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Inhoudsopgave

1 Introduction

This report describes the 2016 update of TNO's 'Speurwerkprogramma 2015-2018: Thema High-tech systems and Materials'. The report shows the contributions of TNO's Demand Driven programs (VP, Vraaggestuurd Programma) to the different Roadmaps of HTSM.
The 2016 updates of the VP's are based on discussions with stakeholders including HTSM Roadmap chairmen during spring 2015, leading to input for the 'Kennis- en Innovatieagenda 2016-2019' of HTSM.

Further reductions in TNO's governmental subsidy (TNO Rijksbijdrage) required changes in focus and approach, for instance Social Innovation is no longer a separate research topic, but linked to the Smart Industry initiative with a focus on Smart Working. The Smart Industry initiative and more specifically the 2015 Program is described in the HTSM Roadmap Mechatronics and Manufacturing chapter of TNO's Speurwerkprogramma 2015-2018. However, Smart Industry activities are performed within other HTSM Roadmaps and other Topsectors as well. Therefore a 'virtual' VP Smart Industry will be created in 2016 in order to tune and coordinate these activities and to contribute to the development of a Smart Industry Roadmap.

Two new VP's are added that will contribute to the HTSM High Tech Materials Roadmap in 2016 and beyond:

- 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) has been included in TNO's 'Speurwerkprogramma 2015-2018 Thema ICT'. The 2016 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	Manufacturing and Mechatronics	Automotive	Nano-technology	HighTech Materials	Space	Advanced Instrumentation	Semiconductor Equipment	Lighting	Solar	Printing	Healthcare	Embedded Systems
Security	X													
Defense Related Industry	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 (QuTech)				X					
Flexible and Freeform Products		X								X	X	X	X	
ESI														X

2 VP Security

2.1 Roadmap Security

2.1.1 Visie en ambitie

In mei 2015 is op de HTSM-website (zie: http://www.hollandhightech.nl/htsm/Roadmaps/Security) een update van de HTSM Roadmap Security gepubliceerd. Het VP Security sluit daarop aan. Daarbij zetten we in op de technologische uitdagingen die te maken hebben met bedreiging van de veiligheid van onze samenleving. We kijken zowel naar oplossingen die bijdragen aan het voorkomen dan wel het beheersen van criminaliteit en terrorisme, als ook naar oplossingen die de schadelijke effecten van incidenten (crises, rampen) beperken, binnen de volgende domeinen:

1. System of systems: voor een geïntegreerde aanpak van de operationele taken op het gebied van crisisbeheersing en openbare orde, veiligheid en beveiliging is ontwikkeling van een ‘systeem van systemen’ essentieel. In de markt is grote behoefte aan robuuste oplossingen voor Real-Time-Intelligence, Opsporing en Handhaving, Crisismanagement en Beveiliging van complexe, multi-stakeholder-locaties.
2. Cyber risk management & system resilience: de steeds grotere invloed van ICT op de bedrijfsvoering bij bedrijven en overheden vergroot ook het belang van cyberresilience en de bestrijding van cybercrime. Voor eigenaren van ICT-systemen is het van essentieel belang om de cyberisico’s kosteneffectief te beheersen. Voor een adequaat functioneren van de systemen is een efficiënte, privacy compliant interactie met klanten en samenwerkingspartners een essentiële voorwaarde. Nieuwe concepten en tools zijn vereist; dit biedt kansen voor IT-bedrijven.
3. Sensoren: voor effectieve beveiliging zijn waarnemingen met sensoren cruciaal. Zowel actieve als passieve sensortechnologieën zijn van belang. Er zijn twee invalshoeken:
   a) Actieve sensoren (radars) verder verfijnen en daarmee intelligentere systemen vormen. Nederland heeft hier een excellente positie op het gebied van R&D, en een leidende marktpositie op de toegankelijke wereldmarkt.
   b) Passieve sensoren leveren steeds meer data. Dat vereist nieuwe concepten voor data processing en het uitfilteren van irrelevante data. Er zijn veelbelovende ontwikkelingen op het gebied van intelligente sensoren en zelflerende systemen.

2.1.2 Interactie en samenwerking

De onderdelen van het VP Security sluiten aan op parallel in uitvoering zijnde kennisontwikkelingsprogramma’s onder regie van de Ministeries VenJ en Defensie:

Deel VP Security	**Belangrijkste aansluitende programma's**
Systems of systems	• VP Veilige Maatschappij (Procesinnovatie; Informatiemanagement), regie VenJ • V1517 Informatievoorziening als operationele capaciteit, doelfinanciering Defensie
Cyber risk management & system resilience	VP Veilige Maatschappij (Cybersecurity & societal resilience)
Actieve sensoren	Diverse defensie-doelfinancieringsprogramma's
Passieve sensoren	Bouwt voort op afgesloten project "Herkennen afwijkend gedrag" in VP Veilige Maatschappij

De gouden driehoek van bedrijfsleven, overheid en kennisinstellingen heeft in de security-sector bijzondere betekenis doordat de overheid niet alleen een beleidsbetrokkenheid heeft maar ook uitvoerende taken in bedrijfsmatig gerunde organisaties.

Van bijzonder belang voor het participerende bedrijfsleven is het optimaal gebruik maken van de kennis die internationaal ontwikkeld wordt en aansluiting op internationaal in ontwikkeling zijnde praktijk van veiligheidsorganisaties. Interoperabiliteit en standaardisatie zijn ook in het Europese kaderprogramma belangrijke aspecten. Vanuit de stakeholders van de Roadmap Security worden initiatieven genomen worden om dit te versterken. De al bestaande sterke deelname van TNO in de Europese arena is hier een goede uitvalsbasis.

Het VP Security 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 Instituut voor Fysieke Veiligheid. Het ministerie EL&I heeft een eigen vertegenwoordiger aan het Roadmapteam toegevoegd.

De samenwerking van bedrijfsleven met GTI's, universiteiten en overheden is in de eerste twee jaren verder vormgegeven en geïntensiveerd. Zo lopen er initiatieven van het roadmapteam Security tot:

- Concretisering van ambities voor via NWO en STW uit te zetten onderzoek.
- Samenwerking voor specifieke aan de deelroadmap gerelateerde issues met de publieke veiligheidsorganisaties (Nationale Politie, Brandweer, Veiligheidsregio's en KMar).
- Publiek Private Samenwerkingsinitiatieven voor innovatie en implementatie van vernieuwingen. Aan de uitbouw hiervan leveren NIDV en *The Hague Security Delta* een substantiële bijdrage.

Specifiek voor de defensie-gerelateerde industrie is door TNO in 2014 een nieuw VP opgestart. De ontwikkelingen op het gebied van actieve sensoren worden in dit nieuwe VP nu en in de komende jaren krachtig voortgezet, naast onderzoek gericht op de HTSM Roadmap Components and Circuits.

Voor elk van de drie genoemde domeinen (Systems-of-Systems, sensoren, cybersecurity) zijn er werkbijeenkomsten georganiseerd om uitdagende innovatietrajecten met een breed draagvlak tot stand te brengen.

2.1.3 Dynamiek

2.1.3.1 TNO VP project voor de deelroadmap Systems-of-Systems

A. Ontwikkeling doelstelling

High Reliability Organisaties belast met de uitvoering van veiligheidstaken, zoals politie, veiligheidsregio's en het meldkamerdomein, staan voor de uitdaging om meer veiligheid te leveren in een toenemend complexe maatschappij. De groei van de vernetting en de dynamiek in de samenleving vraagt om een sterkere focus op:

- Flexibele schaalbaarheid van veiligheidsoperaties.
- Benutting van capaciteiten van mogelijke partners binnen en buiten de organisatie.

Deze ontwikkeling vraagt om een informatievoorziening met een adequaat georganiseerde toegang tot gesloten en open informatiebronnen en het delen van daarmee te produceren analyses; daarbij dient tevens ingespeeld te worden op enorme groei van data en het slim benutten daarvan. Zo ontstaat perspectief op effectievere communicatie, betere besluiten en winst in tijd en efficiency. Door de intensieve interactie met politie en andere operationele veiligheidsorganisaties is er draagvlak opgebouwd voor een Real Time Intelligence Lab, waar met name geëxperimenteerd kan worden met nieuwe benaderingen en tools voor de ondersteuning van veiligheidsoperaties. Dit zgn. RTI-lab zal als spin off van de ontwikkelingen in het project Systems-of-Systems worden doorontwikkeld in het VP Veilige Maatschappij. In het VP project Systems-of-Systems zal de focus gaan liggen op innovatietrajecten voor vraagstukken met perspectief op substantiële betrokkenheid van private stakeholders naast de overheidspartijen; zo nodig zal ook validatie van concepten in het RTI-lab kunnen plaatsvinden.

B. Inhoud project in 2016

Met consortia voor specifieke situaties als pilot wordt de basis gelegd voor oplossingen, die in tientallen overeenkomstige situaties toepassingsperspectief hebben. De betrokken overheidspartijen hebben als belang het realiseren van een oplossing voor hun eigen situatie, terwijl de betrokken bedrijven uit de veiligheidssector bouwen aan een voorsprong in een aantrekkelijke markt met een goed product. De ambitie is twee van de drie al in ontwikkeling zijnde consortia door te zetten naar het daadwerkelijk gezamenlijk investeren in innovatie. De drie in ontwikkeling zijnde consortia betreffen:

- **Veiligheid in de Internationale zone van de gemeente Den Haag**
  Hier gaat het om de Real Time Intelligence functie te ontwikkelen van samenwerkende Security Operations rond de Internationale Zone (IZ) in Den Haag. Onder leiding van HSD en TNO wordt in samenwerking met gemeente Den Haag, politie, Thales en Siemens toegewerkt naar de ambitie van een 'Real Time Security Area', waarin veiligheid hand-in-hand gaat met behoud van leefbaarheid in het gebied. In dit toekomstbeeld zullen de (beveiligers van) Internationale Organisaties en politie nauw samenwerken, en informatie en resources in real time met elkaar delen. Na de 2015 te realiseren identificatie én adressering van de belangrijkste vraagstukken voor het daadwerkelijk bedrijven van Real Time Intelligence vanuit een Systems-of-Systems-perspectief zullen in 2016 de ontwikkelingen gericht zijn op tools en architectuur.
- **Informatiepreparatie voor overstromingsdreiging**
  Met als basis een inmiddels stevig consortium van de bedrijven HKV, Centric

en de Antea-groep en de Veiligheidsregio's Hollands Midden en Zuid-Holland-Zuid wordt gewerkt aan het dichterbij brengen van Real Time Intelligence voor een betere crisisbestrijding in het geval van een overstroming. We streven ernaar dat beslissers in de veiligheidsregio Hollands Midden op strategisch, operationeel en tactisch niveau in staat zijn om in de dreigende, de acute en de nazorg-fase eerder, sneller en beter te beslissen over de te nemen maatregelen (alles wat nodig is om overstromingseffecten te beperken). Hiertoe wordt ingezet op het verbeteren van de informatie uitwisseling tussen Veiligheidspartners (oa Veiligheidsregio, Hoogheemraadschap, Defensie, Vitale infrastructuurbeheerders zoals Alliander) en op het verbeteren van het voorspellende vermogen. Na de in 2015 te realiseren *proof-of-concept van een intelligent platform (kaart en kaartlagen) dat informatie uit verschillende bronnen (en stakeholders) kan combineren t.b.v. Overstromingsdreiging* zal in 2016 de ontwikkeling van een innovatief prototype worden gerealiseerd.

- **Burger Alert Real Time (BART)**
  Het deelproject Burger Alert Real Time (BART) geeft invulling aan de verdieping op de burger als node. De burger is immers onderdeel van het System-of-Systems voor Veiligheid. In samenwerking met de TUDelft, CGI, politie en gemeente Den Haag wordt gezocht naar de contouren van een 'Burgernet 2.0'. In 2014 is een R&D project opgezet rond de ontwikkeling en integratie van systemen en processen voor burgerparticipatie bij handhaving en opsporing. Met name op nieuwe manieren samenwerken met burgers om de heterdaadkracht te verbeteren (burger als participant en sociale, interactieve sensor). Het idee is om de cirkel te sluiten van de informatiegestuurde politie die samenwerkt met informatiegestuurde burgers. Gebruikmakend van de ICT middelen van de 21e eeuw. De in 2015 te ontwikkelen concepten voor real-time burgerparticipatie zullen in 2016 experimenteel worden beproefd, om de haalbaarheid aan te tonen.

2.1.3.2 TNO VP project voor de deelroadmap Cybersecurity

A. Ontwikkeling doelstelling

Het VP project Cyber risk management & System resilience richt zich op het in samenwerking met bedrijven ontwikkelen van innovaties voor veilige IT-infrastructuren; daar waar relevant worden ook overheidsinstellingen betrokken. Na de ontwikkeling van een methodiek voor Advanced risk management en tools voor detectie van ICT-misbruik wordt nu gefocussed op het vergroten van de threat intelligence in samenwerkingsplatforms en technologie en tooling voor specifieke cyberdreigingen. In Shared Research Programma's (SRPs) en Publiek Private Samenwerking (PPS) wordt toegewerkt naar een TRL-level van minstens 6/7 om overdracht naar het bedrijfsleven te kunnen laten plaatsvinden (definitie TRL 6/7: demonstratie van een model of prototype van een systeem/subsysteem in een relevante c.q. praktijk omgeving). Om de ontwikkelingen optimaal af te stemmen op de gebruikers zal gebruik gemaakt worden van bij TNO c.q. HSD uit te bouwen cyberlab tot een cyberrange, een R&D platform dat kan dienen als testbed en als omgeving voor training en oefening.

B. Inhoud project in 2016

Het Strategische Research Programma in samenwerking met de Nederlandse banken zal 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.

Gezien de toegenomen impact van cyberdreigingen zal het budget voor initiatieven in de deelroadmap Cybersecurity in 2016 groeien. Dit maakt het mogelijk samenwerkingsprojecten door te zetten en te ontwikkelen voor een portfolio van onderwerpen met een evenwichtige verdeling van de huidige TRL-niveau's. Prioriteit hebben de volgende onderwerpen ('streams'):

1. Threat Intelligence Sharing
   Technische platforms die op basis van open standaarden Cyber informatie kunnen uitwisselen, om deelnemende partijen proactief weerbaar te maken tegen grootschalige cyber dreigingen. Als doel is gesteld het realiseren van een technisch uitwisselingsplatform voor cyber threat intelligence, op basis van de STIX/TAXII standaard, dat commerciële overlevingskans heeft. TNO werkt daarvoor samen met Rola Security Solutions GmbH en DataExpert voor de technische innovatie. Het platform maakt het geautomatiseerd uitwisselen van cyber threat intelligence tussen Security Operations Centers (SOCs) mogelijk. In meerdere sectoren is hier behoefte aan; met name te noemen zijn: de financiële sector, de telecom sector, de publieke veiligheidssector en de uitvoeringsinstanties van de overheid (belangdienst, UWV ea). Huidig TRL-niveau: 5/6.
2. Resilience van grootschalige IT-infrastructuren-in-wording
   In deze stream is de ambitie om minstens één SRP op te zetten voor het inbouwen van security-by-design technologie in nieuwe IT-infrastructuren samen met de Energiesector (Alliander) en de Logistics sector (DITCM, Havenbedrijf e.a.) waarin de opgebouwde TNO kennis kan worden ingebracht en gevaloriseerd. Huidig TRL-niveau: 5.
3. Beïnvloeding van systemen-op-afstand
   In deze stream wordt cybersecurity-kennis opgebouwd en ingebracht in projecten waarbij systemen op afstand kunnen worden beïnvloed door het afluisteren, manipuleren of storen van verkeer in het radiospectrum. De cyberdreiging hiervan neemt in zeer hoog tempo toe door de explosieve groei van remote sensoring: GPS, navigatie, surveillance, 4G/5G, telemetrie, luchtvaart, logistics, NFC, contactloos betalen, etc. Huidig TRL-niveau 3/4.
4. Gebruik van Darkweb
   Het Darkweb is een steeds grotere bron geworden van cyberdreigingen (malware, DDOS, phishing, ransomware, etc.). Als logisch vervolg op ontwikkelingen van Darkweb Monitoring, dat zich vooral richt op het in de gaten houden van Darkweb events, wordt nu de doelstelling het daadwerkelijk ontwikkelen van tooling om misbruik te kunnen tegen te gaan. Hiervoor wordt samengewerkt met het Nederlandse bedrijf RedSocks, dat met TNO een feed wil ontwikkelen om de Malware Threat Defender appliance te voorzien van Darkweb threats. Huidig TRL-niveau:3.
5. Human factor in cyber
   Onderzoek naar en ontwikkeling van een gepersonaliseerde, maatwerktool voor weerbaarheidstraining waarmee cyber awareness van werknemers wordt beïnvloed, alsmede handelingsperspectief wordt geboden. Ook de Wet

Datalekken vereist dat werknemers actief worden getraind. Huidig TRL-niveau: 2/3.

2.1.3.3 *TNP VP project voor de deelroadmap Passieve sensoren*

A. Ontwikkeling doelstelling

De basisdoelstelling van het VP project Passieve sensoren is het ontwikkelen van intelligente sensoren en sensorsystemen die aansluiten op kansen voor de Nederlandse industrie en daardoor waardevol is voor civiele en militaire toepassingen. Binnen deze basisdoelstelling ligt de focus op instrumenteel ondersteunde herkenning van activiteiten en gedrag bij cameratoezicht. Actuele onderzoekitems zijn: geautomatiseerde filtering voor waarneming van gedefinieerde incidenten, ad hoc uitbreiding camerasystemen bij zich ontwikkelende crises, multi-modale/multi-viewpoint waarneming, mobiele directionele sensoren.

Door de interactie met leveranciers en gebruikers is zichtbaar geworden dat innovatieve ontwikkelingen met name kans op brede toepassing hebben als ze geïntegreerd zijn in toezichtconcepten en daarmee is het gebruik van waarnemingen en andere data en informatie direct van belang. Zo komen ook de deelroadmaps Systems-of-Systems en Passieve sensoren in elkaars verlengde te liggen.

Een apart aandachtspunt in deze internationaal georiënteerde markt is de harmonisatie van sensoren, sensorsystemen en toezichtconcepten.

B. Inhoud project in 2016

De inzetbaarheid van mobiele sensoren, zowel bodycams als platform gedragen opties, biedt nog een breed veld aan technische en ethische onderzoeksuitdagingen. De enorme vergroting van beschikbare beelden en andere data vraagt om geavanceerde dataverwerkingstechnieken en waarnemingsstrategieën. Deze zullen samen met leveranciers en gebruikers worden onderzocht.

Met consortia voor specifieke situaties zal de basis worden gelegd voor nieuwe toepassingen van passieve sensoren en sensorsystemen, die in tientallen overeenkomstige situaties toepassingsperspectief hebben. Hiervoor zijn naast de bijdrage vanuit dit project aan het Systems-of-Systems initiatief voor beveiliging van de Internationale Zone al drie initiatieven in ontwikkeling:

- Het verst gevorderd is de samenwerking met KMar, Schiphol, Bosch en QVI voor het inzetten van intelligente sensoren voor gedragsherkenning bij de beveiliging van Schiphol. De nieuwe perspectieven voor toepassing van geautomatiseerde herkenning van incidenten bieden ook uitzicht op een verantwoorde overgang van *rule based* naar *risk based* aviation security.
- Sensing voor risk based perimeterbeveiliging van vitale locaties en objecten (o.a. ook IZ). Hoewel dit al een jarenlang bekend item is vragen nieuwe dreigingen (UAV's, Charlie Hebdo, etc.) , nieuwe technologische ontwikkelingen (big data, automatische kalibratie, intelligente sensoren) en nieuwe beveiligingsconcepten (risk based beveiligen) om verdere ontwikkeling.
- Verbeteren toezicht middels lichaamsgedragen sensoren en ad hoc ingekoppelde sensoren en informatiebronnen in Operational Fieldlabs van de Nationale Politie en andere toezichthouders zoals Kmar en private beveiligers.

Verder zal in 2016 gewerkt worden aan de ontwikkeling van een internationaal initiatief voor een experimenteel testbed voor validatie en harmonisatie van toezichtstechnieken en –concepten. Hiervoor is in principe al een goede uitgangspositie door de betrokkenheid bij Europese initiatieven (zoals ERNCIP, TACTICS, DRIVER, HECTOS).

2.1.3.4 TNP VP project voor de deelroadmap Actieve sensoren

Zoals eerder toegelicht is dit VP project onderdeel van het VP Defensie Gerelateerde Industrie, maar de onderstaande informatie is ook hier opgenomen omdat het project valt onder de inhoud van de HTSM Roadmap Security.

A. Ontwikkeling doelstelling

De basisdoelstelling is om door sturing op industrieel relevante R&D en snelheid van innoveren impact te generen op exportpositie en werkgelegenheid. Daartoe worden ook in het Platform Nederland Radarland ideeën ontwikkeld om de aan nationale veiligheid gerelateerde Nederlandse OEMs, MKB’s en de supply chain op het gebied van sensortechnologie beter te bedienen. Bij actieve sensoren heeft Nederland zowel aan de kenniskant als aan de industriële kant een toppositie in de wereldmarkt en is een sterke innovatieve speler. Zo is Nederland in de toegankelijke markten wereldmarktleider op het gebied van radar- en commandovoeringsystemen voor marines. Als actieve sensor is radar bij uitstek geschikt voor het waarnemen en herkennen van zogenaamde niet-coöperatieve objecten. Voorbeelden zijn de inzet van radar voor militaire toepassingen, veiligheidstoepassingen als kust- en havenbewaking, vredes- en humanitaire missies zoals anti-piraterij, en calamiteitenbestrijding. Verder ook het voorspellen van extreem weer en het controleren en begeleiden van verkeer en vervoer. Marktonderzoek laat een aanzienlijk wereldwijd marktpotentieel zien. Bovendien is dit brede applicatieveld vaak ook randvoorwaardelijk voor een klimaat waar de economie wel bij vaart.

De komende jaren moet het spectrum waarbinnen radarsensoren functioneren nog verder worden verbreed, bijvoorbeeld voor objecten die via de hoge dampkring of ruimte een bedreiging vormen, of objecten als (geïmproviseerde) mini-UAV’s die qua reflecterende eigenschappen zeer moeilijk van de natuurlijk achtergrondomgeving zijn te onderscheiden. Nieuwe uitdagingen liggen ook in de inzet van radar in een sterk asymmetrische operationele omgeving, ter ondersteuning van flexibele verdedigingssystemen of daar waar vrije propagatie beperkt is, zoals in een stedelijk omgeving. Radarsensoren zullen steeds vaker aan de basis staan van heterogene sensorsuites voor onder meer multi-spectrale waarneming. Vergaande optimalisatie van de fysieke integratie van de suite, naast volledige functionele integratie en de mogelijkheid van reconfiguratie zijn ambities voor deze roadmapperiode.

B. Inhoud project in 2016

Er wordt gericht gewerkt aan projecten die bijdragen aan de nationale Roadmap Radar en Geïntegreerde Sensoren en in het bijzonder aan de sensorsuite voor de volgende generatie fregatten van de Koninklijke Marine. De nationale projecten zijn uitgevoerd met Thales Nederland; de projecten in internationaal verband vonden in verschillende consortia plaats voor de European Defence Agency (EDA). Verwante projecten op het gebied van RF Componenten liepen binnen de HTSM Roadmap Components and Circuits.

Er wordt een uitbreiding van de kennisportfolio beoogd t.b.v. de ondersteuning van de nationale defensie gerelateerde industrie op een breder toepassingsgebied, een aanvang is al zichtbaar in de projectportfolio.
Het jaar 2016 wordt gekenmerkt door verdere invulling – in nationaal en internationaal verband – van de Roadmap Radar en Geïntegreerde Sensorsuites. Een aantal in 2014 en 2015 gestarte projecten zullen worden gecontinueerd in 2016. Dit zijn de Europese projecten MIDNET, ACACIA, SWAP-C EAST en EXIST en de nationale projecten GANS3 en STRICT2 op het gebied van microgolf monolithische geïntegreerde circuits. SWAP-C, GANS3 en STRICT2 worden in het kader van de HTSM Roadmap Components and Circuits uitgevoerd.

De projecten en innovaties voor 2016 behelzen:

1. Europese projecten t.b.v. de European Defence Agency die altijd in een internationaal consortiumverband samen met andere Europese defensie-industrieën en researchinstellingen worden uitgevoerd.
   Het betreft o.a. het nu al in uitvoering zijnde project: ACACIA waarin onderzoek plaatsvindt naar toepassingen van micro-doppler en compressive sensing voor de detectie, identificatie en classificatie van mini-UAV's.
2. Nationale projecten. Dit betreft onder andere DAISY2 (Daring Applications & Innovations in Sensor Systems), een ontwikkeling in het kader van regionale ondersteuning van het bedrijfsleven. Beoogde deelnemende bedrijven zijn NXP en Thales Nederland en TNO, naast een groot aantal MKB's en technische universiteiten. DAISY richt zich op de volgende generatie sterk geminiaturiseerde sensormodules die tevens op een goedkope manier geproduceerd kunnen worden. Door de deelname van de vele MKB's komt de ontwikkelde kennis ook beschikbaar in andere economische sectoren.
3. Projecten in het kader van het Europese kaderprogramma H2020 en de JTI's, CATRENE en ECSEL die altijd in een consortiumverband worden uitgevoerd waarin de Nederlandse industriële deelname altijd een defensie gerelateerd bedrijf is en/of een Nederlands bedrijf dat invulling geeft aan de uit de supply chain hiervoor. In één van de projecten (EXIST) wordt onderzoek gedaan naar nieuwe technologieën voor CMOS-beeldsensoren die nodig zijn in de volgende generatie van de verschillende toepassingsgebieden.

2.1.4 Aansluiting innovatie contract HTSM en Roadmap

Het VP Security maakt gebruik van de generieke technologische ontwikkelingen in andere HTSM Roadmaps, zoals Embedded Systems, ICT, Photonics, Mechatronics Components and Circuits en HighTech Materials. Daarnaast zijn de Security ontwikkelingen van belang voor de domeinen van de Roadmap Automotive, en de Topsectoren Water en Logistiek.

Naast de ontwikkeling van samenwerking in strategische researchprogramma's (zie volgende paragraaf) zijn met betrekking tot de interactie met de stakeholders de volgende punten van belang:

- Viermaal per jaar vergadering van het HTSM Roadmapteam Security.
- Roadmapteam uitgebreid met vertegenwoordigers van politie en veiligheidsregio's.
- Structurele samenwerking met intermediairen: The Hague Security Delta, NIDV.
- Kennisarena op 3 juni met inleidingen directeur Militaire Productie van EZ (de heer P. Taal), Vertegenwoordiger van Nederlandse Politie in Europees

innovatienetwerk ENLETS (de heer P. Padding), de directeur van branchevereniging NIDV (de heer R. Nulkes) en 4 bedrijven (CGI, Siemens, Rola en Dataexpert); 20 deelnemers van bedrijven en 40 deelnemers van overige stakeholders.

- Contacten over de inhoud van projecten met 25 bedrijven in periode 1 februari-1 juni 2015.
- Workshop High Tech Sensoren met 7 bedrijven (najaar 2015).

2.1.5 *Voorziene activiteiten in PPS programma's*

De ontwikkeling van PPS consortia voor strategische innovatietrajecten heeft zich in 2015 gunstig ontwikkeld. In 2016 zal verdere uitbouw worden gerealiseerd. Onderstaande tabel geeft een overzicht van de stand van zaken.

Deel-roadmap	**Stand van zaken ontwikkeling PPS consortia voor strategische innovatietrajecten:**
Systems-of-Systems	1. Onderzoekproject Real Time Intelligence in drie consortia: - Internationale zone (Siemens, Thales, TNO, gem. Den Haag, Eurojust e.a.); in 2015 financiële bijdrage van gemeente Den Haag en in-kind investeringen van bedrijven; in 2016 ook financiële bijdragen van bedrijven - Burgerparticipatie (CGI, Politie, TNO, TU Delft) - Preparatie overstromingsdreiging (VR HM, HR Rijnland, Defensie, vitale infra e.a.) 2. Ontwikkeling R&D faciliteit Real Time Intelligence tools en concepten (vervolg in VP VM i.s.m. Politie e.a.)
Cyber-security	1. Strategisch research programma Cybersecurity; budget 1 M€/jr in 2015 (50% van banken) wordt in 2016 uitgebouwd naar telcom, Internet Service Providers & energie sector (verdubbeling budget) 2. Initiatief veilige publieke communicatiesystemen (UWV, Belastingdienst, Rola , Dataexpert) in het kader onderzoek naar de realisatie van 'Visie Rijks-SOC' 3. Ontwikkeling van cybersecurity scan-tooling specifiek voor MKB (Threadstone)
Passieve sensoren	1. Ontwikkelen concepten voor bewaken en beveiligen in consortia: - Automatische herkenning incidenten en risk based toezicht (Schiphol, KMar, QVI ea) - Inzetconcepten voor mobiele sensoren, UAV's (politie, KMar ea) 2. Initiatief gezamenlijk EU-testbed surveillance (UK Home Office, ERNCIP, lobby H2020)
Actieve sensoren	Uitvoering gezamenlijke Roadmap Radar en geïntegreerde sensorsuites (2010-2020) in gevestigde samenwerking Defensie, Thales, TNO, TU Delft met substantiële investeringen uit bedrijfsleven

3 VP Defense Related Industry

The TNO applied research carried out in VP Defence Related Industry is reported in:

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

The HTSM Roadmap Security released an update of its roadmap in May 2015. The VP Defence Related Industry deals exclusively with the topic *Active Sensors* of this Roadmap.

The HTSM Roadmap Components and Circuits released an update of its roadmap in 2015 which is more focused on the R&D needs of the participating partners. The Roadmap targets electronic *Building Blocks for the Future.* The VP Defence Related Industry contributes in particular to Theme 1 *Dealing with performance, variability, reliability, robustness and degradation in process technologies* and Theme 2 *Components and circuits for radio communications and radar* of the Roadmap and to a lesser extent to Theme 3 *Smart circuitry for IoT, home-, building- and industrial automation*, Theme 4 *More-than-Moore technologies and packaging* of the Roadmap and Theme 5 *Components and Circuits for scientific instruments and harsh conditions* of this Roadmap.

The TNO activities of VP Defence Related Industry in both Roadmaps are described below for each Roadmap separately. In fact the activities in the HTSM Roadmap Components and Circuits are enabling for the topic *Acti*ve *Sensors* of the HTSM Roadmap Security.

3.1 Roadmap Security

3.1.1 Vision and ambition

The running activities in this VP are carried out in the scope of the:

- The national Roadmap Radar en Geïntegreerde Sensorsuites.
- *Platform Nederland Radarland* that is founded in 2002 by Thales Netherlands, TNO, TU Delft, and the ministries of Defence and Economic Affairs.
- D-RACE, the Dutch Radar Centre of Expertise a strategic alliance between Thales Netherlands and TNO regarding radar and integrated sensor suites.

The impact of the VP in the Roadmap Security is aimed at strengthening the global leadership and competitiveness of our national defence industry and related technology suppliers. We aim to achieve this by strengthening the market and knowledge position of the national defence 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.

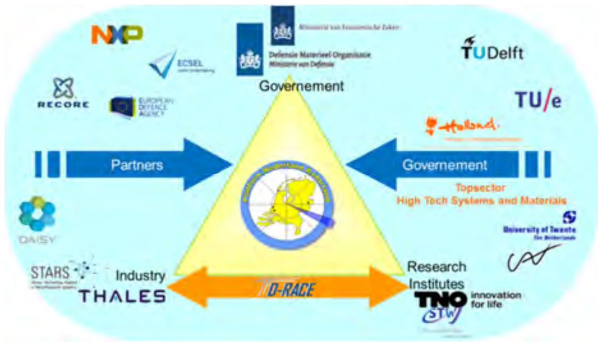
The products and technologies in this domain distinguish themselves compared with others due to the nature of the defence domain. Therefore, the cooperation is crucial in a Triple Helix[1] between knowledge institutions, industries and supplying technology companies and military stakeholders (both national and European level), whereby all together at an early stage can be incurred 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 defined by Joan Robinson in 1933[2]. 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 form 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 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 *Interaction and cooperation*

Dominant is our national *Roadmap Radar en Geïntegreerde Sensorsuites* which is governed by *Platform Nederland Radarland*. Contracts and activities within this context are carried out by several partners within the Triple Helix, a snapshot of the ecosystem in 2015 is given in the figure below.



A snapshot of the ecosystem of the Platform Nederland Radarland in 2015.

Typical activities that we target together with our partners in the ecosystem and that are sponsored by the VP Defence Related Industry, are:

- Sponsored contracts with Dutch defence industry and SMEs.
- Contracts of the European Defence Agency carried out together with Dutch defence industry and other EU defence industries and research institutes.
- Contracts within the scope of national funded programs (FES) and regional funded programs (EFRO) carried out with national industry, national universities and SMEs.
- Contracts within the scope of the Security calls of Horizon2020 carried out with national defence related companies, other national companies and universities and international industry and universities.

[1] The concept of the Triple Helix of university-industry-government relationships initiated in the 1990s by Etzkowitz (1993) and Etzkowitz and Leydesdorff (1995), encompassing elements of precursor works by Lowe (1982) and Sábato and Mackenzi (1982), interprets the shift from a dominating industry-government dyad in the Industrial Society to a growing triadic relationship between research-industry-government in the Knowledge Society.
[2] In 1933 in her book The Economics of Imperfect Competition, Robinson coined the term "monopsony," which is used to describe the buyer converse of a seller monopoly

- Contracts within in Joint technology Initiatives ECSEL and CATRENE of the European Commission carried out with national defence related companies, other national companies and universities and international industry and universities.

In addition, not sponsored by the VP DGI but an essential part to complete the *Roadmap Radar en Geïntegreerde Sensorsuites*, are the activities directly carried out for the Ministry of Defence, these include:
- Several so called *Doelfinancieringsprogramma's*, amongst others in the area of radar and electro-optical systems.
- National Technology Projects that address strategic topics were research and innovation is essential for competiveness.

3.1.3 Dynamics

A. Development Objectives

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 research institutes have a top position in the world and are strong innovative players. 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.

B. Program 2016

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 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 2016 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 is envisaged to support the national defence related industry on a wider scope, in particular in the field of other sensor systems and radio networks. The first examples of this extension are already visible in the project portfolio.

A number of projects launched in 2014 and 2015 will be continued in 2016. These are the European projects MIDNET, ACACIA, SWAP-C, EAST and EXIST and national projects GANS3 and STRICT2 in the field of microwave monolithic integrated circuits. SWAP-C, GANS3 and STRICT2 are implemented within the framework of the Roadmap HTSM Components and Circuits and reported in the associated chapter below.

The projects and new innovations for 2016 include in detail:

1. European projects for the European Defence Agency. It concerns the current projects:
    - ACACIA, a project that provides research applications of micro-doppler and compression sensing for detection, identification and classification of mini-UAVs.
    - MIDNET on robust routing-concepts for distribution of data/information on military radio networks, in a mobile, wireless disruptive environment to improve network performance.

    Projects in development to start in 2016 are:
    - TELLUS2 on transmit/receive modules with a high degree of integration and specifications appropriate to the future military sensor needs in terms of performance and system constraints.
    - MAENA aimed at dynamically adjusting/optimizing a radio network to its RF environment (cognitive radio). Including adaptive waveforms, autonomous dynamic allocation of scarce radio spectrum to current needs of different radio users (time sharing). This is the next step in improving the military radio network performance.
    - WINLAS researches sensor, energy, and information management in large-scale soldier modernization systems.
2. National Projects in development for 2016:
    - 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. DAISY 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.
    - And the development of a fully Evolution Development Model for the benefit of the next generation of functionally integrated sensor suites for the Royal Navy.
3. Projects under the European Framework Program H2020 and the JTIs, CATRENE and ECSEL being carried out in a consortium in which the Dutch industrial participation is always a Defence-related company and/or a Dutch company that fulfills the off supply chain:
    - EXIST on research into new technologies for CMOS image sensors that are needed in the next generation of the various applications.
    - Other projects are continuously in development within the various calls, the ambition is to acquire at least 2 new contract yearly.

3.1.4 Connection to the innovation contract HTSM and Roadmap

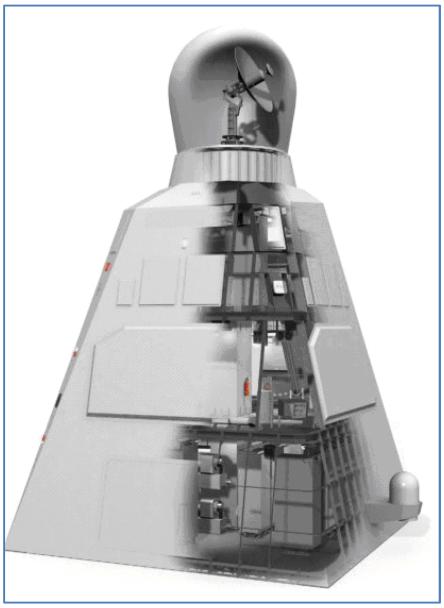
The activities projects and contracts are initiated, discussed, reported and governed in the various Management Boards and Steering Boards of *het Platform Nederland Radarland* and of *D-RACE*.

The HTSM Roadmap Components and Circuits is a strong and necessary enabler for this work.

We have links with the topic *Passive Sensors* of the Roadmap Security.

3.1.5 Activities in PPP

The Netherlands has an excellent position in this technology domain and in this market. Market analyses show a significant potential in this segment. We have in this field as well as in knowledge as well as to the industrial side a top position in the world market with strong and innovative players in this area.
Our activities are carried out within the scope of:



A typical example as result of the Roadmap Radar and Integrated Sensor Suites.

- The national Roadmap Radar and Integrated Sensor Suites. This Roadmap is jointly prepared by The Netherlands Royal Navy, Thales Netherlands and TNO: the Triple Helix. The first version is from 2004. The latest update is from September 2010 and covers the period 2010-2020. This long term plan is guiding and informing on future policy choices for Government, industry and knowledge institutions. This triple helix is consistently steering on implementation of this roadmap taken into account actual policies.
- The national Platform Nederland Radarland which is a joint effort of TNO, Thales, TU Delft and the Ministries of Economic Affairs and Defence. TNO being one of the founding fathers. The importance of the partners in this platform is the Netherlands leading position in the field of research and development related to radars by intensification of mutual cooperation in all aspects regarding product development, R&D and education. Several large programs and educational activities are initiated within the framework of the Platform Nederland Radarland.
- D-RACE, Dutch Radar Centre of Expertise being a strategic alliance between TNO and Thales Netherlands. The aim of cooperation is to accelerate innovation and enhance knowledge and market position (i.e. a faster implementation of the Roadmap). D-RACE aims at a worldwide distinguished knowledge and market position. D-RACE mobilizes synergy in innovation, combines joint resources and stimulates economic growth. With this, customers profit from efficient and rapid knowledge creation and accelerated innovations.
- The activities are also aligned with the Strategic Research agendas of the European Defence Agency (EDA), in particular in the fields of radar (EDA Capability Technology Area Radio-Frequency Sensors Technologies),

miniaturized electronics (EDA Capability Technology Area Radio-Frequency Sensors Technologies) and Electro-optical systems (EDA Capability Technology Area Electro-Optical Sensors Technologies). These strategic research agendas of the EDA are partly initiated and set up from this Roadmap.
- Future activities will also be more and more aligned with the ECSEL and CATRENE Joint Undertakings from the EU.

3.2 Roadmap Components and Circuits

3.2.1 Vision and ambition

Building Blocks of the Future

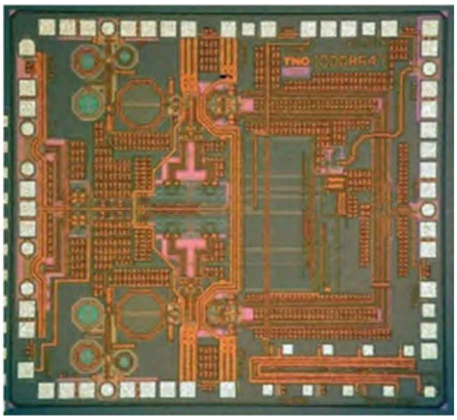
The HTSM Roadmap Components and Circuits released an update of its roadmap in 2015 which is more focused on the R&D needs of the participating partners. The Roadmap targets electronic *Building Blocks for the Future.* The incredible flow of products from the Information, Communication and Consumer industries has changed our lives dramatically over the last 40 years and will continue do so for the coming decades. At the basis of these innovations is a continuous drive for smaller, better, cheaper and more efficient electronic components and circuits. The technology developments in the Roadmap hence target the so called *More-Moore* technologies (i.e. more and more functions are integrated on one chip) and so called *More-than-Moore* technologies including: sensors and actuators, high-voltage and energy circuits, low-cost electronics, THz and packaging and antennas. Those technology developments are enabling for energy applications, mobility, healthcare systems, food security/logistics, security/privacy and avionics/space.

The Netherlands is one of the most important European Components and Circuits design and manufacturing countries. Some of the world's major players in this field have their headquarters or a subsidiary over here. Our national knowledge infrastructure is perfectly matched hereto. Regarding above mentioned technology developments and market/societal applications, the TNO contribution focusses in particular on high-frequency integrated circuits on SiGe, GaAs, GaN and RF-CMOS material substrates for defence, space and communications applications.

The TNO activities contribute in particular to Theme 1 *Dealing with performance, variability, reliability, robustness and degradation in process technologies* and Theme 2 *Components and circuits for radio communications and radar* of the Roadmap and to a lesser extent to Theme 3 *Smart circuitry for IoT, home-, building- and industrial automation*, Theme 4 *More-than-Moore technologies and packaging* of the Roadmap and Theme 5 *Components and Circuits for scientific instruments and harsh conditions* of the Roadmap.

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 the 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 radars (AESA radars, also referred to as active phased-array radars). MMIC technology has a major impact on cost, functionality and performance of these systems.

Our ambition is to act as the number one fabless design house for advanced highly integrated MMIC circuits.

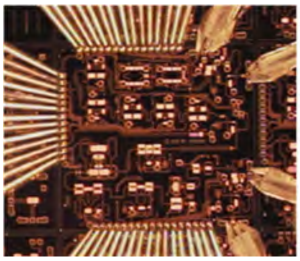


SiGe receiver from 10-18 GHz designed by TNO and manufactured by NXP within the STARS program.

Monolithic Microwave Integrated Circuits (MMIC's) are used to implement specific parts of the AESA hardware: they form the heart of the Transmit/Receive modules. They tend to receive a lot of attention, as their performance dictates a number of system specifications such as noise figure, output power and dissipation. More-over, the components can often not be obtained as commercial off-the-shelf components but are application-specific and are realized in very dedicated IC processes such as Gallium Arsenide (GaAs) or Gallium Nitride (GaN) microwave processes. Increasingly, also Silicon Germanium (SiGe) technologies are used. The profession of developing state-of-art MMIC components is fully mastered, including outstanding relations with the technology providers (foundries), in-house modelling capabilities, an excellent workforce and network in the scientific community, well-established procedures for development and testing, design facilities, measurement facilities and a world-class track record.

Our impact of this MMIC technology is aimed at strengthening the global leadership and competitiveness of our national defence industry and related technology suppliers. In addition our national semiconductor industry is supported and also some space programs.

3.2.2 *Interaction and cooperation*

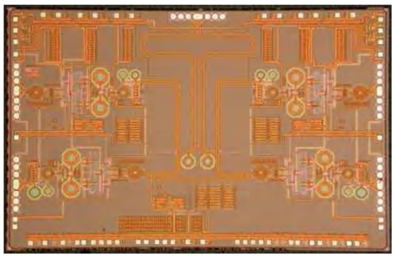


TNO facilities for measurement and parameter extraction of MMICs.

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 2016. 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 mm^2 integrated circuit. The technology base was chosen to be SiGe BiCMOS for reasons of receiver robustness and linearity SiLC).

Within the framework of STARS, a running FES project, we cooperate with Thales Nederland, NXP, RECOR, TU Delft and the University Twente. STARS is aimed at reconfigurable sensors for the national security. Reconfigurable sensors are a trend that we picked up in The Netherlands about 6 years ago and which is just recently addressed by a DARPA program in the US. STARS is a good example of the innovative nature of this Roadmap and its spin-off to other economic and social sector. Within STARS fully integrated receivers are developed and manufactured.

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.



A SiGe dual channel transceiver from the DAISY program.

As a result of both STARS and DAISY 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.

In the framework of the European Defence Agency, the European JTI's CATRENE and ECSEL and the H2020 Framework Program we cooperate with almost all major European defence companies and RF semiconductor manufacturers such as UMS, OHMIC, Thales, SAGEM, SELEX, SAAB, AIRBUS etc., with research companies like FOI in Sweden, Fraunhofer in Germany, II-V labs in France etc. and with European companies and research institutes in the semiconductor area.

A new *TKI-Toeslag* project is foreseen in which we work together with UMS in France, Thales Nederland, NXP and Philips Research on fundamental research for extreme high-power GaN amplifiers and fully integrated phase drivers on SiGe.

In addition, not sponsored by the VP DGI but an essential part to enable our activities complete the *Roadmap Radar en Geïntegreerde Sensorsuites*, fundamental research is carried out directly for the Ministry of Defence and forms the basis of the work reported in this VP, these include:

- *Doelfinancieringsprogramma* in the area of radar technology.

- National Technology Projects.

3.2.3 *Dynamics*

A Development Objectives

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 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.: GaNS3: sponsor contract)
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.. DAISY-2: EFRO funding). Next generation transceivers generation transceivers with greatly enhanced properties (i.e.: European project TELLUS2)
	Breakthrough to fully integrated transmit chains		Integration of distributed power amplifiers in order to minimize volume and cost. Improve spectrally pure signal generation, integrated transceiver switch (i.e.: het CATRENE project EAST)

B Program 2016 in more detail

The program in 2016 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 2016 or are 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 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.

A number of projects launched in 2014 and 2015 will continue in 2016. These are the European projects SWAP-C, EAST and EXIST and national projects GANS3 and STRICT2.

The projects TELLUS2 and DAISY2, both at radar system level but with a significant part regarding RF electronics are reported in the Roadmap Security.

The projects and innovations for 2016 include in detail:

1. European project for the European Defence Agency. It concerns the current project:
   - SWAP-C on the development of new transmitter architectures that enable significant cost reduction of transmit/receive modules for future phased array radars.
2. National Projects:
   - GANS3 on research into reducing the cost of GaN-based S-band power amplifiers using COTS plastic QFN housings.
   - STRICT2 researches stacked transistors based on GaAs technology for use in power amplifiers for future communication and sensor applications.
3. Projects under the European Framework Program H2020 and the JTIs, CATRENE and ECSEL being carried out in a consortium in which the Dutch industrial participation is always a Defence-related company and/or a Dutch company that contributes in the supply chain:
   - EAST on defining, researching and demonstrating signal generation and distribution in array antennas.
   - GANIC researches GaN on Silicon.
4. The year 2016 will also be characterized by a *TKI-Toeslag* program that is focussed on fundamental research on extreme high power power-amplifiers on GaN that should make available ITAR free circuits from a European source. Also fully integrated phase drivers on SiGe will be subject of research.

3.2.4 Connection to the innovation contract HTSM and Roadmap

The Roadmap Components and Circuits is enabling for the Roadmap Security.

Technology developed within the Roadmap Components and Circuits finds a dual-use application in the Roadmap Space.

3.2.5 Activities in PPP

The Netherlands has an excellent position in this technology domain and in this market. Market analyses show a significant potential in this segment. We have in this field as well as in knowledge as well as to the industrial side a top position in the world market with strong and innovative players in this area.

Our activities are carried out within the scope of:

- The national Roadmap *Radar and Integrated Sensor Suites*. This Roadmap is jointly prepared by The Netherlands Royal Navy, Thales Netherlands and TNO: the Triple Helix. The first version is from 2004. The latest update is from September 2010 and covers the period 2010-2020. This long term plan is guiding and informing on future policy choices for Government, industry and knowledge institutions. This triple helix is consistently steering on implementation of this roadmap taken into account actual policies.
- The national *Platform Nederland Radarland* which is a joint effort of TNO, Thales, TU Delft and the Ministries of Economic Affairs and Defence. TNO being one of the founding fathers. The importance of the partners in this platform is the Netherlands's leading position in the field of research and development related to radars by intensification of mutual cooperation in all aspects regarding product development, R&D and education. Several large

programs and educational activities are initiated within the framework of the Platform Nederland Radarland.

- D-RACE, *Dutch Radar Centre of Expertise* being a strategic alliance between TNO and Thales Netherlands. The aim of cooperation is to accelerate innovation and enhance knowledge and market position (i.e. a faster implementation of the Roadmap). D-RACE aims at a worldwide distinguished knowledge and market position. D-RACE mobilises synergy in innovation, combines joint resources and stimulates economic growth. With this, customers profit from efficient and rapid knowledge creation and accelerated development.
- The activities are also aligned with the Strategic Research agendas of the European Defence Agency (EDA), in particular in the fields of radar (IAP2), miniaturized electronics (IAP1) and Electro-optical systems (IAP3). These strategic research agendas of the EDA are partly initiated and set up from this Roadmap.
- Future activities will also be more and more aligned with the ECSEL and CATRENE Joint Undertakings from the EU.

4 VP Sociale Innovatie

4.1 Roadmap Manufacturing/Mechatronics

4.1.1 Introductie

Onder deze HTSM Roadmap zal in 2016 een virtueel VP Smart Industry ontwikkeld worden, waaronder de TNO bijdragen aan Smart Industry initiatieven worden geclusterd en gecoördineerd. TNO zal, in verschillende rollen, betrokken zijn bij een aantal Smart Industry Fieldlabs: Regions of Smart Factories, Smart Dairy Farming, Multi Materiaal 3D Printing, Smart Food, Flexible Manufacturing en Digitale Fabriek. Een en ander is sterk afhankelijk van beschikbaarheid van financiering, waaronder EFRO middelen. De TO2 middelen genoemd in TNO's 'Speurwerkprogramma 2015-2018: Thema High Tech Systems and Materials' zijn in 2016 niet langer beschikbaar. Verder zal TNO bijdragen leveren aan de ontwikkeling van een topsectoren overkoepelende Smart Industry Roadmap.

Dit hoofdstuk gaat verder over het VP Sociale Innovatie dat volledig gericht is op Smart Industry.

Smart Working is het sluitstuk van Smart Industry. Met Smart Industry wordt de stap gezet naar slimmere productieprocessen, robotisering en een verregaande digitalisering van de Nederlandse industrie. Die digitalisering en robotisering vereisen dat al diegenen die betrokken zijn bij het produceren, ook optimaal digitaal worden ondersteund. Dat vergt dat werkplekken maximaal geautomatiseerd en gedigitaliseerd (big data) worden, en dat medewerkers met digitale ondersteuning de productieprocessen op de meest optimale wijze kunnen doorgang laten vinden. Een maximale digitale ondersteuning vergt ook dat de organisatie van het werk zelf anders wordt ingericht. Smart Working bouwt op een maximale autonomie van de medewerker, laat toe dat nieuwe kennis ontstaat en maximaal wordt gedeeld. Smart Working is gekoppeld aan de verdere upgrading van het kennisniveau van medewerkers in de industrie. In de afgelopen tien jaar is het percentage hooggeschoolden in de industrie sterk gestegen. De verwachting is dat het percentage hooggeschoolden relatief op peil blijft of stijgt, maar in absolute aantallen loopt het aantal hooggeschoolde medewerkers in de komende vijf jaar met bijna 10.000 medewerkers terug. Dit gegeven vergt dat bedrijven er alles aan moeten doen om meer (laaggeschoolde) medewerkers te laten doorstromen. Smart Working betekent ook hier ondersteuning ontwikkelen opdat medewerkers eenvoudiger kunnen leren en delen.
Bedrijven investeren momenteel bijna evenveel in 'Smart Working' als in harde of digitale technologie. Deze ontwikkeling zal zich verder doorzetten. Dat betekent dat de markt voor Smart Working aanzienlijk zal blijven. In dit VP wordt vorm gegeven aan nieuwe kennis en sociale innovatie om in deze groeimarkt een belangrijke plek te veroveren. Het VP Smart Working is de voortzetting van het programma P207 Sociale Innovatie dat in 2015 in het Thema Gezond Leven is uitgevoerd. Het programma wordt nu onder de Roadmap van de Topsector HTSM ('Smart Industries') uitgewerkt, als een samenwerking tussen de thema's Gezond Leven en Industrie van TNO.

4.1.2 Visie en ambitie

Het algehele doel van het project is het bevorderen van duurzame innovaties in Smart Working door voldoende inzicht te verkrijgen in de mogelijkheden voor betere interactie tussen robots en medewerkers, in de mogelijkheden om kennisontwikkeling te stimuleren en beter te standaardiseren zodat kennisdeling wordt vergroot. In 2016 zal dit doel verder worden uitgewerkt. Daarnaast zullen verschillende initiatieven die in 2015 zijn opgestart worden doorgezet.
De context voor deze doelstelling is dat de Nederlandse industrie achterloopt voor wat betreft de mate van robotisering. Op dit moment is de discussie over robotisering terecht gekomen in de spagaat van angst voor meer robotisering en aan de andere kant de behoefte aan meer investeringen in robotisering. Een context van Smart Working helpt om deze discussie te sturen in de richting van een gezamenlijke inspanning van bedrijven, sociale partners en overheid in ‘geregelde door-automatisering’: door een beter begrip van de mogelijkheden van Smart Working en van de noodzaak aan meer robotisering, vorm geven aan programma’s die bedrijven en medewerkers meer opleveren. Het Fieldlab Sociale Innovatie dat door het Ministerie van SZW, de FME en FNV is opgericht, biedt een kans om de discussie een andere richting te geven.
Op Europees niveau zet de Europese Commissie vol in op industriële herstructurering. Smart Working heet op dat niveau ‘workplace innovation’. Voor Nederland is van belang een voorloperpositie in workplace innovation uit te bouwen opdat de kansen voor robotisering en digitalisering worden versterkt.

Het programma Sociale Innovatie 2015 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 is sprake van continuïteit en een lichte verschuiving naar nieuwe thema’s:

- *Human Factors Engineering*: het doel is om samenwerking van mens en technologie op drie vlakken te verbeteren: bij cobots, wearable robots en operatorsystemen voor foutloos produceren (cognitive support systems).
- *Skills for the future*: het verkrijgen van inzicht over cohortespecifieke 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.
- *Flexible and Innovative Organisations*: 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 sociotechnische ontwerpen en 24/7 roostersystemen, maar ook Collective Awareness Platforms ter ondersteuning van multi-actor netwerken.

De ambitie is op deze drie onderwerpen met bedrijven en sociale partners nieuwe initiatieven te realiseren. Het Fieldlab Sociale Innovatie zal een belangrijk instrument hierin zijn.

4.1.3 Interactie en samenwerking

In toenemende mate vindt er overleg plaats tussen de Ministeries EZ en SZW over het thema ‘Smart Working’. Hierdoor bestaat er ook synergie tussen activiteiten in dit VP en de maatschappelijke thema’s; bijv. de gezamenlijke opzet van Fieldlab Sociale Innovatie. Resultaten van het onderzoek naar Smart Working vinden onder andere via dit platform hun weg naar de (MKB) praktijk. Dit Fieldlab zal in staat zijn

om workshops met het bedrijfsleven, sociale partners en overheid te organiseren. Deze lijn van interactie tussen Topsector(en) en maatschappelijk thema zal worden voortgezet. Bovendien zal TNO vanuit dit VP deelnemen in een aantal grote EU FP7/H2020 projecten, waaronder ROBOMATE, Use-IT-Wisely, MakeIT, Horse, SI DRIVE en SIMPACT, waarin voor TNO de specifieke focus ligt op toepassing van bewegingswetenschappen, organisatiekunde, ICT en sensorkunde.
In dit programma wordt samengewerkt met een groot aantal instituten op het gebied van sociale innovatie, robotisering, intrapreneurship: Universiteit Utrecht, INSCOPE, Vrije Universiteit Amsterdam, KU Leuven, Hogeschool Utrecht en Hogeschool Windesheim. Ook zijn bedrijven aangesloten zoals Philips, Centric en Vanderlande Industries, maar ook Topsectoren zoals HTSM en Logistiek. 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 door middel van samenwerkingsverbanden met partners binnen het European Workplace Innovation Network (van DG GROW).

4.1.4 Dynamiek

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. Zo’n driekwart van het budget ligt vast in gemaakte SMO afspraken. Zo’n kwart van het programma is nog vrij inzetbaar om in PPS-en te worden ingezet. De marktontwikkeling is erop gericht om de gevraagde multiplicator van 3 te halen. Voor het programma wordt onderzocht in hoeverre gebruik kan worden gemaakt in 2016 van TKI-Toeslag uit HTSM.

4.1.5 Aansluiting innovatie contract HTSM en Roadmap Prevention, Work & Health

Het nieuwe programma sluit aan bij de initiatieven binnen de HTSM om tot een Fieldlab Sociale Innovatie te komen. Over dit Fieldlab is in het afgelopen jaar met het Ministerie van SZW, de FME, de FNV en andere stakeholders een eerste afspraak gemaakt. Het programma Smart Working zal samen met deze stakeholders het Fieldlab verder concretiseren en ontwikkelen in de komende jaren. Juist dit Fieldlab laat toe om ook bij te dragen aan de doelstellingen van de Roadmap PWH. Met name de onderzoekslijn ‘Better Jobs’ zal baat hebben bij de oprichting van het Fieldlab.

4.1.6 Voorziene activiteiten in PPS programma’s

Het programma 2015 zal worden uitgevoerd in het kader van nieuwe afspraken die moeten worden gemaakt met het Ministerie van SZW en EZ. Met de sociale partners in de industrie zal het Fieldlab Sociale Innovatie vorm moeten worden gegeven. In HTSM wordt samengewerkt met het projectbureau Smart Industry. In Logistiek wordt samengewerkt met de TKI Logistiek.

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.

In de volgende tabel zijn de geplande initiatieven voor 2016 aangegeven:

Ontwikkellijn	PPS Initiatieven voor 2016
Human Factors Engineering	CobotNL/RoboNed JIC Wearable Robots FOF2_Robosurf Fieldlab Flexible Manufacturing FOF-4 Levels of Automation Hoogleraarschap Prof. de Looze
Skills for the Future	Fieldlab Sociale Innovatie StayMobil Intrapreneurship
Flexible and Innovative Organisations	EUWIN 2016 USI CAPS 2016 Co-Creation-07-2017 Ecosystemen Hoogleraarschap Prof. Dhondt

5 VP Automotive Mobility Systems

5.1 Roadmap Automotive

5.1.1 Inleiding

Het Vraaggestuurde Programma ‘Automotive Mobility Systems’ (VP AMS) sluit aan bij de Topsector HTSM, Roadmap Automotive en richt zich dus 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 kennisontwikkelingsprogramma 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 drie deelprogramma’s:

- Automated Driving
  Het ontwikkelen van controle oplossingen en methodologie voor het automatiseren van voertuigfuncties.
- Cooperative Mobility
  Het verbeteren van doorstroming, energie efficiëntie en voertuigveiligheid door gebruikmaking van V2X communicatie.
- Low Carbon HD Transport
  Het ontwikkelen van oplossingen voor significante broeikasgas reductie in het Heavy Duty transport (trucks en bussen).

5.1.2 Visie en ambitie

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, effectiever en wettelijk toelaatbaar te laten functioneren. Dit in een complexe omgeving met verschillende weggebruikers in uiteenlopende omstandigheden.
Belangrijkste doel is om de toepassing mogelijk te maken en te versnellen. Dit door zowel de onderliggende technologieën te ontwikkelen, als de methodologie om efficiënt (tijd en kosten) te ontwikkelen en te valideren.

Cooperative & Connected Mobility:
In een land als Nederland, maar ook in (internationale) grootstedelijke omgevingen met een dicht wegennet met hoge verkeersintensiteit, leidt een kleine verstoring in de verkeerstroom al snel tot een file. Dat vormt een maatschappelijk en ook een economisch probleem.
Met geavanceerde communicatie kunnen we auto's laten samenwerken met elkaar en met de omgeving waarin ze rijden om filevorming te verminderen, de wegcapaciteit te vergroten, veiligheid te verhogen en uitstoot te reduceren.
Kern van het programma is het samen met partners realiseren van gecontroleerde grootschalige implementatie van coöperatieve mobiliteit op zowel het hoofdwegennet en onderliggend weggennet, als in een grootstedelijke omgeving.

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 2016 gefocusseerd op het modelleren en virtualiseren van de applicaties. Hierdoor kan een scenario gebaseerde aanpak worden toegepast, met als concreet doel het toepassen en tegelijkertijd aantonen dat het als versneller werkt op ontwikkeltijd van coöperatieve control oplossingen.
Dit zal o.a. in een TKI project met industriële partners worden opgepakt, in kader van de Next Milestone '2-truck platooning'.

Cooperative & Connected Mobility:
In 2016 staat realisatie van de volgende Next Milestones centraal: real life demonstratie van coöperatieve automated applicaties voor personenwagens gebaseerd op aansturing en integratie met wegkantsystemen:

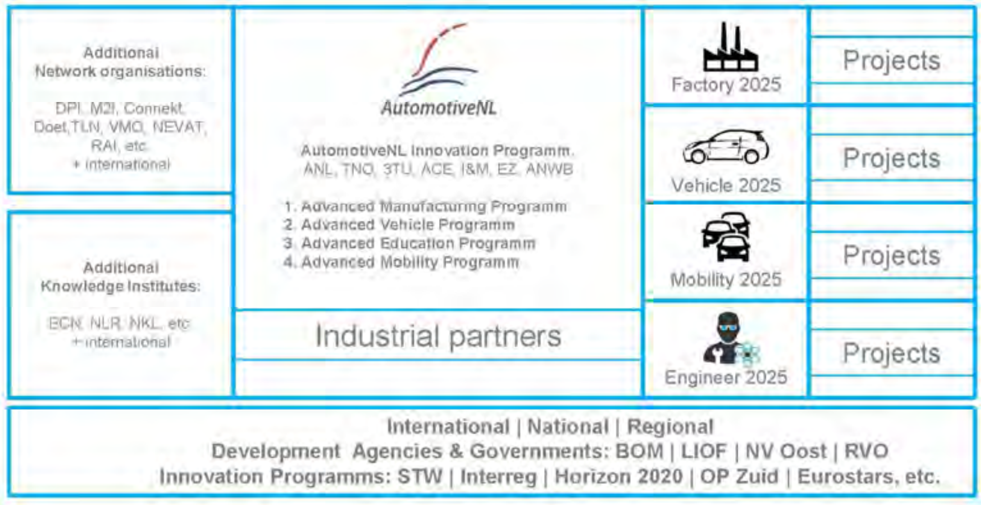
- Real life implementatie van C-ITS (snelheidsadvies en schokgolfdemping) op een schaalgrootte van > 1000 voertuigen op het baanvak A58 Tilburg - Eindhoven. Deze oplossingen worden ontwikkeld en geïmplementeerd in het kader van het Beter Benutten A58 project.
- Demonstratie, in real life situaties op C-ITS infrastructuur Tilburg – Eindhoven, van de mogelijkheid om vanuit de wegkant in te grijpen in voertuigen (opleggen snelheidsbeperking d.m.v. ingrijpen in het voertuig).

Low Carbon HD Transport:
In 2016 staat de realisatie van de Next Milestone ‘Self Learning Energy Management’ centraal, gedemonstreerd in een elektrische stadsbus. Dit concept wordt in 2015 samen met industriële partners ontwikkeld en in 2016 verder uitgebreid en gedemonstreerd in een voertuig. Dit moet leiden tot een reductie van >20% energy verbruik.
Daarnaast zal voor conventionele aandrijving een virtual engine model worden ontwikkeld met real-time capability en nauwkeurige emissie schatting. Het TKI project op het gebied van advance combustion zal in 2016 worden afgerond met een demonstratie op een motor. Het Multilevel Energy Optimisation project zal in 2016 eerste toepassing in opdrachten vinden.

5.1.3 Interactie en samenwerking

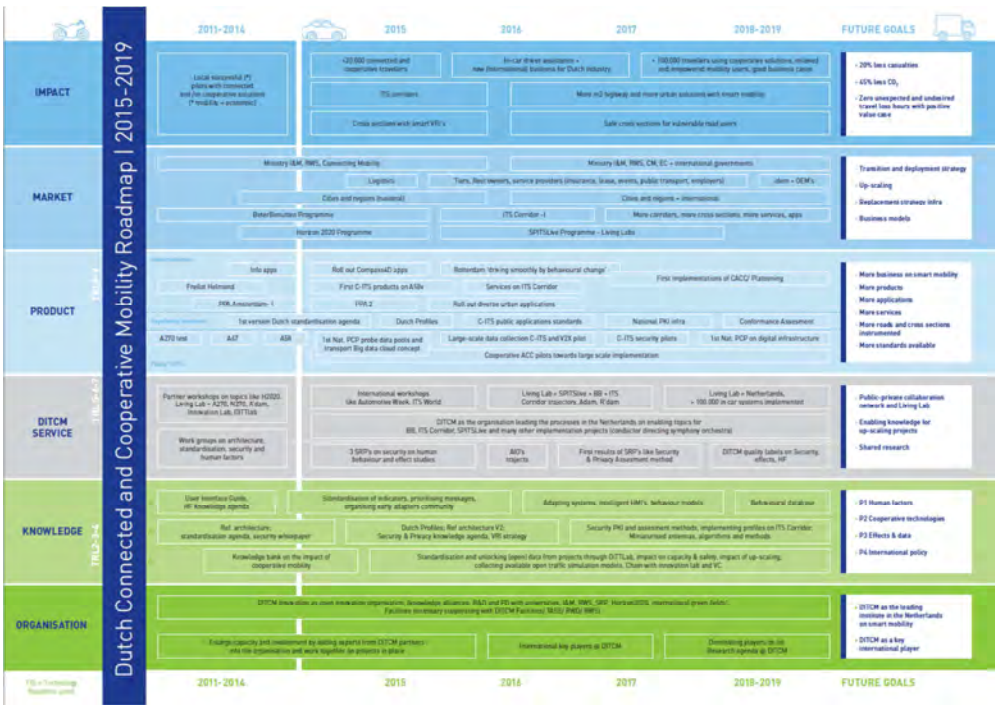
Samenwerking
Het dominante partnershipmodel voor dit VP blijft samenwerking met de automotive sector in Nederland binnen Publiek Private Partnerships. Hiervoor worden in de deelprogramma’s specifieke initiatieven genomen.
Daarnaast is AutomotiveNL voor TNO de belangrijkste vertegenwoordiger van de sector 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. Gelukkig zal TNO ook 2016 in staat zijn (dankzij haar significante internationale B2B portefeuille) om een significante bijdrage aan TNO toeslag te genereren.
Op Europees niveau blijft TNO actief in samenwerkingsverbanden als EARPA, ERTRAC, ERTICO, etc.

Interactie
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 HTSML 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 zal ook richtinggevend zijn voor de inhoud van het TNO programma binnen VP AMS.



Figuur 1: AutomotiveNL innovation program.

DITCM is het samenwerkingsverband op gebied van coöperatieve mobiliteit waarin naast automotive bedrijven ook bedrijven uit de mobiliteitssector en overheden zijn vertegenwoordigd. DITCM heeft een Roadmap die geheel past binnen de TKI Roadmap en die voor het TNO deelprogramma 'Coöperatieve Mobiliteit' de vraagsturing invult. DITCM heeft in haar gedetailleerd innovatieprogramma gepubliceerd op haar website:
http://www.ditcm.eu/images/Publications/DITCM_programma_2015-2019_WEB.pdf.



Figuur 2: DITCM Roadmap 2015-2019.

5.1.4 *Dynamiek*

Binnen de drie 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 in 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.

Cooperative & Connected Mobility:
In opdracht van het Ministerie van IenM organiseert DITCM ronde tafels/gesprekstafels rond een 7 tal, met coöperatieve mobiliteit verbonden, inhoudelijke thema's. Deelnemers aan de ronde tafels zijn overheden, industrie en kennisinstellingen. Vanuit de ronde tafels wordt vraagsturing geformuleerd richting kennisinstellingen/TNO en tevens worden vanuit de TNO Vraaggestuurde Programma's de ronde tafels gevoed met kennis inzichten. Dit geeft een versnelling aan de gezamenlijke kennisagenda.

Low Carbon HD Transport:
In dit programma wordt gezocht naar oplossingen die nu al economisch attractief zijn zonder dat wetgeving voor CO2 emissies noodzakelijk is. Dit betekent aansluiten bij eisen als zero-emission stadsbussen, geluids- en milieueisen voor stadsdistributie, inzet van low-carbon brandstoffen en CO2 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.

5.1.5 *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 Coöperatieve en Connected Mobiliteit) 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 borgt TNO dat er met Nederlandse bedrijven wordt samengewerkt en dat de kennis die bij TNO 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 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 speurwerkactiviteiten 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 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 drie 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, waarmee de stap naar een daadwerkelijke PPS gemaakt kan worden. Ook de interactie met de overheid (coöperatief automatisch rijden) is daar een onderdeel van.
In 2016 zal de PPS samenwerking verder uitgebreid worden.

Coöperatieve & Connected mobiliteit:
TNO heeft een leidende rol in de systeemontwikkeling van coöperatieve mobiliteit. Het in triple helix verband samenwerken aan de ontwikkeling, test, implementatie en verdere uitrol van coöperatieve systemen gebeurt binnen de PPS DITCM.

- DITCM's doelstelling is het versnellen van smart mobility oplossingen.
- DITCM Innovations heeft bijna 30 partners die gezamenlijk een onderzoeks- en testomgeving beheren voor het ontwikkelen van nieuwe vormen van intelligente voertuigen en de bijbehorende intelligente wegkantsystemen.
- DITCM heeft een strategische samenwerking met het ministerie van IenM (Beter Benutten, Connecting Mobility, RWS).

Low Carbon HD Transport:
Samenwerking in PPS verband blijft het dominante samenwerkingsmodel. 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 mogelijkheden om in bredere (internationale) consortia samen te werken.

5.1.6 Voorziene activiteiten in PPS programma's

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 2016 richten op het meer 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 voorstellen voor TKI projecten 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 2016

Advanced safety for automated driving vehicles
De truck-platooning activiteiten zullen eind 2015 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 2016 loopt. Naast realisatie van een demonstrator (level 3 automated truck) die mee gaat doen aan de truck platooning challenge van RWS/I&M/RDW richt het project zich op architectuurontwikkeling van het automated truck platform, safety concept en safety case ontwikkeling en een simulatieomgeving van de truck voor assessment van sensor systemen (level 3). 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 Crossing
Dit project wordt eind 2015 opgezet en zal eind 2015/begin 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. Samen met industriële partners wordt een geavanceerd combustion platform gerealiseerd waarop m.b.v. closed-loop combustion control, real time cilinderdruk en engine-out NOx schatting wordt gerealiseerd en dual fuel RCCI geïmplementeerd. Dit project leidt tot een significante verhoging van het thermisch rendement, en daarmee lagere CO2 uitstoot, van de verbrandingsmotor.

Multilevel Energy Optimisation
Dit TKI project zal eind 2015 starten en tot in de tweede helft van 2016 doorlopen. In dit project worden geavanceerde tools ontwikkeld voor beoordeling/voorspelling van het brandstofverbruik (CO2 uitstoot) van voertuigen in real-life situaties en de effecten verbruiksreducerende maatregelen die aangrijpen op voertuigniveau of via de interactie tussen het voertuig en zijn omgeving (verkeersysteem, logistiek systeem, energiesysteem). Bijzondere aandacht wordt besteed aan de invloed van de chauffeur en het ritprofiel.

E4Bus
Dit project is een beoogd vervolg op het huidige E3Bus project dat in 2015 wordt uitgevoerd. Doel van dit project is om het predictive energiemanagement, dat zich in E3Bus focusseert op het klimaatsysteem van de elektrische bus, uit te breiden naar het integrale voertuig (incl. BMS).
Het integrale energiemanagement zal worden geïmplementeerd in een modulair en robuust framework (passend bij het modulaire.

Voortzetting bestaande programma's
De focussering van het programma in 3 deelprogramma's zal worden voorgezet in 2016. 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 2016 aangegeven. Deze zullen de komende periode verder uitgewerkt worden.

- Realisatie van 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 2016 ligt o.a. op het opnemen van een empirisch sensor model in een simulatieketen
- Technologieën voor het vergroten van de veiligheid van inzittenden als ook kwetsbare verkeersdeelnemers.
  - Bestuurdersmodellen voor adaptive ADAS (adaptie C-ACC controller gebaseerd op bestuurderstype)
  - 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 fietser technologie
- 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)

Cooperative & Connected Mobility:
De focus in dit deelprogramma ligt op het in real life implementeren en opschalen van coöperatieve mobiliteit. Hiervoor wordt op drie proposities ingezet.
- Implementatie en opschaling van coöperatieve mobiliteit op hoofdwegennet en het belangrijkste onderliggend wegennet. Voorbeelden van onderliggende proposities en applicaties zijn real time verkeersmodelleringen en data, snelheids- en rijstrookadvisering, schokgolfdemping en doorontwikkeling naar cooperative automated mobiliteit.
- Implementatie en opschaling van coöperatieve mobiliteit in grootstedelijke omgevingen. Voorbeelden van onderliggende proposities en applicaties zijn VRI optimalisatie, load balancing.
- Verbetering verkeersveiligheid van kwetsbare verkeersdeelnemers door middel van coöperatieve mobiliteit. Voorbeelden van onderliggende proposities zijn intelligente fiets en intelligent kruispunt.

Low Carbon HD Transport:
De focus ligt op verlaging van uitstoot van broeikasgassen in het Heavy Duty transport. Hiervoor wordt op vier proposities ingezet.
- <u>Real World Performance</u>
  Verbeteren van het brandstofverbruik van diesel motoren (binnen de randvoorwaarden van emissiewetgeving) door gebruik van real-time modellen. Investering zullen zijn op het gebied van real-time schatters en control optimalisatie in real-world omstandigheden. De focus ligt daarbij op schatten van engine out emissies (o.a. NOx en GHG emissies). Daarnaast op verbeteren van methoden en tools voor offline kalibratie.
- <u>Predictive Energy Management</u>
  Gebruik maken van Adaptive en Predictive strategieën om het energie management van hybride en elektrische aandrijving te verbeteren. Investering zullen worden gedaan op het gebied van predictie methoden en op modellering en control optimalisatie van de aandrijving.
- <u>Flex Fuel Control</u>
  Geavanceerde engine control strategieën die motoren meer robuust maken

voor toekomstige brandstoffen en spreiding in kwaliteit. Dit wordt gecombineerd met verbetering van het rendement (BTE) van de motoren. Toepassing van aardgas (als een low-carbon transitie brandstof) heeft bijzondere aandacht en hiervoor zal gezocht worden naar een oplossing voor verlaging van methaan slip.

- Multilevel Energy Optimisation
  Tools en methoden om het energieverbruik door het hele transportsysteem heen te optimaliseren. Met deze methoden zal het meest kosteneffectieve optimalisatiepotentieel worden geïdentificeerd in de voertuigen, maar vooral ook daarbuiten (verkeersysteem, logistiek systeem, energiesysteem). Vooral het verbinden van belangen van overheden, verladers, vervoerders en truck/bus OEM’s zal een belangrijke focus zijn.

6 VP Human Health RM Nano

6.1 Roadmap Nanotechnology

6.1.1 Vision and ambition

Great expectations surround the potential for manufactured nanomaterials (MN) to be key elements in the development of innovative materials, products and applications. MN are already produced in great 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 MN-enabled products. Risk Assessment procedures currently recommended by the European Chemicals Registry Agency are not adequate for Risk Assessment of MN due to the small sizes of the MN. The current exposure limits of conventional materials cannot be easily translated to MN and the continuous development on new MN ask for a suitable models that are able to predict the risks of nanomaterials over the complete life cycle of a nanomaterials. To predict the risks of the nanomaterials currently on the market as well as the next generation of nanomaterials the following knowledge is essential to be developed.

1. Quantitative models for exposure modeling. To reach this goal there should become available sufficient exposure data for MN gathered in a harmonized way.
2. A database to store the phys/chem properties, system biologic effects and the toxicity of MN in a consistent way to predict the safety of a MN of existing and future nanomaterials.
3. Development of an approach to determine the risks over the complete life cycle including the uncertainty assessment.

By knowing the risks of MN over the whole life cycle, the human health of the worker, consumer and generic population can be monitored.

6.1.2 Interaction and cooperation

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 participated in the following projects:

EU project	Period	Short description	Role TNO
NANoREG 1	Apr 2013 - March 2017	A common European approach to the regulatory testing of Manufactured Nanomaterials.	Development of a database to store the phys/chem properties, system biologic effects and the toxicity of MN in a consistent way to predict the safety of a MN of existing and future nanomaterials.
NANoREG 2	Sep 2015 - Aug 2018		Further development of the phys/chem - toxicity database based developed in nanoREG 1.

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.	Development of a quantitative exposure assessment strategy, development of a risk assessment strategy including senstiitvity analysis, 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. Value chain based.
NanoSolutions	Apr 2013 - March 2017	Development of a safety classification for engineered nanomaterials (ENM) based on an understanding of their interactions with living organisms at molecular, cellular and organism levels.	Inclusion of human health risks of nanomaterials in a life cycle assessment.
Nanofase	Sep 2015 - Aug 2019		
NanoSTReeM	Jan 2016 - Dec 2018	Support and coordination of activities in relation to research and development of novel nanoscale or nanofunctionalized materials enabling further increase of semiconductor manufacturers' productivity and innovation.	Translate current risk assessment strategies to semiconductor industry.

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 is chair of the working group on exposure.

TO2

Within NanoNextNL , strong collaboration was set up with TO2 institute RIKILT and RIVM. Especially the collaboration with RIVM is very good. The collaboration is continued and intensified in various FP7 and Horizon 2020 projects.

Universities
Within NanoNextNL, TNO had a strong collaboration with Institute for Risk Assessment Sciences (IRAS) of the University of Utrecht which is expected to result in the promotion of a Ph.D. student on the topic of exposure assessment and modelling of nanomaterials.
In addition, TNO has recently intensified their collaboration with the University of Maastricht to match the database of phys/chem 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 in 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 know the risks for the production and use of solar panels.
In NanoNextNL there is a strong participation of SME companies. 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.

6.1.3 Dynamics

Expectations about the social and economic potential of manufactured nanomaterials are high. The Dutch Cabinet seeks to exploit the social and economic opportunities in a sustainable way. It focuses on increasing knowledge and the precautionary principle. 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. 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 nano products 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.

In September 2012, OECD, after 6 years of work, it was 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 also fall under REACH 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 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. 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; this undertaking may require the development of novel risk assessment strategies that will replace the current one, 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.
(http://www.ttl.fi/en/publications/Electronic_publications/Nanosafety_in_europe_2015-2025/Documents/nanosafety_2015-2025.pdf).

6.1.4 Connection to the innovation contract HTSM and Roadmap

This plan 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 of October 2014, 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.

Another stakeholder of the results will be the Ministry of SZW. The results will contribute to the protection of the workers that come into contact with nanomaterials.

7 VP Environmental Technology

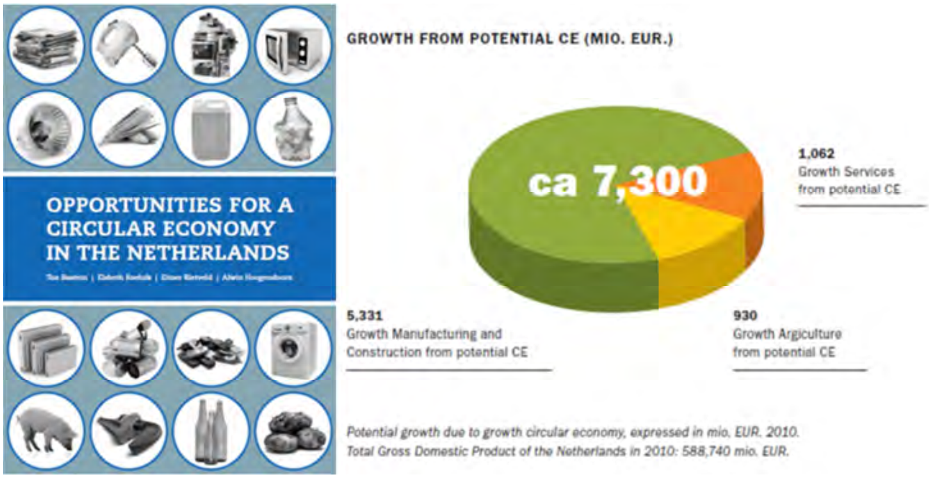
7.1 Roadmap High Tech Materials

7.1.1 Introduction

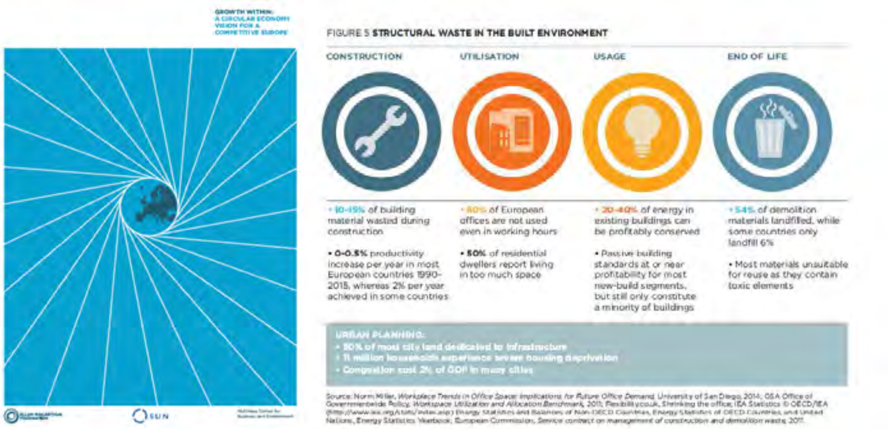
Challenges
A growing global population with an unprecedented level of affluence places a burden on the sufficient availability of a wide range of resources and on the ‘carrying capacity’ of the earth we live on. This message was made loud and clear by the Club of Rome in the early 70’s. Although over the years the environmental impact has improved, the world at large has an ever increasing need for resources with the global middle class growing from 1 billion people now to 3 billion people or more in 2050. At the same time we face an enormous urbanisation with 50% of the world’s population living in cities, with an expected rise to 70% by 2050, resulting in opportunities to deal more effectively with resources and environmental impacts. Current production and consumption patterns continue to result in air pollution which is associated with adverse impacts on human health, loss of biodiversity as well as climate change. Air pollution thus still is the main environmental health hazard, resulting in high costs for health care systems, unhealthy workers and an estimated 400 000 premature death in Europe in 2011.
These major trends make it all the more clear that Europe and the Netherlands require a comprehensive approach to the way we deal with our resources, environmental impacts and safety issues.

Shifting perspectives
We see an important change in society where responsibilities for the environment are shifting from government to a situation where companies and citizens also take a share. This transition must be steered and made robust to end with a new but 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. McKinsey (Sept 2015) estimates a potential of 1.8 trillion annual economic benefit in 2030 for Europe.
There is also a growing field of individual citizens that are heavily involved in environmental sciences through application of low cost, personal sensors (Quantified Self movement and Dutch test with iSPEX for fine particles exposure are interesting examples of this trend). Citizens are getting conscious about effects of pollution and are asking for smart and direct insights in their actual venues and vicinity. Hence, the challenge but also the advantage of sustainable development is taken up by industry and citizens, globally and in the Netherlands, and is made a

core element in the sustainability policies of Ministry of Infrastructure and the Environment and Economic Affairs.



TNO, Kansen voor de circulaire economie in Nederland, 2013.

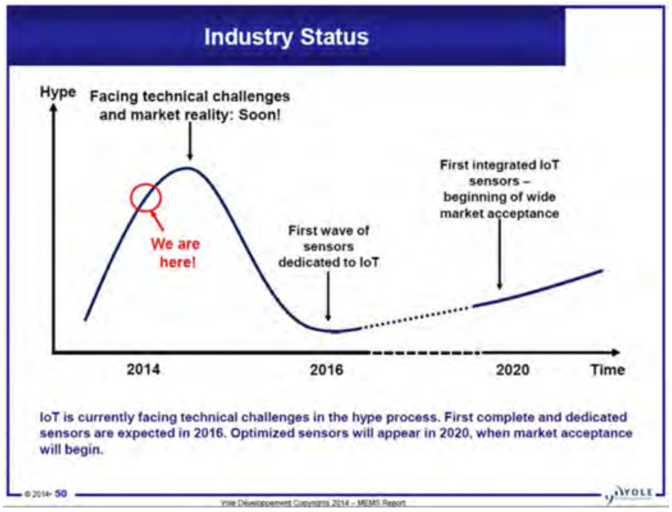


McKinsey Growth within: a circular economy vision for a competitive Europe, 2015.

7.1.2 *Vision and ambition*

This shifting perspective in stakeholder involvement is a prerequisite to provide solutions for one of the greatest challenges that we face in the 21st century. TNO is innovating to help stakeholders in this transition and to combine knowledge and momentum already present in industry, government and individual citizens.

By combining our expert knowledge of environmental impacts and new sensing and modelling output, we are able to offer smart solutions for a broad array of environmental high concern issues. Embedding environmental sensors in networks, combining the sensor data with other information sources and translating the data into actionable information, follows the Internet-of-Things approach. According to Gartner, the IoT is not at its hype peak and will reach full market acceptance in 2020.



Gartner, Hype cycle of Internet of Things.

With recent and ongoing advances in low-cost, wearable, personalised, environmental sensors and ICT we foresee a shift from monitoring and subsequent policy making to directly managing the environment to monitoring and managing exposure at the personal level. This is of special interest for the chronically ill, and employees in high-risk environments, and will increase the quality of life and independence of the general public.
We develop new sustainable technologies and approaches for re-use and recycling of waste and wastewater flows in urban regions and combine this with innovative materials and production technologies to introduce ‘circular’ approaches for specific value chains. Data-driven models and tools enable stakeholders to make informed decisions on waste and resource flows, their impacts and opportunities for economic reuse in the urban environment. Urban regions then produce less waste and have introduced sustainable technologies for re-use and recycling of waste and wastewater flows: we contribute in creating a more circular economy and society.

Impact goals 2020
To realize the ambitions above, research will focused along 2 research lines (subprograms) Sense4Environment (S4E) and Circular Economy (CE) with impact goals

- Sense4Environment: improved quality of the urban environment in regional hotspots, contributing to two healthy living years extra per person and 20% less annoyance reports of citizens. We focus on the following important environmental issues: air and water quality, and external safety.
- Circular Economy: reduction of ecological and resource footprint through designing and implementing of scalable and replicable circular economic solutions in urban field labs, which result in 25% reduction of raw materials and resource input and 10% reduction in greenhouse gas emissions in selected value chains.

Program 2016-2018
The 2 research lines S4E and CE each serve 3 demand driven programs: Environment & Sustainability (stakeholder Min I&M), Water Technology (stakeholder topsector Water) and Environmental Technologies HTSM (stakeholder Topsector HTSM).

The program Environmental Technologies HTSM is new in the 2015-2018 overall envelope of programs of TNO directed towards the domain of the Topsector High Tech Systems and Materials and specifically focuses on the development and validation of new material solutions for environmental sensing and circular products.

7.1.3 *Interaction and cooperation*

The Open-innovation sensor Lab CASTEL (Centre for Alligned STudies on Environment & Life) with shared facilities with University Utrecht and Deltares in the ‘Gemeenschappelijke Milieulaboratorium’ will be launched in September 2015. Opportunities for new partnerships with shared facilities will be explored in Utrecht CASTEL. Possible innovation partners include sensor and service providers (e.g. NXP-NL, Philips, Common Invent, Airsense Analytics), air-cleaning equipment providers (e.g. Philips, Siemens), manufacturing and petrochemical industry, municipalities, waterschappen, health insurance companies, RIVM, DCMR, University Utrecht, Deltares. The sensor lab will be tightly connected to existing networks such as the local AiREAS initiative with Eindhoven as pioneering example, living lab Rotterdam Rijnmond, and NanoNextNL.

Circular economy research is e.g. driven by existing cooperation within the Amsterdam/Almere region and the cooperation in the Circularity Centre in Rotterdam, leading to joint workshops and technology projects. Needs and options for next generation plastic recycling were discussed during a joint workshop with the Circularity Centre and industry in July 2015. TNO is actively involved in various initiatives with NL Ministries (I&M, EZ, BuZa) to identify critical resource areas, as well as various EC initiatives such as the KIC Raw Materials, projects with DG ENV and DG Clima etc.

Apart from the cooperation mentioned above, for longer term knowledge development on environmental sensing TNO has a standing cooperation with University Utrecht. This cooperation can be expanded in the area of materials development for new environmental sensors. The existing TNO cooperation with e.g. the groups of Weckhuijsen and Meijerink could be the basis.

For circular economy TNO has a lasting cooperation with RU Leiden (group Tukker) and has initiated discussion with NWO for strong cooperation under the umbrella of the expected NWO program Circular Economy (Annemieke van der Kooij), preferably to be extended with TO2 partners. It is expected that the existing cooperation with TUD and EUR on logistic processes can be expanded by cooperation in the joint NWO-TNO program Grip on Complexity to improve our knowledge on logistic approaches for circular economy. Fundamental material development such as relevant for design for disassembly and recycling technologies will be organized through STW and FOM initiatives, e.g. STW Perspectief or M2i-STW initiatives. Also the activities in the Brightlands Materials Centre could be a basis for further cooperation with universities and industry.

7.1.4 *Dynamics*

The envisaged research program in 2016 has the next two elements.

- Development and validation of materials for low-cost, wearable, reliable sensors for air pollution and asbestos. Solutions are likely found in the deposition of functional surfaces on optical fibres through e.g. sol-gel processing in combination with nanopatterning to realise special, engineered, optical properties. TNO has a successful track-record in this area by developing reliable optical fibre sensors for extreme conditions in oil & gas applications. For environmental sensing much more emphasis must be directed towards low-cost solutions with long lifetime and high selectivity. Performance and lifetime testing to monitor, explain and remedy degradation of the functional layers thus will be of importance. Connections with research carried out in TNO for Semicon/Space, Large Area (Holst, Solliance) or Biomedical Applications will be explored.

- Development of material solutions for design for recycling. This includes identification of debond strategies for selected applications, formulation of material options, testing and characterization. It also includes design of materials that can be recycled more easily through mechanical, chemical or plasma recycling such as mixtures of polymers, building materials, materials for technical infrastructure in buildings (HVAC, PV-panels, batteries e.g.). Electrochemistry and catalysis know-how are likely to play a crucial role in developing these technologies. Solutions are tested for specific value chains but have the characteristic to be generally applicable (replicability) and scalable.

7.1.5 Connection to the innovation contract HTSM and Roadmap High Tech Materials

The alignment of the research plan 2016 with the HTSM Roadmap High Tech Materials has been discussed with Mr. van Wingerde and van Haastrecht of M2i as representatives of Mr van der Meer, the roadmap chair.
The activities in the subprogram Circular Economy fit in the Roadmap HTM industrial sector Civil “In the Civil sector buildings are responsible for 40% of energy consumption and 36% of CO2 emissions in the EU5 and Construction and demolition waste (CDW) accounts for approximately 25%-30% of all waste generated in the EU6. Securing resource and energy efficiency are key drivers to improve sustainability of buildings and civil constructions” They also fit in the Roadmap HTM societal theme “Resource Efficiency: Materials have to be used more efficient (reduce), alternatives have to be developed where materials are scarce (replace) and materials have to be reused (recycle)”.

The material development in the subprogram Sense4Environment fit directly in the Roadmap HTM domain “Design functional metamaterials. A fast growth in the understanding of how material behaviour emerges in complex materials makes it possible to design functional (meta) materials with specific predetermined properties and functionalities. The metamaterials derive their functionality from their structure and offer unusual properties, examples include negative refraction of light, different magnetic properties and recently also acoustic, thermal and electronic features. Advanced processes (such as 3D printing, self assembly, lithography and atomic scale manipulation) are being developed to make an unprecedented range of materials using control down to the atomic scale”.

Further alignment in these areas can and will be achieved by setting up joint initiatives with M2i and industrial partners.

7.1.6 Activities in PPP

For 2016 PPS activities will be developed in both subprograms.

- Circular Economy: the collaboration with and within the Circularity Centre is topic of discussion to expand its scope to include not only business development but also shared research activities with industrial partners (PPS structure). The same applies to cooperation in the Amsterdam/Almere region. The cooperation with NWO and industry will be shaped, preferably in a TO2 cooperation model.
- Sense4Environment: the Open-innovation sensor Lab CASTEL will be a focal activity for environmental sensing development in cooperation with industry and academia.
- Various initiatives in Horizon 2020 are in different stages of progress for both subprograms.

TNO's contribution to CASTEL on Environmental Sensors: lab facilities and field experiments for sensor development, models & simulation suites to translate data from sensors and sensor networks into actionable information supported with ICT and big data architectures.

8 VP HTSM-Bouw Innovatie

8.1 Roadmap High Tech Materials

8.1.1 Vision and ambition

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 that require innovations of building materials are 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 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.

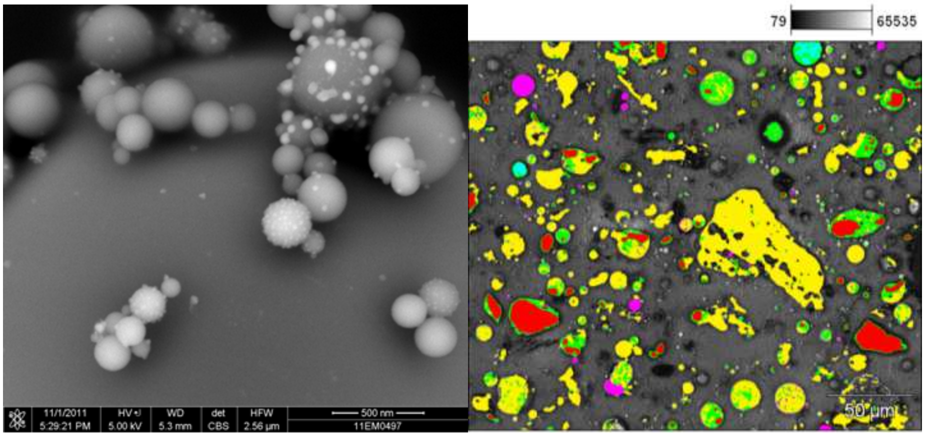
Activities get additional support because they are matched with funding from the EU Framework Program/Horizon 2020 and by co-funding of companies.

This program focuses on the following materials for the construction sector:
- Construction materials
- Asphalt
- Responsive materials

Construction materials
The focus is on concrete and masonry, but composites are becoming increasingly important also in the built environment.
For degradation mechanisms of concrete and masonry, limited predictive models are available.

	Concrete	Masonry
Re-bar corrosion (chloride)	Partly	n.a.
Re-bar corrosion (carbonatation)	Partly	n.a.
Constructive effects corrosion (direct)	No	No
Fatigue	?	?
Alkali-silicareaction (ASR)	No	n.a.
Frost-thaw	No	No
Sulfate damage	No	No
Salt cristallisation	n.a.	No
Hygro-thermal	n.a.	No
Shrink-creep	Partly	n.a.
	After repair	
Decrease of adhesion	No	
Compatibility	No	

There are no models for coupled degradation mechanisms. Improve the fundamental understanding of the behavior of materials and from there understanding and modeling of degradation mechanisms and materials performance will be an important activity.

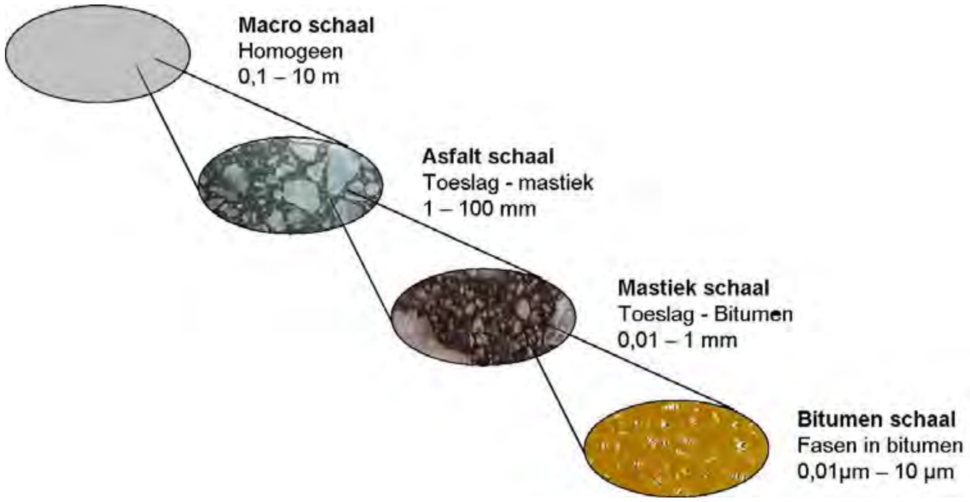


Advanced characterization secondary resources for binders: understanding (un)wanted properties. Left: High resolution imaging FEI NovaNanoSEM 650; Right: Phase mapping using SEM/EDX (Valcke, unpublished).

Asphalt

Knowledge about the material behavior of asphalt was until recently mainly empirical in nature, based on trial-and-error and practical experience. A major component of asphalt binder is bitumen. Bitumen is a mixture that remains after the distillation of oil, and is a mixture of more than 1000 different molecules. The interaction between these molecules and the resultant microstructure determines the behavior of the bitumen. However, due to the large number of complex molecules the behavior is difficult to understand and predict. Also molecular composition differs because of differences in sources of the oil and distillation processes. As a consequence, the behavior of bitumen has a large variation. Further, the microstructure changes in time through interaction between different molecules and under the influence of time and load. The type of aggregate and its surface chemistry, and polarity are also of great influence on the formed microstructure. Because of these complex processes, asphalt and bitumen research was until some time ago mainly of descriptive nature.

To predict asphalt behavior and improve it, it is essential that the transition towards a fundamental understanding of material behavior is continued. This is achieved by further developing models for life time predictions on the basis of physical and chemical processes that take place over the lifetime of an asphalt road. This provides specific targets to improve the service life of road surfaces and also forms a basis for enhanced qualification methods.



Responsive materials

Release of biocides

Bio-resistancy of building and finishing materials usually requires addition of dedicated bioactive chemicals, so-called *biocides*. Traditionally, the action of biocides in materials, (e.g. coatings, plasters) is based on a passive and uncontrolled release principle. This poses two challenges; i) Short bio-resistance of materials leads to early replacement. Coatings in the built environment usually exhibit biocidal functionality between 0.5 and 2 years, whereas the desired service life in building practice is at least 10 years. ii) European Environmental legislation restricts use of biocides and chemicals. As a consequence technology is needed to prolong the release of biocides, via slow or better triggered release.

Effective maintenance via signaling materials

A result of a trend towards longer maintenance interval it is apparent that this means that monitoring and planning, next to highly performing materials, becomes a key issues. Status of facades should be known at any given moment, so that early warning is possible and scheduling of maintenance can be performed. In case of wooden constructions this trend is clear. Damage may result in higher moisture content and can start degradation processes. However, externally not always a warning is apparent, as a consequence early warning would be handy. Early signaling combined with a protective action could implemented into the material. The typical trigger in this case can be pH and humidity.

Corrosion

Corrosion related issues are clearly of great importance. In addition to economical costs, and technological delay corrosion can lead to structural failure that have dramatic consequences. Both understanding of the process and prevention are key aspects to reduce corrosion related damage. E.g. understanding transport of water and ions, and mitigation chemicals such as corrosion inhibitors.

Switchable glues

Bonding and debonding is key for materials for the built-environment. To enable urban mining it is of major importance to easily separate materials. New technological methods are being developed in the field of adhesives, to enable switchable bonds triggered upon external stimulation, e.g. stimulation by mechanical, heat, or induction.

8.1.2 Interaction and cooperation

The European Construction Technology Platform (ECTP) is a PPP of companies and knowledge institutes focused on the formulation and implementation of a medium-term research programs, including materials programs. TNO is one of the actively participating parties. The ECTP aims at improving coordination of RTD activities and networking between all interest groups in order to gain speed in the development of fundamental understanding, thus enabling breakthrough innovations. It underlines that recent advances in nanotechnology, modelling, analytical techniques and other technologies have the potential of creating breakthroughs in the production, properties and use of building materials. It stresses that any strategy to achieve economic, ecologic and social objectives within Europe must include measures to improve functionality, durability and efficiency of materials used for construction. Therefore it works on improved coordination of demand driven RTD activities and networking between all interest groups, thus enabling breakthrough innovations. These developments are needed to maintain and strengthen the competitiveness of European building materials producers and the entire construction sector.
(see ch. 8.1.5 for the national activities)

TNO is cooperating in the field of building material science with many universities and RTO's in the Netherlands and abroad. TNO has in this area two part time professors at Delft University of Technology and two at Eindhoven University of Technology. They are supporting a number of PhD students. Moreover, the cooperation also extends to usage of facilities. Furthermore, there is in the Netherlands among others also cooperation with Utrecht University. TNO is also participating in M2i projects and part of the M2i network.

8.1.3 Dynamics

The envisaged research program in 2016 consists of activities in the following areas:

- Re-use of waste streams
- Concrete/mortar with extra features (i.e. self-healing.)
- Innovative repair materials and material conservation treatment techniques
- Rapid assessment of performance over the years of innovations
- Controlled release of biocides
- Coatings signaling moisture intrusion
- Switchable glues
- Development of physical-chemical models for the performance of asphalt in time
- Asphalt with other binders and aggregates (fibers)

8.1.4 Connection to the innovation contract HTSM and Roadmap

This program is focused on drivers for the Civil Sector Buildings and Infrastructure identified in the Roadmap in HTSM High Tech Materials. In the Civil sector buildings construction and demolition waste (CDW) accounts for approximately 25%-30% of all waste generated in the EU6. Securing resource and energy efficiency are key drivers to improve sustainability of buildings and civil constructions. It also fits in the

Roadmap HTM Societal Theme Resource efficiency. Materials have to be used more efficient (reduce), alternatives have to be developed where materials are scarce (replace) and materials have to be reused (recycle). The material development fit in the philosophy of the Roadmap HTM domain Design functional metamaterials. A fast growth in the understanding of how material behavior emerges in complex materials makes it possible to design functional materials with specific predetermined properties and functionalities. This also holds for building materials.
The alignment of the research plan 2016 with the HTSM Roadmap High Tech Materials has been discussed with Mr van Wingerde and van Haastrecht of M2i as representatives of Mr van der Meer, the roadmap chair. Further alignment in these areas will be achieved through regular progress meetings.

8.1.5 Activities in PPP

Rijkswaterstaat, Delft University of Technology and TNO joined forces in the field of roads and structures in InfraQuest. (www.infraquest.nl). Given the strategic importance of InfraQuest is an important part of the knowledge in the field of infrastructure, aligned with the Master Plans of InfraQuest. InfraQuest is the core from which a PPS in this field will be further developed. In InfraQuest project various companies are participating. TNO will contribute substantially to further extending the ecosystem, e.g., by contributing the InfraQuest Market Day in which many parties from the value chain will participate.

9 VP Space and Scientific Instrumentation

9.1 Roadmap Space

9.1.1 Introduction

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 Vision and ambition

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 Interaction and cooperation

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.
Recently TNO has coordinated an EFRO budget application for the development of a compact Remote Sensing instrument for nanosats (TROPOLITE), within the framework of the Dutch Optical 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 are preparing to play an 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:

- 3MI, 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 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.
- FLEX, an imaging spectrometer for vegetation monitoring; either CarbonSat or FLEX will be selected by ESA for further development.
- Tropolite, a smaller size spectrometer, also having an improved spatial resolution (2x2 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 technology, identified in recent years, consists of atmospheric observation instruments built for China, Brazil 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.

The Netherlands has the opportunity to address the full value chain of space mission design and development, in combination with space data utilization. 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.

Instrumentation for space borne astronomy

Instrumentation for space borne astronomy is another important business line for TNO’s space program. Our research activities are guided by ESA’s Cosmic Vision program, which contains a Roadmap for at least the next 20 years. 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 is now 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.

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.

Research program 2016
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 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, but 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). Additive manufacturing allows for structures impossible to make in the traditional way, leading to more compact and lightweight instruments with improved mechanical properties.

9.1.5 Connection to the innovation contract HTSM and Roadmap

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 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. At present TNO is 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.

9.1.6 *Activities in PPP*

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.

9.2 Roadmap Advanced Instrumentation

9.2.1 *Introduction*

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 *Vision and ambition*

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, etcetera.

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 *Interaction and cooperation*

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 high-tech 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.
- 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 kilometres that - located at the bottom of the Mediterranean Sea.

Research program 2016

In 2016 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.

9.2.5 Connection to the innovation contract HTSM and Roadmap

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 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.

9.2.6 Activities in PPP

Also the activities in the Roadmap Advanced Instrumentation will take place in the joint R&D centre Dutch Optical Centre. It's mission is described in the Roadmap Space on page 58.

10 VP High-Tech Semicon

10.1 Roadmap Semiconductor Equipment

10.1.1 Vision and ambition

The two biggest challenges for the semiconductor equipment industry in the coming 5-10 years is the step beyond the 7 nanometer node (i.e. the smallest feature size on a chip) and the implementation of full 3D chip features on an atom-scale. Besides the societal drives like cloud computing and big data as well as the need for improved power efficiency, the industry pursues these challenges out of economy of scale (Moore's Law: more chips per wafer together with higher yield). However, a significant industrial consolidation in expected at IC manufacturers' side as well as at the supplier side. This is directly related to the enormous R&D investments required to launch a new tool and the introduction of a smaller node. Therefore, the industry is also more and more working towards collaboration and in consortia in order to raise the funding for the expected investments needed to realise these game changers.

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 for current challenges while at the same time creating innovative environments to challenge the current technological pathways.

In particular, TNO focusses on:

- Significantly improved the strong Dutch position in semiconductor manufacturing equipment by developing new technology to sustain Moore's Law by kick-starting breakthrough technology developments in the large semiconductor industry transitions: sub-7 nm lithography, 3-D transistors and systems, application of non-silicon materials, and application of photonics.
- Continue to serve as the world leading institute on contamination control (International Centre for Contamination Control: ICCC). TNO ICCC specifically aims to provide the competitive edge to the Dutch parts and assembly producers to strengthen their position as THE supply chain of the international semiconductor industry by world-wide leadership in ultra-clean and production technology. Besides shared knowledge development, ICCC aims at establishing a complete infrastructure portfolio on contamination control, including a new EUV Beam Line, to enable access to state-of-the-art testing and qualification technology and services to the Dutch (and international) high-precision manufacturing ecosystem.
- Establish the ecosystem on Nano-Opto-Mechatronical Instrumentation (NOMI) geared at a paradigm shift in atom-scale 3D manufacturing.

10.1.2 Interaction and cooperation

Our main mode of cooperation will be jointed programming (PPP Public Private Partnerships) in which TNO remains responsible for creating the innovation for the business & society of tomorrow. A large part of this PPP will be the establishment of two ecosystem based knowledge development programs on (a) contamination control and (b) SPM-based metrology and patterning. The PPPs are open to partners like end-users, OEMS and suppliers. With respect to the last category

emphasis will be placed on Dutch SMEs. Besides shared development a part of the program will remain direct industrial application projects for partners.
For longer term knowledge development a strong relationship with Dutch universities is established. Active support of research in the field of EUV mirror development (DIFFER, UTwente) is set up as well as a partnership with the recently established Institute for Nanolithography (an initiative of ASML). Furthermore, TNO is and will be a partner in NanoNextNL as well as in several EU programs especially on a series of projects on the 7 nm node step. TNO has been involved over the last 3 years and is currently involved in the set-up of the next project for 2014-2016. Co-operations are foreseen with ASML, FEI, ASMI, AMAT, Carl Zeiss, and IMEC.
For shared research and development IPR is described and agreed in participation contracts. In general foreground IP is shared between the participating partners in dedicated application program lines.

10.1.3 Dynamics

The trend towards 3D complex nanostructures continues to push the boundaries of current technologies. The Dutch industry remains the world leader as supply chain to the semiconductor industry in particular and the world-wide high-tech industry as whole.
Following the input gathered from several partners, TNO will focus even more on emerging technologies (still low TRL) in the field of nanofabrication, where nanofabrication is defined as “any technology used to manufacture nanoscale objects or mechanisms”. This also means that the program will focus on nanoscale fabrication in other application areas than only wafer-based semiconductor manufacturing, although that will remain the largest application field. However, interest from the flat panel display industry, quantum computing (as detailed in the roadmap Quantum Computing), and exploring application bio-nano applications.
2016 therefore is a transition year towards a newly titled (and focused) program: Nanomanufacturing Equipment. Already today TNO is recognized more and more as a nanoscale manufacturing expert than as a semiconductor equipment expert (see for instance the partnership of European Space Agency in ICCC).

Due to the diminished VP funding in 2016 (a reduction for VP Semiconductor Equipment by 0.5M€), the programs will even stronger than before focus on only four technology lines as recognized and requested by the Dutch industry (and fitting the broader nanomanufacturing field), namely contamination control, positioning & stability control, materials processing and next-generation patterning technology.

The reduced funding will also lead to a smaller participation of TNO in matched-funding programs and only be engaged in when strictly fitting to the four topics mentioned above.

10.1.4 Connection to the innovation contract HTSM and Roadmap

At the highest level the bi-annually updated International Technology Roadmap of Semiconductors (ITRS) describes the worldwide R&D agenda for the semiconductor industry. The national HTSM SCE TKI Roadmap, derived from this ITRS, is composed by representatives from the Dutch semiconductor industry, TNO, and STW and approved by all other Dutch semiconductor parties. The current

TNO Roadmap is based on (and naturally adheres to) the two Roadmaps mentioned above, plus publications by leading international companies.

To utilize the diminished funds as effectively as possible, TNO has established the International Centre for Contamination Control (ICCC), an ecosystem based knowledge development program on contamination control. The program is subdivided in “knowledge programs” and “application programs”. In specific knowledge programs the scientific foundation is developed that is needed in a variety of applications. Knowledge transfer will be organized by courses, workshops, and reports. In specific application programs, the knowledge will be translated into industry ready solutions.

Next to contamination control, TNO has established a recognized position in Nearfield (and especially SPM) technology. A platform has been developed that significantly increases speed and throughput of SPM-based applications inside and outside of the semiconductor market. In order to capitalize on this development an ecosystem will be constructed in which TNO plays the role of platform-innovator and developer, in conjunction with institutions (e.g. TU Delft, ARC-NL) and other companies (e.g. Leiden Probe Microscopy). Commercial outlets can then be established either via spin-off companies (in the form of a product or module supplier) or direct industry projects (with TNO in the typical role of technology supplier). Such an ecosystem will sustain the relevance of the Netherlands in the field of nano-opto-mechatronic instruments (NOMI) and contribute to the overall impact goal of this roadmap in sustaining and strengthening the Dutch nanoscale manufacturing equipment industry.

10.1.5 Activities in PPP

In 2016, as part of the ICCC and NOMI programs, the VP will focus on the following main topics.

Particle detection technologies

All Roadmaps for the semiconductor equipment industry point out the demand for capabilities to detect particles as small as 10nm, and the current limitations thereof. TNO is already developing technology for particle detection down to 20nm, and enabled by the ERP 3d Nanomanufacturing, reaching down to 10nm particle sizes.

Molecular Contamination Control

TNO holds a strong position in both particulate and molecular contamination control, built up during 2004-2015. The field of molecular contamination is expending from carbon contamination to other (organic and inorganic) contamination as well. This technology holds relevance to Space applications. Of major importance to this field is the large investment in a new EUV Beam Line (EBL2) which will enable the industry true understanding of mechanisms involving high-power photon-material interaction.

Sub-wavelength optics

Recent developments show the potential of optical elements based on materials with structures smaller than the wavelength of light. Next to conventional diffractive elements one can think of combined refractive/diffractive elements or metamaterials. Such elements have the potential of combining multiple functions of an optical design in one element. This may lead to a lower number of elements, resulting in lower volume, lower costs, lower mass, and higher reliability. We think of sensor systems for lithography systems (very little space available; mass on wafer stage critical), but also space applications (launch costs scale with mass). Applications of 'nanoparticles' vary from absorption enhancement (e.g. for photovoltaic cells) and direct write imaging (alternative to lithography) to additive manufacturing. TNO shall gain experience in simulations and application of these new materials as complement to conventional optical design and/or innovation in sensor systems. This technology holds relevance to Space and Solar, too.

Picometer stability
The Semiconductor Roadmap is all about resolution and overlay enhancement, but also throughput. This means that the mechanics (a module or machine) shall be constructed in a way that it can be positioned with unprecedented accuracy and stability, but this position shall also be reached faster. TNO will contribute to these challenges by, e.g., miniaturization of components (e.g. SPM) and dynamic mode shape control. Applications vary from advanced wavefront correction to probe-to-wafer approach for metrology. This technology holds relevance to Space, Solar, and Scientific Instrumentation, too. These developments were initiated on ERP- and VP projects during 2012/2013, guided by two Principal Scientists of Optomechatronics and will be brought from generic platform development to application-specific technology in the coming years.

Nanoscale 3D (additive) metrology and patterning
As explained above (see sub-wavelength optics) there is a trend towards control over nanostructures and applications thereof. Besides simulations and optical design, also some expertise on the manufacturing of these materials, and the equipment therefore, is needed. Applications vary from anti-reflective coatings to direct write imaging and additive manufacturing.

10.2 Roadmap Nanotechnology (QuTech)

10.2.1 Vision and ambition
The motivation to develop quantum computing and quantum internet has not changes over the last years. Driving are (1) future applications of the unprecedented computing power for sciences and Grand Challenges (including faster developments of drugs for the aging society and development of high-temperature superconductivity for the energy challenges), (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. Many companies and institutions still share the strong believe in the great potential of quantum technologies. This 'buzz' in the market is materialized in multiple (international) initiatives. More and more companies and institutions have made or will soon make their interest in quantum technologies concrete. A few examples are described below.

The scientific interest in quantum technologies is only increasing. Many groups around the world research specific, intriguing aspects of it. No new insights undermining the feasibility of applications based on quantum technologies whatsoever.

QuTech, the quantum technologies research center by TNO and TU Delft, has made significant progress in 2015. Some of the successes, both scientifically and financially, are described below.
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 *Interaction and cooperation*

The main partner in QuTech for TNO is of course the TUD. Also in 2015 multiple achievements have been published in high-impact journals, demonstrating the outstanding knowledge position. E.g.

- edge-mode superconductivity in a two-dimensional topological insulator (Pribiag, Kouwenhoven, et al, Nature Nanotechnology, May 11, 2015);
- one minute parity lifetime of a NbTiN Cooper-pair transistor (Woerkom, Geresdi, Kouwenhoven, Nature Physics, May 25, 2015); and
- independent, extensible control of same-frequency superconductiviting qubits by selective broadcasting (Asaad, Deurloo, DiCarlo, et al, submitted for publication August 2015);
- quantum ‘spookiness’ passes toughest test yet, comment on Nature New based on the paper by Ronald Hanson et al, submitted for publication.

The third paper in this list is the first joined TUD-TNO paper as a result of the QuTech cooperation.

Due to the cooperation with TUD, multiple colleagues of TNO are now familiar with quantum computing research. Those colleagues work side-by-side with the colleagues of TUD to learn about quantum theory, to distil the requirements for the quantum computer and secure quantum internet, and to validate their ideas for solving the related engineering challenges. Multiple examples demonstrating these unique capabilities already exist. For example, the team working on room-temperature electronics for qubit control, consisting of TNO engineers from the Radar Technology Group and TUD scientist for the transmon qubit group, has developed a ‘vector switch matrix’ which is now used to effectively send control signals to qubits. This work has led to a patent, a joined presentation at the most important scientific conference on quantum computing, the APS March meeting, as well as a joined paper (as mentioned above).

In this way, TNO educates and trains the first generation of ‘quantum engineers’. These colleagues now master a unique combination of disciplines (quantum + RF technology, quantum + optics, quantum + nanofabrication, etc.) and will turn out to be very valuable for the Netherlands in future commercialization or implementation of quantum technologies.
Moreover, the challenges being addressed in QuTech demand state-of-the-art engineering. Thus also in their single discipline, the engineers are pushed to the limit. Other departments/markets of TNO benefit from this as well, as is described below.

QuTech makes use of the expertise (and colleagues) of the Research Groups of Optics, Nano-Instrumentation, Radar Technologies, Optomechatronics, Intelligent Imaging, Instrument Manufacturing, Information Security, Material Solution, and Thin Film Technologies. Some examples of work packages within QuTech, which also contribute to knowledge development for those departments and/or their markets.

- A deformable mirror was designed into an experiment on secure quantum internet by the TUD to boost the optical efficiency. Control engineers of TNO developed an algorithm to control the shape and position of the deformable mirror, based on the algorithm of a former project. This was the first time, however, that an algorithm was based on a power signal instead of the signal from an wavefront sensor. This expertise is potentially useful for application in, e.g., space engineering projects of TNO.
- TNO's expertise in nanofabrication is applied to make better Majorana qubit devices. The newest challenge for this is lithography in three dimensions. This feature of TNO's electron beam lithography systems was never used before. In the future this expertise may be useful for the development of optical gratings for space applications.
- TNO's expertise in the field of non-linear optics, coupling light into optical waveguides, and cleaning of optical surfaces turned out to be essential for the experimental setup for wavelength conversion for secure quantum internet. It was also a good practice for TNO however, as the number of projects with non-linear optics is too small to have regular experimental exercises.
- Other examples of technology developments that could find applications in the field of quantum technology as well as other markets, relate to FPGA design and 'RF through optical fiber' for qubit control respectively other applications; multi-scale physics simulations for nanowires or IC reliability, optics for secure quantum networks or satellite optical feeder link, optical cavity design for secure quantum networks or multi-parallel light source development, and RF technologies for qubit control or radar technology.

10.2.3 Dynamics

The following developments are indicative for the international perspective of this field, as well as the role of QuTech/the Netherlands in it.

Following Google, IBM, and Microsoft, in 2015 also Intel starts a research program on quantum computing. QuTech is proud to announce that Intel has chosen QuTech as Intel's first partner for this program!

The quantum technologies program in the United Kingdom is progressing, with a focus on quantum sensors and military applications. About 100 companies are involved in this program of 270 M£. Representatives of EZ and QuTech have visited the UK Department of Business Innovation & Skills (BIS) and Innovate UK in July 2015 to exchange experiences with and ideas on closing the gap between academia and industry in the field of quantum technologies. As a result the people of BIS/Innovate UK and EZ/QuTech work together in this field. We join forces in the initiative of the 'Industry white paper' (vide infra) and envision a correlation between activities organized by the Dutch and UK governments is the light of their respective EU presidencies.

The European Commission has the ambition to support quantum technology developments in Europe, and has invited 'the field' to generate proposals. 'Quantum research and quantum technologies' are mentioned in some 'calls' within the Horizon 2020 program. But the ambition is to focus more on possibilities to close the gap between the research and applications, or between academia and industry. A first workshop "Quantum Technologies and Industry" was organized on May 6th, 2015 in Brussels. The Netherlands were well represented (EZ, QuTech, ASML, NXP, Single Quantum). Other non-academic participants included Thales, Siemens, Airbus, e2V, IBM, IMEC, Toshiba, and representatives of DG Connect.

The European academic quantum research groups are developing a joined Roadmap already. But relatively new in this, is the vision by multiple groups that this Roadmap should not only contain purely scientific ambitions but also engineering. QuTech/NL is partnering with, o.a., Charles Markus (Copenhagen University) and John Morton (University College London) in this arena.

In parallel, and initialized by the meeting on May 6th, 2015, a 'Industry White Paper' is in the process of being put together. Innovate UK is in the lead. QuTech managed to have the Netherlands well represented in this forum, by introducing representatives of FEI, NXP, and ASM.

On October 13th, 2015 a 'Quantum Industry Round Table' is organized for European 'Captains of Industry' (SAP, Robert Bosch, ASML, Siemens, etc.) and Commissioners Oettinger and Moedas. The Dutch government is organizing, together with QuTech, a Quantum Conference in May 2016 as part of the European Presidency in 2016. This all indicates the ambitions of at least The Netherlands, Great Brittan, and Europe, to boost the development of and investments in quantum technologies.

By September 2015, TUD and TNO submitted two proposals to the IARPA call "Logical qubit program".

QuTech (Rogier Verberk, TNO) will participate in a new Coordination and Support Action (CSA) on quantum technologies.

10.2.4 Connection to the innovation contract HTSM and Roadmap

On June 1st, 2015, six partners signed an agreement providing firm foundations for the QuTech institute for a ten-year period. Alongside TU Delft and TNO, these partners are the Ministries of Economic Affairs and Education, Culture and Science, NWO/STW/FOM and the High Tech Systems and Materials (HTSM) sector.
QuTech works together with Leiden Cryogenics; the start-up company that supplies QuTech (and academic groups around the world) with dozens of cryostats (about 500k€ each).
In the second half of 2015 KPN and QuTech investigate a potential cooperation in the field of secure quantum internet. In parallel, ASM and QuTech investigate a potential cooperation in the field of material developments. QuTech shares its information about the developments in this early research field with, o.a., Fox-IT, FEI, and ATOS. Future cooperation with those Dutch companies, and hopefully also commercial benefits for those companies at a later stage, is not unlikely.

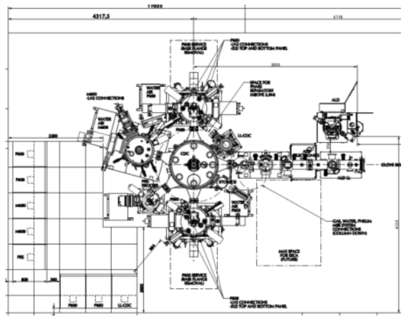
Finally, the cooperation with Microsoft (continued) and Intel (since September 2015) has motivated senior managers of those companies to visit Delft already. We use these new relationships to promote Delft and the Dutch high-tech industry in general.

10.2.5 *Activities in PPP*

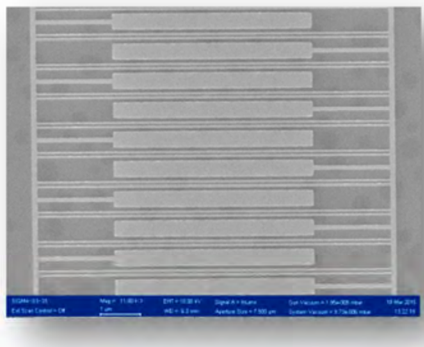
The activities during 2015 were roughly executed according to the overall plan. Besides this, an effort was made to develop the plans further, and to incorporate parts of the plans in (IARPA-, VICI-) proposals and in project plans for cooperation with, mainly, Intel. QuTech will work on more work packages and scientific questions than described here. This chapter describes only the activities TNO personnel is mainly involved in.

Roadmap A

In 2015 a customized, state-of-the-art MBE cluster tool was designed and manufactured by our supplier, while TNO's cleanroom has been modified significantly, to enable growth of nanowires in our cleanroom. In 2016 this system will be tested and calibrated, and nanowires will be grown for the Majorana devices. A specialist formerly working at Lausanne and IBM is now employed by TNO for this purpose. In parallel, 3-dimensional lithography is currently under development. All of these efforts will be applied to grow high-quality and cross-like nanowires in 2016.



A substrate with buried gates and flatness of only 0.2 nm RMS was developed, compared to several nm RMS in 2014. (The image on the right shows the gates after lithography.)



Simulations on nanowires and their environment helped us gaining insight in the relationship between stress and electrical performance.
In 2016 emphasis will be on the development of the complete manufacturing scheme of a Majorana-based qubit. Abovementioned building blocks will be incorporated.

Roadmap B

The newly developed vector switch matrix used to 'broadcast' RF signals to multiple qubits, has led to a patent, a presentation at the APS March Meeting, and a scientific publication (and was used for a demonstration to Mrs Bussemaker, Minister of OCW). In 2016 this technology will be developed further to support the goals of the 17-qubit surface code.

The design of the FPGA-based feedback control of 2015, will be materialized in 2016.

Other work packages for 2016 are: improving the quality of the transmon qubits (better controlled nanofabrication), design of 17-qubit circuits, and design of efficient implementation of 17-qubit surface code algorithms.

Roadmap C
Experience in pattern recognition and automation was applied in 2015 to develop algorithms to initialize circuits of two spin qubits. In 2016 this development will be continued and extended to initialize circuits of more than two qubits (from the point of symmetry this is a non-trivial step) and to have the computer recognize the status of such circuits.

TNO will continue the work on the connectivity for spin qubit circuits. Ideas exist to develop a multipurpose connectivity board (‘interposer’) to deal with this challenge independently from the configurations/generations of qubit circuits.

Roadmap D

In August 2015 the group of TUD/Ronald Hanson demonstrated teleportation over more than one kilometre distance. While this is big news to the community, TNO and TUD focus on the next challenges:
In July 2015 a team of TNO and TUD managed to have the first conversion of 637nm light to wavelengths used for telecommunication in our labs. This was done by means of a dedicated optical waveguides and several surface cleaning and alignment tricks. In 2016 this technology shall be developed further to demonstrate similar wavelength conversion, *on the level of single photons*.

The collection efficiency of the currently used solid immersion lens for N-V centres in diamond is not sufficient to support further progress. In 2015 a control algorithm developed by TNO was applied to the deformable mirror to correct for the imperfections in the solid immersion lens (SIL) and misalignments of this SIL relative to the position of the N-V centre. A 5 times higher collection efficiency was reached. In 2016 further improvements are planned: a better and faster algorithm, which can work without feedback signal.

11 VP Flexible and Freeform Products

11.1 Roadmap Components and Circuits (Holst)

11.1.1 Vision and ambition

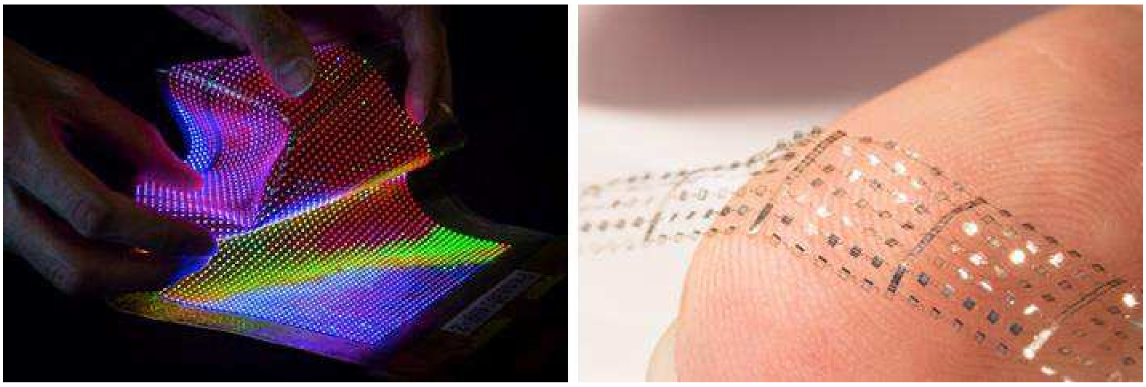
There is an increasing need for flexible and lightweight electronic systems. Examples are: wearable medical devices such as skin patches, smart garment, flexible displays and large-area (X-ray) imager sensors, seamlessly integrated human machine touch interfaces and wireless nfc playing cards. Holst Centre aims to develop materials, processes and manufacturing platforms that allow such flexible electronic systems to be made economical for mass-production: Flexible electronics draws equipment, materials, design and manufacturing processes from three established industries: semiconductor, display and traditional print processing. Holst Centre works on a number of applications that are described in different chapters in this document. This chapter describes the activities related to microelectronic components and circuits on unusual substrates such as plastics, rubbers, textile and paper.

11.1.2 Dynamics

No major adjustments of the 2015 plans are foreseen. The two 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.

(i) In the previous period, Holst Centre has engaged in a number of technology transfers to the production facilities of its industrial partners. It is expected that this number increases given the maturity of some of the Holst Centre technologies. Such technical transfers are typically carried out in a bilateral setting, rather than a shared research setting. Also, Holst Centre is more frequently asked to make a multitude of its prototypes for field-trials and/or early market studies. To accommodate these requests, Holst Centre is actively working to more reproducible and reliable prototyping realized using standardized baseline processes on pilot lines equipment.

(ii) Whereas initially our technologies were geared towards high-volume, low-cost applications, Holst Centre is increasingly asked to direct its activities more towards higher added-value flexible electronic systems. Examples lie in the domain of (bio)medical and automotive. This represents an excellent opportunity for Holst Centre to strengthen the industrial relationships with European and US companies.



Left: stretchable and conformable oxide thin-film transistor (TFT) driven LED display laminated into textiles. Right: stretchable oxide TFT sensing array on 2 □m polyimide substrate.

Holst Centre activities can be clustered in two large activities: hybrid printed electronics for wearables (health patches, smart garments) and in-mould electronics (HMI) applications, and flexible transistors and its applications in displays, imagers and circuitry.

Hybrid printed electronics (HPE)
The base technologies underlying hybrid printed electronics (printing of base circuits, component integration) on *flexible plastic films* (polyesters) have been brought to a mature level in recent years. There is clear interest from the market to use the technologies to realize concrete applications like smart garments and health patches, see also furtheron. This does require some technology optimizations (reliability, reproducibility) but no fundamentally new technology developments are needed anymore.
In parallel to this, there is also an interest from the market to develop new HPE technologies to go *beyond flexible,* e.g. stretchable or formable electronics. This requires the development of printing and integration on substrates like silicones, polyurethanes (stretchable) and polycarbonates (formable). First exploration has started in 2015 but will intensify in the following years.
And finally there is also a clear interest from the market to realize more functionalities using printing technologies. In particular printed sensors (temperature, humidy) have gained an increase in interest. Also here the work has intensified in 2015 and will further increase beyond 2015:

- Technology improvement for flexible foils as far as needed for applications.
- Technology developments for stretchable and formable substrates/devices.
- Functionality developments for printed sensors, in particular temperature and pressure.

Oxide transistors
Oxide transistors offer advantages in terms of process simplification, performance and compatibility with flexible plastic substrates. 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 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, see also further on. Processes are designed to be compatible with standard display fabrication methods where possible, to provide the shortest possible path to market introduction. The program has delivered Indium Gallium Zinc Oxide TFTs for a wide variety of flexible display, imager, and circuit applications. IGZO transistor technology will mature further. Emphasis will be on:
- Reproducibility and repeatability using our 320x352mm pilot line infrastructure.
- Scaling of TFT dimensions to enable high-resolution arrays, in-pixel intelligence and high-speed, smaller circuits.
- In addition to IGZO, we investigate alternative materials and deposition methods for oxide materials that do not require high vacuum.

Smart garments

Wearable devices such as healthcare monitors and activity trackers are now a part of everyday life for many people. Today's wearables are separate devices that users must remember to wear. The next step forward will be to integrate these devices into our clothing. Doing so will make wearable devices less obtrusive and more comfortable, encouraging people to use them more regularly and, hence, increasing the quality of data collected. Key steps towards realizing wearable devices in clothing have been demonstrated by Holst Centre and its partners in the form of a solar shirt that can power your mobile phone, a stretchable display that can be integrated into textiles to allow interaction with the wearer, and an ECG-monitoring shirt (Figure 1).
- Two iterations of smart garments will be made. One in which the multisensor health platform (e.g. for measuring ECG and bioimpedance) will be integrated as unobtrusive as possible.
- The second one will be related to the use of LEDs in clothing. For example integrated lighting or signage/display. The latter is generally considered to be one of the most compelling smart garment functionalities.

Health patches

Health patches using silicon, thin-film transistors or both are developed. Offering both technology options to industry we consider to be a strength, and we have in fact companies working with us on health patches using the two different technology options. What these applications have in common, is the need for soft, flexible and bio-compliant materials, dedicated electronic circuitry for spatiotemporal measurements of (small but slow) bio-signals typically consisting of a multi-electrode array. The patches must adhere to the intrinsic contours of the skin. This puts specific constraints on form factor. Mechanical wearability and stretchability of the health patch are important. Thin, plastic films containing the electronic components are laser machined in rigid islands separated by meander-shaped interconnects that accommodate mechanical strain, resulting in reduced body motion artefacts.
- A high end multisensor (ECG, bioimpedance) health patch will be realized that can be worn on the body for 7 days. The electronics can remain autonomous for that period and the materials and design are such that the patch is comfortable and does not cause skin irritation.
- A skin temperature patch is designed, fabricated and characterized using thin-film components. A resistive thin-film sensor will be screenprinted with a relative resistivity change of 4% per degree Celsius. This sensor will be combined with

a three-bit ADC based on oxide transistors, giving an accuracy of 0.1°C in the range of 35-42°C.

Displays
Flexible OLED displays have entered the market (Samsung Galaxy S6 Edge), but are produced at relatively high cost and poor yield. Holst Centre has a strong IP position on oxide transistors, that have a performance in between amorphous and low-temperature polysilicon transistors, and –leveraging its thin-film encapsulation technology – was among the first in the world to demonstrate rollable OLED displays. In 2015 the total stack thickness was reduced to decrease the radius of curvature, to make foldable displays. Stretchable LED displays are made and integrated in textile for clothing and car interior.

- In 2016 Holst Centre is focusing on high-resolution (600+ ppi) OLED display technologies for mobile applications using self-aligned transistor structures, and a new approach to pattern the OLED pixels.
- In parallel, Holst Centre is developing new display drive schemes that reduce power consumption and improve image quality. Stretchable LED displays with higher resolution will be made by integrating smaller LEDs.

Imagers
Higher uniformity was demonstrated in larger imager arrays, while keeping the high sensitivity. Several prototypes were made of flexible imagers with slotdie coated organic photodetectors that meet medical X-ray requirements after processing. Application-specific reliability tests show no apparent bottlenecks. A transfer of the organic photodetector to an X-ray plate manufacturer is in progress.

- Organic photodetector technology will be transferred to a US-based company that supplies X-ray plates to amongst others Philips Medical.
- The organic photodetector technology will be developed further for advanced imager applications (think near-infrared organic photodetectors, multispectral imagers) in close cooperation with imager companies. See also ‘intuitive interfaces/HMI).

NFC labels
Today, NFC tags are made using traditional silicon technologies. The main applications is to identify individual items or products and track them based on the information stored on the tag. Similar NFC tags made in thin-film transistor technologies can offer many advantages. Thin-film tags can be much thinner, mechanically flexible and robust. Large-area volume manufacturing can drive their cost below the cost points of traditional silicon towards the level of item level product tagging (eurocents). Embedded in products at affordable cost, thin-film electronics intelligence can be further enhanced by integrated sensors (e.g. temperature, light, chemicals) and user-interfaces (e.g. low-power display or near-field communication (NFC) connection to a smartphone app). Such NFC-based smart systems enable many new applications in various areas, such as in the food industry (e.g. tracking products from production to consumption, or giving information on the food’s freshness), in marketing and retail sectors (e.g. customer interaction with products, brand enhancement), in security and brand protection (e.g. in pharmaceutical industries).

- In 2016 we will continue pursuing NFC tags as a minimum viable product of thin-film transistor integrated circuits.

- A substantial leap forward beyond the state of the art will be attempted towards IGZO NFC tags compatible to the standard communication protocols (ISO14443 or ISO15693). The protocol compatibility enables NFC tags to interact with standard NFC readers and smartphones.

Intuitive interfaces
Touch screen use has changed user interface and our user behaviors in these years. Besides improving mature projected capacitive technology, the industry is thinking of enhancing user experience of touch screen use with new features and functions. Force sensing, touchless interaction, haptic feedback and biometrics are emerging. These applications are inherently large area, and represent another example of large-area sensing surfaces.

- Polymer actuators are integrated with oxide TFT backplanes to develop 3D haptic feedback, that can be integrated with mobile displays. Light sensitive surfaces are achieved using organic photodetectors for gesture recognition.

Via academic collaboration and exploratory funded projects, Holst Centre is exploring **in-body electronics**. Steerable catheters are developed based on polymer actuators. Organic photodetectors – originally developed for imagers by Holst Centre– are part of an academic collaboration working on artificial retina.

11.1.3 Connection to the innovation contract HTSM and Roadmap

Holst Centre was founded in 2006 as a partnership between academia, industry, and government to collaborate on the development of a new generation of innovative OLED products and electronic sensor circuits that are flexible, lightweight, low power, and rugged. 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. The multi-year roadmaps of the relevant programs are also embedded in the HTSM Roadmap Component and Circuits. Wearable electronics and IoT (integration of electronics in everyday objects) are key drivers for our technology development. 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 led to a well-above average success rate for Holst Centre in competitive funded projects such as H2020 and Ecsel.

Universities play a crucial role in understanding the fundamental aspects as well as demonstrating new concepts and ideas. The good relationship between Holst Centre and academia is substantiated by two newly appointed professors (prof. Groen, TU Delft and prof. Gelinck, TU Eindhoven). But there are also strategic collaborations with academic groups outside of The Netherlands, such as KU Leuven and the university of Ghent, Imperial College (UK) and many others.

11.1.4 Activities in PPP

All activities described in this chapter take place in the frame of the PPS programs executed by Holst Centre.

11.2 Roadmap Lighting (Holst)

11.2.1 Vision and ambition

Energy efficient solid state lighting is set to replace traditional light sources, bringing huge reductions in global energy consumption. There are two solid state lighting technologies: LEDs (point source) and OLEDs (large area source as shown in Figure 1 left hand side). Holst Centre/TNO's vision is to realize the potential to create next generation free-form, robust, novel lighting with customized designs based on ultrathin films containing either or both of these two technologies. These films could then be seamlessly integrated into a wide range of product forms.
The technical ambition of the OLED lighting program at Holst Centre/TNO is to develop a production process for flexible OLEDs at a cost of less than 100 €/m2 (a reduction by a factor of 20 compared to commercially available rigid glass-based devices today), 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. For LEDs the ambition is a bit different. Here the aim 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). An example of such a matrix is shown in Figure 2, right hand side.

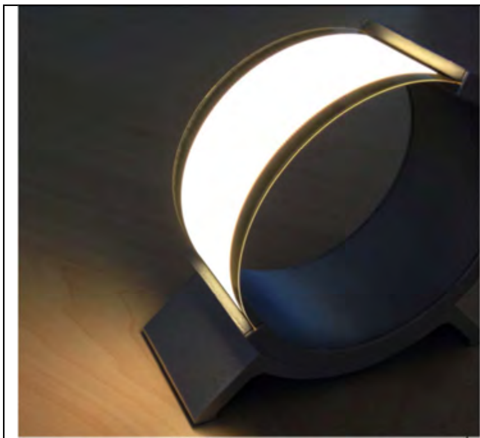


Figure 1

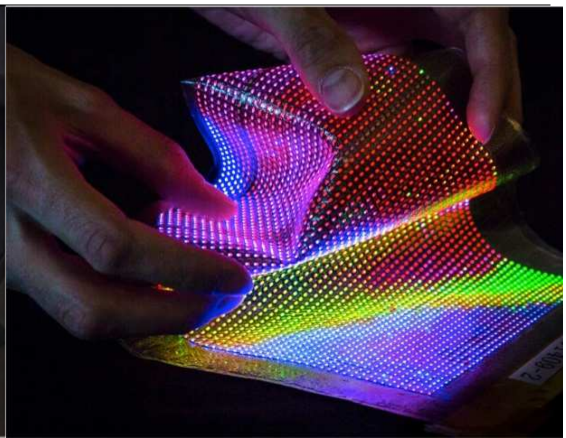


Figure 2

Key to its shared innovation model, Holst Centre/TNO has the ambition to bring together value chains and ecosystems of companies for the fabrication 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.

11.2.2 Dynamics

During 2015 there were a number of key milestones achieved in the development of flexible OLED production processes at Holst Centre/TNO. One of these was the demonstration of the (roll-to-roll) flexible moisture barrier substrate developed and made at Holst Centre/TNO in more than 100 flexible OLED lighting prototype products, where the OLED layers were deposited in an industrial production tool at Philips Lighting. This allowed a simple replacement of glass substrates with a flexible ones in Philips' OLED production process, whilst maintaining the high

performance moisture barrier properties as well as the OLED efficiency. Another, was the first OLED fabrication runs on the new state-of-the-art, roll-to-roll solution processing line at Holst Centre. 100m of flexible OLED foil could be coated with OLED layers in one run, and devices were produced with more than 80% yield. A third was the development of a specialist tool to allow intermittent slot-die coating at high speed. This makes it possible to pattern solution processed (OLED) materials, improving materials utilization and reducing production costs.
These developments have important implications for the work plan of 2016. With the successful demonstration of a large number of prototype devices, we find ourselves in the position to be able to accept the increasing number of requests from end-users (for example suppliers for the automotive industry) to make customized flexible OLED product prototypes (typically 10 -100 devices per case). In 2016 we will also address, together with these end users, the technical challenges of integrating these OLEDs into product forms, including lamination processes and integration of other flexible electronics. The increasing maturity of the high performance moisture barrier, and our ability to now produce it roll-to-roll on length scales of km, also means that we can work closely with companies who wish to manufacture flexible OLEDs, or other flexible electronic devices, to integrate this substrate into their production process. In 2016 this will involve adaptations to the barrier film technology to produce barrier films with cost-performances specific to the requirements of their particular applications, and to create flexible demonstrator devices. Approaches (tools and materials) to increase yield by preventing damage to the top surface of the barrier film, and to add an electrode layer in a roll-to-roll process will be developed in 2016. We have now come close to a complete roll-to-roll production process for solution processed OLEDs. The remaining technology challenges are around developing processes for roll-to-roll deposition of (patterned) electrodes and increasing the production yield in order to lower cost, and these will be key manufacturing issues addressed in 2016. Longer term goals include developing concepts for OLEDs with added functionality such as flexible, conformable, stretchable and cut-able light sources, and the possibility of further integration with other thin film electronics.
From the beginning of 2016 we will also establish a European open access pilot line service for flexible OLEDs for lighting and signage applications. This will done in collaboration with number of European institutes and companies leading in OLED technology, by combing the existing complementary (sheet-to-sheet and roll-to-roll) infrastructure and expertise of the pilot line partners. Our ambition is to have a capacity of up to 5000 m^2/OLEDs/year, which will bridge the gap between research and development (100m^2 OLEDs per year) and mass production (20 000 m^2 OLEDs per year. In this way we will be able to test up-scaled processes for materials companies, as well as produce customized prototype flexible OLEDs on a small-medium scale. This pilot line will be co-financed by Horizon2020 EC pilot line funding under the project name PI-SCALE (start January 2016, Holst/TNO is coordinator).
In 2016 activities for the flexible LED light sources will focus on inclusion of active matrix driving and further increasing the resolution of the information display.

11.2.3 Connection to the innovation contract HTSM and Roadmap

The Roadmap Lighting (OLED) has a very strong link to the Roadmap Printing and its associated partners and collaborations and a lot of technology overlap with Roadmap OPV. This includes sharing of roll-to-roll and sheet-to-sheet production infrastructure and techniques for production of moisture barrier, and deposition of layers by solution coating. The LED activities have a strong link with the Roadmap Components and Systems. The same base technologies (printing, integration, thin film circuits) are being used.

11.2.4 Activities in PPP

These activities are fully part of Holst Centre which is a PPS (Publiek Private Samenwerking) in itself. Current R&D and industrial partners in RM lighting (OLED) also collaborate in, and coordinate, some EU projects such as, Flex-o-fab, SOLEDLight, INREP and ALABO. The H2020 PI-SCALE flexile OLED pilot line project, due to start in 2016, will be a key activity within the PPS of Photonics21. The Roadmap Lighting (OLED) is also part of NanoNext NL, and involved in STW projects. New and continuing industrial partnerships with OLED materials companies, equipment manufacturers and flexible OLED device and substrate manufacturers are envisaged. We also expect increasing numbers of collaborations with end-user companies who wish to integrate free-form OLED or LED lighting and signage foils into products for various applications.

11.3 Roadmap Solar (Solliance)

11.3.1 Introduction

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 200 GWp PV power expands at a rate of 45 GWp/year. The market growth of 45%/year over the last decade was enabled by increase in product quality (conversion efficiency and performance ratio) with a simultaneous steep decrease in cost (factor 10 over past 20 years). The breakthrough for PV energy is the realization of grid parity (PV electricity to be competitive with retail electricity prices) in increasing parts of the world. 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%).

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.

11.3.2 Vision and ambition

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 and (building) components, through custom designed free form PV module formation (“Smart industry for PV”) followed by adaptable automated integration processes. In addition, it is generally expected that the next leap in efficiency improvement of PV modules will be enabled by combining crystalline Silicon and thin film technologies in tandem structures. Ambition is here to develop device solutions where high band gap thin film absorbers are combined with transparent electrodes, to be used in tandem with crystalline Silicon.

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 Dynamics

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, Greenhouses and Automotive 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.

Perovskite Solar Cells (PSC)

By the end of 2014 it was decided to switch all Organic based PV (OPV) activities towards perovskite based PV. The main reasons are, apart from the much higher and seemingly easier achievable efficiencies, strongly increased industrial interests and activities on PSC, easier material access and the potential re-use of the current available expertise, skills, processes and equipment developed so far for OPV.

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 and stability by controlling the perovskite active layer formation and introducing novel contacting layers
2. Mid-term: demonstration of efficient (≥ 8% PCE) perovskite based devices processed on 6”x6” rigid and flexible substrates using scalable processes
3. Mid-term: integration of thin film PV modules in the envisaged applications
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, tune-able 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 Cell

The Shared Research Program for CIGS/CZTS comprises 5 work packages, with the following milestones/results:

1. Platform for reproducible realization of CIGS demonstrator modules
   - Stable process for realization of encapsulated modules based on coevaporated CIGS (reference line 14% cell efficiency, best cells >16%) and sputtered CIGS (base line >12%)
   - Accelerated life time testing (detection of life time determining factors and underlying basic mechanisms; life time prediction)
   - Cost of ownership model (capable to predict cost implications wrt current state of the art)
2. Atmospheric absorber formation
   - Sequential process for electrochemical deposition of CIG and RTP selenisation/sulphurisation (base line >12%)
   - Establish process for spatial ALD of ZnOS buffer layers (improved light transmission with at least comparable electronic properties as CdS), demonstrate in completed CIGS module, demonstrate large area equipment for fast ALD processing on sheet glass (30 cm width)
3. Light management
   - 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%)
   - Develop model for performance/cost optimization of light capturing/trapping by nano textured layers
   - Development of transparent conductors with broader wavelength transmission windows (for tandem formation of thin film with underlying c-Si): demonstrate improved TCO compositions by spatial ALD
4. Back end interconnection
   - Demonstrate integrated high speed laser scribing and printing of conductors and insulators for monolithic module interconnection by free 2D patterning (50% deadzone reduction, reduced alignment, improved yield)

- Develop and validate model for optimized module efficiency 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)

5. High bandgap kesterites
    - Development of CIGS and CZTS –based absorbers with higher bandgap, also aiming at realization of high efficiency tandem concepts in combination with crystalline Silicon; material development by Solliance partners, TNO participates in process development and evaluation

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) components and flexible/colored/transparent/free form modules for optimized integration in products. New production concepts, where thin film PV is first mass produced at low cost, and then in a second stage (locally) tailored for customer specific module designs will be made possible. A very important factor will be the aesthetics of integrated PV, as the desired introduction of much larger scale application of PV energy generation would be greatly enhanced if the current public acceptance of PV technology can be maintained: this will require aesthetic and cost-efficient integration of PV in the (built) environment.

11.3.4 Connection to the innovation contract HTSM and Roadmap

The HTSM Roadmap Solar has been established in close collaboration with the TKI Solar (now renamed as TKI IDEEGO) 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, is under development. Several industrial partners have joined the programs on longer term membership basis (DSM, Dyesol, 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/e (Prof. Kessels, Prof. Janssen), TUD (Prof. Zeman, Prof. Groen), UG (Prof. Hummelen), AMOLF (Prof. Polman), Radboud University (Prof. Vlieg, Schermer) to further strengthen the program's scientific foundation.

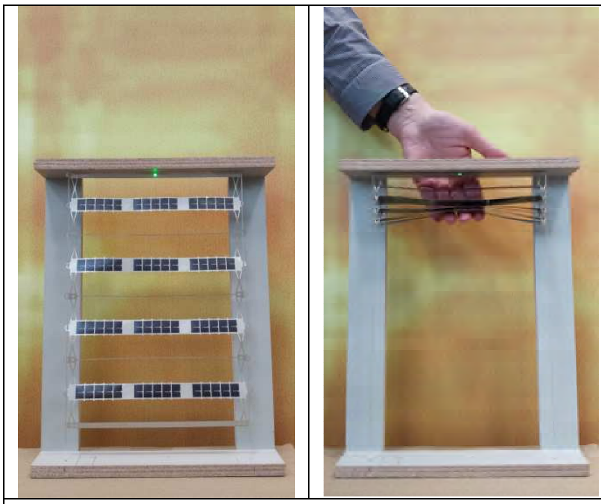
On EU level, the TNO/Solliance research activities fully comply with the European PV Roadmaps of EPIA (international PV industry) and the EU PV Technology Platform. On all three program topics (CIGS, PSC and Integrated PV) TNO and Solliance are very well connected to the European network of industrial 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.

11.3.5 Activities in PPP

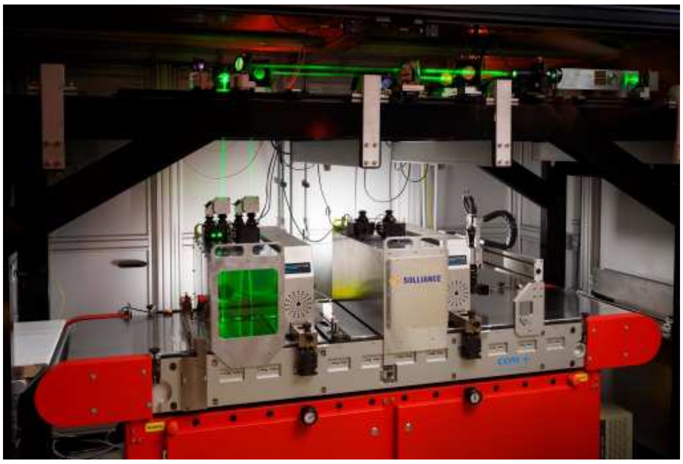
All solar activities at TNO, as performed in line with the HTSM Roadmap Solar, are executed within the framework of the research collaboration Solliance. Research partners in Solliance are TNO, ECN, imec (B), TU/e, FZ Jülich (D), TU Delft and Hasselt University (B).
The Solliance programs (CIGS, PSC, and Integration) are performed as Public Private Partnerships (PPP) in a shared research mode. Private partners can join the shared research program, executed with the joined research partners in Solliance, through longer term (typically 3 years or more) membership. In addition to this programmatic approach, public private collaboration also takes place on project base (e.g. EU, TKI, STW, M2i).

The novel Solliance roll-to-roll line constructed by VDL-ETG for PSC processing, viewed from the coating site in the clean room of the Solliance building at HTC21.

Part of the STS dryer system as installed in the Solliance building.



Demonstrator of an easy-to-produce thin film PV integrated greenhouse screen.



Back end interconnection tool for in-line patterning and interconnection of thin film PV modules.

11.4 Roadmap Printing

11.4.1 Vision and ambition

Additive Manufacturing (AM) is an enabling technology with numerous advantages compared to the conventional subtractive manufacturing technologies. AM 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. AM integrates very well with design tools and CAD software and as a result, the AM approaches can significantly impact both time and cost savings, as well as inventory, supply chain management, assembly, weight, and maintenance. AM is seen as 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 made of ceramic or metal with multi-material or grading material properties, human centric products (like dentures, prostheses, implants). 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 2014, 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), which represents the future AM needs of the industry, see Figure 1.

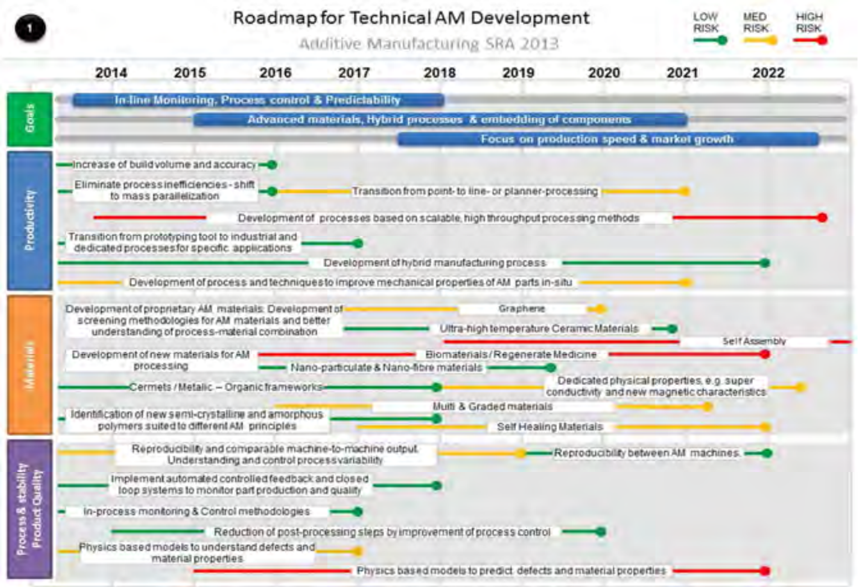


Figure 1: technology roadmap, from the European Strategic Research Agenda.

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.
To address the identified needs, TNO has launched the Additive Manufacturing Joint Innovation Centre AM with focus on process control and predictive modelling to improve product quality, improved material and process capabilities (engineering polymers, ceramics, printing concepts) for Vat photo-polymerization and other technologies and integration of Additive Manufacturing in production chains, making it an integral part of a ‘next generation industry’ approach. These needs are addressed via two pillars with corresponding ecosystems.
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 ‘Systems for AM’ program 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 program has a strong link with the Dutch Smart Industry action agenda. The program brings AM concepts from prototyping to industrialization with emphasis on new functionality and cost-effective manufacturing while maintaining system flexibility, stability & reliability. The program focusses on the development of 1) new concepts for multi-material/multi-technology digital manufacturing 2) high-speed/continuous AM technology (speed capabilities @ single pass deposition) 3) in-line metrology technologies 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 program targets medical-related markets (insoles, braces, exoskeleton etc.) with spin-off to other markets that require personalized, customized, on-demand manufacturing. The ‘Systems for AM’ program is positioned with the High Tech Systems Centre - TU/e.

11.4.2 Dynamics

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 2015, 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 High Tech Systems Centre – TNO program ‘Systems for AM’. The focus in the program 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 HTSC initiatives and programs.
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. A virtual selective laser sintering simulation tool will be developed for process modelling and to feed the laser-array data path. Input for virtual tool is a basic model to predict temperature-time and microstructure during continuous SLS.
The high-speed thermal wax print technology, developed for 1 m/s part printing showcased high accuracy part manufactured at 1 m/s. The technology will be further improved (synchronization, z-adjustment) to achieve 2 m/s manufacturing, higher resolution (down to 30-50 micron) and will be expanded to multi-material

deposition. Also new high-speed metrology concepts for improved part quality, manufacturability (target 10X yield), productivity (target 10X faster) will be investigated.
Another development is the further advancement of multi-material AM technology, including design, materials, processes and deposition concepts (mainly polymer-based, composites, ceramics). A concrete objective for 2016 is the development of a free-form electronics demonstrator, to showcase the integration of 3D printing, printing of free-form electrical tracks (with a resistivity of 10 times that of bulk material), and the integration of passive components (LEDs). In particular the integration of free-form electrodes in a 3D printed part and the patterning of optical wave guides in the 3D part face the challenge of process compatibility (both during the deposition and post-processing).
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. 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.

11.4.3 Connection to the innovation contract HTSM and Roadmap

Activities within the programs support the ambitions of the HTSM Roadmap Printing to extend the range of available AM materials with a full set of functional properties (structural, optical and electrical), to improve part quality and precision of AM manufactured parts and to develop concepts for enhanced functionality and manufacturing systems. Within the framework of the Brightlands Materials Center (BMC), the strategic collaboration with knowledge institutes (including TU/e, UM and HZuyd) and industrial partners will continue and be expanded, for instance to the biomedical field. In 2015, 8 PhD projects were initiated in the scope of the 'Materials for AM' program.
Within the framework of the High Tech Systems Centre, a co-creation platform between industry and academia is in development, including PhD projects (at this moment 3 PhD projects are defined, 2 projects in preparation), industrial partnerships and collaborations with other academia. The 'Systems for AM' program has also a strong representation in EU (involved and leading several EU programs on hybrid manufacturing and multi-technology digital manufacturing and strong involvement in the AM platform) and has positioned the Multi-Material 3D print Fieldlab in the context of the national Smart Industry action agenda. Within this Fieldlab, a collaboration with ECN on ceramic technology and applications is established. Also strong collaborations with industry and academia are established to develop models for thermal additive manufacturing, including a multi-year collaboration with NLR, M2I, UTwente and TUD on thermo-mechanical modelling and topology optimization (3 PhD projects), and representation in a number of EU projects.

11.4.4 Activities in PPP

- The existing activities in the field of vat technology @ dental applications will be continued and expanded via the 'Materials for AM' and 'Systems for AM' programs. 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), and embedded electrodes (free form electronics).

- The MultiM3D Fieldlab will be kicked-off as part of the ‘Systems for AM’ program representing a future factory, and is designed as a network organization 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 will be executed, the developed knowledge will be transferred to industry and other application Fieldlabs.
- The ‘Materials for AM’ program will expand its existing ecosystem of industrial and academic partnerships, among others by making use of the available infrastructure and business opportunities around the Brightlands campus in Geleen. A number of new EU partnerships is foreseen. Also opportunities in the field of biomedical applications such as microfluidic diagnostics, organs-on-a-chip or 3D printed tissues will be explored. To enable activities in multi-material AM, we will explore thermoreversible materials for support-less building and interactions between different (photo-curable) materials such as wetting, adhesion and cross-contamination. AM materials with customized optical properties, e.g. for optoelectronic components will be explored in the BMC program as well.
- The ‘Systems for AM’ program will expand their ecosystem of industrial and academic partnerships, making use of the high-tech ecosystems in the Eindhoven area. In addition to the existing EU programs, new EU projects around for instance medtech cases and free-form electronics will be added as well. The program will also embrace opportunities in the pharma and food printing domains, where in particular novel concepts for scalability and high-resolution printing are foreseen (for food texturing and controlled drug release).
- The collaboration with NLR and M2i in the field of thermal models will continue. New opportunities in the field of models for multi-material AM are considered, among others via new EU projects or via a new PPS program.

11.5 Roadmap Healthcare

11.5.1 Vision and ambition

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 Van ‘t Hoff 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 various technologies will affect health outcomes in various ways. Better and faster diagnosis and monitoring of diseases in (a)symptomatic stages and personalized treatment will open up possibilities for better (drug related) treatment of patients leading to increased self-reported physical and mental health, prolonged participation to society, decrease in hospitalizations and visits to clinicians, and/or increased life time expectancy. Also, the non- or minimal invasive character of the technologies results in no or less burden to the patient. Minimally invasive surgical procedures are characterized by real time discrimination of tissue structures, leading to faster surgery, improved surgical quality (less multiple operations needed), preservation of function and a decrease of the use of (toxic) contrast agents.

The program was set up in 2012 by TNO. Within the Van ‘t Hoff program, TNO collaborates with (Dutch) health, several industrial partners in the field of optical sensing and diagnostics as well as several leading (medical) research institutes and academic hospitals.

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.

11.5.2 Dynamics

In 2016 we will focus our research activities on 4 of the above-mentioned long-term goals:

<u>‘Selective ion measurement for dialysis”</u>

In 2015 the Laser Induced Breakdown Spectroscopy (LIBS) sensor was redesigned in order to improve performance to expected system goals that where derived from (potential) partners and stakeholders of the program. We designed for the use of components that result in a viable business case, hence many expensive

components in the original system are no longer required to achieve the system requirements. Furthermore the system is tested and validated in a relevant environment.
In 2016 the focus will be miniaturization and robustness of the sensor system: the system is reduced to the expected size, weight and shape. Furthermore the system is made robust in terms of mechanical and thermal stability. The system will be tested in a dialysis clinic and interface with the dialysis equipment. Extensive tests will be ran to demonstrate the reliability of the system. The tests will be used to identify possible engineering problems, and will result in an iteration of the design. This model will be made in close collaboration with the partners that will eventually produce the sensor. The 2016 developments will be done in close collaboration with potential new partners which allows us to introduce minor design changes for cost-effective manufacturing at an early stage of the r&d process.

Deliverables:
Miniaturized TRL 6 model of the sensor system designed and built (Q2)
TRL 6 model of the sensor system tested in a clinical environment(Q4)

<u>‘Detection and monitoring of neurodegenerative diseases’</u>
In 2015 we have worked on, and generated IP on, signal processing for multi-biomarker detection in small patient samples. This results in the ability to simultaneously read-out 4 ring resonators, which is the maximum for the currently used optical Integrated Circuit (IC).
In 2016 focus will be on design, fabrication and characterization of a new photonic IC. The new IC will be optimized for multi-marker detection (aim is 10), such that more biomarkers will be detectable in one sample. Additionally the new IC will carry parts of the optical read-out system on-chip, which will significantly reduce both cost and volume of the analyzer that is used to read out the IC, such that it can be miniaturized towards a hand-held device. Finally, we will design new ring resonators that are optimized for high-sensitivity, such that lower concentrations of biomarkers can be measured, and more reliable and industrializable receptor immobilization. Analyser software will be adapted to work with the new IC and read-out will be validated by performing assays on the new chip with localized receptors.

Deliverables:
Optimised photonic IC including software and partially integrated read-out system (Q3)
Multimarker validation tests on at least 3 assays (Q4)

In 2015 a research trajectory started to develop a fully non-invasive optical method to detect neurodegenerative diseases using the eye as a “window to the brain”. We identified a set of candidate biomarkers that are ND related and that manifest themselves in the retina. We designed and developed a first optical platform that combines several imaging modalities to image and facilitate measurement of both the size distribution as well as the retinal localization of biomarkers in vivo.
In 2016, the list of candidate biomarkers will be updated continuously based on literature evidence, novel insights and the results from our experiments. We will initially design and synthesize 5 fluorescent probes (tracers) with high affinity for our main candidate biomarker alphasynuclein (AS). The binding affinity and specificity of the selected fluorescent tracers will be first assessed in human retinal neuronal cell cultures in vitro, using a.o. competition assays with unlabeled tracers and

antibodies against AS. To perform this task we will use an advanced cell incubator and monitoring system using fluorescence imaging. In parallel we will investigate what the most appropriate PD mouse model is to test the specificity of the fluorescent tracers *in vivo*, and to demonstrate the feasibility of the approach. The results of our *in vitro* and *in vivo* experiments will be used to improve our ophthalmic imaging platform to allow the visualization of multiple biomarkers simultaneously (using multi-spectral excitation and detection) that will start by the end of 2016. In 2016, we will also focus on improving our real-time eye-tracking technology for high resolution imaging and that will enable longer exposure times for improved signal to noise ratios, as well as developing a method for monitoring of patients based on retinal landmarks used for eye-tracking purposes.

Deliverables:
Binding affinity and specificity of fluorescent tracers measured in vitro(Q2)
Method for 'land marking' based on improved eye tracker technology (Q4)

<u>'Non-invasive glucose measurement'</u>
In 2015 the research activities focused on extending and analysing the dataset of measurements with the Raman spectroscopy based prototype in a clinical setting in order to develop and improve the method used for prospective analysis. Furthermore we focused on preparing the technique and method for future adaptation in a true point of care (PoC) device. In 2016 the research activities will focus on the one hand on the miniaturization of the prototype that was used for the clinical measurements. Therefore, functional and technical requirements will be inventoried and a conceptual optical design will serve as input for a detailed design, all design activities will be conducted with respect to a viable business case and a compact and easy to use system. On the other hand, we will focus on further improving the method for prospective analysis and making it applicable for a broad range of skin types. The hardware and software components will be integrated into a prototype of the PoC device and demonstrated in a relevant environment.

Deliverables:
Re-design (hw +sw) for miniaturized POC device (Q2)
PoC demonstrated in relevant environment (Q4)

<u>'Modular fiber optic sensors for non- and minimally invasive diagnostics and surgery'</u>
In 2015 we started the development of an easy to use screening instrument for risk assessment of (the development of) cancer by a simple measurement of mucosal tissue. The instrument will be based on multi-diameter single fiber reflectance spectroscopy for quantified light scattering properties of biomarkers for carcinogenesis. In 2015 we designed and developed a sensor system that will be used for in vivo testing in a clinical environment. Furthermore we developed protocols for the testing and staining of biopsies.
In 2016 we will build 3 prototypes of the sensor system. The prototype systems will be tested on homogeneous tissue-mimicking phantoms. The systems will be shipped to a hospital where an *in vivo* study will be performed and spectral data will be acquired. Furthermore the correlation between measured scattering properties of mucosal tissue and underlying differences in tissue ultrastructure will be measured by acquiring optical measurements of the tissue ultrastructure of the buccal mucosa in patients that are suspected of having (pre)malignant disease in the head and

neck. The biopsies will be stained and statistically analysed. The nanoscale mass-density variations will be quantified from cryo-transmission electron microscopy.

Deliverables:
3 prototypes of the sensor system ready for clinical testing (Q1)
Relation between optically measured refractive index correlation length and TEM-measured mass density correlation length established (Q4)

11.5.3 Connection to the innovation contract HTSM and Roadmap

The HTSM Roadmap was revised in 2015 and while the 2015 version builds upon the original as well as the 2013 and 2014 updates, an extensive review has taken place. The manager of the Van 't Hoff program is also the secretary of the HTSM Healthcare Roadmap and has fulfilled an editing role for the 2015 Roadmap revision. The Van 't Hoff team contributed to the revision process and the Van 't Hoff activities are well embedded in the 2015 Roadmap. The Van 't Hoff partners were introduced in the Roadmap as partners who are collaborating in the healthcare ecosystem. Van 't Hoff activities are also embedded in the Knowledge and Innovation Contract of Life Sciences and Health.
In 2016 we envision to extend the program with at least 3 more participating companies and (international) health foundations and collaborate with at least 1 RTO. Furthermore -as a follow up to a TKI grant which we applied for in 2015- we will apply for at least 2 new TKI projects together with industry partners.

11.5.4 Activities in PPP

The content of the program is defined in close cooperation with each partner, whereby TNO coordinates the program and 'guards' the overall program goals. TNO consults each participant on the course to be taken, taking into account progress made previously and relevant external developments. Based on this input TNO updates the program description(s) annually. In the fourth quarter of each year, TNO issues to the partners updated description(s). TNO informs the partners on the progress via dedicated quarterly reports and meetings and the annual partner meeting.

12 VP ESI

12.1 Roadmap Embedded Systems

12.1.1 Positioning TNO-ESI embedded systems Roadmap

The high-tech industry in the Netherlands requires access to an open innovation ecosystem that strongly facilitates strategic innovation. The Topsector High Tech Systems and Materials (HTSM) has been established to facilitate this ecosystem. A large number of application- and technology-based Roadmaps form the heart of HTSM, of which the Embedded Systems Roadmap represents an important building-block. The TNO activities in this area are centered around the business domain ‘embedded systems innovation’, as represented by the research group TNO-ESI.

TNO-ESI is a leading member of the HTSM Roadmap team for Embedded Systems. This guarantees a strong link between the TNO-ESI strategic research agenda and the HTSM Roadmap for Embedded Systems, as well as its broad (industrial and academic) ecosystem of stakeholders and participants.

The HTSM Roadmap for Embedded Systems has obtained an update in 2015. This update has been developed and reviewed by about 40 persons from industry and academia, representing key stakeholders in the Topsector HTSM, using a structured analysis process that is identified as ‘line of reasoning’. This emerges from the societal and economic needs that drive new industrial activity. The associated innovation needs, especially those for high-tech product design and engineering, act as driver for new technology and scientific research. Together these form the foundation of the current HTSM Embedded Systems Roadmap.

12.1.2 Ambition and impact

Embedded systems are at the heart of most technological advances. Embedded systems technology plays a prominent role in most state-of-the-art products, applications and services, such as in cars, advanced manufacturing systems (e.g. ‘Smart Industry’), healthcare diagnostics, security provisions, public infrastructures, and many others. Many societal innovations incorporate application of technology in one form or another, as to improve quality-of-life or enhance effectiveness and efficiency of service. Therefore, societal innovation has become ever more reliant on latest innovations in embedded systems technology.

This universal application of embedded systems technology in all segments of industry and society has created challenging new opportunities for the Dutch high-tech industry . New industrial products, with enhanced functionality and better cost-performance represent a key element of the competitive position of our high-tech industry.

As a result of the speed by which today’s innovations take place, a continuously growing gap has emerged between the available technologies and the professional capabilities to effectively leverage on those. The bottleneck for future products is in efficiently and effectively developing highly intelligent, well performing and adaptive systems, where embedded systems technology acts as the key integrating discipline. This requires special attention to be paid to system engineering practices for product innovation, the accommodation of requirements from operational use, but also to the appropriate education and training of knowledge workers.

Comparing the Embedded Systems Roadmap version 2013 with the updated version 2015, two major additions can be observed:

1. Virtualization of design processes
   Traditionally, a high-tech product design process relies on the development of (partial) physical prototypes of the system design. These physical prototypes are constructed to test and evaluate functional and non-functional characteristics of the system. Typically, these systems are used to manage project risks by providing early proof of correctness of the design decisions. The weaknesses that are detected during physical testing of the prototype serve as drivers for redesign, allowing faults to be corrected as early as possible in the design stage.
   Design virtualization addresses the techniques to create a virtual (as opposed to physical) version of the system design. This is done by creating computer generated models that accurately represent key (functional, non-functional) characteristics of the system with the objective to simulate its behavior and performance in the real world. This allows key design decisions to be validated before committing a physical prototype or the product itself. The benefits of virtualization are clear – less mistakes in the early phases of system design, shorter time-to-market, improved internal communication, lower cost of product development, etc.
2. Expanding focus from products to services and solutions
   The high-tech systems industry is being confronted with a number of key trends:
   - *Customer-adaptable products*. The traditional business model of ‘selling boxes’ has steadily becoming obsolete. As a result, companies need to adapt their business models and reposition themselves in the value chain. This is especially driven by the fact that today’s markets require products that satisfy ‘individualized’ needs and flawlessly integrate with other (networked) products and applications, often from other manufacturers.
   - *Networked solutions*. To support the required added-value functions in a client application, the high tech system needs flawless integration in the customer workflow, being connected through intelligent networks, wireless communications, and data processing means.
   - *Globalized supply chain*. The globalization of the European industry requires the involvement of a large number of partners, suppliers, and re-sellers. This emphasizes the need for much stronger information flow across the value chain.

These trends require a much stronger emphasis on services and total solutions.

12.1.3 Vision on the program 2015 - 2018

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 VP

Embedded Systems Innovation supports these needs in a number of important ways:

- *Design and engineering*. Design and engineering of complex high-tech systems currently relies on fundamentals and models developed in computer science, physics, mathematics, mechanical engineering and electrical engineering over recent decades. The engineering discipline is in strong need to address the heterogeneity and multi-disciplinary aspects of the designs, to scale in the number of cooperating components and sub-systems, as well as to incorporate extra-functional requirements such as system performance and dependability.
- *Development processes*. There is a significant need for a more fundamental basis of embedded systems engineering to improve on the efficiency, effectiveness, quality and costs of the design/development process. The main needs are for: (i) a significantly increase efficiency of product innovation, (ii) early identification of system level design trade-offs, (iii) significant improvements in multidisciplinary design capabilities, (iv) design for integration and test.
- *Expend scope towards adaptive systems*. Today's products must be designed for tuning to customer specifications, must provide flawless cooperation with other products and applications (each with their own lifecycle) and be sufficiently future-proof to accommodate continuously changing operating needs during the product lifecycle. This leads towards emerging application fields of 'systems-of-systems' or 'cyber-physical systems', driving entirely new product design challenges and knowledge needs.
- *Human capital development*. In terms of human skills, based on the points mentioned above, there is a significantly growing need for systemic investment in education and training to develop the broader capabilities of the high-tech knowledge workers. In the area of embedded systems, this translates into a special need for education in the area of system architecting and multidisciplinary engineering to accelerate the relevant learning curves. But also, with the quickly changing technology base, life-long learning programs must be developed that address these ever changing knowledge needs.

A summary of these needs is presented in Figure 1, where the concept behind most of the Roadmaps of today's high-tech OEM industry is summarized.

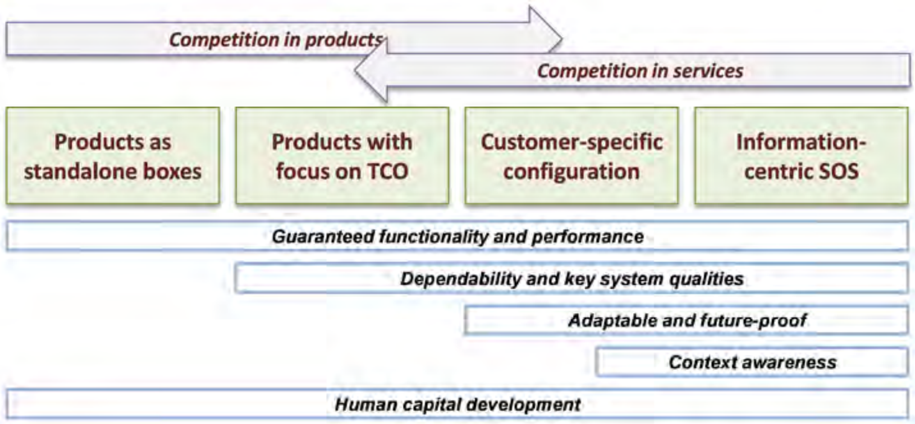


Figure 1: companies undergo a market paradigm shirt, by adapting their mix of products and services. This requires distinguishing technology innovations.

12.1.4 *TNO-ESI 2015 - 2018 Research Agenda*

The 2015-2018 TNO-ESI research agenda addresses a number of key system-level challenges in multidisciplinary system architecting, design and engineering. It emphasizes the fact the ever increasing complexity of high-tech system design cannot be dealt with by the current, mainly mono-disciplinary design methods and tools. It comprises four key lines of innovation that are embedded in the system level challenges of the HTSM Embedded Systems Roadmap and that address the key industrial market trends. These are:

- *System performance.* This research area focuses on quantitative design criteria for embedded applications and their resource utilization in trade-off with costs. Design for system performance focuses on satisfying the (often conflicting) extra-functional requirements and is determined by a complex coordination and balancing of inter-related events in subsystems and components. Achieving the desired system performance involves trade-offs between all disciplines involved in the design. The outcome of the TNO-ESI research program in this field can be used in a wide variety of application areas, leading to more reliable and robust products. The long-term goal is to realize multidisciplinary design approaches that realize full 'performance-by-construction'.
- *System quality and reliability*. Research in this area focuses on the relation to the correct functioning and overall behavior of a high-tech system. Design for system quality and reliability focuses on deployment of architectural principles, rules and patterns that focus on preventing design flaws and ensuring robust system operation. The TNO-ESI research in system quality and reliability focuses, amongst others, on methods and techniques for early system validation and certification, such as model-based methods for integration and test. These incorporate techniques for validation of highly configurable and adaptive systems-of-systems.
- *Future-proof systems.* The research focuses on the design of systems that allow for easy modification and upgrade during their operational life. Future proof systems allow for the accommodation of changing application needs, the ability to incorporate additional functionality, extend connectivity and incorporate new technology or components. Future-proof system designs are based upon platforms of design components or libraries of compatible hardware and software components, intended to maximize operational upgrades and thereby reduce investment risk and prolong a system’s useful economical life. The TNO-ESI research program addresses 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.
- S*ystems in context.* Research focuses on the design of systems that are context-aware and incorporate adaptive behavior. These technologies are applied in various fields of application to address pressing societal concerns, e.g. for security, health care, intelligent traffic and smart buildings. The TNO-ESI research program focuses on information-centric architectures in which embedded intelligence reflects and reasons on the system’s own operations and the interaction with its environment.

12.1.5 *Demand driven interaction*

The applications of embedded systems technology in the various industrial and societal fields, all rely on comparable technology building-blocks, methods and techniques. Because the management of complexity, functionality and interoperability of embedded systems is almost always at the heart of a technology concern, it is of utmost importance that new knowledge is not only generated for individual products or applications, but that opportunities for synergy 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. This provides benefits to all parties through a ‘knowledge multiplier’ and an ‘investment multiplier’.
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 of 3 key steps, where each step adds value and depth to the previous step:

1. *Programming*. This incorporates the translation of industrial and societal requirements into the TNO-ESI research agenda, programs and projects. This includes active support to national and international initiatives for setting up related research agendas, in particular for the HTSM Embedded Systems Roadmap.
2. *Research & Development*. This incorporates the execution of applied research programs that are driven by strategic research questions from industry and society. This includes the capture and generalization of research results into a sustainable knowledge base for general (re)use by the stakeholders in the TNO-ESI ecosystem.
3. *Innovation Support*. This incorporates the transfer of knowledge through collaboration with industry, network activities, seminars, workshops, events, publications, special interest groups and training. Furthermore an extensive competence development program for life-long learning is executed, addressing the development of professional competences for system architecting and engineering.

TNO-ESI and its academic partners work in close cooperation with their industrial counterparts, often at the physical location of the industrial partner. This direct collaboration between industrial and research partners gives a much better insight, understanding and appreciation of the particular problems at hand. It allows the research findings to be directly validated by application to the realistic complexity of industrial cases. In other words, valorization is pre-built into the process.
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. Without this explicit attention to the transfer and adoption of knowledge, the added-value of the results of the research projects may be lost.

12.1.6 *Target groups*

TNO-ESI works in long-term programs with a restricted but highly loyal stakeholders, mainly focusing on high-tech OEM industry and their (SME) suppliers. These customers span a wide range of markets and applications.

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

1. *OEM companies*. These are the industrial OEM's, including large international companies ASML, Océ, Philips, NXP, and Thales.
2. *Industrial suppliers*. These are the partners and suppliers of the larger OEM's.
3. *Tool vendors and process integrators*. These are the partners that professionalize the TNO-ESI tooling and integrate such tooling in the industrial development processes.
4. *Academia*. These are the universities that are involved in research and teaching in topics relevant to the embedded systems domain, such as TUD, TU/e, UT, RU, VU and UvA.
5. *Public and societal organizations*. These include the public bodies and industrial branches that are involved with high-tech industry . Our key contacts include, amongst others, HTSM Topteam, High-Tech NL, and regional development agencies; e.g. BOM and NV Oost.

12.1.7 TNO-ESI Program 2016

TNO-ESI is performing its research in close relationship with both academic and industrial partners. As the foundation of our research, TNO-ESI has a 1:1 research contract with the industrial partners. To create mass and volume, and to couple to the more fundamental aspects of academic research, this foundation is expanded with academic research projects. In addition, this combination is expanded via the European programs such as H2020, Ecsel and Itea; see Figure 2. All involved TNO-ESI and academic researchers in this stacked setting operate in the 'industry-as-laboratory' setting in close cooperation with their industrial counterparts; often at the location of the industrial partner.

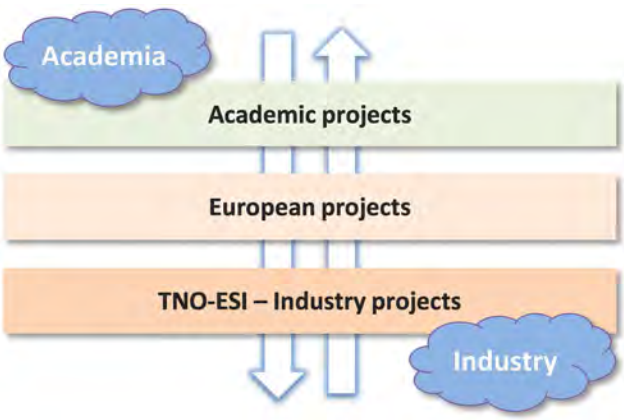


Figure 2: stacking of research to create mass and volume.

The anticipated TNO-ESI 2016 research program is depicted in Figure 3. The research activities are arranged around the four research themes: 'system performance', 'system quality & reliability', 'future-proof systems' and 'systems-in-context'. In addition, the stacking of academic, European and TNO-ESI/Industry projects is indicated. For each project, the key industrial partner is indicated and a one-line summary is highlighting the research essentials.

As a next step and an important step to maximize valorization impact, the research results obtained from each of these research projects are generalized for redeployment in other application areas, transferred for further exploitation in other research projects, demonstrated and discussed with interested parties and incorporated in training and education material. As such it forms the basis for an extensive TNO-ESI program for knowledge consolidation, dissemination, education and training (all part of “innovation support”). Please refer to Figure 4 for details.

System Performance	Academic projects	CPS CPS Health4FA Pacsal	ASML Océ ASML Océ	System-level performance prediction for timed supervisory control Integrated scheduling and control System health monitoring, anomaly detection and identification Design space exploration
	European projects	AAA4CPS	Philips HC/ Thales	Autonomy & adaptivity for Cyber Physical Systems Optimized use of resources in a dynamic and complex environment
	TNO-ESI – Industry	Concerto Octo+	ASML Océ	Performance by construction, virtualization of the design process Model-based design for data-intensive embedded systems
System Quality & Reliability	Academic projects	Sumbat t.b.d.	ASML Philips Lighting	Develop model-based test methodology Robustness of IP-based sensor networks
	European projects	OpenAIS	Philips Lighting	Architectural analysis of sensor networks Integration approach for sensor networks in application context
	TNO-ESI – Industry	TheMa Prisma	ASML Philips Lighting	Methods and techniques for model-based testing Model-based analysis of sensor network robustness, system start-up & system configuration
Future Proof Systems	Academic projects	CPS	Panalytical	Model-based approaches for mechatronic control
	European projects	Crystal Enable-S3	Philips HC Philips HC	Model-based systems engineering in a certification & safety context Virtual product development for Cyber Physical Systems
	TNO-ESI - Industry	Octo+ Allegio+ Prognosis	Océ Philips HC Thales	Virtual product development – architectural requirements and approaches Virtual product development and from legacy systems to model-based Virtual product development with focus on flexibility and multiple configurations
Systems in Context	Academic projects	S4-drive t.b.d.	NXP Océ	Self-diagnostic sensing systems for highly-automated driving applications Product data analytics and feedback to design rationale
	European projects	EMC2 Reflexion	NXP Philips HC / Océ	Integration of applications with different safety/security levels on a computing platform Run-time & offline analysis techniques that observe the system, provide feedback to product design, product validation and service
	TNO-ESI - Industry	TheMa i-Follow t.b.d.	ASML DAF/NXP/Ricardo Thales Service	Process mining for context aware system behavior Cooperative truck-platooning, architectural concepts and robustness Techniques and approaches for predictive maintenance

Figure 3: anticipated 2016 TNO-ESI research program.

Programming	**Agenda**	**If necessary, update HTSM embedded systems roadmap** **Align roadmap with other initiatives** **Align roadmap with strategic directions high-tech industry**
	Programming	**Programme definition and programme management** **Define/detail the TNO-ESI programmes in alignment with industrial trends and needs** **Definition of coherent set of programme objectives**
	Projects	**Definition of research projects (academic, European, industry)** **Coherency between project and programme objectives**
Innovation Support	**Consolidation**	**Definition of re-usable knowledge items**
		Generalize, extend, key knowledge items
		Transfer knowledge items to other projects, ecosystem and competence development programme
	Dissemination	**Inform the ecosystem**
		Share and demonstrate; e.g. ESI Symposium
		Discuss and experiment in networks
	Competence Development	**Program definition and creation** **New concepts for global roll-out (blended, on-line, scalable)**
		Alignment of program objectives with customer objectives
		Execute programme for key customers

Figure 4: summary of 2016 TNO-ESI programming and innovation support program.

13 Ondertekening

Eindhoven, 21 september 2015 TNO

A.J.A. Stokking
Managing Director Industry