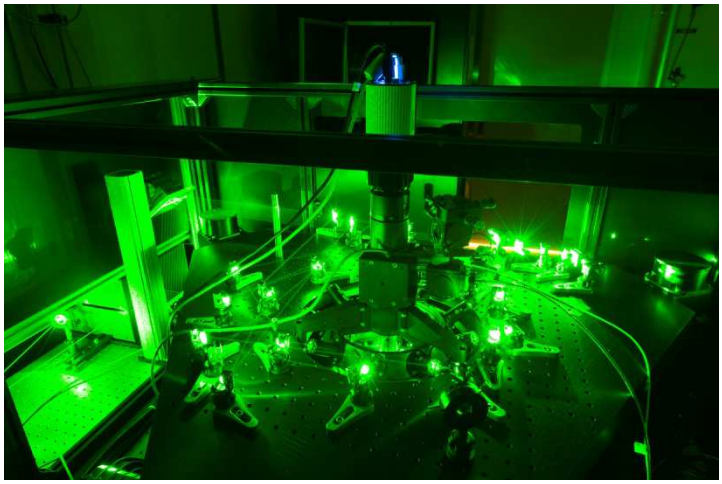
10 VP High-Tech Semicon

10.1 Roadmap Semiconductor Equipment

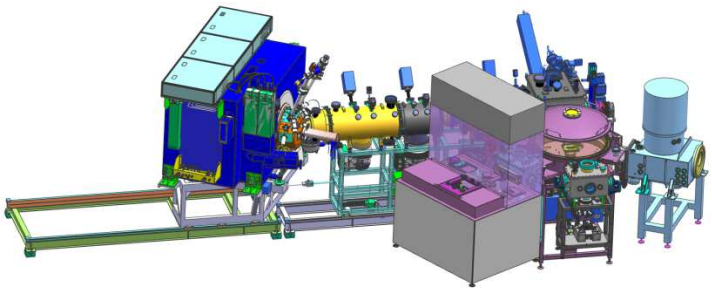
Responsible TNO: Rogier Verberk

10.1.1 Summary

In 2017 TNO will continue its R&D activities on contamination control for EUV lithography. The introduction of EUV lithography is a prerequisite for the required progress in device shrinkage also known as Moore's Law. The success of EUV lithography is also of great importance to ASML and thereby to the Dutch economy. The primary potential show stopper for introduction of EUV lithography is the risk of contamination of the reticles, also known as defectivity. TNO is the internationally renowned expert in contamination control and has invested in the development of three unique facilities, which will all become available for (industrial) partners early 2017, which will enable TNO and its partners to find new solutions to these challenges. These facilities will enable research on the interaction of materials and contamination with EUV light, the detection of particles as small as 23 nm, and the mechanical handling of reticles without generating particles.



Caption: TNO's Rapid Nano (third generation) is capable of detecting 40 nm particles. The fourth generation of this tool will become operational early 2017 and will be capable of detecting 23 nm particles.



Caption: TNO's (second) EUV Beam Line will enable TNO and its partners to investigate the behavior of optical components, contamination, and other materials under intense EUV illumination.

The capabilities in metrology, i.e., techniques to measure aspects of processed devices like Critical Dimensions, Overlay, or Defect Inspection, can barely cope with the fast progress in lithography and processing. In 2017 TNO will continue its search for potential solutions to this challenge in two technology domains: Scanning Probe Microscopy (SPM) and optical techniques. In the field of SPM, TNO will work closely together with Nearfield Instruments BV, a spin-off company of TNO, which is initiated in 2016 for commercial validation of part of TNO's SPM portfolio.

In 2017 TNO will start two new activities in the crossover field between semiconductor equipment and life sciences. First, TNO will investigate the potential of metrology technologies, developed for the semiconductor industry for research on, e.g., protein folding. Secondly, TNO will participate in a European project where it will investigate the potential of SPM-technologies for inspection of viruses.

In 2017 TNO will continue to participate in H2020 EU programs and in the Dutch Smart Industry Fieldlabs for the high-tech manufacturing industry, semicon industry and agriculture. TNO will participate in consortia at European level (ECSEL, PENTA, EFFRA, H2020) at National level (the Fieldlabs of the Dutch Smart Industry) and at regional level (together with ROMs such as NOM, BOM, MRDH). TNO will develop innovative prototype solutions (up to TRL5/6) for flexible manufacturing to stimulate Dutch industry to remain agile and competitive. The combination of advanced measurement instruments and manipulators together with sophisticated control and big data will be investigated to improve efficiency and yield in high mix low volume production lines.

10.1.2 Short description

TNO aims to secure the position of the Netherlands as leading semiconductor manufacturing equipment supplier to the world, by helping the industry to find solutions to current challenges, as well as by continuously searching for new technological pathways for the near and far future. This will not only bring job security to the Netherlands for the years to come but also enables the electronics industry to play its pathfinder role in solving some of societies largest future challenges.

More concrete, TNO will concentrate on developments supporting the introduction of EUV lithography, and on the development of new technologies and economic activities in the Netherlands in the field of metrology. On top of this TNO will execute pathfinding research in the field of SPM for life-science applications.

In the ambition to solve the gap between technology development and market introduction of systems based on these technologies, TNO will explore new models for finance, partnerships, and risk mitigation by means of the Dutch Optics Center (DOC). Close cooperation with Dutch companies, both equipment vendors and first and second tier suppliers, is key.

10.1.3 Goals

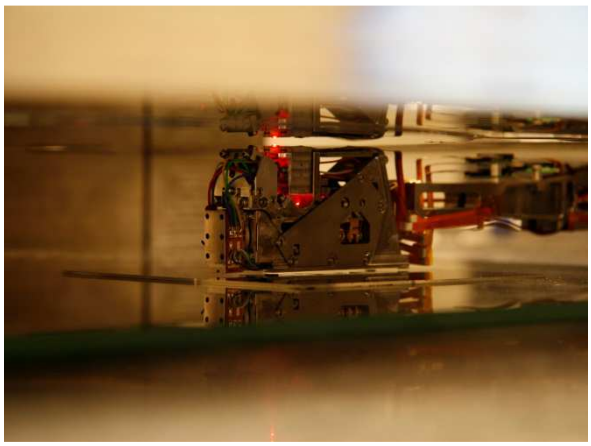
The aim for VP High-Tech Semicon is to maintain and strengthen the role of TNO, its main partner/customer ASML, and the Dutch supply chain, in the field of EUV development. TNO's knowledge investment will be mainly focused on new metrology and contamination control (defectivity) solutions. Regarding Defectivity our aim is to extend our project portfolio towards a programmatic approach together with ASML.

On a more fundamental research level, TNO will continue the cooperation with Twente University on EUV optics. TNO will also work together with ASML and TU Delft in an STW project dedicated to new concepts in scatterometry for defect detection and pattern analysis.

The four large European projects TNO will (continue to) participate in in 2017 aim at more mature technologies, including, e.g., metrology equipment for pilot lines. Key partners in these projects include Applied Materials, ASML, Carl Zeiss, CEA-Leti, FEI, and IMEC. TNO will work on topics like 3-dimensional metrology and metrology for devices with high-aspect ratio's, and particle detection.

The development of the new EUV Beam Line (EBL2) aims for the first business to business projects together with our key partner Carl Zeiss and secondly ASML in 2017. Thereby we are in contact with integrated device manufacturers (IDM; like Intel, Toshiba and Global Foundries) and original equipment manufacturers (OEM) and other companies (like DNP, Hoya and Toppan) and to start up projects when EBL2 is up and running. This is expected to start with relatively small projects to build up the relation and mutual interests. It is an important opportunity, however, to expand the circle of partners/customers of TNO, and to accelerate progress in technology fields so critical to successful introduction of EUV lithography.

Our scanning probe microscopy activities will be continued and extended towards sub-surface-, soft material-, and true 3D metrology in 2017. Together with Nearfield Instruments BV we aim for a first customer in Nearfield Instruments BV's product-market domain.
In parallel, a start will be made with SPM metrology on viruses to explore bio-nano technology and therewith the life-sciences market. This activity will be started up with a consortium in an EU project which has recently been granted.
Moreover, TNO will work together with TU Eindhoven, ASML, and Bruker in an STW project aiming at tip development for massive parallel SPM.



Caption: Picture of the SPM scan head developed by TNO. This new scan head, in combination with multiple other innovations, could allow for fast metrology at high resolution.

The particle inspection tool Rapid Nano, developed by TNO, is a unique facility regularly used in customer projects. Our aim to develop such a system for a third party will be a use case for the Dutch Optics Centre (DOC). TNO is currently in discussion with a potential partner to bring the Rapid Nano system to a high-technology readiness level (TRL), suitable for end users.

10.1.4 Dynamics

The introduction of EUV lithography is delayed compared to the estimates at the time of writing the 2015-2018 Roadmap. This means that TNO, like the rest of the industry, has been working a bit longer on certain topics, while other aspects gained less attention. However, the activities fall within the technology and application domains as planned.

In 2014/2015 it was not yet foreseen that TNO would become active in the field of bio-nano-technologies. The recent growth of activities in this field inspires TNO, however, to assess the potential of metrology technologies developed for the semiconductor industry, in this case SPM technologies, are of added value to the life sciences.

The ambition was to initiate a new Dutch metrology OEM (= Original Equipment Manufacturer) start-up in 2018. Fortunately, this start-up has been initiated in 2016 already. This success is related to a much faster progress in SPM technology developments (and larger investments) as anticipated back in 2014/2015.

Industry's interest in DSA (Direct Self Assembly) has gone up and down over the last decade. In the 2014/2015 timeframe TNO estimated DSA not to be of strategic importance to TNO. In 2016 this topic has gained new momentum (due to other developments in the market), and TNO was invited to work on this topic as part of an European project in 2017.

The Fieldlabs of the Dutch Smart Industry are delayed between 2015 and 2016. In 2017 TNO expects a scale-up in activities and exposure moments.

10.2 Roadmap Nanotechnology (QuTech)

Responsible TNO: Rogier Verberk

10.2.1 Summary

An increasing number of companies and institutes share the motivation to develop quantum computing and quantum internet. Driving are (1) future applications of the unprecedented computing power for sciences and Grand Challenges (including, e.g., development of high-temperature superconductivity for the energy challenges, and in the long run faster developments of drugs for the aging society), (2) computing power for industrial applications (big data search, logistical tasks), (3) being among the front-runners in the development of quantum communication (for national security as well as commercial applications), and (4) to develop a new industry based on Europe's leading scientific position in this field.

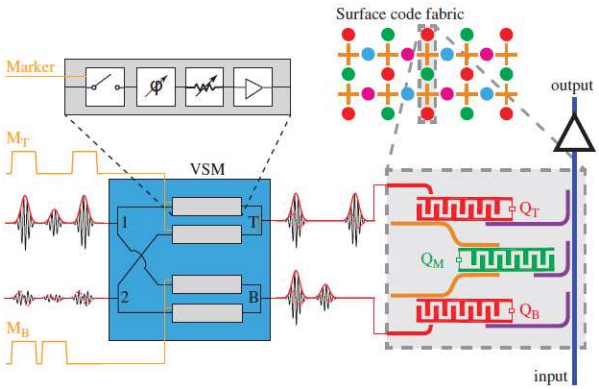
QuTech, the quantum technologies research center by TNO and TU Delft, has made significant progress in 2016. Besides the cooperations with Microsoft and Intel, in 2016 IARPA granted a large project to a consortium led by QuTech. QuTech hosted together with the European Commission and the Dutch department of Economic Affairs a large conference in Amsterdam in 2016 for scientists, policy makers, and representative from industry. At this conference European Commissioner Oettinger announced the initiative for a European Flagship on quantum technologies.

For further information on the ambition and people of QuTech, an introduction to quantum computing, and breaking news, please visit **www.qutech.nl**.

10.2.2 Short description

The TU Delft hosts a team of world class scientists in solid state quantum technology. Four out of the ten most-sited scientists of the Netherlands (all fields of expertise) work in Delft in this field (source: Volkskrant, October 2012). This team also had 10 papers in the Nature magazines in 2013. This is the scientific foundation of QuTech.
On the other hand the Netherlands has a large ecosystem of high-tech/high-precision equipment manufacturing companies including an extended supply chain. This sector has developed and successfully commercialized tube technology for radio and television, transistor and chip technology, lighting and medical equipment, and wafersteppers. Each wave of innovation has led to a new wave of employment. And like ASML and FEI started as spin-off companies from Philips, it is now time to create the new seed for high-tech business. This infrastructure of high-tech industry will accelerate the development of the quantum computer now. In the future the quantum technology shall be a new unique selling point of this Dutch ecosystem.

TNO is experienced in multiple technologies which are critical for the development of the quantum computer, and complementary to the knowledge of the TU Delft. Secondly, TNO brings to QuTech its experience in prototyping, mission oriented project execution, and contacts to the industry.
By building prototypes and demonstrators, TNO/QuTech shall be positioned as a pioneer in quantum technology. Moreover, TNO/QuTech will invite industrial partners to participate in the development of the demonstrators to strengthen the relationships and have some of this work funded by industry and European projects.
On the other hand TNO has to develop some of its existing technologies further to meet the requirements of the quantum computer (e.g. RF-technology, nanofabrication, multiscale physics simulations). This will improve the competitive position of TNO in the existing (non-quantum technology) markets like nano-technology/semicon and RF-technology/Radar. These markets are already very important to TNO.
Finally, the further development of existing and new technologies generate possibilities for unforeseen spin-off.



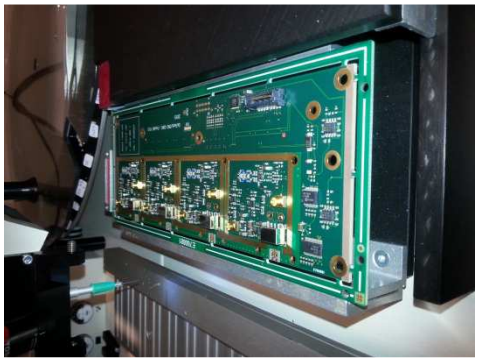
Caption: The electronics to broadcast microwave signals to multiple qubits as developed by TNO in 2015, has been used by scientific experiments by QuTech/TU Delft on transmon qubits in 2016. The results were published in a joint paper in a journal related to Nature.

10.2.3 Goals

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.
QuTech works according to four Roadmaps, one for each type of qubit. The most critical enabling technologies that will be developed during the coming years are incorporated in the most relevant Roadmap.

2017 will be the first full year of the IARPA project. QuTech will have to show a more detailed plan as well as some first results towards a logical qubit.

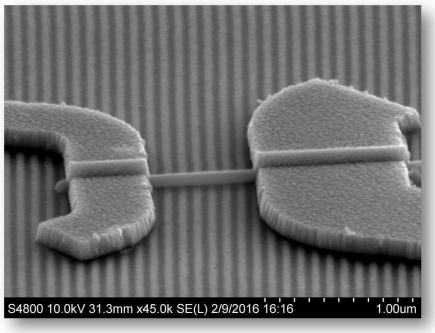


Caption: TNO has developed and built, based on the expertise of the Radar Technology Department, dedicated electronics to control circuits of multiple (transmon) qubits.

The European Commission has announced an European Flagship on quantum technologies as well as the High Level Group, the group of people that will manage the initialization phase of this Flagship. QuTech will have to position itself in view of these European developments.

QuTech is in contact with multiple players in the communications and aeronautic industries. TNO/QuTech is currently developing plans to come to demonstrations of quantum technologies in these domains. In 2017 TNO/QuTech hopes to set up a first consortium with participants from academia, institutes, and industry.

An important scientific milestone for 2017 is the growth of semiconductor nanowires in the new MBE cluster tool. QuTech has made enormous investments in setting up a dedicated lab for this purpose in 2015/2016. In 2017 the first nanowires shall be grown, and mounted and connected for the electronic measurements. In the long run these nanowires may become the basis for a quantum computer based on Majorana bound states.



Caption: Inspired by industrial processing technologies TNO developed an ultra-flat substrate including buried electrodes for scientific experiments on Majorana bound states in semiconductor nanowires.

10.2.4 Dynamics

The timing of the start of an European Flagship was difficult to estimate. The announcements by the European Commissioner in 2016 have made the timeline a lot more concrete. 2017 Will be a year of preparations, making it an important year to decide on QuTech's ambitions within this Flagship and to make these ambitions heard by the stakeholders.

Under project name 'QuSpace', QuTech is investigating the possibilities to bring quantum technologies to satellites. After initial discussions with important industrial (KPN, ATOS, OHB, Airbus) as well as academic players (Prof. dr. D. Bouwmeester, Leiden University), some ideas for consortia for scientific and demonstator-like experiments are developing. In 2017 QuTech hopes to align with ESA and initiate new activities in this domain.

11 VP Flexible and Freeform Products (3F)

11.1 Roadmap Components and Circuits (Holst)

Responsible TNO: Gerwin Gelinck

11.1.1 Summary

There is an increasing need for flexible and lightweight electronic systems. Examples are: wearable medical devices such as skin patches, smart garment, flexible large-area displays and (medical) imagers, and seamlessly integrated human machine touch interfaces. In 2017 TNO-Holst Centre continues to develop materials, processes and manufacturing platforms that allow such flexible electronic systems to be made economical for mass-production.

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. 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. 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 Goals

TNO-Holst Centre activities can be clustered in three large activities: (1) hybrid printed electronics for wearables (health patches, smart garments) and in-mould electronics (HMI) applications, (2) flexible transistors and its applications in displays, imagers and circuitry and (3) 3D Lithium ion batteries for applications including wearable & portable electronics as well as mobility.

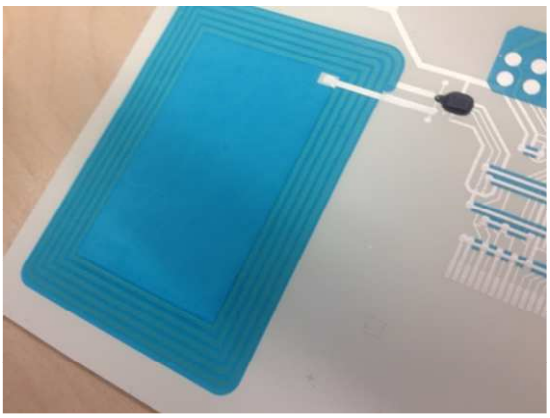


Figure: Electronics printed directly on stretchable rubber.

Hybrid printed electronics (HPE) for wearables (health patches, smart garments) and structural electronics (HMI) applications
The HPE activities are in essence about combining printed functionality with standard silicon-based components for realizing 'PCB-alike' devices that are flexible, stretchable or formable.

The use of printing technologies to realize electronic functionality has several key advantages. First of all, as only material is added where it's needed ('additive') it is in many cases cheaper than the subtractive processes normally used for electronics manufacturing. Secondly, the technology is very *versatile*. Printing can in principle be done on every substrate (e.g. plastic foils, paper, textiles), which makes many different materials suitable as a base carrier for the electronics. Finally, printing technologies are very *scalable* in volume and throughput. Both sheet-to-sheet and roll-to-roll processes are available in industry. However, not all functionality can be printed. For example logic, communication and several types of passives are a challenge or impossible to print. The HPE activities therefore additionally focusses on the hybrid combination of this printed functionality with more traditional components like chips, passives and LEDs. The base technologies have been brought to a mature level in recent years and there is currently clear interest from the market for using the technologies in applications. In particular the 'wearables' (patches, clothing) and 'structural electronics' (smart plastic objects like HMI) domains show strong interest in HPE technologies.

For the domain of wearables, the focus for 2017 will be on deployment of HPE technologies on substrates that are more 'friendly' to the human body than the standard polyester-based substrates that have been used up to now. This for example concerns substrates that are stretchable, breathable and thin. It will enable a next generation of patches that show an increased level of wear comfort. Besides this, a second focal point will be on printing 'more' of the electronic functionality than is currently done. For example this concerns printed sensors that can measure temperature, pressure and/or humidity. This will enable better performing wearables (more sensoric input) while retaining the advantages of printing (low cost, additive, etc.).

The deployment of HPE technologies for structural electronics is much more recent. Here the focus for 2017 will be rather on development of the base technologies. This involves learning to print and integrate on polycarbonate substrates (typically used in HMI applications), learning to combine HPE technologies with forming and injection moulding processes etc.

Flexible transistors and its applications in displays, imagers and circuitry
Oxide transistors offer advantages in terms of process simplification, performance and compatibility with flexible plastic substrates as compared to other existing and emerging transistor materials. Sputtered IGZO on glass is the current industry standard for oxide semiconductors. With the current market trends, glass-display applications are driving the short-term developments of oxide TFT. Future applications are foreseen for IGZO (and other oxides) on flexible plastic films (polyesters and polyimide). The base technologies underlying flexible IGZO transistors (TFT and backplane development, integration in flexible display prototypes) have been brought to a mature level in recent years in TNO-Holst Centre, and now we see a clear interest from the market to use the technologies to realize other applications like sensor backplanes, intelligent labels, and other forms of flexible electronics.

Figure: Curved (left) and semitransparent optical imagers.

Already for more than 2 years we run the necessary baseline processes in our pilot line TFT facility to fabricate IGZO thin film transistors on 320x352 mm plastic foil. The TFTs are used for flexible display, imager, and circuit prototypes. This will continue in 2017. We investigate alternative materials and deposition methods for oxide materials that do not require high vacuum. Specifically, we will develop transistors in which the metal oxide semiconductor is not sputtered but deposited either by slotdie coating (using soluble precursors), and by spatial atomic layer deposition (S-ALD) (using vapor precursors). Slotdie coating is a technique that is used in the industry (for coating photoresist for instance). S-ALD is a new technique but shows great prospects in outperforming sputtered oxide materials. In close collaboration with companies we look into the (business) potential of S-ALD equipment for the display industry, to deposit semiconductor layers over large area and low TAC time, initially to deposit oxide semiconductors but later perhaps also for other functional display layers (think: thin film encapsulation). In 2017 the challenge is to integrate our new S-ALD equipment prototype that can deposit up to 320x352mm substrates, while maintaining good performance and uniformity.

In addition to alternative materials, we investigate printing techniques to scale down the transistor dimension to less than the value of 1.5 micrometer that is currently the limit for FPD lithography tools. We intend to realize 1 micrometer TFTs using imprint technology. Scaling of TFT dimensions will enable high-resolution arrays, in-pixel intelligence and high-speed, smaller circuits.

The work on displays and imagers is geared towards increasing the pixel resolution. High-resolution TFT backplanes will be made using a new transistor architecture (with smaller footprint) and optimized pixel designs with minimum number of components. This backplane will be combined with a high-resolution RGB OLED frontplane that can in principle be scaled to >500 ppi, something that is out of reach with current OLED pixilation technologies, and with 500-ppi imagers (for biometric imagers such as fingerprint and palm sensors). We will built further on our circuit work. In 2016 we developed thin film NFC circuits in game cards. In 2017 we will combine this technology and add (thin film) intelligence to game boards. It is expected to lead to a whole new set of exciting board games.

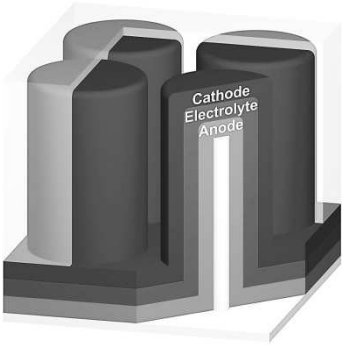


Figure: Schematic of a 3D thin film battery based on an array of micropillars; the anode, electrolyte and cathode are coated as thin films around the current collecting pillars.

Thin film batteries

Wearable and portable electronic devices of today, due to the increasing functionality embedded in them, demand a high energy capacity battery that need not be charged multiple times per day. The state-of-the-art Li-ion batteries are today limited in energy density; meaning that a higher energy capacity can only be provided by a bulkier battery. However, the demand for thinner and smaller wearable & portable electronics is increasing day-by-day, which in-turn demands compact batteries having a higher energy density (double that of state-of-the-art batteries). Moreover, the consumers do not prefer an increase in charging time with an increase in battery capacity, which is typically the case for state-of-the-art batteries.

The battery R&D activity at TNO-Holst Centre strives to develop high energy density (400 Wh/kg and 800 Wh/L) and quick chargeable Li-ion batteries (fully charged within few minutes). And in order to enable safe integration into body wearable electronics, solid-state device materials are chosen that are intrinsically safe when compared to the flammable liquid electrolyte used in today's batteries. For ensuring quick chargeability, a novel 3D structured thin film design is adopted for the batteries being developed at TNO-Holst Centre.

The battery activity at TNO-Holst Centre focusses on R&D at multiple levels: cell design & modelling, novel electrode & electrolyte materials, 3D structured current collectors, conformal coating processes, and the analysis as well as interfacing of all these. In the past year of its inception, the battery program has showcased the possibility to make high aspect ratio conductive pillars on a metal foil, which forms the basis of the 3D Li-ion batteries. Besides, also a good electrochemically performing high specific capacity electrode material as well as its conformal deposition has been demonstrated. The present work is focused on developing a conformally depositable solid-state thin film electrolyte, which is a vital element in the battery build-up. The reel-to-reel and sheet-to-sheet thin film deposition and patterning techniques, which form a part of the core-capabilities of TNO-Holst Centre, are used also for the battery activities. Apart from that, newer 3D structuring processes and Electrochemical capabilities have been added into the competence portfolio.

By end of 2017, the battery program targets to demonstrate a working prototype of the novel 3D battery, for which TNO-Holst Centre has filed several patents by now. Apart from developing the 3D battery technology, customer development is being pursued simultaneously. TNO-Holst Centre is currently in discussions with multiple companies who have shown interest in partnering in the battery program activities for different application domains.

11.1.4 Dynamics

No major change in direction is foreseen. Wearable electronics and IoT (integration of electronics in everyday objects) 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. In 2016, several sessions have been organized to connect the Component and Circuit Roadmap to other (more application-oriented) Roadmaps of the HTSM, as it was thought that the C&C Roadmap itself is more supporting these Roadmaps rather than being the end stage.

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.

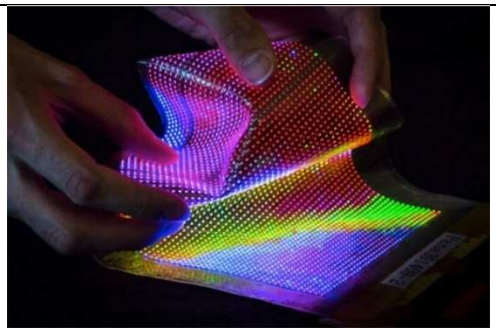
Prof. Gelinck (Holst Centre + TU Eindhoven) was actively involved in several group sessions related to the NWA (Nationale Wetenschaps Discussie), as universities play a crucial role in understanding the fundamental aspects as well as demonstrating new concepts and ideas. Collaborations (by projects, PhD's or student exchanges) will be continued/initiated with TU Eindhoven (Prof. Kessels, Prof. Janssen), TU Delft (Prof. Groen), KU Leuven (Prof. heremans, Prof. Genoe,), University of Ghent (Prof. Jan Vanfleteren, Imperial College (Prof. Anthopoulos, Prof. McCulloch and Prof. Stingelin).

11.2 Roadmap Lighting (Holst)

Responsible TNO: Joanne Wilson

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 below Figure 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 Goals

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. 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.

In 2017 the high performance roll-to-roll flexible moisture barrier film, with an electrode added, will be used for both sheet-to-sheet and roll-to-roll devices made within the PI-SCALE pilot line. The goal is to have stable, high yield process flows for making both evaporated and solution processed devices in the pilot line. From mid-2017, devices made with these process flows will be used to serve the existing pilot line customers AUDI, REHAU, Emdedesign and Pilkington, as well as new customers. Typical flexible device lifetimes required by these applications will be in the range of 10 years shelf lifetime by 2018.

The process flows for OLEDs made using the multilayer solution coating tool will also be improved, with the intention of reaching 90% yield and device performances at least 50% of those of all evaporated devices in 2017. This optimization will be done within the PI-SCALE project, and process flows combining solution coating and evaporation for stack deposition will be investigated using the tools of various PI-SCALE partners.

Further customized OLED prototyping and integration projects will be performed by Holst Centre for its partners. Within this work we will also improve the 80% transparent OLED concept and work towards longer term goals which include developing concepts for conformable, stretchable and cut-able OLEDs or LED systems, and further integration with other thin film electronics.

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)

Responsible: Ando Kuijpers and Ronn Andriessen

11.3.1 Summary

The TNO/Solliance research activities have been restructured in 2015 in order to make the connection between development of cell manufacturing processes and product integration more effective. The overall Solliance approach now considers 3 main steps:

1. Technology scouting and development, i.e. Research & Development projects for New Materials, Processes and equipment (NMP).
2. Platform development and implementation, i.e. released combination of processes, materials and equipment with reproducible results.
3. Integration of thin film PV for focus applications: Building Integrated PV, Infrastructure Integrated PV and Vehicle Integrated PV.

The first two steps are performed in both the CIGS and Perovskite program, and these programs are guided by market driven interest in specific integrated PV applications.

11.3.2 Short description

A reliable, affordable, clean and safe energy supply is a prerequisite for the future economic and social development. Amongst others, this requires a change to energy generation by renewable sources, like wind and solar. The Dutch High-tech Industry is well placed to exploit the opportunities arising from this need for renewable energy sources, in particular with respect to photovoltaics (PV).

The present volume of the solar cell market is more than 100 billion Euro/year, and the installed capacity of 250 GWp PV power expands at a rate of 60 GWp/year. The market growth of 45%/year over the last decade was enabled by an increase in product quality (conversion efficiency and performance ratio) with a simultaneous decrease in cost by a factor of 10 over the past 20 years). The levelized cost of energy (LCOE) of PV is on the verge to become competitive with every other generation technology of electricity, including coal, gas and wind (2016 Dubai bid of 800MWp PV power plant at 0,03 $/kWh). And still the main driver in the PV industry is the reduction of solar energy generation costs, as there is a huge potential for further cost reduction and efficiency increase, with the potential for a two orders of magnitude market growth up to 2050, and a considerable contribution of PV to the worlds electricity production (>50%).

The recent international COP21 deal will catalyze government, companies and in general the society to accelerate implementation of sustainable energy harvesting sources. Seen the densely built environment of the Netherlands (and by extension Europe), seamless integrated PV elements will become an important de-centralized energy harvesting technology for the near future. Not only for efficiency reasons,

but also because it is crucial to maintain the high level of social acceptance for solar energy, it is important to develop PV products which can be integrated more aesthetically and efficiently on the desired large scale. The Roadmap not only aims at developing more efficient processes and production equipment for solar cell manufacturers worldwide, but also at automated production of customized PV integrated (building-, infrastructure-, automotive-) components and products. Crystalline Silicon PV modules dominate the growing PV market, but the market volume and -share of thin film PV devices are 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 is therefore not only to provide process and equipment solutions for low cost high volume production, but more importantly also for integrated products with focus on building, infrastructure and vehicle components with seamless integrated PV. This will be realized 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 (like CIGS and perovskite) are combined with transparent electrodes, to be used in tandem with crystalline Silicon.

Europe is leading in development of PV production technology, and Dutch industry has around 5% market share of global PV equipment production. Quality improvement, cost reduction and product diversification are driven by the technological development of low cost, large area (evolving from sheet-to-sheet towards roll-to-roll) thin film technology. Using its broader background in large area electronics, thin film technology, material science and high-end equipment, the TNO program is focused on development of processes and equipment for production and integration of thin film photovoltaics, more specifically on CIGS- and Perovskite based technologies.

11.3.3 Goal

Perovskite Solar Cells (PSC)

Since 2015, Solliance is running its perovskite based PV program. Already in Q1 2016, a 6x6 inch^2 up-scaled and packaged module with 10% efficiency could be demonstrated. This was only possible by using the available skills and teamwork, developed during the running of the previous organic based PV program.
The aim of the Solliance PSC Program is the development of industrially relevant platforms for the processing and integration of perovskite based PV modules.
For this new perovskite based PV technology, four main targets have been defined:

1. Mid-term: improve cell efficiency above 20% and improve stability by controlling the perovskite active layer formation and introducing novel contacting layers.
2. Mid-term: demonstration of efficient (≥ 15%) perovskite based modules processed on 6”x6” rigid substrates and (≥ 10%) perovskite based modules processed on flexible substrates using scalable processes.
3. Mid-term: integration of thin film PV modules in the envisaged applications, including in tandem configurations with c-Si modules.
4. Longer term: pre-industrial S2S on glass and R2R on flexible substrates process for efficient, inexpensive and stable perovskite PV modules and the integration in applications thereof.

Perovskite based PV has the potential to revolutionize the photovoltaic market. PSC made on glass or flexible foils have or can have a number of beneficial properties, such as free-form factor, tuneable color, semi-transparency, being difficult to break and light weighted when using flexible foils as carrier substrates, and being potentially very efficient and low cost at long operational lifetimes. These last three points have not been proven satisfactorily yet by industry or research institutes, and are therefore the main issues dealt with in the Solliance PSC Program.
For the application and integration work, process compatibility of PSC on metal foil for BIPV applications will be further evaluated together with proper BOS included LCoE calculations.

CIGS Solar Cells
The aim of the Solliance CIGS Program is to develop industrially relevant platforms for the processing and integration of CIGS based PV modules, through development of generically applicable innovative process technology. The following main targets have been defined:

1. A stable process for realization of encapsulated modules based on coevaporated CIGS with >12% module efficiency, and best cells >16%, to serve as an open reference line for shared research on individual process steps and device properties.
2. A stable process for realization of encapsulated modules based on CIGS by innovative (lower cost, higher yield) sequential processing with >13% module efficiency, best cells >17%, and with focus on in-line atmospheric processing.
3. Improved CIGS device life time and improved life time predictability (25-30 years) through identification of basic mechanisms and measurement of life time determining factors (accelerated life time testing, module analysis).
4. Develop process and equipment for spatial ALD of ZnOS buffer layers (improved light transmission with at least comparable electronic properties as CdS) on sheet glass and R2R foil, and demonstrated in completed CIGS module.
5. Demonstrate improved light capturing under variable angles of light incidence by nano imprinted textured layers (window- and backside), aiming at higher efficiency (5% relative efficiency) at reduced CIGS absorber thickness (50%).
6. Improved efficiency and/or reduced absorber thickness by CIGS interface passivation through application of ALD layers.
7. Develop transparent conductors with broader wavelength transmission windows for tandem formation of thin film with underlying c-Si: demonstrate improved TCO compositions and TCO stability by spatial ALD.
8. Demonstrate integrated high speed laser scribing and printing of conductors and insulators for monolithic module interconnection by free 2D patterning (shuntless scribing, 50% deadzone reduction, reduced alignment, improved yield).
9. Develop and validate model for optimized module interconnection designs for higher efficiency and making full use of freedom of shape and size of module interconnection (5% relative efficiency improvement; more value creation by product diversification without additional cost).

Integration of thin film PV
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, infrastructure and vehicle) components and flexible/colored/transparent/free-form modules for optimized (seamless) 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 (seamless) integration of PV in the (built) environment.
For this new integration program, four main application areas, being building, infrastructure and vehicle components and tandem PV modules, have been defined in which the versatility and USPs of thin film PV will and can be emphasized by the manufacturing dedicated demonstrators:

1. Mid-term: three different Building Integrated PV components, all assembled into operational and monitor-able large area outdoor demonstrators.
    a. Light Weight PV Roof Panels
    b. Coloured PV Façade Panels
    c. Semi-transparent PV Windows
2. Mid-term: two different Infrastructure Integrated PV components on the level of feasibility demonstrators.
    a. SolaRoad → SolaRoll: low-cost R2R application feasibility of thin film PV on roads
    b. Crash Barrier with PV: thin film PV integration feasibility on/in crash barrier components
3. Long-term: integration of thin film PV modules in/on.
    a. Interior vehicle components
    b. Vehicle windows
    c. Vehicle outdoor body parts the envisaged applications, including in tandem configurations with c-Si modules
    d. Systems for energy storage, including CO_2 conversion and solar fuels
4. Long-term: demonstration of a c-Si PV module with a semi-transparent PSC (or CIGS) module in a tandem configuration with a net efficiency gain.

11.3.4 Dynamics

The HTSM Roadmap Solar has been established in close collaboration with the TKI Solar (now renamed as TKI Urban Energy) of the Topsector Energy. Apart from the overlap between the two Roadmaps, the HTSM Roadmap puts strong accent on required high end production technology for the Solar sector, whereas the Energy Roadmap has a strong focus on developments to increase the share of PV technology in the total energy mix. As a result, both PV Roadmaps are not only supported by the industrial parties united under HTSM, but also by private and public stakeholders along the whole value chain that aims to integrate PV technology at an increasing scale in the total energy system.
All solar activities at TNO, as performed in line with the HTSM Roadmap Solar, are executed within the framework of the research collaboration Solliance. Research partners in Solliance are TNO, Holst Centre, ECN, IMEC(B), TU/e, FZ Jülich (D), TU Delft and Hasselt University (B). Of these, TNO, Holst Centre and ECN have brought together their thin film PV work force and facilities on one location at HTC Eindhoven.
The Solliance programs CIGS and Perovskite based Solar Cells (PSC) are performed as Public Private Partnerships (PPP) in a shared research mode.
A third program, aiming at Integration of PV will be launched end of 2016 beginning of 2017. Within this program two phases in the development of new integrated PV products in the application domains of building, infrastructure and vehicle components and tandem PV modules can be distinguished:

- Phase 1: Realization of integrated thin film PV demonstrators for the above mentioned application areas.
- Phase 2: Together with partner companies, further maturing (increase of TRL and MRL) of these integrated products by refinement & optimization of product

and system designs and development of processes and equipment for future up-scaling and commercialization.

Phase 1 will most probably run in project mode in order to allow to manufacture integrated demonstrators, whereas Phase 2 will most probably run in shared research mode.

Several industrial partners have joined the programs on longer term membership basis (DSM, Dyesol, Panasonic, Solartek, Nano-c, VDL-ETG, Bosch-Rexroth) and the programs are continuously open to new partners. Together with these companies, the technical annexes (R&D Roadmaps) of the programs are annually revised and updated. This ensures that the program continues to address the needs of the industrial partners. Industrial partners can participate in all activities, from meetings to experiments. They have access to all infrastructure at Solliance. Apart from regular six-weekly program meetings, individual partner follow-up meetings are organized if desired. Annual partner satisfaction questionnaires are organized to assist further improvement of the program and collaboration.

Around the program, additional collaboration with industrial partners and research entities takes place on project basis. Further, the TNO/Solliance strategy is discussed on regular basis with an Industrial Advisory Board, formed by directors of representative companies, together with BOM and Brainport Industries. Collaborations (by projects, PhD's or student exchanges) will be continued/initiated with TU Eindhoven (Prof. Kessels, Prof. Janssen), TU Delft (Prof. Zeman, Prof. Groen), UG (Prof. Hummelen), AMOLF (Prof. Polman), Radboud University (Prof. Vlieg, Schermer), UHasselt (Prof. Dirk Vanderzande) to further strengthen the program's scientific foundation. On EU level, the TNO/Solliance research activities fully comply with the European PV Roadmaps of EPIA (international PV industry) and the EU PV Technology Platform. On all three program topics (CIGS, PSC and Integrated PV) TNO and Solliance are very well connected to the European network of industrial and research leaders in these fields, and participate in consecutive collaborative EU projects, with a focus on process, device, equipment development, application related integration and quality control.

11.4 Roadmap Printing

Responsible TNO: Erwin Meinders

11.4.1 Summary

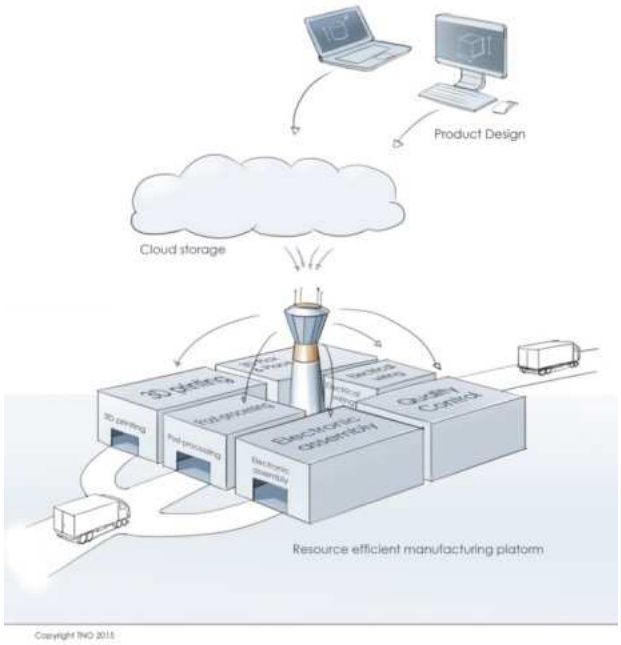
Additive manufacturing will play an important role in specific manufacturing chains, based on the benefits of customization and personalization, freedom of design and cost-effective small-scale and on-demand manufacturing. TNO focusses on the development of next generation additive manufacturing technology for manufacturing chains for the medical, dental, free-form electronics and pharma/food 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.

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.

Our vision is to help make Additive Manufacturing technology the next wave of industrial revolution, catering to high-tech and human centric applications. AM will create an industry that will enable a true circular economy through efficient production paradigms. We will constantly push the boundaries of technology which will enable customized products in a resource efficient way.

An artistic impression of such a factory is given in the figure below, and will employ high-tech equipment (like new printing technologies, new materials, multi-materials and advanced manufacturing concepts) and a high level of integration. Moreover, such systems have to deal with management of big series of personalized data (like network centric approach for one-product series manufacturing, IP and copyright protection).



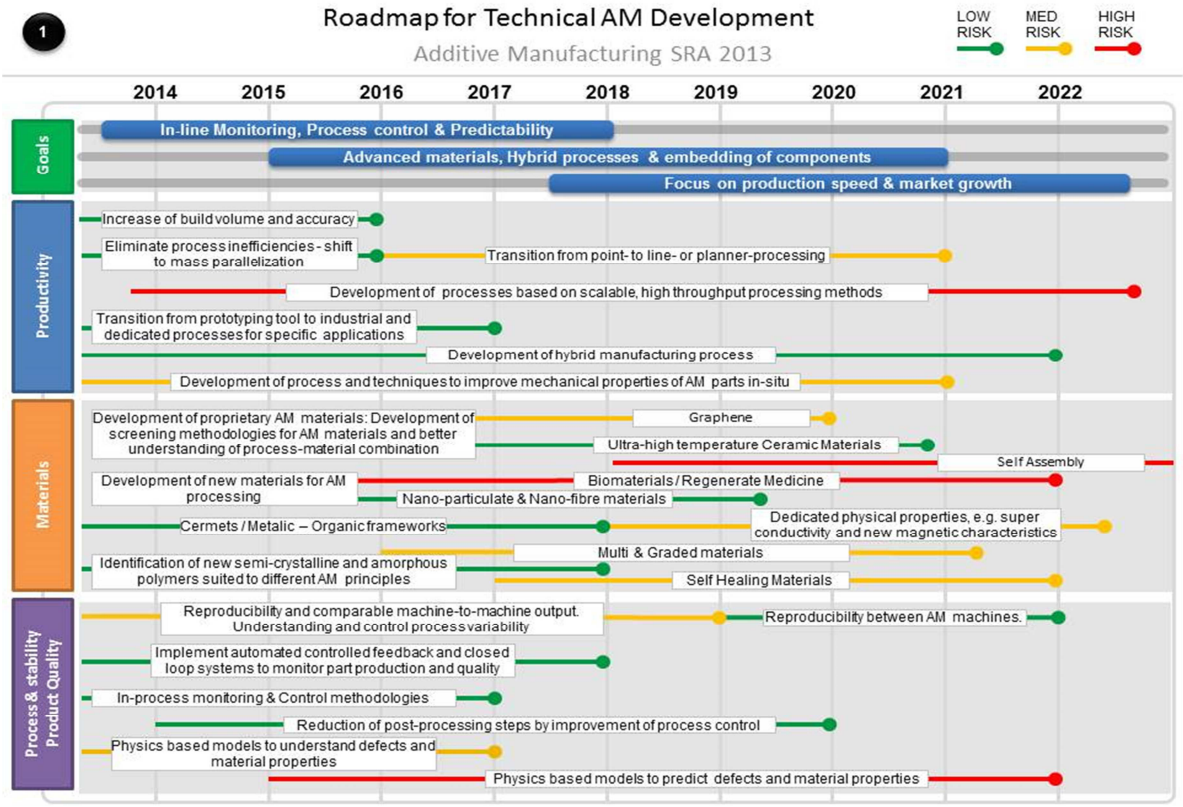
Artists' impression of a smart factory to enable industries to produce resource efficient customized smart products.

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.

Based on the ambition towards future smart factory, by aligning with its strategic partners such as the High-tech systems center and Brightlands Material Center , the Additive Manufacturing activities in TNO will focus on attributes such as materials, novel AM tools and processes.

While new materials and manufacturing technologies are introduced in the market, we see that for many applications the technology is still immature: product quality is inferior to that obtained with conventional methods, the choice of available materials is limited, yield is low by process-induced defects, manufacturing costs are high, and productions speeds are typically low. The technological challenges are indicated in the strategic research agenda on Additive Manufacturing (SRA) of the AM platform, and in several related Roadmaps (like the consolidated Roadmaps on metals, polymers, ceramics from the Brainport and high-tech companies and the Dutch Topsector HTSM Printing Roadmap, and the Smart Industry Roadmap), which represents the future AM needs of the industry, see below figure.



Technology Roadmap, from the European Strategic Research Agenda.

11.4.3 Goals

To address the identified needs related to product quality, capabilities, productivity, and integration in production chains, TNO has launched 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 integration challenges are addressed in the AMSYSTEMS Center, a new research

center established together with the High-Tech Systems Center – TU Eindhoven in 2016.

The ‘Materials for AM’ program 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 photo-curable 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. The ‘Materials for AM’ program is positioned via the Brightlands Materials Centre to co-create with the industry and academia next generation polymer technology for a number of appealing 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. The 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 and human centric markets (3D printed electronics, insoles, braces, exoskeleton etc.) with spin-off to other markets that require personalized, customized, on-demand manufacturing.

11.4.4 Dynamics

Synergies with various strategic partners are important for the successful realization of the additive manufacturing ambitions of TNO. For that strategic collaborations between partners are made for materials, tools and process development. The dynamics are described in detail in this section.

Since mid-2015, the AM material development within TNO is positioned via the Brightlands Materials Centre. In addition to the extension of the activities performed in 2016, more emphasis will be on linking material development with materials modelling to speed up material development and improve product performance (mechanical as well as geometrical quality). In collaboration with material suppliers, materials with different curing chemistries will be explored. The equipment and system aspects of digital manufacturing are addressed in the AMSYSTEMS Center.

The focus in the center will be on novel solutions for multi-material/multi-technology digital manufacturing and mass-customization solutions for human-centric applications, like medical, dental, free-form electronics and pharma/food. The integral approach of TNO is seen as a key selling point and will be secured by a strong interdependency between these BMC and AMSYSTEMS Center initiatives.

The patented laser-array based additive manufacturing systems will be further expanded in close collaboration with OEM companies active in customized manufacturing. In 2016 the sectors of the shoe industry (insoles) and the medtec industry (exoskeletons) were addressed, other sectors are planned to follow in 2017. A TNO supported start-up initiative to bring this technology to the market is currently being investigated. The collaboration with the Danish Technology Institute in the area of flexible Hybrid Manufacturing combined with nanotechnology (nano inks for printed electronics) will also be intensified.

One of the key objectives is the development of a laser-array technology for in-line SLS (thermal sintering) for mass-customization application. For this solution, high-speed polymer material deposition (~10cm*10cm area), high-speed laser-array laser sintering (target 1 m/s) and system integration need to be developed. 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 will be developed for product modelling to be used for design optimization and machine planning. For this purpose the tool must be highly optimized for speed. To guarantee the required accuracy, the model will be 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). In collaboration with the HTSC-TU Eindhoven, the Fieldlab MultiM3D was initiated. Within this Fieldlab, a project on 3D printed large SiC/SiN ceramic parts for high-tech applications started in 2016. Furthermore, a multi-year proposal was funded through EFRO on three topics: multi-color dental printing, printing of large SiC/SiN ceramic parts for high-tech, and free-form electronics.

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. A close cooperation is set up with the colleagues from TNO Holst Center and ICT and common research proposals are initiated. The goals of this program is to combine TNO knowledge from flexible electronics, materials development, systems engineering and additive manufacturing to address market needs. A concrete objective for 2017 and subsequent years is the development of structural electronics in both fast SLS and fast SLA by integration of direct writing of conductive tracks, and pick & place of components. Another challenge for the coming years is the patterning of optical wave guides in the 3D printed parts.

The multi-laser array technology, used for high-resolution, high speed photo-polymerization, will be further improved to demonstrate high-quality polymer and ceramics part manufacturing, with resolution down to 20-30 micron, and sizes beyond 10 cm. For this purpose further developments are needed in improving the light engine and the recoating technology. In addition, the platform will be expanded towards multi-technology applications, among others jetting for conductive track deposition and for color dosing. Free-form electronics and multi-color dentures are two key applications in need of such a multi-technology approach.

The line integration of Additive Manufacturing activities as demonstrated in the Printvalley platform for laser post processing of metal parts will be further improved by integrating additional inspection modules to realize a versatile and mature production technology. Future exploitation of the technology at development end is arranged by an existing consortium of (international) industrial experts (2SEAS initiative). Actions are ongoing to further exploit this technology in cooperation with industry partners (Denmark made 2017, Neuchatel Kanton).

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 will be further detailed and validated in 2017. Also a number of use cases will be 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.

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. In 2017, large area ceramics demonstrators (10cmX10cm) will be showcased for selected high-tech applications.

The program ‘3D Printed Electronics’ combines knowledge from flexible electronics, materials development, systems engineering and additive manufacturing to develop and enable the transforming of dump objects into smart devices (IoT, internet of things). First demonstrators were made in 2016, showcasing the potential of electronics integrated in 3D printed parts. The program will demonstrate the 3D printing of free-form conductive tracks and integration of components (LED, sensors, battery) in 3D printed parts in 2017.

11.5 Roapmap Healthcare

Responsible TNO: Arjen Amelink

11.5.1 Summary

Main goals for 2017 are:

- Development of a low-cost hand-held retinal imaging device for use in primary care.
- Development of a fluorescence fundus camera for retinal detection of curcumin-labeled senile plaques associated with neurodegenerative diseases.

- Development of a novel ‘quantitative retinal imaging’ platform capable of measuring the light scattering, absorption and fluorescence properties of retinal tissue, including hardware development and development of image analysis algorithms based on tissue optics modelling.
- Assessment of the expression of systemic diseases in the retina.
- Development of the innovation eco-system for quantitative retinal imaging.

Other activities include:
- Further development and clinical analysis of the ion-selective sensor for dialysate.
- Exploit TNO’s nano-photonic biosensing platform jointly with industry.
- Transfer the non-invasive glucose sensor to industry.
- Continue to provide clinical evidence that cancer can be detected non-invasively at an easily accessible, distant location based on the field-effect using our fiber-optic sensor platform.Continue to provide technical support for the EU project “Exist” with respect to clinical applications of multi-spectral imaging.

Additionally, we will investigate opportunities for cross-over application of our technology platforms. As an example, we are exploring the potential of our fluid characterization platform in the dairy, horticulture and waste-water markets.

11.5.2 Short description

The Van ‘t Hoff program is a shared research and innovation program, initiated by TNO, in the field of biomedical optics. Within the program we combine the strong points of partners throughout the value chain in medical technology in order to accelerate medical and technological innovations and their implementation in health care. The Van ‘t Hoff program thus forms an ecosystem where industry, university hospitals, research institutes and health foundations collaborate.
The program aims to improve medical diagnosis and therapy through the development of innovative medical devices based on photonics and biomedical technologies. Specifically, 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.
By innovating together with industry we aim to ensure the actual application of the developments while creating economic impact.

The program has several long term goals:
- “selective ion measurement for dialysis”: we develop a miniature selective ion sensor (Na, K, Ca) to enable personalized haemodialysis and the reuse of dialysate in portable artificial kidneys.
- ”detection and monitoring of neurodegenerative diseases”: we develop simple technology for safe, accurate and cost-effective diagnosis and monitoring of neurodegenerative diseases (e.g. Alzheimer’s disease, Parkinson’s Disease).
- “non- invasive glucose measurement”: we develop a commercially available non-invasive glucose sensor.
- “modular fiber optic sensors for non- and minimally invasive diagnostics and surgery”: we develop an easy to use screening instrument for risk assessment of (the development of) cancer.

- “surgical imaging/image guide surgery”: we develop spectroscopic devices for vision enhancement of critical anatomical structures (nerves, vessels, tumour borders) during surgery and other medical procedures.

Several optical technologies are integrated on our technology platforms being a nano-photonic biosensing platform, a tissue characterization platform, a fluid characterization platform , an ophthalmic imaging platform and a fiber optic sensor platform and are used as underlying technologies for our developments.

11.5.3 Goals

Based on the dynamics as described in the previous section, the program goals for 2017 are the following:

- “fluid characterization platform”: our ion-selective sensor for dialysate will be further developed and its performance analyzed together with our clinical, industrial and public partners (MUMC, NeoKidney and Nierstichting). Spin-offs of this relatively mature technology in other application areas are emerging and will be further pursued in 2017. The potential of our fluid characterization platform in the dairy-market will be explored with Lely, in the horticulture market with Priva, and in waste-water management with Endress and Hauser.
- ”nano-photonic biosensing platform”: discussions are taking place (with e.g. Lionix) to exploit TNO’s high TRL nano-photonic biosensing platform jointly with industry. The industrial and developmental activities with respect to this technology are expected to increasingly be funded in bilateral settings, with current interest from KE Instruments (TBC detection as a first case), Sanquin (concentration of expensive medicine), Erasmus MC (virus and antibiotic resistance detection) and Randox (diagnostic essays).
- “ophthalmic imaging platform”:
  - Together with an industrial partner (IDCP) TNO has developed a prototype low-cost hand-held fundus camera for use in primary care. This is expected to continue to be developed into a next generation prototype in 2017, including industrial design, manufacturability and analysis software, together with industrial partners IDCP and Thirona.
  - Through a EU Horizon2020 grant (“Moon”, 2017-2020) TNO will design and build a fluorescent fundus camera for curcumin imaging, which binds to protein (senile) plaques in the retina and can be visualized using fluorescence imaging. Additionally TNO will develop in vitro systems for assessment of the optical molecular fingerprint of protein plaques with different protein compositions (associated with different neurodegenerative diseases). This project will be performed together with Medical University Vienna, Leibniz Institute of Photonic Technology, Innolume, Horiba Jobin Yvon and Carl Zeiss.
  - For the novel ‘quantitative retinal imaging’ platform we will start to develop a bread-board fundus camera capable of measuring the light scattering, absorption and fluorescence properties of turbid media in 2017. This development includes hardware development as well as development of image analysis algorithms based on tissue optics modelling; for the latter we will seek collaboration with the VU. Initial application of this platform is foreseen to be quantification of VEGF to monitor the therapeutic efficacy of anti-VEGF drugs; this will be investigated together with Oogziekenhuis Rotterdam and one or more industrial partners (e.g. CHDR, Heidelberg, Carl Zeiss). Biological research to assess the expression of systemic

diseases in the retina is in parallel performed, in collaboration with pharma (e.g. Shire) and industry (e.g. Phoenix research). Finally, the innovation eco-system for quantitative retinal imaging will be further developed in 2017.

- “tissue characterization platform”: after extensive clinical testing of the non-invasive glucose-sensor with apparently positive outcomes, a partnership for further development with industry is now in preparation.
- “fiber-optic sensor platform”: 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 this research topic with clinical and industrial involvement.
- “multispectral imaging for image guide surgery”: clinical and technical support was provided in an EU project (“Exist”), which will continue in 2017.

11.5.4 Dynamics

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:

- “selective ion measurement for dialysis”: a functioning model of the developed miniature selective ion sensor based on our fluid characterization platform will be transferred to industry (NeoKidney). Spin-offs of this relatively mature technology in other application areas are emerging and will be pursued in 2017 in preferably bilateral settings.
- ”biosensor based on ring resonators”: discussions are taking place (with e.g. Lionix) to exploit TNO’s high TRL nano-photonic biosensing platform jointly with industry. The industrial and developmental activities with respect to this technology are expected to increasingly be funded in bilateral settings.
- “retinal imaging”: 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, in 2016 a feasibility study has been executed on ‘quantitative retinal imaging’. This novel (low TRL) ophthalmic imaging platform 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). At the moment of writing this feasibility study has not been completed yet, but if the outcomes are positive, this topic will be central to the Van ‘t Hoff program in 2017 and onwards. An extensive consultation is done of (academic, clinical and industrial) interested parties, including Carl Zeiss, Heidelberg Engineering, FujiFilm, Optomed, IDCP, Phoenix, Imagine Eyes, Medical University Vienna, VU Amsterdam, Singapore Eye Research Institute, Centre for Human Drug Research, Oogziekenhuis Rotterdam, Erasmus MC.

- “non- invasive glucose sensor”: after extensive clinical testing with positive outcome, a partnership for further exploration with industry is now in preparation.
- “modular fiber optic sensors for non- and minimally invasive diagnostics and surgery”: 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.
- “multispectral imaging for image guide surgery”: clinical and technical support was provided in an EU project (“Exist”), which will continue in 2017.

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

Responsible TNO: Frans Beenker

12.1.1 Summary

A common denominator in the Dutch high-tech industries is that these companies require access to distinguishing technology innovations, a state-of-the-art product development process, leading capabilities for design and engineering, an effective and efficient supply chain, a highly qualified workforce, and an open innovation ecosystem that strongly facilitates strategic innovation and cooperation. The key elements of their needs are as follows:

- *Multidisciplinary design and engineering*. Addresses the heterogeneity and multi-disciplinary aspects of high-tech system designs, scaling the number of cooperating components and sub-systems, as well as the incorporation of extra-functional requirements (e.g. system performance, dependability).
- *Effective and efficient development processes*. (i) Significantly increase efficiency of product innovation, (ii) early identification of system level design trade-offs, (iii) improvements in multidisciplinary design capabilities, (iv) design for integration and test.
- *Advancements in virtualization of design process.* Provide an early proof of correctness on basis of models instead of building physical prototypes.
- *Need for highly adaptable systems.* Design products that are configurable to customer needs and that can be adapted or tuned to a specific user need, user environment and/or application over time.
- *From products to services and solutions.* Companies need to adapt their business models and reposition themselves in the value chain. Today's markets require products that flawlessly integrate with other (networked) products and applications, often from other manufacturers.
- *How to cope with legacy*. Industry is in strong need for automated methods and techniques that allow for conversion of legacy code into state-of-the-art software constructs.
- *Human capital development.* A systematic investment in a life-long learning program for education and training of embedded system architects.

Together these key elements represent the focus areas of the TNO-ESI research program for 2016 and 2017.

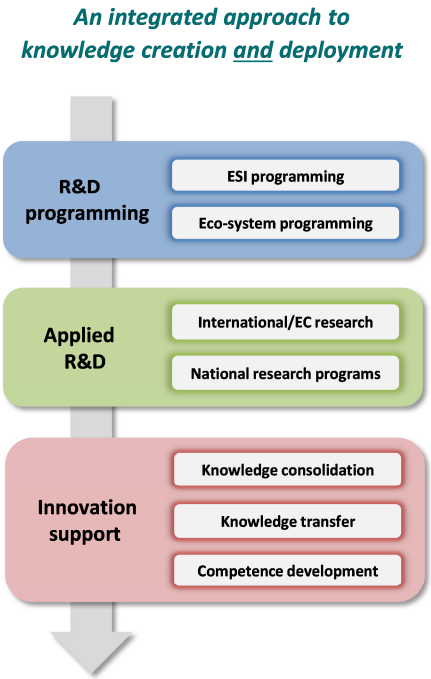
12.1.2 Short description

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 though 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.

For successful innovation and value take-up by the ecosystem, it is essential that systematic attention is given to all required elements of the knowledge chain. TNO-ESI follows a process, with each step adding value and depth to the previous step.



Baseline components:

1. ***R&D programming***
   - Translation of (industrial, societal) knowledge needs into strategic research agenda and roadmaps
   - Alignment of programs with Top Sector HTSM
2. ***Applied research***
   - International research programmes for exploration of new/emerging fields
   - National research projects based on strategic research questions from industry or societal domain
3. ***Innovation support***
   - Development and maintenance of a sustainable knowledge base for general use
   - Transfer of knowledge through network activities, seminars, workshops, publications, special interest groups, etc.
   - Competence development program for training of professional competences in system architecting and engineering

The 2015-2018, the TNO-ESI research agenda addresses a number of key system-level challenges in multidisciplinary system architecting, design and engineering that relate to the key elements presented in the previous section. It comprises four key lines of innovation that are embedded in the system level challenges of the HTSM Embedded Systems Roadmap and address the key industrial concerns, mentioned in the previous section.

- *System performance.* The quantitative design criteria for embedded applications and their resource utilization in trade-off with timing and costs.
- *System quality and reliability*. The correct functioning and overall behavior of a high-tech system.
- *Future-proof systems.* The design of systems that allow for easy modification and upgrade during their operational life.
- *Systems in context.* The design of systems that are context-aware and incorporate adaptive behavior.

12.1.3 Goals

The TNO-ESI research and development results are expressed in terms of methods, techniques and, if necessary, supporting SW-tools. Application of TNO-ESI results requires these methods to be incorporated into industrial development processes, including the adequate training of personnel. The target results are as follows.

- *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.
- S*ystems 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 4 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 OEMs, including large international companies. In 2015, this included ASML, NXP, Océ, Philips Healthcare, Philips Lighting and Thales. We gradually expand the set of involved OEM companies and in 2016-2017 Barco, DAF and FEI are included.
2. *Industrial suppliers*. These are the partners and suppliers of the larger OEMs 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 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 Eindhoven, UT, RU, VU and UvA.

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 SR 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. End of 2015, Twente University has resigned from the PB and in 2016, the Radboud University has joint the PB. We expect that Twente University will retake its PB position in 2017.

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; and
- 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, 29 september 2016 TNO

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