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TNO-rapport

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Contents

1 Introduction

The report describes the TNO speurwerk plans for 2015 in the domain of the Topsector HTSM. In previous years a different layout with TNO Demand Driven programs (VP, Vraaggestuurde Programma's) was used. This time we use the HTSM Roadmap structure as starting point.

A HTSM Roadmap council chairman has to read the specific chapters only. Internally TNO is organized different. The size of our contributions to different Roadmaps differs and internally TNO is organized around expertise, not markets such as the majority of HTSM Roadmaps. An example is the TNO Space and Scientific Instrumentation program with a lot of optics expertise active in the Space and Advanced Instrumentation Roadmap. Or the TNO Free Form and Flexible Products program with a lot of material and processing expertise is responsible for the Holst Centre, Solliance and other organizational units and contributes to multiple Roadmaps. All programs, expect Automotive and Security, are part of TNO Industry, chaired by Mr Arnold Stokking.

Besides this simplification this year other small changes took place. In particular we merged the Additive Manufacturing completely in the printing Roadmap. And the Mechatronics and Manufacturing Roadmap will get fully aligned with the Smart Industry (manufacturing) initiative with a separate workgroup on Mechatronics.

Finally in certain area's we narrowed our focus towards certain aspects because of the decreasing financing. We stopped activities in the areas of Photonics and Aeronautics. In the area Nanotechnology we now introduce a new subject. Sofar we did not do anything formally within the HTSM Nanotech Roadmap as all nano related subjects were dealt with in application HTSM Roadmaps, we now face a technology 15 years ahead of the market: quantum computing.

2 TNO applied research in HTSM Roadmap Semiconductor

2.1 Introduction

It is difficult to imagine the modern world without electronics. The internet, electronic banking, mobile communication, GPS, digital archiving and retrieval, and surveillance, to name a few, rely on advanced electronic circuitry, particularly integrated circuits (chips). With further microchip advancements, it is anticipated that electronics will enable a more sustainable society in many ways. Electronics consuming less power, or improving power efficiency in, e.g., GSM base stations and street lighting, are foreseen to contribute to a less power hungry developed world. Wireless network systems will gather and deliver ambient information to foster safety and security, for instance in automated dike monitoring, road traffic control and airport security; and enable “smart buildings” where climate control is automatically adjusted to real demand. New electronic systems for point-of-care medication and diagnosis will contribute to the needs of an ageing society.
The aforementioned rapid advancement of microchips is made possible by three mechanisms: the miniaturization of components, the increasing size of chips and substrates (wafers), and the advancement of manufacturing technology. This means that an enormous amount of R&D work is still ahead of us. (Early) production tools (i.e. patterning tools from ASML and MAPPER, metrology tools from Carl Zeiss, Applied Materials, Bruker and wafer processing tools from, a.o., ASMI) become available for process development (pilot lines) during 2015 and will be continuously upgraded thereafter. This also puts a stress on the Dutch supply chain of these OEMS (Demcon, Bronkhorst, VDL, AAE, …) to produce on an even larger scale while at the same time improve to an unprecedented level of nanoscale cleanliness.

2.2 Program 2015-2018

TNO aims to bridge the ‘valley of death’ in technology transfer from fundamentals to applied knowledge for semiconductor applications. Especially for semiconductor there is a large gap between understanding the fundamentals and use in applications. For instance for particle detection below 10 nm there are techniques being developed at academic institutes, however introducing these techniques also means looking at throughput, high volume manufacturing, large area processing and costs. On molecular level several models are being developed for contamination growth in very specific circumstances and in well controlled environments, translating these to ‘real’ life situations and being able to predict behavior of very complex systems as found in the semiconductor industry require a large effort. In addition the levels of contamination which are going to be acceptable for the industry in order to maintain the yield and quality of the processes is continuing to become more strict and are already below what can be measured with state of the art measurement systems. New technologies have to be developed for detection of particle and molecular contamination as existing technologies have reached their physical boundaries. In order to keep the industry up to pace huge investments are needed in the coming years to develop proof of principle and prototypes which fulfill the industry needs for process development and pilot line production.

2.2.1 *Background, context, definitions and long term visions*

The technology that TNO develops/applies to the semiconductor market is of extreme performance. Either in stability, precision, resolution, or cleanliness.
For the coming years TNO will focus its knowledge development in a multi-disciplinary approach at the following new technologies:

- Sub-wavelength optics, local spectroscopy
- Picometer stability (active and passive)
- Contamination control extension to non-carbon materials and <20nm particles
- Nanoscale 3D (additive) structuring

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.

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 can contribute to these challenges by, e.g., miniaturization of components (e.g. AFM) 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 are initiated on ETP- and SMO projects during 2012/2013, guided by two Principal Scientists of Optomechatronics.

Contamination Control

TNO holds a strong position in molecular contamination control, built up during 2004-2013. But for particle contamination we expect to be able to extend our knowledge. All Roadmaps for the semiconductor industry point out the demand for capabilities to detect particles as small as 10nm, and the current limitations thereof. TNO is positioning itself already for particle detection down to 20nm. With our capabilities in optics and equipment development TNO should be able to reach for 10nm particle detection. This development is already ongoing for several years. A critical development step, i.e., from 40 to 20nm particles, is being taken during 2013/2014.
In parallel, the field of molecular contamination is expending from carbon contamination to other (organic and inorganic) contamination as well. This technology holds relevance to Space and Scientific Instrumentation, too.

Nanoscale 3D (additive) structuring

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.

2.3 Ambition and Impact

At the highest level the impact goals and underlying objectives are derived from the ITRS, EU PPP/KET/H2020 Roadmaps and the national SCE TKI Roadmap. For TNO, the impact goals for semiconductor manufacturing Roadmap are all related to sustainability:

- ***Economical sustainability*: In 2025 there will be 10.000 extra jobs in the Netherlands by strengthening the position of the Netherlands as THE nanoscale manufacturing equipment supplier of the world.**
  - Retain the strong Dutch position in semiconductor manufacturing equipment by developing new technology to sustain Moore's Law and broaden the portfolio (for instance patterning for the photovoltaic market, Flat Panel Display, or Electronic Circuit Patterning).
  - Provide the competitive edge to the Dutch parts and assembly producers to become THE supply chain of international semiconductor industry by world-wide leadership in ultra-clean and additive production technology.
  - Create a new Dutch OEM for niche inspection & metrology equipment.
  - Be a world-class player in disruptive technology development towards atom scale 3D manufacturing (AFM-lithography, additive or direct write patterning, etc.).
- ***Ecological sustainability*: in 2025 30% per die area saving in chemicals and energy consumption.**
  - Be the world leading institute on contamination control for electronics manufacturing with an emphasis on waste reduction by yield improvement ('better machine and process control') and lower chemical usage in necessary contamination prevention and removal steps.
  - Be a kick-starter technology provider to enable the change in Moore's law from dies/area to Energy/function by kick-starting breakthrough technology developments in the large semiconductor industry transitions: EUV lithography, 3D transistors and systems, application of III/V materials, and application of photonics.

2.4 Demand driven interaction

The instruments of TKI additional projects (currently already running on molecular and particle contamination, additive manufacturing and alternative lithography technology are demand driven in itself as the industrial partners actively join in the knowledge development as well as providing the application background to the knowledge development.
Next to this TNO plans to have a half yearly partner meeting with the industrial partners taken part in the TNO International Centre for Contamination Control (ICCC). Here, the partners can jointly steer the direction of the knowledge investment while at the same learn of the progress made in the running projects on a shared basis.
Finally, for the non-contamination control subjects TNO will organize a round-table meeting to inform the industry on knowledge progress as well as to solicit for new ideas and directions the industry requires. This input could then quickly turned into TKI and/or EU-projects.

2.5 Cooperation

Foreseen impact and target group

TNO aims to secure the position of the Netherlands as semiconductor manufacturing equipment supplier to the world, by helping the industry to find solutions for current challenges while at the same time constantly challenging the current technological pathways. This will not only bring job security to the Netherlands for the years to come but also enables the electronics industry to play its pathfinder role in solving some of societies largest future challenges.

Cooperation

1. Our value proposition in 2015-2018 (our product/services portfolio) will be joined 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 International Centre on Contamination Control (ICCC). This will attach new partners like end-users, OEMS and suppliers, especially Dutch SMEs.
2. To strengthen our knowledge position but at the same time our visibility in the semiconductor community partnering with SEMATECH (USA), Imec (BE) and/or MIRDC and NAR Labs (Taiwan) is foreseen. Again this will be centred on our contamination control ambitions.
3. 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 Institute for Nanolithography (UvA).
4. Furthermore TNO is and will be a partner in NanoNextNL as well as in several EU programs especially on a series of projects on 7-nm node implementation. TNO has been involved over the last 3 years and is currently involved in the set-up of the next projects for 2015-2017. Cooperations are foreseen with the likes of ASML, ASMI, AMAT, Carl Zeiss, FEI and Imec, amongst others.

2.6 Program 2015

TNO Semiconductor Equipment is divided in two programs. The first focusses on the primary production process, Semiconductor Manufacturing Equipment (SME). Like previous years this program will focus on (a) Extreme Machine Control and (b) Front-End Processing.
The second program targets on the periphery of the primary (secondary) production process, Yield Improvement Equipment (YIE). Also this program will continue its investments from previous years in (a) metrology and inspection and (b) high-sensitive, ultra-clean part infrastructures.
In other words, the projects in SME add value to the end product and projects in YIE prevent value-loss of the end product.

<u>Semiconductor Manufacturing Equipment – Extreme Machine Control</u>
Process independent sensor systems – aims to develop innovative polarization and distance measurement sensors to meet the Picometer stability required in next-generation patterning and metrology systems.
Sub-wavelength Optics – aims at understanding and applying the new possibilities current research in metamaterials and metasystems to the semiconductor industry.

Advanced Process Control algorithms – aims to develop complex, but generic algorithms for fully integrated, through-fab process control. Part of the EU Integrate project.

Semiconductor Manufacturing Equipment – Front-End Processing
3D nanomanufacturing – following the sub-wave length optics workpackage, a first exploration in the field of true 3D (additive) nanostructuring will be made.

Yield Improvement Equipment – Metrology and Inspection
Sub-20nm optical particle inspection – aims at realizing a low-cost particle inspection system for qualification of ultra-clean systems.
High-Thoughput Scanning Probe Microscopy – aims at a disruptive application of AFM for defect review for 7-nm node and below.

Yield Improvement Equipment – Ultra-clean parts infrastructure
Ultra-clean mask handling – aims at developing the ultimate particle free EUV substrate handling system, both for parts and module qualification as well as supporting the EUV mask infrastructure developments.
Standardization of Outgassing qualification – aims at improving the knowledge level of the supply chain in delivering ultra-clean parts, especially in low-cost, industry-accepted procedures of qualification.
Low-waste cleaning – aims to reducing the amount of chemicals required to clean patterned and sensitive surfaces during manufacturing.

3 TNO applied research in HTSM Roadmap Nanotechnology (QuTech)

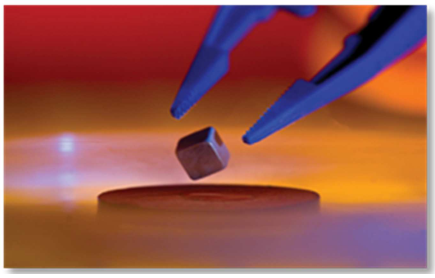
3.1 Introduction

TNO is applying nanotechnologies in our application fields given the more shorter time focus in applied research versus academic research. So far we had no separate Nanotech program planned within the HTSM Nanotech Roadmap. The QuTech program however has a 15 year time scope and is most suited within today's HTSM Nanotech Roadmap.

Quantum mechanics is the theory to describe the (interaction between) elementary particles. Academic research has confirmed the validity of this intriguing theory as well as many of its counterintuitive aspects. But only due to recent breakthroughs is it possible to demonstrate important quantum mechanical concepts on systems large enough to be visible to humans. The concepts of 'superposition' and 'entanglement' could now be used in a controlled way, and thereby open the path to applications like the most powerful computer ever imagined, the Quantum Computer, and communication which is inherently safe for eavesdropping, called Secure Quantum Internet. Or as the Nobel Prize Committee formulated it in 2013: "Perhaps the quantum computer will change our everyday lives in this century in the same radical way as the classical computer did in the last century".

The Netherlands is very well positioned to take a leading role in this currently ongoing international competition to develop and industrialize these applications. This shall have a huge impact in many fields:

- A Quantum Computer shall finally provide the society with the required computational power to work on some of the Grand Challenges: The development of room-temperature superconductivity will provide us with lossless energy transport and storage which in its turn solves our energy shortage. The development of new medicines will be done by rigorous calculations instead of trial and error, which reduces both costs and time. And more.



1. Superconductivity is now only possible at low temperatures.

- Secure Quantum Internet is the ultimate encryption: there will be no means to listen in to secured communication. The quantum computer on the other hand, will be able to crack most classical encryption schemes. It is therefore of vital importance for the Netherlands to be one of the first countries in the world to have access to the most advanced quantum technologies. Related (Grand) Challenges are Cyber Security, Digitalization, and Safe Society.
- The Netherlands could be a centre of excellence on quantum technologies. This will be a new impulse to the Dutch economy by generating thousands of high quality, sustainable jobs.
- This centre of excellence will lead to significant knowledge transfer to other sectors like nanotechnology, electronics, and semiconductor industry, and

thereby improving the relative competitive position of our industry and safeguarding employment.
- Like the development of the transistor, the core component of the classical computer, the development of the quantum bit and quantum computer will lead to numerous spin-off.

For all those reasons, the Minister of Economic Affairs Mr Kamp announced in September 2013 the start of QuTech. This institute has been founded by the Technical University of Delft (TUD) and TNO to cope with the challenges in research, development, commercialization, and coordination & cooperation with industry and institutes still ahead of us. This ERP "Quantum Computer and Quantum Internet" forms within TNO the basis for QuTech.

2. The QuTech logo

During 2014 the TUD and TNO laid the foundations of QuTech (Development of technical plans, contracts for cooperation, discussions with industry and closing contracts with first commercial partner). In the years 2015-2018 QuTech will make the change from academic research at the university to mission oriented development of the quantum computer and secure quantum internet. As part of this ERP, TNO will develop a series of experimental process flows, proof of concept components and setups, to demonstrate the feasibility of several core technologies.

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

3.2 Program 2015-2018

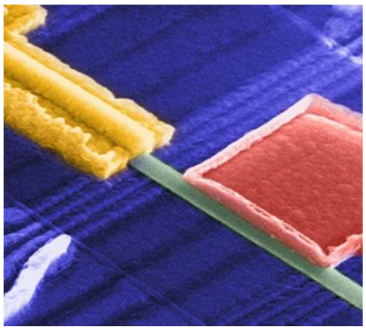
The envisioned developments cover many TRL's, multiple disciplines, and thereby about 15 years. This will result in a different approach during the subsequent phases of the development. The first phase (2014 – 2017; Proof of Principle) will be dominated by solving the current bottlenecks to accelerate the research, and by making the transition towards the mission-based way of working. The latter includes, amongst others, a better defined goal of the project, working out the project plan, system architectural considerations, and involving third parties.
The second phase (2018 – 2022; Proof of Concept) will be used to demonstrate progress on key technologies (critical milestones), benchmarking, defining the requirements and system architecture, and updating the project plan including contributions by third parties and potential spin-off. Also a relevant and mathematical challenge shall be selected for the demonstration. This challenge shall be mapped to the electronic hardware.
During the third phase of the project (2023 – 2029; working demonstrator) all technologies shall be developed to the level of a working demonstrator. A convincing demonstration shall be executed. Positioning the Dutch industry (by knowledge transfer) is critical during this phase.

QuTech works according to four Roadmaps, one for each type of qubit. The most critical enabling technologies that will be developed during the coming years are incorporated in the most relevant Roadmap. The state-of-the-art, knowledge gaps, and planned developments will be described per Roadmap. (Beyond 2018 Roadmaps will likely be organized according to components and modules of the quantum computer or setups for secure quantum internet.)

Roadmap A: Topologically protected qubits

So called zero state- or Majorana qubits have the potential of very long coherence times. The most convincing experiments on the demonstration of the appearance of Majorana quasi-particles have been performed by the TUD in 2012/2013. This was done on devices based on InSb nanowires in which superconductivity is induced by a connected superconductor. A qubit based on Majorana quasi-particles actually requires braiding of those Majorana particles which in turn requires the integration of a few nanowire crosses (instead of nanowires) in combination with a few Josephson Junctions.

The research in this Roadmap is focused first on improvements in materials, device technology, and measurement techniques. Improvements in materials are needed to reach higher electron mobility in the nanowires/nanocrosses. A new process flow shall lead to better control/prevention of contamination, and in-vacuum growth of superconductor and semiconductor material shall lead to ultimately well-defined interfaces. Several properties of the current superconductor material NbTiN, like the quasi-particle density of states within the superconducting gap, are unknown. This material will therefore be characterized better by means of tunneling studies.



3. SEM image of Majorana device (false colours; TUD).

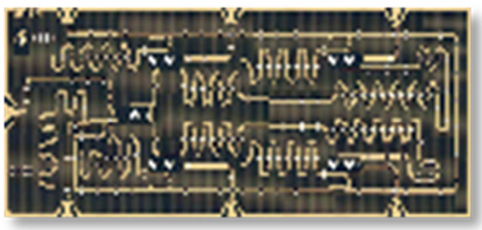
The interface between the semiconductor and superconductor materials is the most critical and very sensitive to imperfections like oxidation, dangling bonds, chemical residues, or non-homogeneous coverage. To improve this interface we will investigate etch recipes which are more gentle than the current Ar sputtering (needed to remove native oxides that show up due to transport of the nanowires from the growth chamber at TU/e to the deposition chamber at TUD). High-resolution electron microscopy will be used to investigate the precise interface coverage. Deposition of the superconductor material by means of sputtering maybe replaced by other techniques or materials. A new deposition tool will be installed and a new process flow will be develop to ultimately execute all material growth and deposition steps in one system without breaking vacuum. The device is grown on top of an insulating Si substrate with gate pattern. This ‘gate chip’ will be improved by better planarization (even CMP seems to result in too rough surfaces), and selection of a dielectric material which is both high quality (no charge noise on timescales of days at low temperatures) and enables a non-reactive and hydrophobic surface to avoid reactivity in ambient conditions.

TNO will work on most of the challenges mentioned above: TNO’s experience with nano-fabrication and contamination control will be required. Also the new deposition tool will be installed in the cleanroom of TNO and a specialist in this technology will be hired. Finally TNO will execute simulations on multiscale physics to understand, amongst others, the effects of stress induced in the nanowires by cooling down from room temperature to 15 mK on electron mobility.

Beyond these developments this Roadmap will focus more on the development of so called Majorana-Cooper pair Boxes (MCPB), superconducting-insulating-superconducting (SIS) junctions, integration into a circuit, and finally the actual braiding of Majorana’s.

Roadmap B: Surface Code & transmon qubits

The transmon qubits are relatively speaking the most mature type of qubits. Circuits with 5 qubits with controlled interaction are currently being studied. The activities over the next few years will be dedicated to the development of



4. Circuit with multiple transmon qubits (TUD).

a 17-qubit design. This is the smallest set of qubits required to demonstrate surface code protection. This protection against decoherence is based on a set of primary qubits plus ancillary qubits. The latter will be used to probe decoherence at the primary qubits (parity check), followed by repair of the states of the primary qubits. Important technological developments on which TNO will work include the development of electronics architectures for circuits with more than 8 qubits, more compact resonator designs (to make devices with more than 17 qubits fit on one chip), and FPGA- and RF technology for fast electronic feedback control.

Roadmap C: Surface Code & spin qubits
Spin qubits may intrinsically have longer coherence times. Still surface code protection is required. Current research topics include scaling to circuits of 5 qubits, and integration on the devices of the superconducting transmon qubits.
Important technological developments on which TNO will work include investigation of potential 2D architectures (required for scaling beyond about 5 qubits), a PCB/interposer for connection of about 100 DC-, RF-, and microwave signals to/from the circuit, nano-lithography and contamination control for higher quality devices and miniaturized qubits (to reduce the number of imperfections in the device which limit the coherence times).

Roadmpa D: Encryption & N-V centers
The fourth type of qubit is based on the N-V color centers in diamond. One of the advantages of this type of qubit is the possibility to read the state of this qubit by means of visible photons. This makes this type of qubit attractive for applications in encryption and communication via glass fibers. Entanglement over 3 meters distance has been demonstrated by the TUD last year.
Challenges include the efficiency in coupling light to the fibers, wavelength conversion (from the intrinsic wavelength of N-V centers near 637nm to the wavelengths used for telecommunication, needed to make use of known technologies and reduce the transmission losses in fibers), generation of arrays of color centers in a controlled way.

Grouwing the ecosystem 2015-2018
Discussions with industry are already aimed at participation of industry in the envisioned developments. Industrial partners could accelerate these developments on the one hand, and industry could use the experience with working with qubits in other markets. Some examples:
ASM could advise QuTech on challenges in material deposition and interface control, and could even execute some test for us. In return ASM could have early access to state-of-the-art nanowires and use this to develop new processes and equipment before the industry will incorporate nanowires in CMOS.
FEI could help QuTech with its state-of-the-art microscopes. In return QuTech could provide FEI with samples with unique combinations of materials which can be used to develop the microscopes further.
IDQuantique and Fox-IT have a strong interest in Quantum Key Distribution. Those companies could advise QuTech on the availability of current technologies and the specifications as set by (potential) end users. In return QuTech could give early access to the latest quantum communication demonstrators.
Similar cross-over may be possible with companies, large and small, working in the field of low-temperature electronics, cooling technology, multiscale physics simulations, fiber array technology, etc. QuTech will actively work on the development of such cooperations. In parallel QuTech is looking for partners who share the ambition of developing the first quantum computer, like Microsoft.

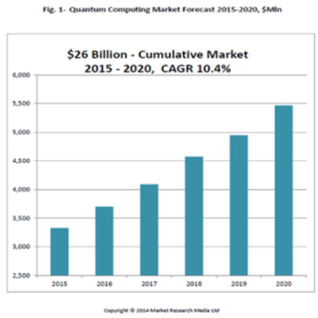
3.2.1 *Vision*

International perspective

Some quotes from the “Quantum Computing Market Forecast 2015-2020” (2014) by consultancy agency Market Research Media Ltd illustrate the international focus on quantum computing:

- Quantum computing is a geopolitical game changer.
- Quantum computing opens new horizons almost in every aspect of human life, whether it’s new medicine or renewable energy.
- Quantum computing is an economy game changer, with a potential of disrupting entire industries and creating new ones.

This report also states that the quantum computing market is of significant size and growing fast: 3.3B$ in 2015 to 5.5B$ in 2020. Although for the coming years the vast majority of the budgets are related to investments, of course.
Companies like Google, Lockheed Martin, and IBM invest heavily in quantum technology. The latter is developing technology itself, the other two are mainly buying in knowledge from American universities. Also institutes like NASA and the NSA allocate huge budgets to it as could be read in The New York Times, The Washington Post, and MIT Technology Review over the last two years.
Also Microsoft invests in quantum computing. Microsoft works on the theory and architecture of quantum computers and has selected a few partners for the development of hardware. Microsoft has selected the TUD/QuTech as one of the main partners and is funding the current developments in Delft already.
Currently only D-Wave, a Canadian company, claims to manufacture commercial quantum computers. Whether this computer really is a quantum computer is subject to debate, however.



5. Quantum computing market forecast.

6. Former boss of Microsoft send a message on twitter about the importance of quantum computing.

The best international institutes working on quantum technology are universities like Sante Barbara and Berkely, as well as Innsbruck, Munchen, and Zurich. Most universities focus on fundamental research and are therefore no direct competitors for QuTech. The initiatives in the German speaking region do have a technological focus, but their expertise is in the field of optical quantum technology, whereas Delft is more experienced in solid state quantum technology.
QuTech has the ambition to initiate a European Flagship on quantum technology. The joint European institutes have a leading position in fundamental research in quantum computing. The solid state technology in Delft, the optical technology of the German speaking region, and the more fundamental research in England, France, and Denmark are complementary and together ahead of any other region in the world. QuTech, with the highest ambition towards industrialization of quantum technology seems to be the natural leader for such initiative.

Dutch perspective

The TUD hosts a team of world class scientists in solid state quantum technology. Four out of the ten of most-sited scientists of the Netherlands (all fields of expertise) all work in Delft in this field (source: Volkskrant, October 2012). This team also had

10 papers in the Nature magazines in 2013. This is the scientific foundation of QuTech.
On the other hand the Netherlands has a large ecosystem of high-tech/high-precision equipment manufacturing companies including an extended supply chain. This sector has developed and successfully commercialized tube technology for radio and television, transistor and chip technology, lighting and medical equipment, and wafersteppers. Each wave of innovation has led to a new wave of employment. And like ASML and FEI started as spin-off companies from Philips, it is now time to create the new seed for high-tech business. This infrastructure of high-tech industry will accelerate the development of the quantum computer now. In the future the quantum technology will be a new unique selling point of this Dutch ecosystem.
Mayor of Eindhoven Mr Rob van Gijzel confirmed already the importance of quantum technology, developed in Delft, for his city: ”Ik ben zeer verheugd over de krachtige voorwaartse ontwikkeling van Quantum Computing in Nederland die door het QuTech centrum gerealiseerd wordt. Dit is een toekomstige technologie die van groot belang is voor de technologiesector in de regio Eindhoven”. (private communication).

TNO perspective
TNO is experienced in multiple technologies which are critical for the development of the quantum computer, and complementary to the knowledge of the TUD. Secondly, TNO brings to QuTech its experience in prototyping, mission oriented project execution, and contacts to the industry.
By building prototypes and demonstrators based on the state-of-the-art scientific knowledge of the TUD, TNO/QuTech shall be positioned as a pioneer in quantum technology. Moreover, TNO/QuTech will invite industrial partners to participate in the development of the demonstrators to strengthen the relationships and have some of this work funded by industry and European projects.
On the other hand TNO has to develop some of its existing technologies further to meet the requirements of the quantum computer (e.g. RF-technology, nanofabrication, multiscale physics simulations). This will improve the competitive position of TNO in the existing (non-quantum technology) markets like nanotechnology/semicon and RF-technology/Radar. These markets are already very important to TNO.
Finally, the further development of existing and new technologies generate possibilities for unforeseen spin-off.
The first 6 months of QuTech enabled TNO already to discuss potential cooperation with Agilent, ASM, ASML, ATOS, Dept. of Defense, FEI, Fox-IT, ID Quantique, NL-NCSA, and NLR.

3.3 Demand driven interaction

TNO Themes and Programs
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.

Technological developments in QuTech are directly connected to the following Themes and Programs:

- Industry – Semiconductor Equipment. The semiconductor industry will soon be fabricating devices with critical dimensions of 7 nm and below. At those scales quantummechanical effects cannot be ignored anymore. Experimental experience with quantummechanical effects as well as experience with the

applications of new materials that will be applied in conventional CMOS is relevant for TNO and its industrial partners like ASM and FEI.
- Industry – Flexible & Free Form Products. This Roadmap is frequently inspired by the state-of-the-art knowledge from the semiconductor industry.
- Industry – Space & Scientific Instrumentation. Quantum technology enables the development of beyond state-of-the-art detectors which can be applied in this domain. Single Quantum and SRON already work on the application of sensors based on those technologies.
- Defense & Security – Cyber Security & Resilience. Quantum technology will enable inherently interception-safe communication, as well as quantum computers able to break many conventional encryption schemes.
- Defense & Security – National Security & Crisis Management. See above.
- Other Roadmaps will ultimately be affected by the availability of unprecedented computing power. But this impact is not expected to materialize before the end of this four year plan.

National Topsectors and Themes/Stakeholders
The TopSector Nanotechnology has adopted QuTech already. The HTSM TKI-Board has allocated funding to QuTech/TNO for the years 2014-2016.

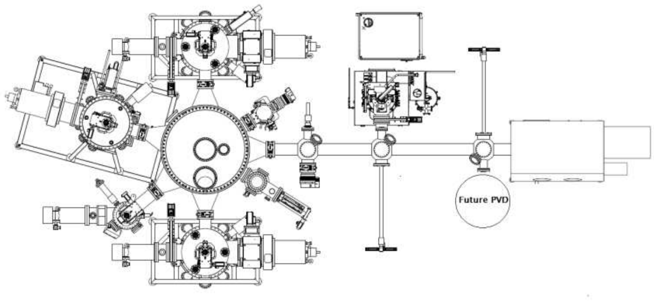
Academic patners/programs
The main partner in QuTech for TNO is of course the TUD. The world-class scientific heritage of the TUD forms the foundation for QuTech. The TUD invests tens of millions of euros in QuTech: about 20 staff members (professors and supporting staff) and renovation of the building/laboratories is funded by the TUD. Moreover, the TUD has already about 70 scientists working in Qutech, funded by FOM/NWO- and European grants and industrial sponsoring.
Also the Technical University of Eindhoven participates in the work of QuTech by means of the group of professor Erik Bakkers, specialized in the growth of semiconducting nanowires.
The Leiden University participates in QuTech by means of the group of theoretical physics headed by professor Carlo Beenakker, specialized in mesoscopic physics.
The University of Twente may participate in the future as well, likely in the field of materials science. Discussion are ongoing but no concrete activities yet.

EC H2020 opportunities
QuTech has the ambition to initiate and lead an EU Flagship like cooperation. Discussions with ‘Brussel’ are ongoing already, with support from ‘The Hague’.
In parallel QuTech will submit proposals to regular calls of H2020, STW, FOM, etc. Some upcoming calls in H2020 open opportunities for funding of research and development in the field of quantum computing, quantum communication, or quantum technology in general. Some technological developments may also find funding by calls related to, e.g., low temperature electronics, integration of new materials into the process flows of More Moore. TNO and TUD are currently studying which proposals will be submitted to which calls in the coming years.

3.4 Program 2015

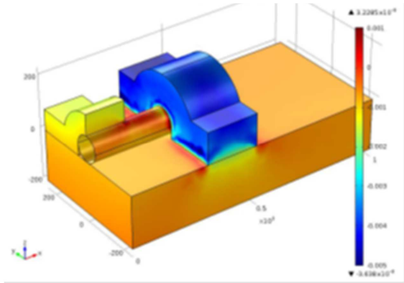
QuTech will work on more work packages and scientific questions than described here. This chapter describes only the activities TNO personnel is involved in.

Roadmap A
For the topological protected qubits it is most critical to get the new cluster tool up and running. This will enable for the first time the growth of nanowires and subsequent deposition of superconducting material without breaking vacuum. Calibration and testing of this complex setup and related process flows is expected to take significant time and effort in 2015.



7. Layout of the new deposition cluster tool.

Multiple colleagues will work on nano-fabrication of the devices. The contamination and surface conditions of the superconductor-semiconductor interface is currently being investigated. This shall result in new insights in optimal surface conditioning between process steps. In 2015 the preferred cleaning/conditioning/etching technique shall be validated on realistic devices and implemented in the process flow. In parallel we work on the development of extremely flat basis devices with embedded bottom gates.



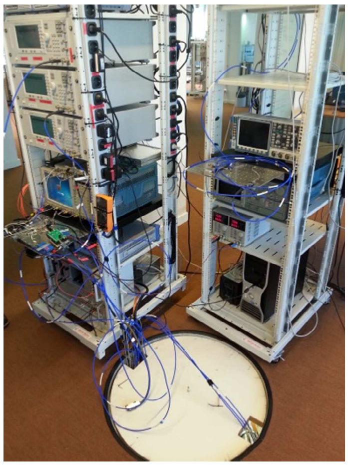
8. Simulations give insight in, e.g., the relationship between stress and electron mobility.

Thirdly, simulations on nanowires and their environment will continue to develop better understanding of the relationship between stress and electrical performance.

Roadmap B
By the end of 2014 the first circuits with 8 transmon qubits shall be tested. While the colleagues from the TUD will investigate more fundamental questions, the colleagues of TNO will focus on implementation of feedback control based on FPGA's (the design thereof is ongoing since mid of 2014).

During 2014 TNO realized the first demonstrators for RF multiplexing for qubit control. In 2015 this technology shall be improved and extended to larger numbers of in- and outputs.

TNO will also improve the contamination control for the device manufacturing of these transmon qubit devices.



9. First demonstrator of RF multiplexor technology (green PCB on the left) incorporated in electronic control for transmon qubit circuits. The actual circuit is mounted in the cryostat one floor below the electronics racks on this picture.

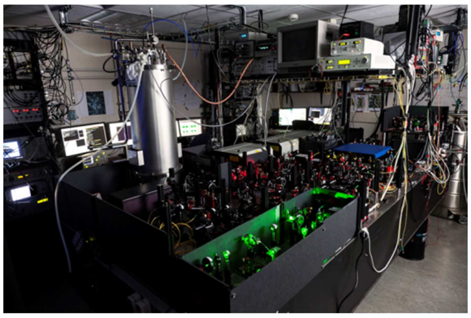
Roadmap C

The initiation of spin qubits is very cumbersome. When future circuits contain more than a few qubits the initiation will take weeks. TNO aims to develop a machine learning algorithm to automate this process. While saving a lot of time in the near future, this technology may open more options for control and feedback to the qubits.

The coherence time of the spin qubits is affected by defects in the substrate material. TNO will investigate the possibilities and limitations in nano-fabrication to reduce the impact by defects.
Finally, TNO will 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

When teleportation is demonstrated over more than one kilometer by the end of 2014, the following technical challenges have to be solved. First, conversion of 637nm light to wavelengths used for telecommunication is required to make use for 'standard' telecommunication technology for further development of the secure quantum internet. The theory of the required non-linear optical effects is studied and a test setup is built in 2014. During 2015 colleagues of TUD and TNO will work on a demonstration of such wavelength conversion with sufficient efficiency to meet the requirements for this application.



10. Setup used by the TUD to demonstrate teleportation over 3 meters.

The collection efficiency of the currently used solid immersion lens for N-V centres in diamond is not sufficient to support further progress. In 2014 TNO developed a control algorithm to apply a 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. Experiments in 2015 shall show the improvements due to this adaptive optics and may raise new challenges.

Future applications require the use of arrays of N-V centres which are optically coupled to arrays of optical fibers. This requires first the technology to generate well defined (positioned) arrays of N-V centres. TNO will work on the controlled positioning of arrays of N-V centers in 2014-2015. The lead time of this research is likely large compared to the effort.

The development of fiber arrays will be started in 2015. TNO will use its experience with this type of challenges from former projects. A very innovative alternative based on the technology of a Dutch SME may be considered as well.

4 TNO applied research in HTSM Roadmap Nanotechnology (Human Risk Management Nano)

4.1 Introductie

Nanomaterialen hebben een enorme marktpotentie vanwege hun unieke eigenschappen. Er zijn al vele nanomaterialen op de markt in verschillende sectoren bijvoorbeeld in de energie, bouw, coating, cosmetica, schoonmaak, kunststoffen en bandensector. De investeringen in nieuwe nanomaterialen zijn fors. Inmiddels dienen zich ook al weer nieuwe generaties van nanomaterialen aan op de markt: hybride nano-moleculaire systemen, organisch-anorganisch of passieve-functionele nanomaterialen.

Tegelijk met de kansen die de ontwikkeling van nieuwe nanomaterialen bieden, is er een groeiende aandacht voor de mogelijke risico's die het gebruik van nanomaterialen met zich meebrengen. Uit een recent TNO onderzoek blijkt dat enkele duizenden werkers van de Nederlandse beroepsbevolking mogelijk wordt blootgesteld aan nanomaterialen. Een snelle groei van het aantal potentieel blootgestelde aantal werkers wordt verwacht door de grote marktpotentie van nanomaterialen. Tevens is er zorg voor consumenten en milieurisico's.

In dit VP wordt samen met het VP 'Human health risk management chemicals' vorm gegeven aan risico onderzoek nano.

4.2 Programma 2015-2018

Bij de introductie van nieuwe technologieën dienen zich naast kansen ook steeds vaker risicoproblemen aan die gekenmerkt worden door grote onzekerheid over de kans op en de omvang van de gezondheidsrisico's. Nanotechnologie is een typisch voorbeeld van een nieuwe technologie waarbij de technologische vernieuwing dusdanig snel gaat dat informatie over veiligheid daarbij sterk achterblijft.

Dit leidt tot onzekerheid omtrent potentiele risico's voor mens en milieu, wat tot vermindering of vertraging van marktacceptatie kan leiden. Dit gegeven onderstreept dat voldoende aandacht moet worden besteed aan de ontwikkeling van alternatieve risicobenaderingen die het tempo van de nieuwe ontwikkelingen aan kan. In dit programma wordt via het NanoNextNL programma en diverse EU projecten gewerkt aan een geaccepteerde benadering voor evaluatie en beheersing van dergelijke nieuwe risico's rond nanomaterialen.

In het programma wordt naar de balans gezocht tussen enerzijds het faciliteren van maatschappelijk gewenste innovaties en anderzijds beleid gericht op veiligheid. In dit programma willen we de kansen die nanotechnologie biedt voor duurzame economische bedrijvigheid, koppelen aan het streven deze kansen ook veilig te benutten.

4.2.1 Strategische ontwikkelingen

De verwachtingen over de maatschappelijke en economische potentie van synthetische (bewust geproduceerde) nanodeeltjes zijn hooggespannen. Het Nederlandse Kabinet streeft ernaar om de maatschappelijke en economische kansen in Nederland verantwoord te benutten. Centraal hierbij staan kennisvermeerdering en het voorzorgbeginsel. Een sterke basis hiervoor is gelegd binnen NanoNextNL, een publiek private samenwerking van meer dan 100 bedrijven. Binnen NanoNextNL is door het programma Risk Assessment and Technology Assessment (RATA) een essentiële bodem gelegd voor het verkrijgen van inzicht in de risico’s van nanomaterialen.

Op Europees niveau is nanotechnologie een van de key emerging technologieën die geïdentificeerd zijn door de Europese Unie in de 2020 strategie. Grote investeringen worden gedaan in de ontwikkeling van nieuwe industriële applicaties wat zorgt voor een groeiend aantal nanoproducten die toetreden op de Europese markt (http://ec.europa/environment/chemicals/nanotech/index.htm). Ook op Europees gebied is er een groeiende aandacht voor de veiligheid van nanomaterialen.

Wetenschappelijk zijn er nog vele uitdagingen om de risico’s van nanomaterialen te bepalen. Op het gebied van blootstelling zijn er tal van meetinstrumenten in ontwikkeling voor het meten van nanodeeltjes. Deze meetinstrumenten meten niet allen hetzelfde en hebben een verschillende output. Het ontbreekt aan consensus over de te volgen meetstrategie en hoe de verschillende output naast elkaar te gebruiken om te komen tot een juiste inschatting van de blootstelling aan nanodeeltjes. Op het gebied van toxiciteit zal het onmogelijk zijn om de veiligheid van alle nanomaterialen te bepalen volgens de traditionele methodes die momenteel gebruikt worden voor chemicaliën. Om de snelle vernieuwing van nieuwe materialen te kunnen volgen, moeten er nieuwe concepten ontwikkeld worden om te kunnen afleiden welke parameters van invloed zijn op de toxiciteit van een nanodeeltje en nieuwe screeningsmethodes om in een vroeg stadium te kunnen bepalen of een deeltje veilig is. Ten slotte is de uitdaging om alle beschikbare kennis te combineren tot richtlijnen hoe de risico’s bepaald en beheerst moeten worden over de gehele levenscyclus van het nanoproduct.

4.3 Ambitie en Impact

Het overall doel van het project is het bevorderen van duurzame innovaties in nanomaterialen door voldoende inzicht te verkrijgen in de mogelijke gezondheidsrisico’s van nanomaterialen gedurende de gehele levenscyclus (safety for success).

Het programma heeft de volgende specifieke doelstellingen:
1) Het verzamelen van meetgegevens en het verkrijgen van inzicht in de niveaus van blootstelling aan nanodeeltjes in de verschillende fasen van de levenscyclus te weten synthese-, productie-, gebruik-, en eindfase.
2) Het verkrijgen van inzicht in de determinanten die invloed hebben op de niveaus van blootstelling van nanodeeltjes.
3) Het verkrijgen van inzicht in de invloed van fysisch-chemische parameters op de toxiciteit van nanomaterialen.
4) Het verkrijgen van inzichten in betere voorspellende methodes voor het testen van de toxiciteit van nanomaterialen waarbij gelijktijdig de vermindering van dierproeven wordt beoogd.
5) Het ontwikkelen van richtlijnen en een decision support module om de humane en milieurisico’s te beheersen en te beperken gedurende de gehele levenscyclus.

Foreseen impact and target group
Dit onderzoek biedt de mogelijkheid de (vooraanstaande) kennispositie verder uit te bouwen met betrekking tot:

1) Blootstellingschatting op het gebied van nanodeeltjes door het beschikbaar hebben van een up-to-date strategie die als standaard in EU wordt gezien.
2) Voorspellende inhalatietoxiciteitstesten voor nanodeeltjes.
3) Hazard schatting op basis van fysisch/chemische parameters en/of systeem biologische effecten van nanodeeltjes.
4) Tool ontwikkeling voor het inschatten van de risico's van nanomaterialen gedurende hun gehele levenscyclus.

Nanodeeltjes worden in allerlei soorten en maten door allerlei producenten en formuleerders gemaakt c.q. gebruikt. Potentiele toepassers van de ontwikkelde kennis zijn door de gehele chemiemarkt te vinden, zowel van bulk stoffen door grote industriebedrijven als van gespecialiseerde fine chemicals door zowel grote industriële bedrijven als mkb-bedrijven in bijv. verf, hars en polymeer industrie.

4.4 Vraaggestuurde interactie

In toenemende mate vindt er overleg plaats tussen de ministeries EL&I, I&M en SZW over het thema 'risico's en nanomaterialen'. Hierdoor bestaat er ook synergie tussen activiteiten in dit VP en de maatschappelijke thema's; bijv. de gezamenlijke opzet van 'nanocentre.nl' voor mkb-bedrijven dat als vraagbaak op het gebied van risicoproblemen dienst doet. Resultaten van NanoNextNL op het gebied van risico onderzoek vinden onder andere via dit platform hun weg naar de (mkb) praktijk. Dit platform organiseert ook workshops met het bedrijfsleven en overheid. Deze lijn van interactie tussen topsector en maatschappelijk thema zal worden voortgezet. Bovendien zal TNO vanuit dit VP deelnemen in een aantal grote EU FP7 projecten, waaronder NanoReg, waarin voor TNO de specifieke focus ligt op safe design van nieuwe nanomaterialen en het ontwikkelen van meetstrategieën voor nanodeeltjes.

4.5 Samenwerking

In dit project wordt samengewerkt met een breed aantal instituten op het gebied van toxicologie, blootstellingskarakterisering en risicomanagement: RIVM, Hogeschool Zuyd, Universiteit Utrecht, IVAM, Wageningen Universiteit, Rikilt. Ook zijn bedrijven aangesloten zoals Philips en BECO (E&Y). Vorig jaar is een AIO van start gegaan bij de Universiteit Utrecht op het gebied van blootstellingkarakterisering van nanodeeltjes. Alle activiteiten zijn internationaal verankerd doormiddel van samenwerkingsverbanden met partners binnen het Europese Nano Safety Cluster.

4.6 Programma 2015

Het programma 2015 zal worden uitgevoerd in het kader van het lopende NanoNextNL traject en de EU projecten GuideNano, FutureNanoNeeds, Nanosolutions, SUN, NanoReg. De ontwikkelde kennis op het gebied van blootstelling en toxiciteit wordt geïmplementeerd in praktische tools voor het mkb (Stoffenmanager Nano of ander instrument).

5 TNO applied research in HTSM Roadmap Components and Circuits – High Frequency Integrated Circuits (MMIC)

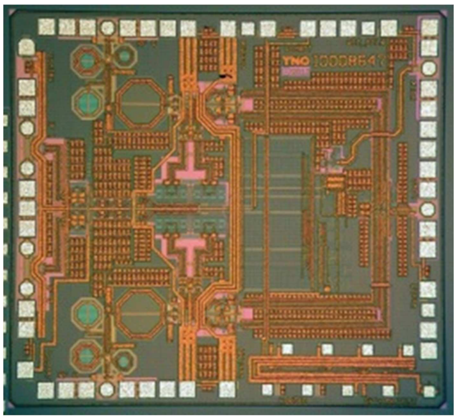
5.1 Introduction

The HTSM Roadmap Components and Circuits released an update of its Roadmap in 2014 which is more focused on the R&D needs of the participating partners. A major update is in preparation for the time frame 2016-2017. The Roadmap aims at 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 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 here their headquarters or a subsidiary. Our national knowledge infrastructure is perfectly matched hereto. Regarding above mentioned technology developments and market / societal applications, the TNO contribution in this case focusses in particular on the following Program line:

- High-frequency integrated circuits on SiGe, GaAs, GaN and RF-CMOS material substrates for defence, space and communications applications. These TNO activities are carried out in VP 104 Defence Related Industries.

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



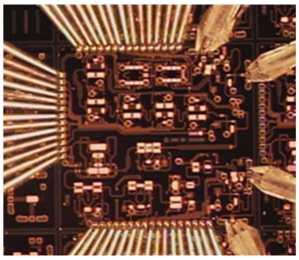
Single chip SiGe receiver from 10-18 GHz designed by TNO and manufactured by NXP within the STARS Program.

5.2 Program 2015-2018

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 be also more and more aligned with the ECSEL and CATRENE Joint Undertakings from the EU.



TNO facilities for measurement and parameter extraction of MMICs

5.3 Ambition and Impact

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

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. Moreover, the components can often not be obtained as commercial off-the-shelf components but are application-specific and are realised 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. 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. To accelerate the speed of innovation is one of the major goals. We do this by consistency in joint Roadmaps and open exchange of knowledge.

Due to the nature of the products and technologies in the defence domain, this domain distinguishes itself from other domains. Therefore, the cooperation is crucial in a triple helix[1] between knowledge institutions, core industries and technology suppliers and the military stakeholders (both at national and European level), whereby all together are involved at an early in the development of an optimal knowledge base that is innovative, trendsetting and which sets the pace.

The technologies developed in the military domain have also a wide social relevance. The technology can be used in a wide range of military and non-military applications. The technologies and products generate demonstrable spill over effects to other economic sectors. It shows a great diversity of activities at related companies.

5.4 Demand and Interaction

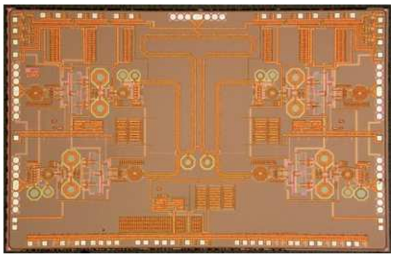
TNO has in the context of D-RACE a very close cooperation with Thales Netherlands. D-RACE steers actively on the implementation and progress in the Roadmap *Radar and Integrated Sensor Suites* that is detailed until 2016. In the ecosystem that is emerging around D-RACE we see as increasingly important 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

[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.

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 3 Technical Universities. Mostly is the cooperation in the Roadmap 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 we cooperate with almost all major European defence companies and RF semiconductor manufacturers such as UMS, OHMIC, Thales, SAGEM, SELEX, SAAB, AIRBUS etc. and with research companies like FOI in Sweden, Fraunhofer in Germany, II-V labs in France etc. Typical programs that are addressed are in the field of high-efficiency high-power GaN amplifiers (MAGNUS) and in the field of enabling technologies for active electronically scanned arrays; in particular local power generation and amplification based on switched technologies with focus on cost and performance (SWAP).

5.5 Program 2015

The Program in 2015 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 2015:

- New national technology developments with focus on:
    - Development of high power GaN amplifiers together with Thales Netherlands.
    - Enabling and disruptive transistor technologies on GaAs and GaN with Thales Netherland.

- The continuation of the national Programs described above:
  - DAISY together with Thales, NXP and several SMEs.
  - STARS together with Thales, NXP, Recor, UT and TUD.
- Participation in new international Programs in the context of EDA on enabling technologies for active electronically scanned arrays together with SAAB, FOI and Thales (SWAP-C).
- The continuation of the EDA Program MAGNUS (described above) in which all major European III-V semiconductor manufacturers and European defence industries are teaming.
- Participation in new international Programs in the context of CATRENE and ECSEL on SiGe transmitter technology (EAST) and of low-cost microwave packaging technologies (THERMISIP) respectively.

6 TNO applied research in HTSM Roadmap Components and Circuits (OLAE Holst)

6.1 Introduction

The use of thin plastic foils as a base substrate will ensure thinner and more flexible electronic devices as compared current PCB-based electronics. It furthermore enables new manufacturing methods, such as continuous roll-to-roll, instead of wafer and/or batch processes. Application areas that will benefit from this technology development are manifold, and the number increases now the technology matures. Examples are: wearable medical devices such as skin patches and flexible X-ray imager sensors, seamlessly integrated human machine touch interfaces and wireless nfc playing cards, disposable food and medication sensor packages.
It is our ambition to progress the state-of-the-art in these so called organic and large areas (OLAE) technologies. 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. Universities play a crucial role in understanding the fundamental aspects as well as demonstrating new concepts and ideas.

6.2 Program 2015-2018

Trends
The past period showed a transition from technology push to market pull for OLAE technologies beyond OLED lighting and display products. Fuelled by the fast technological progress, industrial interests intensify to bring flexible (OLED) products to the market. At the same time, other market segments show an interest in the OLAE technology for their application. As a result, we see two important trends: (i) a stronger focus to bring technologies to a higher TRL level, and (ii) combine the technologies to enable new product categories. Portable X-ray imagers on plastic film are an example. These are in terms of underlying technologies very similar to flexible (OLED) display, and end-users foresee a benefit in terms of lower weight and shatter-proof imagers when plastic film is used instead of glass as substrate materials.

OLAE technologies are seen as an attractive proposition for wearable ‘on-body’ electronics. Typically, on-body applications are mechanically very demanding. The benefit of OLAE is illustrated by the skin temperature patch shown in Figure 1. Mechanical wearability and stretchability of this patch is greatly improved compared to the conventional ‘multi-layer PCB shown on the right.

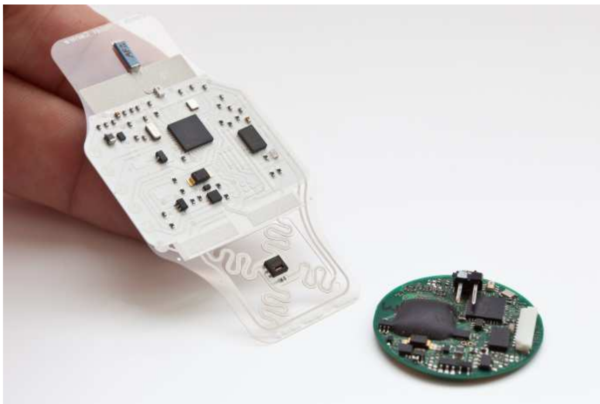


Figure 1. Wireless skin temperature patch as realized with OLAE technologies (left) and in a PCB format (right)

We foresee a great future for OLAE technologies in future skin patches that sense health and well-being, bandages that can -via light- monitor wound healing and intelligent catheters, to multi-electrode arrays that record electrical signals generated by the brain, heart or muscles. 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 circuits must adhere to the intrinsic contours of the skin, heart, brain, or blood vessel. This puts specific constraints on form factor. The integration of electronic functionality into catheters, for instance, is hindered by the restricted dimensions of the catheter and the need to be controlled by and efficiently communicate with the external world.

Outlook 2015-2018
Based on these trends, the overall plan for the period 2015-2018 can be derived.
- Further development to bring the already available process technologies and devices to a higher TRL.
- A move from cost-sensitive simple applications to functionally more complex (biomedical) devices, specifically on-the-body/in-the-body applications.
- Further development of the underlying OLAE technologies and design guidelines to enable realizing such more functionally complex devices. In particular a smart combination of TFT circuits and traditional silicon technology is of relevance.

6.3 Demand driven interaction

The program is an integral part of the Shared Research effort of Holst Centre/TNO. As such, the contents are defined by the industrial partners. Current partners for example include Philips, Panasonic, Cartamundi, Evonik and Henkel.

6.4 Program 2015

Applications:
- Continued from 2014: Low cost health patch v2. X-ray detector on foil.
- New 2015: steerable catheter, nfc game cards, smart garment v1, NIR imagers.

Technologies:

- Continued from 2014: ultrathin silicon chip integration, down to 20 um thickness, 50 um pitch based on high resolution printed interconnect materials; transistor backplanes on ultra-thin substrates, incl. peripheral circuitry (partly thin-film, partly silicon based).
- Continued from 2014: maturing stretch technology. improving on stretchability and thickness.

7 TNO applied research in HTSM Roadmap Printing (Additive Manufacturing)

7.1 Introduction

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.

TNO believes 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, high-tech equipment, integrated electronics and aerospace 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 an Additive Manufacturing innovation program with focus on: 1) process control and predictive modelling to improve product quality during powder bed fusion (PBF) 2) improved material and process capabilities (engineering polymers, ceramics, printing concepts) for Vat photo-polymerization and 3) integration of Additive Manufacturing in production chains, making it an integral part of a ‘next generation industry’ approach.

Powder Bed Fusion
The goal of the PBF program is to develop next generation PBF technology to improve part quality, production yield and dimensional stability, and dictate material properties. The major elements of this program are process modelling for understanding and prediction and novel inspection and control technology.

Vat polymerization
The goal of the program is to accelerate the adoption of Vat photo-polymerization additive manufacturing technology for high-end production processes by bridging the gap between research and commercialization, by developing processes,

materials and applications to manufacture fully functional, end-use parts using Vat photo-polymerization. The program has four focus areas: (1) new and improved materials, (2) Improved resolution and surface quality, (3) Improved accuracy and repeatability, and (4) improved production cost efficiency.

The initial focus of the program has been on the dental market (personalized, customized, on-demand manufacturing, but will be extended to other sectors in the high tech market.

Hybrid Manufacturing
The main challenges that drive the Hybrid Manufacturing program are 1) the necessity to increase the efficiency of current AM processes to allow cost effective production 2) transform the layout to allow integration of layer wise production in an industrial production sequence. The program brings additive manufacturing from prototyping towards industrialization with emphasis on price/speed while maintaining system flexibility, stability & reliability. Furthermore, the program targets for increasing production efficiency to allow creation of products a minute instead of products a day (factor 100).

The program focusses on orthotics (insoles, braces, exoskeleton etc.) market (personalized, customized, on-demand manufacturing).

7.2 Program 2015-2018

Powder Bed Fusion
TNO brings more than a decade of PBF fusion experience to the table, with a strong track record in European projects, mechanical design optimization routines such as topology optimization, and materials processing knowledge. In addition, the breadth of TNO activities in the high-tech and aerospace markets, position TNO in a central role to introduce next generation manufacturing technologies. Specifically, TNO will focus on: Processing window vs materials property determination, Multi-scale microstructural material modelling to predict mechanical behavior during build (towards virtual SLM) and Material-Laser interaction and inspection technology for novel in-line inspection and process control (feed forward, closed loop control).

Vat polymerization
A strong knowledge in the field of biocompatible polymers has been developed in cooperation with research partner NextDent. Dental materials certified for temporary use in the mouth (up to 1 month) have been introduced in the market. Materials for long term use are in the final stages of the certification process. A ceramic Al_2O_3/binder slurry for production of crack free ceramic parts with wall thicknesses of up to 10mm and sizes up to 50mm has been developed.

Tool development is focusing on the patented forced feedback (Lepus 1 development) and next generation laser diode array exposure systems which will be a breakthrough in resolution/build area and speed (Lepus Next Gen tool), recoating technology. For this system also a patent application has been filed. Recoating technology to be able to handle high viscosity resins is under development. This opens the way to develop resin systems with greatly improved material characteristics.

Hybrid manufacturing
The technology proposition her is high-speed/continuous AM, speed capabilities @ single pass deposition using inkjet implemented in a continuous production

approach (target Dec 2014, implementation of Océ print heads), plt2012-033: hybrid manufacturing platform, continuous moving belt, plt2014-46: powder based AM processes in relation to continuous production layout. In addition in-line inspection technologies, high-speed, 2.5 D inspection, and integration/architecture (next generation AM platform), plt2014-012: variable speed in continuous system reducing file-in, product-out time with a factor of 10.

7.2.1 Vision

To make AM an attractive need-to-have technology for modern manufacturing, the following challenges need to be addressed:

- Improved equipment performance by increasing manufacturing speed, increasing the build/product volume and size, increasing the object resolution (feature size), improving the surface quality and guaranteeing material performance and specifications (required material properties), improving the yield of processes and reducing the need for handling and post processing.
- Extending the portfolio of materials towards high-tech polymers, ceramics, metals and hybrid materials; increased strength and durability (ceramics, metal), compatibility with other materials (biomedical, biocompatible, electronic components), multi-material printing and direct printing of conductive tracks and functionalities like sensors or actuators.
- Incorporation of technology in the manufacturing chain; pre- and post-processing, industrial standards, reliability, integration with pick and place technology of components, and the introduction of design for function at the start of product development.

Powder bed Fusion

The heart of powder bed fusion technology is currently located in Europe, with many German OEM companies producing PBF machines (EOS, SLM solutions, and Concept Laser), along with research initiatives of Direct Manufacturing Research Centre (DMRC), and the Fraunhofer Additive Manufacturing Alliance. In Belgium, research organizations like the KU Leuven, Sirrus, and Imec are working on improving the technology, while private companies LayerWise and Materialise have strong market postions. Activity in the rest of the world is starting to accelerate. For example in Asia, ITRI has a strong R&D focus, and OEM companies are surfacing in Taiwan, Japan, and China. In the USA, the aerospace, defense, and medical sectors are also accelerating their efforts with companies like GE, Optomec, Boeing, Ford, and research programs such as the National Additive Manufacturing Innovation Institute, and the America Makes campaign. In The Netherlands, research institutes NLR, TNO, and M2I all have strong positions to bring the next generation PBF technology to the market, while smaller collaborative initiatives have started in recent years such as the AddLab cluster.

Vat polymerization

Apart from the hearing aid market, Vat photo-polymerization is currently mainly aimed at prototyping or sacrificial casting (especially in the jewelry business). Industry consultation and Roadmap meetings organized in 2013 confirmed that VP technology is very promising in the field of resolution and surface quality but industrial breakthrough is hampered by insufficient mechanical properties of currently available materials. The field of material suppliers for VP is dominated by two main players (3D Systems and DSM) but innovative start-ups are emerging. So far material development at TNO has been focused on niche applications. The introduction of biocompatible AM materials for long term use in the mouth by NextDent is a world leading innovation.

AM of ceramics is a relatively new field. Market introduction has been done by two start-up companies Lithoz (TU Wien spinoff) and Admatec (ECN/Formatec joint venture). TNO technology for ceramics AM has not yet been introduced in the market.
Current state of the art of VP equipment is mainly based on either beamer or single spot laser scanning technology compromising either resolution or build area or speed. Scanning laser diode array technology, as developed and patented by TNO, will be a breakthrough in this dilemma.

Hybrid manufacturing
When TNO introduced its hybrid manufacturing platform on the Euromold December 2011 the AM community was amazed, as described in the Economist (The Economist, Special report: Manufacturing and innovation, Apr 21st 2012). The platform showed how the future of additive manufacturing could look like, where addition of processing steps does not immediately impose extra processing time, due to the parallel layout. To step beyond batch wise production has proposed a challenge for most AM manufactures. Now almost three years later only 3D systems took a step in this direction. The development is directed towards 3D printed electronics (modular phone) as a collaboration between Google and 3D Systems (Ara project). As can be seen on http://youtu.be/UFb3TkC7OMo the concept is very similar to the TNO system.

The platform does not only provide high speed production it also allows a continuous output of products, to allow integration in an industrial production cycle. This combination of high variety of products which are produced at high speed impose challenges similar to those addressed in the Industry 4.0 initiative in Germany as well as the Smart Industry initiative in the Netherlands. How to handle these data streams and optimize process layout. Where the modular production platforms currently under development such as the smart factory platform (http://smartfactory.dfki.uni-kl.de/de/) are not suitable with conventional AM process the TNO Hybrid Manufacturing approach can bridge this gap.

For the TNO concept several patents have been filed (plt2012-033/plt2014-012/plt2014-46). The first European novelty search report looks excellent.

7.3 Demand driven interaction

Powder Bed Fusion
While TNO believes that PBF will play a major role in many markets, the current focus is with high-tech equipment and aerospace markets (freedom of design, lightweight, functionality), with research partnerships established with Technical University Delft, University of Twente, the Industrial Technology Research Institute of Taiwan (ITRI), the National Aerospace Laboratory of The Netherlands (NLR), and The Materials Innovation Institute of The Netherlands (M2I).

Vat photo-polymerization
Current program partners include NextDent and RapidShape. In addition, research partnerships with ITRI, ECN (in preparation), TUDelft, Fontys University of Applied Science, Hebrew University have been initiated.

Hybrid Manufacturing
The program has established research partnerships with Fraunhofer IPT, DTI.

7.4 Program 2015

Powder Bed Fusion
Below the 2015 work plan is described, along with the corresponding deliverables.

- Processing window vs materials property determination with focus on:
  - Study into fundamentals PBF process, laser-material interaction, Macro-scale material model, connected with micro-scale property determination.
  - With theoretical guidance, development of baseline metal powder fusion process on existing commercial tools (via partners) for 99.0% dense products.
  - With theoretical guidance, Improved material or process settings to increase yield of dense printed metal parts to 90.0%.
  - Development of novel write strategies to improve process parameters and product quality.
  - Correlation between in-line measurement data and process quality (melt pool, hot spots and material properties.
  - Deliverables: 1) report study with basic principles, parameters to improve quality of process. 2) Baseline metal print process with proof of concept 90.0% yield dense metal parts. 3) Basic and advanced write strategy evaluation.

- Development of a three dimensional simulation that can predict thermally-induced mechanical stresses and deformations in metal PBF processing.
  - Baseline simulation of thermally-induced mechanical stresses and deformation in the selective laser melting process.
  - Baseline simulation of process parameter influence.
  - Deliverables: 1) Multi-phase material models 2) 2D thermo-mechanical simulation of the PBF process 3) Baseline 3D thermo-mechanical simulation of the PBF process.

- Development of PBF process control technology to improve product quality (homogeneity, material performance) and to increase system reliability.
  - In-depth analysis of PBF system performance.
  - Evaluation of novel in-line monitoring concepts, such as optical interferometry, infrared thermography (pyrometer, or camera).
  - Development of in-line surface and sub-surface monitoring methodologies and strategies.
  - Closed-loop control strategies and architectures for improved product quality.
  - Deliverables: 1) Report with analysis for current performance and recommendations for improved product quality 2) Report on state of art in-line monitoring systems, and exploration of next generation inspection technologies suitable for PBF. 3) Proof-of-concept of next generation inspection technology 4) Proof-of-concept of sub-surface monitoring technology. 5) Baseline development of system control (closed loop) architecture.

Vat Photo-Polymerization
Description of plans, including concrete deliverables:

- Development of photocurable polymers with improved mechanical properties, especially at elevated use temperatures, is an important requirement for functional products. The program aims to develop a material with ABS-like properties, combining impact strength and high stiffness at elevated

temperatures, in three years. In 2015, focus will be on improving stiffness at elevated temperatures, without compromising impact strength.
Deliverable: proof of concept of vat material with improved mechanical properties (tensile modulus: 2000 MPa, Izod impact strength (notched): 0.6 J/cm, heat deflection temperature: 70ºC).

- Both polymer and ceramic formulations developed in 2014 will be implemented on the Lepus Next Gen platform, leading to demonstration of large size (up to 20x10x20 cm for polymers, up to 10x10x10 cm for ceramics), high resolution (20 µm) products.
  Deliverable: proof of concept technology to build large size high resolution (20 µm) polymer (20x10x20 cm) and ceramics (10x10x10 cm) products.
- Using improved illumination strategies for raster scanning (as implemented in Lepus Next Gen) we aim to improve dimensional accuracy up to 40 µm in complex 3D polymer products.
  Deliverables: sample products and 3D measurement scans showing the results.
- New concepts for multi-color and multi-material products will be developed, initially aiming at dental applications and support less building.
  Deliverables: concept designs for equipment and sample teeth showing the results.

Hybrid manufacturing
Description of plans, including concrete deliverables

- High-speed AM creating functional products. Development of high-speed polymer powder deposition and laser system for in-line sintering.
  Deliverables: 1) Concepts and proof-of-concept for high-speed powder deposition (up to 1m/s). 2) Proof-of concept high-speed in-line laser-based sintering (increase of factor 10 compared to conventional powder sintering processes).
- Develop in-line inspection and correction technology. Verifying the passing layer, comparing it with de desired structure and proposing corrective measures.
  Deliverables: 1)demonstrate in-line inspection technology (functional up to 1m/s). 2) Demonstrate laser-based post-processing on a moving substrate (substrate movement up to 1 m/s).
- Integration of pick-and place system in Printvalley platform. Expanding the functionality of the PrintValley platform by implementing an industrial drop-on-demand (DOD) system to realize continuous production of a functional demonstrator. Develop universal control algorithms to allow the system to operate continuously, where the host controller drives the flow of products through the system.
  Deliverables: 1) demonstrate on the fly pick-and-place capability. 2) demonstrate continuous manufacturing of basic products (via OCE wax system).

7.5 Addendum TO2-2015 Society

In the framework of cooperation TO2 in 2015 the next project is approved in the theme Society.

Project title
“Multi-Material Additive Manufacturing”

Subject and description of the project
Development of knowledge and technology for Multi-Material Additive Manufacturing.

Description of the project:
Additive Manufacturing is nowadays seen as promising manufacturing technology for several product applications for various market segments. We, however, believe that Additive Manufacturing will become big in specific B2B manufacturing chains, based on the benefits customization and personalization, freedom of design and cost-effective small-scale and on-demand manufacturing. These B2B manufacturing chains will be guided by leading applications, such as medical, high-tech equipment, integrated electronics and aerospace. We believe that we can only create significant impact by partnering with complementary (inter-)national R&D partners and by engaging with industry in shared innovation and bi-lateral developments.

Several technologies are currently developed for these identified markets, such as selective laser melting for metal additive manufacturing, photo-polymerization for polymer and ceramic additive manufacturing. These technologies have in common that these currently target for mono-material solutions. But, eventually, additive manufacturing has the potential to make components or parts from different materials.

Multi-material printing is seen as the next step in additive manufacturing, enabling new application fields in the high-tech, medical, electronics and aerospace markets. Multi-material can bring the additive manufacturing from part to component manufacturing, enabling integrated functionality, material grading, etc. To develop multi-material additive manufacturing technology, we will create a strategic alliance between TNO, NLR and ECN to combine the ceramic, metal and polymer Additive Manufacturing technology competences, offering a competitive advantage w.r.t. initiatives and alliances elsewhere.

The proposed multi-material technology program will include:
1. Review of the state-of-the-art multi materials Additive Manufacturing applications and technologies.
    a. Literature scientific and patent technology review
    b. Commercial company review and status
    c. Market potentials
2. Technological review concerning multi-material Additive Manufacturing consortium.
    a. Identification of key players in the most promising market
    b. Identification of the key technologies for multi-material Additive Manufacturing
3. Development of technology demonstrator for all strengths/thickness, i.e. PBF printed metal part with local alloying (to make mechanical properties better, or for grading).
   Potential demonstrators:
    a. Compliant mechanisms
        i. Aerospace
        ii. Link with topology optimization
    b. Meta-materials for radar technology (polymer/metal)
    c. Medical
        i. Dental implants (polymer/metal ceramics)
        ii. Orthodic implants

            iii. External prostetics/exoskeletons
    d. Internet of things
        i. RF integration into structural components
        ii. Link with high-tech and structural engineering
4. Two strong use cases for which multi-material is a unique selling point (like integrated electronics and MEMS, microfluidic devices, hearing aids and high-tech components) will be explored and developed.
   Selection from:
    a. Single material multi-property
        i. Density grading
        ii. Porosity introduction followed by polymer infiltration
    b. Catalyst materials for oil and gas refinement
    c. Printed circuit boards
    d. Batteries
5. Plan for further cooperation between strategic partners and possible extension: multi-material program with founding research partners ECN, NLR and TNO.
6. Link with university research, such as TU Delft.
7. 1 or 2 multi-material EU project proposals with key EU partners.

Result (end 2015)
In this project we will investigate the possibilities of multi-material Additive Manufacturing by a knowledge and technology watch. On a limited scale the feasibility of these new technology will be tested via modelling and experimentation.

Concrete 2015 deliverables:
1. Creation of a strategic alliance between TNO, NLR and ECN in the field of multi-material Additive Manufacturing, with multi-year plan for continuation of multi-material Additive Manufacturing research.
2. Business case analysis/market intelligence plan with concrete numbers of industrial interest (key applications, market size, etc.) and required technologies.
3. Development of knowledge and technology in the field of multi-material Additive Manufacturing technologies, via literature research and selected experimental validation.
4. Validation of 2 most appealing multi-material Additive Manufacturing technologies, demonstrated via technology demonstrators.
5. Use case analyses, via lab-scale proof-of-concept and demonstration of technological feasibility.

Participation TO2 partners
YNO, NLR and ECN.

Possible research and private partners
This research project is seen as the preparation for a potential multi-year multi-material research program.
We see several possibilities to expand the consortium.
Research partners: Chemelot, 3TU, KULeuven, Fraunhofer, ITRI.
Industrial partners: Dutch and international companies in the high-tech equipment, aerospace, electronics and medical domains (such as ASML, Philips, FEI, Fokker, etc.). We will define an industrial advisory board to advise on the technology and killer applications, and to validate the technology plan and commercial feasibility, eventually to offer partnership in the foreseen multi-year program.

8 TNO applied research in HTSM Roadmap Printing (Printing Holst)

8.1 Introduction

Printing and coating technologies are important building blocks in the field of large area electronics. The goal of the program is to come to an up-scalable sheet to sheet, S2S, and roll-to-roll production, R2R, technology for the making of flexible products like Organic LEDs, Oled, Organics Photo-Voltaics, OPV, displays and other printed electronic products. Also the field of stretchable and conformable electronics is coming up.
The overall ambition of the ‘Printing’ topic is to develop methods and technologies for additive manufacturing of electronic products, following methods that are as simple and efficient as printing a newspaper. The program is split in two parts. The first part concerns the manufacturing of patterned conductive structures. The overall Roadmap is to achieve finer feature sizes, using cheaper materials and processing. The second part concerns printing of large area but thin electro-functional layers. Here the overall Roadmap concerns patterning, layer thickness control and multilayers coatings. For the whole program the interaction and device compatibility of the different layers is of importance. Various modeling approaches are being employed to come to a better understanding of layer formation, pinning and drying of layers. An important part of the work concerns curing and sintering technologies to achieve an effective and time efficient process. An novel method is the so-called photonic sintering where with the use of “light” the printed layers on polymer substrates can be processed in a very efficient way.

8.2 Program 2015-2018

Trends
Over the last years the work has evolved from the printing of small areas and patterns using laboratory equipment to R2R printing of layers on pre-pilot lines. The focus is therefore moving from lab-scale experiments to R2R experiments. Holst Centre is very active with its partners to come to this final goal and is even considering a spin out in the field of printing flexible electronic products in the near future.

Outlook 2015-2018
Based on these trends, the overall plan for the period 2015-2018 can be derived.
- Further maturation of various printing technologies (slot die, screen printing, inkjet printing) by moving from laboratory equipment and processes to volume capable processing and equipment (higher TRL levels).
- Development and exploration of new printing technologies that expand the portfolio. For example laser printing, enabling finer features than can be achieved with current technologies. Or photonic printing, enabling more efficient deposition of materials.
- Making of state-of- the-art demonstrators showing the capabilities of the developed processes and equipment.

8.3 Demand driven interaction

The program is an integral part of the Shared Research effort of Holst Centre/TNO. As such, the contents are defined by the industrial partners. Current partners for example include Philips, Panasonic, Dupont, SPG Prints b.v., Roth & Rau, VDL Flow, Bosch Rexroth and Smit Ovens.

In addition to the partners the program is working together in the DPI program on Large Area Thin Film Electronics (LATFE) on fundamental studies (model/experiment) of droplet formation and impact, and drying of ink jet printing of non-newtonian fluids (e.g. high speed camera). Furthermore we are involved in the Hi-Prins (High Precison Inkjet Printing,System /Tue, TUD, UT, Océ, Roth and Rau, Thales, NTC, Demcon). The goal of the HiPrins Project is to make fundamental steps in several areas in inkjet printing technology.

The printing program is actively involved in a number of European projects: Lotus (low cost conductive inks), Clean4Yield, Extend(X10D), Light Touch Matters and Flexofab.
Finally, the program is closely linked with the Solliance OPV program and people from ECN are actively working together.

8.4 Program 2015

Large area printing
In 2013 the start has been made to come to an integrated coating and drying R2R line where 2 coating processes for large areas are integrated. This equipment is now becoming operational. The main targeted features are as follows:

- Physical separation (different rooms) between application processes and drying process because of contamination risks (clean room requirements).
- No rollers touching the top surface after application of the first layer in order to enable a very clean and damage-free operation.
- High flexibility regarding processing sequences. For the next years the R&D efforts will be focused on making this line fully functional.
- Finally, it is of high importance to come to a process where pattering of the individual layers can be done.

Conductive structures printing

- Together with SPG Prints b.v. work is being done on R2R ink jet printing. Currently it is possible to print over a width of 7cm. This will be extended to full web width (30cm in this case) by using multiple print heads.
- Further development of rotary screen printing, achieving higher resolution and focussing on multilayer printing for enabling more complex devices.
- New technologies for high resolution as LIFT and Phatt. This will also open the route to printing on 3D surfaces.
- Drying and curing of the functional inks is process for which now conventional furnaces are used is a process which typically takes relative long times. Especially when a R2R process is required this will require long furnaces. Over the last years photonic sintering and curing sometimes in combination with infra-red has been shown to come to an effective process. Further research on this process will be done where also modelling will be done to come to a better understanding of the process.
- Extension of photonic sintering incl. laser sintering.

9 TNO applied research in HTSM Roadmap Lighting (OLED - Holst)

9.1 Introduction

At present lighting accounts for around 20% of electricity consumption worldwide. So the move to replace traditional light sources by more efficient solid-state lighting based on inorganic (LED) and organic (OLED) semiconductors constitutes an important factor in reducing global energy consumption and thus limiting carbon dioxide emissions. Inorganic LEDs are a more established technology, but OLEDs offer attractive design features and potential for low cost, high volume production since they are intrinsically a large area light source and can be deposited as thin, flexible, robust, patternable, color tunable layers on glass or on plastic or metal foils by evaporation or solution processing. It is estimated that OLEDs could represent up to 10% of the World lighting market by 2018. OLED lighting technology has already been commercially available on glass substrates, deposited by evaporation since 2009, from a number of companies including Philips, and typical power efficacies are now 50 lm/W for panel sizes of around 100 cm^2. A rapid improvement in efficacies of such products is expected since, on a research scale, OLED efficacies of more than 150 lm/W have already been shown. However production costs of the glass-based OLED devices are currently high, and there is not yet an established process, device structure or materials to make flexible (solution processed) OLEDs for lighting. So the full potential for low cost, high volume production and design freedom of OLEDs for lighting has not yet been realized.

9.2 Program 2015-2018

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, 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.

9.3 Ambition and Impact

In collaboration with the industrial partners of Holst Centre/TNO, it is our ambition to make low cost, flexible OLEDs for lighting a reality by solving technology issues, establishing a manufacturing process and setting up the supply chain of materials, equipment, manufacturing and end-user companies.

Cost performance breakthroughs for flexible OLEDs (approximately factor of 100 reduction compared to existing glass-based devices), positioning high efficiency flexible OLED general lighting as an economically and ascetically attractive alternative to traditional light sources, and resulting in an increased uptake by public and private customers.
A significant global reduction in the energy consumption from general lighting as less energy efficient traditional light sources are replaced by flexible OLEDs.

Creation of a value chain of companies for the fabrication and commercialization of flexible OLEDs.

Offering a new flexible, robust, thin and lightweight OLED technology with great design freedom and in this way stimulating industry around design and integration of flexible OLEDs into novel products.
Secured and reinforced industrial technology leadership of Europe in the global lighting market as a result of technological, industrial and commercial developments in this new solid state lighting technology area.

9.4 Demand driven interaction

Strategic research collaborations with industry are developed by definition of Shared Research Programs with technology partners along the value chain for manufacturing flexible OLED lighting panels. Goals and key performance indicators are defined in a Technical Annex, which is written annually by TNO/Holst Centre after discussion with the flexible OLED for lighting industrial partners. We are in daily or weekly contact with the industrial partners and the results and content of the program are reviewed by all partners together each quarter.

The RM lighting (OLED) has already established long term collaborations/agreements with industrial partners, contributing to the financial assets and R&D goals of the OLED lighting program and working according to a shared innovation model. These companies include: Philips, Panasonic, DuPont Teijin Films, Mitsui Mining and Smelting, Rolic, Roth and Rau, Solvay, Sumitomo, and Cambridge Display Technology. There is also a very strong link to the RM printing and its associated partners and collaborations including DuPont, Stork Print Group, VDL, Smit Ovens, and nTact, and a lot of technology overlap with RM OPV. Current R&D and industrial partners in RM lighting (OLED) also collaborate in, and coordinate some EU-projects, such as, Flex-o-fab, Clean4Yield, IMOLA and IM3OLED. The RM lighting (OLED) is also part of NanoNext NL, and involved in DPI LATFE and 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 companies who wish to integrate free-form OLED lighting and signage foils into products for various applications. Holst Centre/TNO expects to play a significant role in realizing the Horizon 2020 ambition to accelerate European development in the area of OLED lighting through coordinating and participating in consortia to build pilot lines and by creating bridges between academia and industry.

9.5 Program 2015

Activities
Development of:
- A high performance water barrier suitable for flexible OLEDs and the equipment and processes to manufacture this.
- Light outcoupling technologies for enhancing the performance of flexible devices.
- Large area, high volume (sheet-to-sheet and roll-to-roll) deposition (from solution) processes for OLED layers and electrodes.
- Device designs for OLEDs with added functionality such as flexible, conformable, stretchable and cut-able light sources, and the possibility of integration with other thin film electronics.

Milestones/Results

- Transfer fabrication of high performance water barrier for OLEDs from a sheet-to-sheet to a roll-to-roll production process.
- Demonstration of flexible OLEDs with comparable device performance to glass-based devices.
- Demonstration of fabrication of roll-to-roll solution processed flexible OLEDs on new state-of-the-art roll-to-roll coating line.

10 TNO applied research in HTSM Roadmap Solar (CIGS)

10.1 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 place to exploit the opportunities arising from this need for renewable energy sources, in particular photovoltaics (PV). The present volume of the solar cell market is 90 billion Euro/year, and the installed capacity of 100 GWp PV power expands at a rate of 40 GWp/year. The market growth of 50%/year over the last decade was enabled by increase in product quality (conversion efficiency) with a simultaneous steep decrease in cost. The final breakthrough for PV energy is realization of grid parity (PV electricity to be competitive with retail electricity prices). Therefore the main driver in the PV industry is the reduction of solar energy generation costs. Although the large reduction of PV module cost seems to be driven by several incidental factors (overcapacity, investment crises and a market consolidation), it is common opinion that there is still an enormous potential for further product improvement and cost reduction, 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

10.2 Program 2015-2018

The overall aim of the solar equipment program is to enable easy, affordable and embedded PV technology through development of world class generic manufacturing equipment and process solutions that:

- Close the 5% efficiency gap for CIGS between lab and production using fast and reliable production methods and equipment to achieve > 20% conversion efficiency modules.
- Move from current vacuum processes to atmospheric processes for large area R2R production; electricity generation cost < 10 €c/kWh and > 99% high yield production.
- Allow green production and reduced use of scarce materials.
- Enable and validate > 25 year PV module life time.
- Facilitate smart and easy PV integration (BIPV and integrated products).

These aims are in line with priorities defined in the national Dutch Solar Roadmap written for “Topgebied HTSM” and “Topgebied Energie” (both co-authored by TNO), which in turn was based on a critical assessment of international PV Roadmaps. The Solar Roadmap is the guideline for the research topics of the Solliance Initiative, the research collaboration between TNO, ECN, TU/e, Holst Centre, imec and Forschungszentrum Jülich. In collaboration with industrial partners and investors Solliance aims to generate new (regional) business through research on three thin film-PV technologies: CIGS, OPV and high band gap materials (e.g. Perovskites and Kesterites).

10.3 Ambition and Impact

Traditional c-Si PV modules dominate the PV market, but the market volume and share of thin film-PV devices and in particular CIGS will increase dramatically in the coming decade. Ambition is to provide process and equipment solutions not only for low cost high volume production, but also for custom designed free form module formation.
Also, it is generally expected that the next leap in efficiency improvement of PV modules will be enabled by combining c-Si 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 c-Si.
Europe is leading in development of PV production technology, and Dutch industry has 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 (eventually 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 equipment and processes for thin film photovoltaics, more specifically on CIGS- and the closely related CZTS -based technology.

Generic large area thin film production technologies and materials are developed which can also be applied beyond the field of photovoltaics (e.g.: fast atomic layer deposition, transparent electrode formation, high speed monolithic interconnection of customized free form devices, (re)crystallization, atmospheric deposition of large area thin films with nm-range homogeneity). New business and job generation in High end equipment manufacturing, materials, and more specifically, production of thin film PV for durable energy generation and production of free form flexible electronic products are enabled.

10.4 Demand driven interaction

The Solliance CIGS program is developing in the direction of a Shared Research Program (SRP), executed by TNO in collaboration with Solliance partners imec, ECN, TU/e and university of Hasselt. Two industrial partners have formally joined the program (Smit Ovens and DSM) and several more are considering formal participation. Collaboration with more than 20 other parties (companies and research institutes) takes place in Shared Research Projects (TKI, PiD, EU, etc.). Together with these companies, the technical annex (R&D Roadmap) is annually revised and updated. This ensures that the program is addressing the needs of the industrial partners, and the sector as a whole. Based on the many conversations of potential new partners and their expressed needs, several of the “most wanted” topics are currently also integrated in the program.

Collaborations (by projects, PhD’s or student exchanges) will be continued/initiated with TU/e, TUD, Radboud Univ, Univ Hasselt (B), Univ Nantes (F), Hogeschool Zuyd, and Fontys to further strengthen the program’s scientific foundation.

10.5 Program 2015

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

Reference line for 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).

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).

Light management
- Demonstrate improved light capturing under variable angles of light incidence by nano imprinted textured layers (window side).
- 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.

Back end interconnection
- Demonstrate high speed laser scribing and printing of conductors and insulators for monolithic module interconnection by free 2D patterning.
- Develop and validate model for optimized module efficiency making full use of freedom of shape and size of module interconnection.

High bandgap kesterites
- Development of CIGS and CZTS -based absorbers with higher bandgap; material development by Solliance partners, TNO participates in process development and evaluation.

10.6 Addendum TO2-2015 Energie

In het kader van bevordering samenwerking TO2 in 2015 is het volgende project goedgekeurd in het maatschappelijke, veilige en schone en efficiënte energie thema.

Projecttitel
Het beste van twee werelden: hoog efficiënte hybride zonnepanelen

Onderwerp en beschrijving van het project
Commerciële zonnepanelen op basis van siliciumcellen halen een rendement van 15 tot 22%. De bovengrens zal in de komende jaren naar verwachting toenemen tot zo'n 24 à 25%, waarmee deze technologie qua prestaties zijn fundamentele limiet dicht benadert. Om het rendement verder te kunnen laten toenemen is het noodzakelijk om silicium te combineren met een ander materiaal in een zogenaamde tandem- of hybridestructuur. Door een speciaal daarvoor ontwikkelde ("breedbandige") dunne-film zonnecel te stapelen op een efficiënte siliciumcel is het mogelijk om een rendement van 30% of meer te halen. Dit project behelst het ontwikkelen van breedbandige dunne-film materialen (bijvoorbeeld kesterites, III-V,

perovskieten), en het demonstreren van hun effectiviteit in een gestapelde hybride cel met een efficiënte silicium bodemcel. Daarnaast beoogt het project het uitvoeren van modellering en praktijktesten van nieuwe dunne-film cellen en hybride cellen, met het doel om de effecten van variaties in lichtspectrum, intensiteit, hoek van inval en temperatuur te kwantificeren. Het project vormt een integraal onderdeel van het TKI Solar Energy innovatieprogramma.

Resultaat (eind 2015)
De ontwikkeling van efficiënte hybride zonnecellen en -panelen is een meerjarentraject met een hoge relevantie voor zowel de silicium als de dunne-film PV-industrie. Eind 2015 zal een cruciaal tussenresultaat worden geleverd: *de demonstratie van een geschikt breedbandig dunne-filmmateriaal in een losse en een gestapelde cel*. Daarnaast zullen de resultaten van modellering en praktijktesten van nieuwe dunne-film technologie voor hogere efficiency cellen (in het bijzonder CIGS/CZTS en organische zonnecellen en verbeterde lichtinvangst) worden gepresenteerd, als input voor de technologische optimalisatie.

Deelnemende TO2 partners (plus wat zij bijdragen in dit project)
ECN en TNO, als partners in Solliance en als initiatiefnemers van SEAC (Solar Energy Application Centre). Daarnaast wordt samengewerkt met andere Solliance partners, in het bijzonder TU/e en imec. ECN en TNO werken samen aan de ontwikkeling van breedbandig dunne-filmmateriaal en aan de constructie van hybride structuren, ECN ontwikkelt en levert geschikte hoog-rendement silicium bodemcellen, SEAC en Solliance voeren praktijktesten uit.

Mogelijke overheidspartners en private partners
Het project verbindt en integreert de twee onderdelen van de *upstream* PV-sector: wafer-silicium en dunne-films. Mogelijke private partners zijn alle TKI Solar Energy partners uit de programmalijn P- Technologieën, waaronder Smit Ovens, DSM, Tempress, e.a. In de publieke (universitaire) sector zijn RUN, TUD, UT, RuG en UU mogelijke partners.

11 TNO applied research in HTSM Roadmap Solar (OPV - Holst)

11.1 Introduction

Organic PhotoVoltaics (OPV), although not yet commercialized on a large scale, is considered to be an unique thin film PV technology. Its annual energy harvesting yield seems to surpass those of the currently known and established other PV technologies like Si PV, CIGS and other; its estimated energy payback time is one order of magnitude lower compared to Si PV and by introducing roll-to-roll (R2R) manufacturing technologies, its upscaling potential is vast whilst keeping production costs low. Further, due to the possibility of tuning color and/or semi-transparency, the ease of adapting shape and form and the compatibility with flexible low T_g substrates, makes OPV technology ultimate suited for seamless integration in e.g. BIPV elements, vehicles, greenhouses.
Before this can happen, several hurdles still need to be taken:

- Transfer of lab record efficiencies to production environment by up-scaling of materials, inks and implementing (R2R) deposition processes with high reliability and reproducibility.
- Improving stability by material design, stack design, process choices and packaging technologies.
- Integration technologies compatible with current application carriers.

11.2 Program 2015-2018

In 2015, the newly installed (Dutch) R2R will be made operational for running the predefined OPV baseline process. Once it is running, new efficiency and stability improving materials, concepts and processes will be gradually introduced. This in order to improve efficiency, lifetime and yield. The aim is to be able to reliably run a baseline process in 2018 that produces modules with ≥ 8% efficiencies, with extrapolated outdoor lifetimes of ≥ 10 years and with an extrapolated (full capacity estimated) yield of ≥ 85%.

Focus will also be on developing a R2R and plastic substrate compatible back-end module manufacturing process, suitable for seamless integration into building elements (walls, roofs and windows), vehicles (cars, busses, trains, ...) and greenhouses. This will be done stepwise: (1) reliable P1, P2 and P3 scribing processes on “flat” plastic, (2) R2R, (3) reliable back end process development and (4) development of invisible scribe technologies (for e.g. windows application or vehicle integration.

A R2R packaging baseline process will be developed and implemented. Once running, further improvements will be gradually introduced, depending on the industrial and final application needs.

Integration challenges will be identified and investigated. IP will be generated together with possible new equipment development.

11.3 Ambition and Impact

The ambition of the Solliance OPV Program is to further strengthen the collaboration of the different R&D partners by focusing further on the current industrial demands of the current partners as well as the non-partners. This in turn should allow to expand the current industrial partnership portfolio further along the value chain of OPV. This should allow to further strengthen Solliance's OPV technology position to become world leader in OPV R&D.

The Solliance OPV Program strives to become unique and world top in R2R handling and R2R manufacturing technologies (including module technologies), packaging technologies, and integration technologies. The developed technologies will be implemented by our industrial partners for the manufacturing of their commercial products. This will initiate the growth of new and greener products.

11.4 Demand driven interaction

The Solliance OPV Program runs currently mainly in shared research mode. Several industrial partners currently have joined the program (Materials: Nano-c; Equipment: SmitOvens, VDL-ETG, Bosch-Rexroth, Maan; Manufacturing: ThyssenKrupp; Application/Integration: ThuyssenKrupp). Together with these companies, the technical annex (R&D Roadmap) is annually revised and updated. This ensures that the program is addressing the needs of the industrial partners. Based on the many conversations of potential new partners and their expressed needs, several of the "most wanted" topics are currently also integrated in the program (e.g. back-end laser module manufacturing technologies, R2R packaging, integration technologies, …). The results of these activities should help in attracting new partners.

Industrial partners can participate in all activities, from meetings to experiments. They have access to all Solliance's OPV infrastructure. Apart from the 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.

Currently discussions are on-going for possible new partnerships with:

- Materials: Solvay, Merck, PolyEra, Solarmer, DTF
- Equipment: Roth&Rau, SPGPrints
- Producers: DisaSolar, Eight19, Belectric, Armor, Heliatek, DyeSolar, Oxford PV, CSEM Brazil
- End-users: AGC, St-Gobain, Fiat, Svenson, Havecon, …

Collaborations (by projects, PhD's or student exchanges) will be continued/initiated with UG (Prof. Kees Hummelen), AMOLF (Prof. Albert. Polman) and Radboud University (Prof. Miro Zeman) to further strengthen the program's scientific foundation.

11.5 Program 2015

The Solliance OPV Program consists of four work packages: Efficiency, Up-scaling, Lifetime and Integration/Applications. For 2015, the following major Milestones/Results have been defined:

Efficiency

- Lab cell efficiency of ≥ 13% @ 1 sun, 25℃ for cell area of 1 cm^2. Novel materials of TU/e/UG/UHasselt/Nano-c and new device designs of TU/e and imec will be implemented.
- Submodule efficiency of ≥ 9% @ 1 sun, 25℃ for module area of ≥ 15 cm^2.
- OPV optimized light incoupling nano-structures identified (TU/e, AMOLF, Raboud University, DSM).
- Assessment of perovskites: compatibility with OPV envelope and OPV (R2R) baseline process flow.

Up-scaling

- Baseline OPV deposition process on new Solliance R2R line up and running (in collaboration with VDL-ETG, SmitOvens, Bosch-Rexroth and Maan).
- Scalable flexible (R2R) module with ≥ 6% efficiency @ 1 sun & 25℃ for ≥ 100 cm^2.
- Baseline laser based module manufacturing on plastic substrates, R2R compatible.

Lifetime

- Baseline R2R packaging process up and running.
- Stability assessment of baseline devices/annual harvesting.

Integration and Application

- Economic and performance assessment (together with end-user, e.g. AGC) of semi-transparent OPV directly deposited on glass for BIPV + demo’s.
- Economic and performance assessment (together with end-user, e.g. ThyssenKrupp) of non-transparent flexible OPV for BIPV + demo’s.
- Economic and performance assessment (together with end-user, e.g. Svensson) of semi-transparent flexible OPV for greenhouses + demo’s.

12 TNO applied research in HTSM Roadmap Healthcare

12.1 Introduction

The van ‘t Hoff program is a collaborative research and innovation program combining the strong points of partners throughout the value chain in medical technology to accelerate technological innovation and their implementation in health care.

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 hospitals.

12.2 Program 2015-2018

The program has several long term goals, that are embedded in 5 program lines:

- In the “selective ion measurement for dialysis” program the goal is to develop a miniaturized selective ion sensor for sodium, potassium and calcium that can be integrated in a portable kidney and has sufficient accuracy to validate reuse of dialysate.
- In the “detection and monitoring of neurodegenerative diseases” program the goal is to develop a simple screening technology for safe, accurate and cost-effective diagnosis and monitoring of neurodegenerative diseases (e.g. Alzheimer’s disease, Parkinson’s Disease).
- In the “non- and minimally-invasive glucose measurement” program the goal is to develop a commercially available non-invasive glucose sensor and a commercially available minimally-invasive glucose sensor.

- The “non-invasive measurements for cardiovascular risks in diabetics” program aims to improve the risk assessment for diabetic complications and cardiovascular events in diabetic patients by developing a modular fiber-optic sensing platform that allows real-time quantitative measurements of biomarkers such as chromophores, fluorophores and scattering properties of tissue.
- In the “surgical imaging/image guide surgery” program the goal is to develop spectroscopic devices that allow real-time imaging and identification of relevant tissue structures (nerves, vessels, tumour borders) during surgery and other medical procedures.

12.3 Demand driven interaction

The content of the program is defined in close cooperation with each partner, where TNO coordinates the program and ‘guards’ the overall program goals. TNO consults each participant in the Shared Research Programs 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. TNO will issue the partner of the program description(s) in the 4th quarter of each calendar year. TNO updates the partners on the progress via dedicated quarterly reports and meetings and the annual partner meeting.

What are the present and envisaged new partners, both from industry and universities/fellow RTO’s?

<u>Present van ‘t Hoff partners</u>
Health Foundations:
Dutch Kidney Foundation, Dutch Diabetes Foundation, Dutch Brain Foundations, Dutch Alzheimer’s Foundation, Dutch Parkinson Association, Stichting Pienter Meten
Industry:
DEMCON, Tornado Spectral Systems, NeoKidney, Kadex, Inreda Diabetic
University:
Maastricht University Medical Centre
VUmc
RTO:
TNO

<u>Envisaged Partners</u>
Industry:
1 Company on integrating components on interrogator level +Integrators on chip level
1 Large dialysis company
1 High tech medical device company on in vitro diagnostics
1 High tech medical device company on diagnostic instruments for eye care
1 Pharma company
University:
AMC
London University College
Tallinn University of Technology – Technomedium
RTO:
Lazer Zentrum Hannover

12.4 Program 2015

In 2015 we will focus our research activities on three program lines. Furthermore we will focus on growth of the program by bringing in new partners on all 5 program lines, which will result in acceleration of the research in the 3 program lines listed below and/or continuation of research activities of the other program lines.

Selective ion measurement for dialysis
In 2014 a working setup for quantified LIBS measurement of Na, K and Ca in spent dialysate is realized within a laboratory setting (TRL3). In 2015 research starts with tests that will be conducted in a clinical setting leading to the identification of functional and technical requirements of a diagnostic sensor for 1) clinical application when measuring relevant ions in spent dialysate (ergo a Single Pass Measurement System; SPMS) that provides the nephrologist with information for adjusting the dialysate composition at the next dialysis session and 2) an Electrolyte Feedback Control System (EFCS) for closed loop regulation of electrolyte levels during the dialysis session. Furthermore, we will design a “blue-print” for the LIBS sensor, all with respect to a viable business case and a compact and easy to use system. A SPMS will be built and tested in a laboratory environment to assess the key performance indicators to confirm the performance of the integrated device. The activities aim at a TRL advancement from 3 to 6 to enable testing and validation of the system in a large-scale test in a clinical environment in 2016. Furthermore, we will start with the design of feedback loop algorithm, research that will be finalized in 2016.
Deliverables:

- Design of blue print LIBS sensor ready (Q3)
- Single Pass Measurement System built based on system requirements (Q4)

Detection and monitoring of neurodegenerative diseases
In 2014 the work focused on the development of a ring resonator biosensor for single-analyte measurements of Amyloid Beta, tau and p-tau (neurodegenerative disease markers) in CSF and cortisol (stress marker) in saliva. In 2015 the research efforts will focus on the advancement from single to multiplexed measurement of Amyloid Beta, tau and p-tau. To do so, we will re-design the photonic IC enabling the simultaneous interrogation of at least 4 (target is 10) ring resonators and leading to improved sensitivity. Furthermore we will improve the signal processing in the interrogator software and we will investigate techniques to locally apply different antibodies to the chip surface. Experiments will be performed to test the performance of multiplexed measurement of Amyloid Beta, tau and p-tau. The new design will subsequently be fabricated and characterized. The interrogator software will be improved: new (adaptive) signal processing techniques will be introduced in order to improve the signal resolution and filter out disturbances. This will lead to a factor 10 improvement in detection limit.
Deliverables:

- Optimization of process for locally applying antibodies (Q3)
- Re-design (hw +sw) for accurate multiplex measurements of at least 4 analytes (Q4)

Furthermore, since partners have expressed a wish for a fully non-invasive technology, the feasibility of starting research activities that aim to develop an optical method to detect neurodegenerative diseases via the eye based upon (several simultaneously applied) optical imaging techniques will be investigated.

<u>Non- or minimally invasive glucose measurement</u>
The research activities for the noninvasive glucose sensor focused in 2014 on extending the dataset of measurements with the Raman spectroscopy based prototype in a clinical setting in order to improve the method used for analysis. In 2015 we will focus on preparing the technique and method for future adaptation in a true POC. Therefore the research activities will on the one hand consist of 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. The hardware and software components will be integrated into a prototype and demonstrated in a relevant environment.
Deliverables:

- Improved method for prospective measurements (Q3)
- Re-design (hw +sw) for miniaturized POC device (Q4)

For the research on minimally invasive sensor the 2014 focus was on the effects of confounding biological factors and optimizing fiber properties of MIR-light transmitting fibers and its availability and cost. In 2015 we will focus on the optical design and procurement of a sensor prototype. Therefore, functional and technical requirements will be inventoried and a conceptual 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. The 2015 research is completed with a test on tissue-mimicking phantoms.
Deliverables:

- Design (hw + sw) integrated in sensor module (Q3)
- Tests on tissue-mimicking phantoms (Q4)

13 TNO applied research in HTSM Roadmap Security

13.1 Introductie

Veiligheid is een primaire voorwaarde voor welzijn en economische ontwikkeling. In de open economie van ons land maakt de veelheid van risico's kwetsbaar. En daar waar de fysieke veiligheid in Nederland is toegenomen, hebben veel vormen van onveiligheid zich verplaatst naar het cyberdomein.
De tegelijkertijd optredende schaalvergroting van economische systemen en van de bedreigingen voor onze veiligheid vereist een toenemende samenwerking. Politie, veiligheidsregio's en andere diensten (veiligheidsdiensten, operationele diensten, parate diensten, hulpverleningsdiensten) zetten daarom in op een regie op een grotere schaal. Tussen overheid, bedrijfsleven en burgers ontstaat een nieuw samenspel. De balans tussen privacy en veiligheid is daarbij actueel.
Ook interne of maatschappelijke veiligheid en externe veiligheid ofwel defensie raken onderling steeds meer verweven. Dit uit zich onder meer in civiel-militaire samenwerking en inzet van dual use-technologie.

De HTSM-Roadmap Security
(zie: www.hollandhightech.nl/htsm/Innovatie/Roadmaps/Security) ligt ten grondslag aan dit VP Security. Voor zover het ontwikkelingen betreft die primair gekoppeld zijn aan de defensie gerelateerde industrie zijn deze opgenomen in het VP Defensie Gerelateerde Industrie.

13.2 Visie op het programma 2015-2018

Voor innovaties in het security domein is aansluiting op de behoeften van de publieke veiligheidsorganisaties als politie, veiligheidsregio's en KMar een kritische succes factor. Daar zit de koopkrachtige vraag en terugverdienmogelijkheden voor nieuwe commerciële producten en diensten van de toeleverende veiligheidsindustrie. 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. Door vertegenwoordigers van deze vier groepen stakeholders is in 2012 The Hague Security Delta opgericht met als doel het creëren van een nationaal veiligheidscluster van internationale allure. In The Hague Security Delta trekken de regio's Den Haag, Twente/Enschede en Eindhoven/Tilburg gezamenlijk op.

In de periode 2012-2014 hebben de kennisinitiatieven vanuit de onderdelen Systems of Systems, Sensoren en Cybersecurity van het VP Security geleid tot:

- Samenwerking met de Nationale politie op de gebieden Real Time Intelligence en aanpak van problematiek van woninginbraken.
- Samenwerking met de Veiligheidsregio's op het gebied van informatiepreparatie voor overstromingsdreigingen en daarbij optredende domino effecten.
- Samenwerking met Schiphol en KMar voor innovatie van beveiliging op Schiphol.
- Een contour voor samenwerkingsprogramma van de veiligheidsregio's en defensie voor grootschalig geïntegreerd optreden bij crises.
- Diverse tools voor advanced risk management en reductie van specifieke cyberdreigingen voor bedrijfsleven waar cybersecurity een significante factor is voor de business continuïteit.

Bij vier van deze vijf initiatieven zijn al stappen gezet in samenwerking met bedrijven.

De schaalvergroting en de toenemende internationale samenwerking zal in de periode 2015-2018 tot verdere intensivering van innovatie initiatieven leiden. Beleidsinitiatieven van de departementen VenJ, Defensie en Economische Zaken spelen daar nadrukkelijk op in. Ook in het Europese Horizon 2020 programma is Security een thema dat een hogere prioriteit heeft gekregen; een nieuwe ontwikkeling hierbij is de stimulering van innovaties voor versterking van de civiel-militaire samenwerking en gezamenlijk initiatief van de EU en EDA.

In het civiele domein van het TNO thema Defensie en Veiligheid heeft TNO vijf innovatieclusters gespecificeerd, waarbinnen strategische samenwerking voor multi-stakeholderinnovaties gestalte krijgt. Voor elk van deze innovatieclusters is binnen TNO een team gevormd dat verantwoordelijk is voor de strategische positionering van TNO, de relaties met trendsettende stakeholders, de samenwerking met partners en de ontwikkeling van de opdrachtenportefeuille. Vanuit deze clusters wordt ook bijgedragen aan de programmering van de kennisontwikkeling binnen de VPs en de toepassing van de onderzoeksresultaten. TNO breed is - mede op aangeven van het voor innovatie coördinerende Ministerie EZ - een ontwikkeling van strategische researchprogramma's op gang gebracht; kenmerk daarvan is dat TNO en de betreffende stakeholders meer gezamenlijk gaan investeren en zo de investeringsrisico's in innovatietrajecten gaan delen om een beter toepasbaar resultaat te krijgen.
In de innovatieclusters zal ook de benutting van de resultaten van EU projecten aandacht krijgen. Met een acceptabele inspanning kunnen zo de resultaten toegankelijk gemaakt worden voor belanghebbenden buiten de directe projectpartners. Verder kunnen vanuit deze innovatieclusters initiatieven voor nieuwe EU samenwerkingsprojecten worden ontwikkeld.

De civiele innovatieclusters in het TNO Thema Defensie en Veiligheid zijn nagenoeg synchroon aan de Security-innovatiegebieden voor multi-stakeholdersamenwerking in het Europese programma Horizon 2020 en in The Hague Security Delta als de nationale samenwerkingsinfrastructuur voor publiek-private-samenwerking in het veiligheidsdomein: de nationale publiek-private samenwerking (zie onderstaande tabel).

<table>
<tr><th>HSD-veiligheidshuizen</th><th>EU-Security H2020</th><th>Innovatiecluster in TNO-thema VM</th></tr>
<tr><td>Nationale Veiligheid</td><td rowspan="3">Disaster Reduction and Resilience</td><td rowspan="2">Crisismanagement en CIP</td></tr>
<tr><td rowspan="2">Veiligheid van vitale infrastructuur</td></tr>
<tr><td rowspan="2">CBRNE</td></tr>
<tr><td rowspan="2">Forensics & Intelligence</td><td rowspan="3">Fight against Crime and terrorism</td></tr>
<tr><td>Intelligence</td></tr>
<tr><td rowspan="2">Veiligheid in steden en mainports</td><td rowspan="2">Toezicht, bewaken en beveiligen</td></tr>
<tr><td>Bordersecurity</td></tr>
<tr><td>Cybercrime en Security</td><td>Cybersecurity</td><td>Cybersecurity</td></tr>
</table>

Door deze keuze van Clusters kunnen de nationale netwerken van de HSD-innovatiehuizen optimaal invloed hebben op de definitie van onderzoekstrajecten en het ontwikkelen van de samenwerking met in natura en cash investering van de meest belanghebbende partijen. Bovendien wordt zo toegang tot de resultaten van

EU projecten en ontwikkeling van samenwerking met buitenlandse veiligheidsspelers gefaciliteerd. Door de clustering wordt ook voorkomen dat ieder EU project afzonderlijk gemonitord moet worden door individuele organisaties.

13.2.1 Strategische ontwikkelingen

Binnen de programma portfolio van de kennisontwikkelingsmiddelen van TNO wordt in het Thema Maatschappelijke Veiligheid ook een VP Veilige Maatschappij uitgevoerd. Dit laatste VP richt zich op kennisontwikkeling voor vraagstellingen van overheden, waarbij bedrijven geen dominante stakeholders zijn. Mede naar aanleiding van een verzoek van het Ministerie VenJ wordt voor de strategie periode 2015-2018 de afstemming van het VP Veilige Maatschappij en het VP Security geïntensiveerd en ook de betrokkenheid van de The Hague Security Delta verankerd. De basis voor de afstemming wordt gekozen op clusterniveau (zie paragraaf 2). Elk cluster heeft belang bij meerdere VP onderdelen:

VP-onderdelen / Innovatie-Clusters	VP-Veilige Maatschappij			VP Security		
	Informatievoorziening	Proces innovatie voor performance-ververbetering	Cybersecurity & Societal resilience	Systems of systems	Sensoren	Cyber risk management & System resilience
Crisismanagement & CIP	++	++	+	++		
CBRNE		+			++	
Intelligence	++			++		
Toezicht, bewaken en beveiligen		++	+	+	++	+
Cybersecurity			++			++

Daarnaast is een ontwikkeling in gang gezet van Defensie als een structurele veiligheidspartner naast de politie en de veiligheidsregio's bij ongevallen en rampen. In het overleg van de Ministers van Veiligheid en Justitie en van Defensie op 30 januari 2014 is dit als uitgangspunt voor nieuwe initiatieven bekrachtigd en verankerd in een afstemmingsstructuur. Als prioriteiten voor Versterking Civiel Militaire Samenwerking (VCMS) zijn twee thema's benoemd: OTOTELSim (Opleiden, Trainen, Oefenen, Testen, Evalueren, Lessons learned en Simulatie) en de samenwerking tussen Defensie en de Nationale Politie. TNO is op verzoek toegetreden tot de werkgroep VCMS en de taskforce OTOTELSim. Zowel voor defensie als voor de politie is de ontwikkeling van UAV's en slimme inzetconcepten daarvoor een prioriteit issue. TNO denkt hier op in te kunnen spelen met een bredere ontwikkeling van waarnemingscapaciteiten met behulp van mobiele sensoren, waarbij ook de ontwikkeling van bodycams en voertuiggedragen sensoren wordt meegenomen.

Een derde strategische ontwikkeling betreft de versterking van de samenwerking tussen de zes nationale instituten voor toegepast onderzoek (Deltares, DLO, ECN, MARIN, NLR en TNO). Aan het samenwerkingsverband TO2 is in dit kader door EZ een plan gevraagd voor gezamenlijk onderzoek op de zeven maatschappelijke thema's van het Europese programma Horizon 2020. Voor het thema Veilige Samenleving hebben NLR, TNO, Marin, Deltares en DLO een plan gemaakt met als onderdelen Crisismanagement, Critical Infrastructure Protection en Inzetbaarheid en betaalbaarheid van de krijgsmacht. Het voorlopig gealloceerde budget voor 2015 is 2 M€; In het gezamenlijke plan is aan TNO bijna 50% van het totaal aangevraagde budget gekoppeld.

13.3 Ambition and Impact

Het VP Security blijft in de periode 2015-2018 gefocussed op de drie DeelRoadmaps van de HTSM-Roadmap Security:

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. Hierbij zijn alle stakeholders en hun informatiebronnen betrokken. Het kunnen realiseren van robuuste system-of-systems oplossingen biedt grote kansen op de markt.
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 filteren van irrelevante data. Er zijn veelbelovende ontwikkelingen op het gebied van intelligente sensoren en zelflerende systemen.

DeelRoadmap	Beoogde impact	Aan HSD gelieerde innovatie-clusters voor ontwikkeling PPS-consortia, internationale samenwerking en strategische researchprogramma's
System of systems	Publieke veiligheidsorganisaties: verbetering efficiency en effectiviteit operationele taken	Crisismanagement & CIP Intelligence

	Leveranciers van systemen, tools en diensten: internationaal onderscheidende en erkende producten	
Cyber risk management & system resilience	Eigenaars van ICT-systemen uit bedrijfsleven en overheid: kosten efficiënte beheersing cyberrisico's IT-bedrijven: Nieuwe concepten en tools voor cyber resilience van systemen	Cybersecurity
Sensoren	Publieke veiligheidsorganisaties: verbetering efficiency en effectiviteit waarnemingstaken Producenten van hard- en software voor sensorsystemen: nieuwe producten	Toezicht, bewaken en beveiligen CBRNE

13.4 Demand driven interaction

Het VP Security wordt begeleid door het door de topsector benoemde Roadmap team Security, bestaande uit Thales als industrieel boegbeeld, VenJ, Defensie, NLR, STW/NWO en TNO. Het Roadmap team heeft hieraan als leden toegevoegd: NIDV, Gemeente Den Haag. Het ministerie EL&I heeft een eigen vertegenwoordiger aan het Roadmap team toegevoegd.
Periodiek wordt een kennisarena georganiseerd met een bredere groep van stakeholders uit publieke veiligheidsorganisaties en het bedrijfsleven. De laatste keer vond dit plaats op 28 mei 2014, waarbij HSD een faciliterende rol vervulde. Vanuit HSD worden nu initiatieven ontwikkeld voor het vormen van vijf PPS-innovatieclusters die aansluiten bij de HSD-innovatiehuizen. Deze clusters rond veiligheidsvraagstukken zijn gericht op ontwikkeling van PPS consortia voor innovatietrajecten, van internationale samenwerking en van strategische researchprogramma's. In de volgende paragraaf wordt nader ingegaan op de aansluiting van de DeelRoadmaps en de innovatieclusters.

Specifiek voor de defensie gerelateerde industrie is in 2014 een nieuw VP ontwikkeld. In dit nieuwe VP worden enkele ontwikkelingen op het gebied van actieve sensoren uit het VP Security krachtig voortgezet; daarnaast vinden in dit VP ontwikkelingen plaats die passen in andere HTSM Roadmaps (o.a. Components & Circuits en Materials).

13.5 Program 2015

Deze paragraaf beperkt zich tot de inhoud van de drie onderdelen van het Vraaggestuurd Programma Security in 2015. Per onderdeel zal worden ingegaan op doelgroepen, te betrekken samenwerkingspartners en te bereiken impact.

Systems of systems
Samenvatting bereikte resultaten in 2012-2014

- Kennis:
    - Beoordelingskader voor nieuwe concepten en technologieën voor Real Time Intelligence (voorzien eind 2014).

  - Concept- en visievorming over Real Time Intelligence vanuit System of Systems perspectief. Diverse publicaties en congresbijdragen.
  - Methodiek voor Design Basis Threat Analysis in Systems of Systems context.
- Initiatieven voor doorontwikkeling naar implementatie:
  - Ontwikkeling van platform voor gedeelde Real Time Intelligence in Internationale Zone (consortium Siemens, Thales, TNO, gemeente Den haag, diverse internationale organisaties zoals Eurojust).
  - Samenwerking rond Real Time Intelligence in relatie tot burgerparticipatie (CGI, Politie, TUDelft).
  - Samenwerking rond nieuwe intelligenceconcepten overstromingsdreiging (VR Hollands Midden, Hoogheemraadschap Rijnland, Defensie, Vitale Infrastructuurbeheerders).
  - Opzet van Real Time Intelligence lab onder de vlag van HSD (Initiatiefnemers Politie, TNO, HSD). Diverse bedrijven geïnteresseerd.

Inhoud programma 2015
- Kennis:
  - Interacteren met systemen voor informatievoorziening als basis voor multi-actor-veiligheidsoperaties.
  - Control room technologie (incl. visualisatie en ontwikkeling van virtual reality technieken).
  - Trust en privacy bij Systems of Systems.
- Doorontwikkeling naar implementatie:
  - Uitbouw van in 6.3.1 genoemde initiatieven tot implementatie (Internationale Zone, Grootschalige rampen en crises, en Big Data en veiligheid).
  - Nieuwe producten, processen en diensten voor Real Time Intelligence in veiligheidstaken.
- Standaardisatie en samenwerking
  - Uitbouwen van RTI-lab tot effectief centrum voor *validatie* en *Thought Leadership.*

Beoogde impact en doelgroep
- Richten van kennisopbouw en investeringen in infrastructuur en (personele) capaciteiten voor Real Time Intelligence. Hiervoor worden krachtige samenwerkingsplatformen opgericht met eindgebruikers (politie, LMO, veiligheidsregio's, defensie), kennisinstituten en industriële leveranciers van producten en diensten. De ambitie is het ontwikkelen van samenwerking in een Stragische Research Programma met een faciliteit voor experimentele beproeving van concepten.

Cyber risk management & system resilience
Samenvatting bereikte resultaten in 2012-2014
- Kennis:
  - Advanced Risk Management (ARM 2.0) methodiek ontwikkeld.
  - Kennis opgebouwd van Typosquatting (misbruik van URL's voor phishing).
  - Cost of Cyber modellen voor DDOS en defacement ontwikkeld.
  - Afstudeeronderzoek van de Erasmus Universiteit naar bedrijfskenmerken die de vatbaarheid van organisaties voor cybercrime definiëren.
  - Kennis van de resilience van smart grids en daarvan onderdeel uitmakende componenten voor cyberrisico's.

  - Kennis van gelaagde modellen die de samenwerking tussen Security Operations Centers (SOCs) mogelijk moet maken. Dit is zeer relevant voor het tot stand komen van een virtueel (Rijks)SOC in PPS.
  - Kennis opgebouwd van nieuwe STIX en TAXII uitwisselingsprotocollen voor cybersecurity dreigingen (zgn. Indicators of Compromise of IoC's).
- Initiatieven voor doorontwikkeling naar implementatie:
  - ARM 2.0: Toetsing methodiek voor dynamische en complexe cyberrisico's
    (Consortium: BKWI (Bureau Keteninformatisering en Werk en Inkomen), UWV, Gemeente Utrecht, Complions B.V., TNO).
  - Typosquatting: Tools ontwikkeld om URL misbruik te detecteren en om de aard van het misbruik te achterhalen (parkeersites, mailservers, phishing)
    (Consortium: SIDN, Rabobank, TNO).
  - Experimentele faciliteit voor testen en optimaliseren van resilience van componenten voor smartgrids voor cyberrisico's (Consortium: ENCS, bedrijven uit de energiesector, TNO).
- Ontwikkeling standaardisatie in de markt:
  - Deelname aan standaardisatie in MITRE, volgen van standaardisatie in OpenIOC en IETF; deelname aan ISACs.

Inhoud programma 2015
- Kennis:
  - Onderzoek naar zgn. 'SuperTargets'; dit zijn personen die herhaaldelijk slachtoffer worden van cybercrime. Gestart wordt met ontwikkeling van indicatoren die deze personen vooraf kunnen identificeren (Human Factors) en vervolgens gaat het om mogelijkheden om schade te voorkomen (handelingsperspectieven en vroegtijdige interventie).
  - Kennis van PCS/SCADA security in samenwerking met SecurityMatters en mogelijk Rijkswaterstaat en Verispect.
  - Kennisopbouw van security op het gebied van Smart Mobility (DITCM).
- Doorontwikkeling naar implementatie:
  - Implementatie van ARM 2.0 in de risico tooling van Complions B.V.
  - Ontwikkeling van nieuwe (beter beveiligde) componenten voor smart grids.
  - Ontwikkeling van een technische omgeving waarin STIX en TAXII de uitwisseling van threat informatie (IoC's) ondersteunt.
- Standaardisatie en samenwerking
  - In HSD vormgeven van innovatieclusters "Cybercrime en Security".
  - Mogelijk inbrengen van een study item in MITRE voor STIX/TAXII.

Beoogde impact en doelgroep
- Een consortium van bedrijven die ARM 2.0 willen adopteren in hun risicoanalyse methodieken (Complions B.V. en TNO zijn hier net mee gestart).
- Een breed consortium van belanghebbenden om veilige componenten voor smart meter te bouwen, bijvoorbeeld ENCS, bedrijven uit de energiesector, Siemens, Iskra, V&J, EZ en TNO.
- Een consortium van bedrijven om de monitoring van PCS/SCADA systemen in een managed service mogelijk te maken, samen met SecurityMatters, Verispect en mogelijk Rijkswaterstaat.
- In HSD verband bij elkaar brengen van IT industriepartners (IBM, Dell, DataExpert, HP, CompuMatica, Fox-IT) voor ontwikkelen van geïntegreerde SOC-solutions. Hiervoor is een strategische samenwerking met een gezamenlijke researchinspanning voorzien.

- Breder consortium voor SuperTargets, zoals BZK, SIDN en de andere banken.

Passieve sensoren
Samenvatting bereikte resultaten in 2012-2014

- Kennis:
    - Kader voor beoordeling toezichtconcepten (o.a. publicatie in Multimedia tools and applications).
    - Sensorfusie voor gedragswaarneming en het automatisch signaleren van dreigingen zoals zakkenrollerij.
    - Concept-ontwikkeling voor inzet van UAV's (o.a. concept White paper).
- Initiatieven voor doorontwikkeling naar implementatie:
    - Software ontwikkeling voor gedragsherkenning m.b.v. intelligente camera's (consortium KMar, QVI, TNO; financiële bijdrage NCTV).
    - Productontwikkeling voor preventie woninginbraken (consortium Nationale Politie, vijf bedrijven, TNO).
    - Samenwerking voor nieuwe toezichtconcepten voor Schiphol (Schiphol, KMar, Bosch, TNO e.a.).
- Ontwikkeling standaardisatie in de markt:
    - Inbreng van in Nederland gedragen visies en Roadmap voor toezicht in de thematic Group Surveillance &Video Analytics in ERNCIP.

Inhoud programma 2015

- Kennis:
    - Mobiele sensoren; naast UAV's ook bodycams, voertuig gedragen sensoren.
    - Infrastructuur voor ad hoc uitbreiding van camerasystemen bij crisissituaties; onderdeel daarvan is automatische kalibratie van camera's.
- Doorontwikkeling naar implementatie:
    - Uitbouw van bovengenoemde initiatieven tot implementatie (software QVI, consortium woninginbraken, consortium Schiphol).
    - Nieuwe producten en systemen voor herkennen van afwijkend gedrag in het OOV domein.
    - Civiel-militaire samenwerking bij waarnemingstaken in crisissituaties met optimaal gebruik van wederzijds specialistisch materieel.
- Standaardisatie en samenwerking
    - Bijdragen aan vormen van innovatieclusters "Toezicht, bewaken en beveiligen" en "CBRNE" in HSD-verband.

Beoogde impact en doelgroep

- Richten van kennisopbouw en investeringen in infrastructuur en (personele) capaciteiten voor waarnemingen m.b.v. passieve sensoren ter ondersteuning van veiligheidstaken. Hiervoor worden één of twee krachtige samenwerkingsplatformen opgericht met eindgebruikers (Schiphol, Rotterdamse Haven, KMar, douane, politie, veiligheidsregio's, defensie), kennisinstituten en industriële leveranciers van producten en diensten. De ambitie is het ontwikkelen van samenwerking in een aan HSD gelieerd Innovatiecluster "Toezicht, bewaken en beveiligen" met aansluiting op de ontwikkelingen in de EU markt. De ambitie is het ontwikkelen van een strategisch research programma met een faciliteit voor experimentele beproeving van concepten.
- Een krachtig consortium van internationale organisaties (OPCW, G7, Europol), Nationale overheden (NCTV, BuZa, Defensie) en toeleveranciers van producten en diensten m.b.t. detectie en monitoring van CBRNE-agentia voor het

ontwikkelen en toepassen van passieve CBRNE-sensoren voor snelle respons en effectieve controle bij veiligheidsincidenten, rampen en relevante dreigingen.

14 TNO applied research in HTSM Roadmap Automotive

14.1 Introduction

The *Speurwerkprogramma* 2015-2018 HTSM Roadmap Automotive is the continuation of the *Vraaggestuurde Programma* VP Automotive Mobility Systems (AMS) 2011-2014[2]. This TNO knowledge development Program is focusing on strengthening the competitive position of the Dutch automotive and mobility industry and is aligned with the Automotive Roadmap of the TKI HTSM.
With the introduction of the 2015-2018 TNO strategy[3] TNO chose to structure its organisation around themes focussing on large societal transitions. The VP AMS knowledge development Program will be embedded in the theme ‘Urbanisation’ focussing on the transition ‘from urbanisation blocking growth towards vital urban development’. This theme is structured in four Programs (figure 1) including the Program Transport and Logistics.
The prime objective of these Programs is to develop sustainable solutions to accelerate these societal transitions. By intensively working with governments and industry a fast market introduction will be secured with the objective to strengthen the competitive position of the Dutch industry.

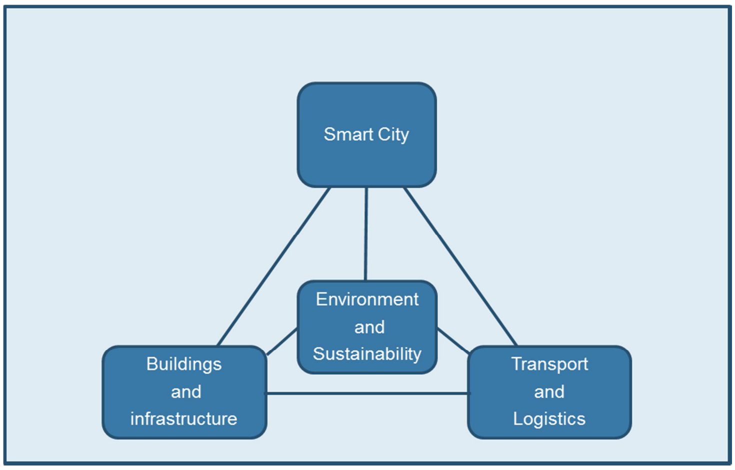


Figure 1: Structure TNO theme Urbanisation

14.2 Program 2015-2018

14.2.1 Long Term vision

Improving traffic safety, zero health effects, reducing climate concern and improving transport efficiency are the main (societal) drivers for further development of our mobility system.
Traffic safety has strongly improved over the past decades. However in the Netherlands we see the death toll stabilising at about 13 deaths per week and the number of serious injuries, until recently also decreasing, is now faced with a disruptive increase from 350 people every week. The total estimated economic and

[2] TNO-rapport (TNO-034-DTM-2010-03505), Meerjarenplan 2011-2014, Burgmeijer en Pelders
[3] https://www.tno.nl/downloads/tno_strategisch_plan_2014_2018.pdf

societal cost of these accident is estimated at 12.5 billion euros per year for the Netherlands.[4] The Dutch government ambition is to reduce casualties further to a below 500 death/year, for injuries a similar ambition for reduction is expressed. Prosperous mobility also needs zero health effects and addressing climate concern. Through EU regulations and national incentives we see, despite the growth in traffic volumes, an enormous reduction in road vehicles emission. The emission of CO_2 (and Green House Gasses (GHG)) caused by road traffic is however not reducing. The EU aims for an 80% reduction of CO2 emission in 2050. For the transport sector a target of 60% is proposed[5].
In our mobility system we see a mismatch in demand and supply (capacity), resulting in a decrease of the mobility system reliability and congestion problems causing transport time delays, incidents and accidents. For Logistics a strong growth is expected in freight flows on specific corridors. For passenger travelling, further growth is expected, but the upward trend seems to decay.

In its strategy TNO is aiming to develop solutions that significantly reduce these trends. These solutions will be smart, integral solutions. Knowledge from different domains will be combined, synergy between solutions will be found and the power from different stakeholders (government, industry and knowledge institutes) will be mobilised for our common goals. The ambition is to use existing (vehicle) technology and infrastructure, but by more efficient use, combining unused potential, smart use of data, exploitation of new ICT possibilities and controls and by the application of future energy sources, a more than incremental improvement will be achieved.

Leading these ambitions are the directions and ambitions set forward in the Roadmaps of the European Road Transport Research Advisory Council (ERTRAC) and the Roadmap of our own Dutch Automotive sector expressed in the TKI HTSM Automotive Roadmap[6].

[4] http://www.swov.nl/rapport/Factsheets/NL/Factsheet_Kosten_verkeersonveiligheid.pdf
[5] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:NL:PDF
[6] http://www.automotivenl.com/images/HTSM_Roadmap_Automotive_2014_V5.pdf

ROADMAP AUTOMOTIVE 2014

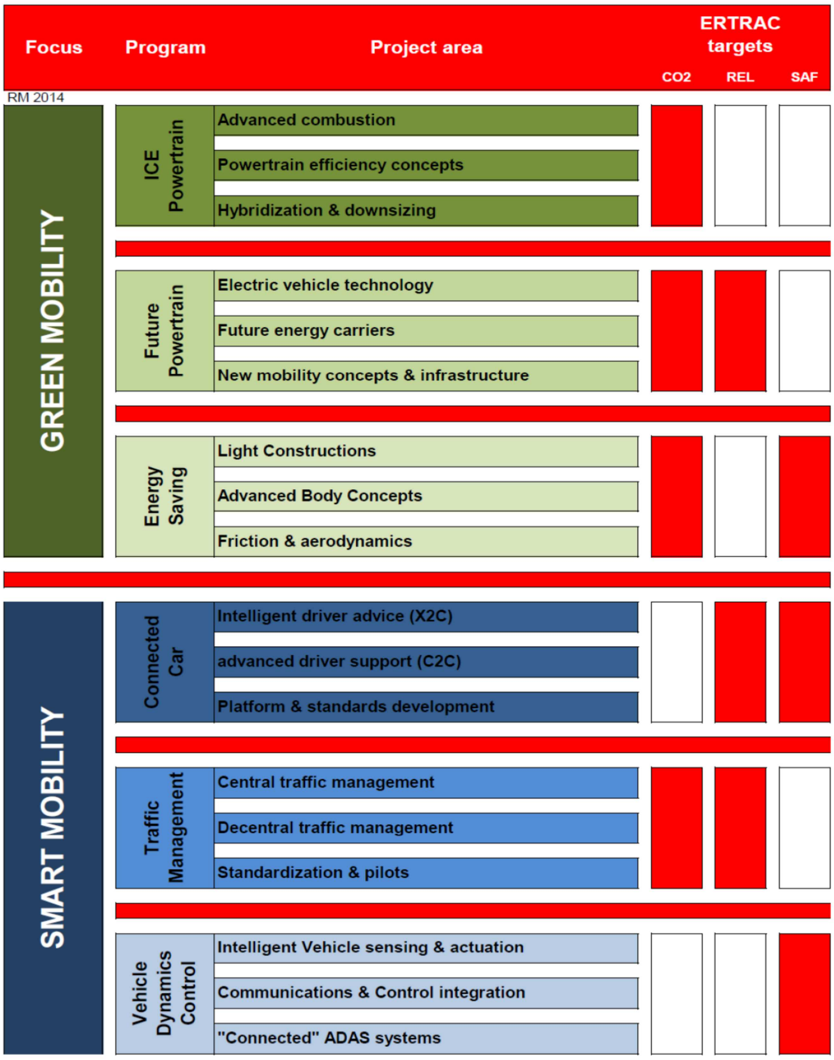


Figure 2: TKI HTSM Automotive Roadmap 2014

14.2.2 Background, context, definitions and long term visions

The VP AMS knowledge development Program will be centred around 3 Shared Innovation Programs (ShIPs). These Programs are the basis for a joined TNO, industry and government innovation Program. A consortium of stakeholders covering all relevant stakeholders necessary to develop breakthroughs in each application. Some of the ShIPS will be communities for open development on a joined Program (e.g. DITCM), others potentially might be Programs that will be composed of selected partners together interested in a specific application domain or partners in a joined supply chain.

The TNO Programs are (in no particular order):

- <u>Automated Driving</u>
  Aims to accelerate the developments and deployment towards high levels of automation in vehicles. It develops breakthrough technology and methodology in the transition from automated safety functions (e.g. Automatic Emergency Braking) towards fully automated driving.

- Cooperative Mobility
  Focusses on developing the benefits of communication (V2X) with respect to traffic flow, energy efficiency, vehicle emissions and traffic safety. This Program is strongly linked to the DITCM (Dutch Innovative Test site for Cooperative Mobility) initiative.
- Low Carbon HD Transport
  Focusses on breakthrough technology and actions to significantly reduce the GHG emissions from road transport, in particular Heavy Duty vehicle related CO_2 emissions.

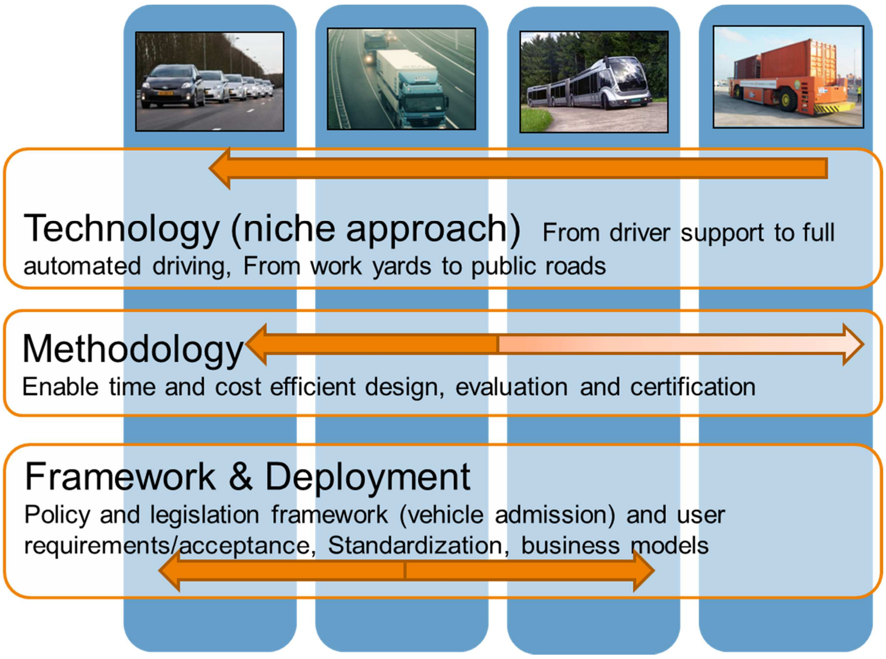
These TNO Programs are fully aligned with the TKI HTSM Automotive Roadmap. The Program Low Carbon HD Transport is aligned with the Green Mobility focus area, the Automated Driving and Cooperative Mobility with the Smart Mobility focus area.

14.2.3 Automated Driving

This Program is (August 2014) in the phase that first partners have committed themselves to participate and first projects are kicked off.
The Program is structured in 4 application domains where activities will focus on technology development, methodology and tools, policy and legislation frameworks and steps towards large scale deployment. Key in all applications domains is a methodological safety approach to make the design, testing, validation and certification effort feasible to allow for deployment of automated vehicles on public roads.
The Program lines are:

- Commercial transport
  Automated two-truck platoon concept that enables unmanned driving and enhance fuel efficiency within real-world emission constraints at high degree of flexibility and scalability.
  Focus on concept development, safety approach (robustness), product validation in pilot and resulting admission on (part of) Dutch public road.
- Private Mobility
  Step-by-step approach to acquire legal framework from test track to deployment on public roads under real life conditions, for the different levels of automation.

Focus is on accelerating the transition from partial automation (e.g. Advanced Driver Assistance Safety Systems) via high automation (e.g. Vulnerable Road User Collision Avoidance) towards full Connected (V2X) Automation.
Public Transport
Optimising the efficiency of public transport by partial automated driving functions (e.g. lane keep assist, docking support), towards higher levels of automation. Focus on concept development and safety approach for application of high levels of automation in (public) transport.
Logistics
Increase intelligence of Automated Guided Vehicles (AGVs) in ports and large logistic centres (terminals). AGVs need to become more intelligent to allow for more flexible, autonomous and decentralised control (distributed systems). This leads to less investment (in expensive infrastructure) and more flexibility in operation.
Focus on smart AGV controls using V2X communication and smart logistics.



14.2.4 *Cooperative Mobility*

This Program is directly linked to DITCM. In this partnership TNO partners with universities and a wide range of industrial and governmental partners. The DITCM Program has 4 program lines in which TNO all participates:

- Human Factors focuses on the interaction between users and cooperative systems and the way systems are designed in order endorse the driving tasks.
- Cooperative Technologies aims to formulate the architecture, data and communication standards and to perform tests to increase quality and reliability of cooperative systems and realize certification on the long term.
- Effect Studies aims to develop and standardize evaluation tools that help us to assess the effects of CS on safety, environment and traffic flow in traffic networks.
- International Policy tries to connect (international) governmental policies and ITS developments.

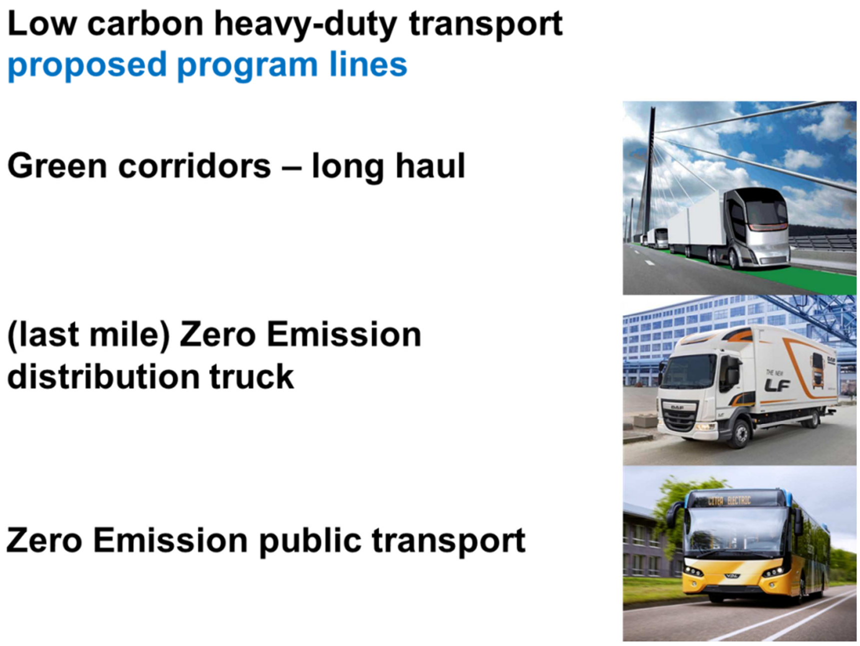
In the VP AMS knowledge Program TNO develops a background knowledge position to optimally support DITCM in its ambition. The activities concentrate on three areas:

- Platform development for Cooperative Systems. Safety oriented Cooperative applications like Vulnerable Road Users Collision Avoidance require platforms that integrate multiple sensor and communication input, real time performance and high levels of reliability. TNO develops specifications and software (architecture) for such high spec application platforms in order to accelerate the application of Cooperative Safety applications.
- Security, Robustness and Scalability or Cooperative Systems. The deployment of cooperative systems from small test applications toward large system integration requires specific knowledge with respect to (Cyber) security, robustness of performance and specific upscaling issues. TNO develops ready to implement solutions for these specific questions.
- Tool chain for Design and Validation of integral cooperative systems. TNO develops an integrated V-cycle based tool chain for the development and the test and validation of cooperative applications and integral systems. These tools will be based on existing proven tools and methodologies, developed in previous projects.

14.2.5 Low Carbon HD Transport

This Program is presently in its exploratory phase. The major stakeholders (HD vehicle OEMs and ministry of I&M) are consulted and together the foundation of the Program plan is laid.
For this Program, 3 Program lines are proposed:

- High efficient long haul trucks on green corridors
  Significant CO2 reduction and transport efficiency improvement on long transport corridors will be realised by combining vehicle efficiency measures (high efficiency combustion, (mild) hybridization, longer vehicle combinations), application of low carbon fuels and the benefits of connectivity and vehicle automation. These solutions will be optimised by using potential dedicated infrastructure and facilities on future smart/green corridors.
- Last mile zero emission distribution truck in a smart city environment
  Future smart cities will have high standards for environmental impact and CO2 footprint for their mobility systems. This will have significant impact on urban logistics and their vehicles. Zero emission capability (at least for the 'last mile') and full exploitation of the (potential) benefits of interaction with the smart city environment (incl. green urban traffic mgt.) will be developed in this Program line.
- Zero emission bus in an advance city transport network
  Public transport in future urban areas will significantly change and will require zero emission capability of the vehicles and full integration of their service in advanced services requiring optimised and flexible operation. Automation and full vehicle energy management optimisation will be key topics. Sharing technology with other vehicle applications to reduce cost will be another topic for this Program line.



14.3 Ambition and Impact

To demonstrate the impact and to focus the activities in the Programs, TNO works towards so-called 'Next Milestones' (NMs). These NMs are concrete results of (series of) projects that demonstrate tangible impact of TNO solutions on the (societal) challenges we meet in mobility. To demonstrate the impact, these NMs should demonstrate a significant base effect (on traffic safety, improved efficiency, CO2 reduction, etc.) and/or demonstrate a tangible upscaling approach towards high volume market introduction (*impact = (base effect) x (market volume)*).
At this moment TNO is working towards a number of NMs such as:

- 'Virtual towbar' in Automated Driving will demonstrate the feasibility and benefits of a two-truck platoon in real traffic. Virtual towbar will demonstrate the possibility of significantly improving transport efficiency while reducing CO2 emissions.
- 'Vision zero' in cooperative systems will demonstrate safety technology implemented in and around a smart intersection to demonstrate the potential impact of an integrated approach on cooperative systems on traffic safety.
- 'Flex fuels' in Low Carbon HD transport will demonstrate the benefit of Diesel and Gas dual fuel application for CO_2 emission on an engine demonstrator. The project will demonstrate the large effect of the application of low carbon fuel (LNG) in combination with high efficient combustion.

These three NMs will be finalized en demonstrated during 2015.
For the 2015-2018 strategy period a number of such NMs will be planned. The exact definitions of these NMs still have to be made, but they will be closely linked to the three Programs and will be defined together with the partners involved.
Potential definitions for such NMs are:

- Dispensation for testing cooperative automated vehicles on Dutch highways will result in a large scale test with automated passenger cars on public roads (comparable to A270 tests in 2010-'11). These tests will mark the step towards large scale implementation of vehicle automation resulting in improved safety, more efficient traffic flow and reduced CO2 emissions.

- SpitsLive (one of the present NMs) will be further scaled up and will result in the large scale implementation of cooperative applications on the road. 100.000 users in 10 different locations in the Netherlands will test and use applications (like Eco-driving support, green wave at traffic lights or shock wave damping) and pave the way towards large scale deployment. Extension towards a European context is anticipated.
- The TNO dual fuel concept will be demonstrated in a truck demonstrating CO2 reduction capability without NO_x aftertreatment. This will be the next step towards high efficient combustion and low carbon fuel application in real traffic.

14.4 Demand driven interaction

AutomotiveNL[7] is the sector organisation promoting and looking after the interests of the Dutch Automotive sector. Strengthening the competitive position of the Dutch Automotive sector is one of the key objectives of AutomotiveNL and stimulating and coordinating a joined innovation Program is one of the core activities. Under the leadership of AutomotiveNL the TKI HTSM Automotive Roadmap is developed and updated on a yearly basis.
The current Roadmap (figure 1, footnote 6) was updated in the end of 2013 in a process that involved consultation of the sector. An automotive Roadmap team (under chairmanship of AutomotiveNL and with DAF as representative in the HTSM Roadmap counsel) is responsible for this process. TNO has an important role in participating as a member of the AutomotiveNL board and as a member of the Roadmap team. Active participation in these bodies will remain the most important instrument for demand driven interaction.
The Automotive market is a global market and most leading industries are global companies. Being connected to this international arena is as important as being connected to the Dutch sector. TNO is an active member in the international automotive research community via our business connections for contract research and via our active participation in the EU research community. Input from these international relationships are taken as a very valuable input for planning our knowledge development Roadmap. The (international) contract research at TNO is significantly contributing to the automotive Roadmap and the TNO knowledge position and as such qualifying as *TKI grondslag*.
Also the relationships with governments are becoming more meaningful. TNO is a recognised partner of the European Commission, for our national Government and for local governments. In our Programs these governments are actively invited to participate and they are playing an important (e.g. as launching customer) in accelerating the introduction from new, high impact solutions, to real implementation. The TNO Programs (Automated Driving, Cooperative Mobility and Low Carbon HD transport) are becoming the partnerships where government and industry can jointly develop and launch effective solutions for our societal challenges.

14.5 Cooperation

Automated Driving
Partnerships in the commercial and logistics Program line will be intensified and further diversified. Existing relations in the passenger car safety business will be attracted to join the ShIP. Partners will be vehicle manufacturers and suppliers,

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[7] http://www.automotivenl.com/nl/over-ons

logistic companies, partners in technology development, (local) governments, road authorities and certification agencies.
To enhance the Human Factors side the VP will collaborate with the Enabling Research Program on Human Enhancement.

Cooperative Mobility
The close relationship with the DITCM Program will remain the prime focus for our knowledge development, securing adequate capability to support (future) DITCM projects. The Roadmap 'connecting mobility' [8] will be a leading foundation for the Program.
For subjects like cyber security and architecture the VP will work closely together with ICT research groups and the Embedded Systems Institute). To support the development towards self-organising system behaviour the VP will collaborate with the Enabling Research Program on complexity.

Low Carbon HD Transport
A consortium on this subject is formed. It will include truck and bus manufacturers and their strategic suppliers, other research institutes, (local) governments, logistic companies and other interest groups. Leading for the agenda of this Program is the action plan of the recently agreed SER energy agreement[9] and the vision on a sustainable fuel mix[10]. The Program will cover both technology and policy development.

14.6 Program 2015

The VP AMS 2015 Program will be further structured along the three Programs (Automated Driving, Cooperative Mobility and Low Carbon HD Transport). In 2015 first transition towards the embedding in the new TNO theme 'Urbanisation' will take place. This means that for funding that is not yet allocated or committed the emphasis will be more explicit towards 'Urban mobility' or 'Smart corridors'. Together with the new TNO themes, a number of Enabling Research Programs (ERPs) will be launched. The VP AMS will work together with the ERP's 'Complexity' and 'Human Enhancement'.

14.6.1 Automated Driving

The development of the Automated Driving Program will continue with intensifying present efforts on building consortia and projects in the Commercial and Logistics Program lines. New knowledge on the safety approach and a legislation framework for testing on public roads will be developed. In 2015 more focus will be given on the development of the private car Program line, connecting existing TNO position on active safety and vulnerable road user (VRU) safety with the Program. Also the human interaction agenda has to be further developed.

- Safety State Estimation and Control application development projects will be aligned with the priorities of the Automated Driving Program.

[8] http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2013/11/04/beter-geinformeerd-op-weg-routekaart-2013-2023-samenvatting.html
[9] http://www.rijksoverheid.nl/onderwerpen/energie/documenten-en-publicaties/convenanten/2013/09/06/energieakkoord-voor-duurzame-groei.html
[10] http://www.energieakkoordser.nl/nieuws/brandstofvisie.aspx

- On Real Life Safety Methodology development, the consortium on Real Life Safety will be up to speed. The CATS consortium on VRU safety will develop first projects. New methodology development will shift more towards the assessment of highly automated vehicle applications and how to reduce test effort for design, testing, validation and certification.
  New EU projects on VRU safety are expected.
- On the area of Situational awareness and controls of automated vehicles the emphasis will shift to more complex scenarios and interaction and improved safety and robustness of the controls implementation. Multi sensor fusion and risk assessment for complex drive scenarios will be addressed in new EU projects.
- On the topic of Human Body Performance modelling we will continue our efforts to develop real time predictive models for VRUs (especially bicyclists) both physically as cognitive. Activities on driver behaviour modelling (e.g. transition of control, adaptive systems) in relation to automated driving functions will be continued.

14.6.2 Cooperative Mobility

The first DITCM knowledge development project (on architecture, security and Data enhancement) will have started in 2014 and will continue throughout 2015. Also the first major application Program ‘SpitsLive’ will ramp up during 2015 preparing first significant steps towards large scale deployment of Cooperative technology. In parallel projects like A58 and the Praktijkproef Amsterdam and similar new projects will prove real life benefits of these technologies.

- Platform development for real-time, safety critical applications will be limited and focussed on application in projects like EU iGAME and SpitsLive.
- Development activities on Security, Robustness and Scalability of Cooperative Systems will further ramp up and stronger linked to the needs of DITCM. TNO will specifically focus on these issues for real-time, safety critical cooperative applications.
- Tool chain development will focus on the interfacing between existing and proven tools and on the validation of these models against real life data.

14.6.3 Low Carbon HD Transport

The further development of the Program, beyond the first main partners and kicking of a number of projects in the Program will be the major focus in 2015. Developing Program lines resulting in appealing demonstrators. On the technology development, current technology development will continue but focus might be steered further towards the interest of the Program partners.

- In improving the real world performance of Engine and aftertreatment more effort will be given to predictive model development allowing improved thermal management which is a condition to improve combustion efficiency. Also methane aftertreatment (required for application of natural gas in engines) will be a focus area.
- In the area of flex fuel control the development of the TNO dual fuel RCCI concept demonstrator will have the highest priority. Real-time/low cost implementation of closes loop combustion control and a single pressure sensor solution for this technology will be further developed with (a) partner(s).

- Our activities supporting the future fuel mix vision and action plan will continue and focus towards developing knowledge to advice industry and governments.
- In the area of Predictive Powertrain Controls we continue to focus on Predictive information for Integrated Powertrain Control and Energy Management. Integration of information form Intelligent Transport Systems and fleet management systems with vehicle behaviour will be the main focus.

15 TNO applied research in HTSM Roadmap Space

15.1 Introduction

Even though many people do not realize, 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 the applied research in the Roadmap 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).

15.2 Program 2015-2018

Being active in the space domain for 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 world-class instrumentation and demand driven downstream applications. 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 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.

Earth Observation (in particular for atmospheric characterization) is clearly the most important business line of TNO Space. 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.

Scientific instrumentation 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. However, in some cases also the Long-term missions give guidance to our technology development, certainly when applications can be found in other areas as well. It should be mentioned that the space borne activities covered in the Space Roadmap, have a lot of synergy with the Earth-bound astronomy activities addressed within TNO's Advanced Instrumentation Roadmap.

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.
The Dutch heritage in optomechanical systems is judged by ESA and the European primes (e.g., Airbus (ASTRIUM), Thales, RUAG, TESAT) as state-of-the-art for realizing high performance (e.g., high performance, compact/light weighted, cost effective) optical communication systems.

15.2.1 Background, context, definitions and long term visions

TNO will cooperate more and more 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. This process can only be successful if the Netherlands, as a small player in the worldwide market, focusses on high-impact topics.
The three research lines for TNO Space have been closely matched with our business lines.
In particular, we distinguish the following research lines:

Research line	**Objectives**	**Partners/ Stakeholders**
Earth Observation Instrumentation	To contribute to, build and calibrate optical and radar Earth-Observation instrumentation, in cooperation with Dutch industry, institutes and academia.	SRON Dutch Space, ISIS Mecon, Cosine, S[&]T KNMI SSBV
	To orchestrate the value chain for space data users and to develop prototype level applications using space data.	RIVM, KNMI BTK Argoss Royal Dirkzwager TomTom, Logica Ursa Minor S[&]T, Fugro
Space Science Instrumentation	To contribute to and build Space Science Instrumentation, in cooperation with Dutch industry, institutes and academia.	SRON NOVA/ASTRON Dutch Space, VDL, Mecon Cosine
Optical Satellite Communication	To contribute to and build instrumentation for Optical Satellite Communication, in cooperation with Dutch industry	Nedinsco, …

Playing a dominant role in the design, realization and calibration of future instruments seems crucial for the survival of this innovation area. Of immediate importance is **Sentinel 5**, where, on top of an existing activity in the Airbus core team, TNO is pursuing a dominant role in design and realization of some of the main optomechanical subsystems. Also very important is obtaining an important role in the actual calibration of the instrument.
Other large instruments where TNO could play a role include:

- **3MI**, a Multi-viewing, Multi-channel, Multi-polarization Imaging radiometer, primarily aimed at providing aerosol characterization for climate monitoring, and

- **Biomass**, a novel P-band synthetic aperture polarimetric *radar* instrument, aiming at measuring forest biomass to assess terrestrial carbon stocks and fluxes.

Future *candidate* missions include:

- **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.
- **Spex2Earth**, a multi-viewing angle polarimeter for climate and air quality research, developed by a Dutch consortium (optical design by TNO).
- **Tropolite**, a smaller size spectrometer, also having an improved spatial resolution (2x2 km^2), aiming at measuring individual emission sources of air pollutants. Also this future instrument is promoted by ESA, and the design work is performed by a team of Dutch organizations.

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 TNO is building an on-board calibration unit for BISME, a leading space institute in China, with which a joint lab agreement has been signed early 2014. In the future, this collaboration is expected to lead to more space business in China (e.g., Optical Ground Support Equipment). It should be stressed that all business with China has to comply with stringent export licenses.

The development of a class of new ***compact*** **earth-observation instruments** is of very high importance. It will allow targeting the commercial markets, with new customers and using different business models compared to the institutional area we encounter traditionally. Instead of flying individual, very expensive instruments, customers could buy into a network of small, relatively cheap satellites, where dedicated, custom tailored functionality is much easier to achieve. The Netherlands has the opportunity to address the full value chain: Instrument design, manufacturing, testing and validation, nanosats and cubesats, and last but not least **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. A special ‘product’ to be mentioned here is the so-called Observing System Simulation Experiment (OSSE). An OSSE is a powerful tool to quantify the actual impact of future satellite observations and to ensure that the performance of these satellites is optimally ‘tuned’ to the intended user community, before the satellite is actually built. As a product, OSSEs will provide a powerful link between TNO’s upstream and downstream activities.

For TNO the upstream part is going to be the most important area, but this does not imply that the downstream part can be neglected.
As mentioned before, the business line Earth Observation does not only rely upon designing and manufacturing (modules of) the above mentioned instruments; **calibration** of these instruments or critical optical components (e.g. diffusers) is crucial for their performance as it translates the instrument’s raw data to physical units. For the past 20 years TNO has built up substantial heritage in this area and in view of ongoing investments in necessary facilities is very keen on strengthening our position in this field.

Particularly based upon the strong position obtained in the field of optical fabrication, TNO has the ambition to manufacture and deliver specialty optical

components, like free from optics and super gratings, to the international space industry.

Scientific Instrumentation
ESA is building its future in space science based on a 'Cosmic Vision'. The following table provides an overview of the corresponding ESA Science missions:

	Name:	Science:	Launch:	Member state provision:	ESA payload provision:
L1	JUICE	Jupiter	2022	Instrument suite	
L2	ATHENA	hot and energetic Universe	2028		
L3	LISA	gravitational Universe	2034		
M1	Solar Orbiter	Sun	2017		
M2	Euclid	mapping geometry of the dark Universe	2020		
M3	PLATO	detect terrestrial exoplanets	2024	Payload Cameras	CCD detectors and payload optical bench
S1	CHEOPS	detect terrestrial exoplanets	2017		

Our activities for the near future are mainly focused on the **S**hort and **M**edium-term missions. Contract negotiations are going on regarding **CHEOPS** (Thermal Vacuum and Dimensional Stability Tests on the CHEOPS Optical Telescope Assembly) and **Solar Orbiter** (High temperature attitude sensor and Polarimeter for METIS). **SPICA**, including the **SAFARI** instrument, was part of the M-program. As such it has been cancelled. The SAFARI program still continues, based on national funding. A proposal to add this mission back to the ESA list, as an M-4 science mission is expected toward the end of 2014. TNO has been involved in the optical design of the **SAFARI** instrument and in the concept development of the SAFARI Fourier Transform Spectrometer (FTS). In case the SPICA is put back on the ESA list. It is the ambition of TNO to claim a bigger role again.
Regarding the **L**ong-term mission **LISA** is of particular importance. An important step in the feasibility of LISA and LISA Pathfinder was the testing of 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 TRP TNO has developed a prototype of the LISA Point Ahead Angle Mechanism (PAAM). In the context of the LISA Formulation Study of ASTRIUM, and based on ASTRIUM, PEP and TNO funding, TNO had 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 LISA 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.

A first step in the area of laser communication is taken by running a joint ESA project with RUAG, Nedinsco and Meopta. In the coming years TNO will aim at increasing the Dutch contribution in this Space submarket.

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

15.3 Ambition and Impact

Ambition of TNO Space: development of efficient instruments that can be reproduced and sold by the national space industry, in combination with development of 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.
Impact: strengthening the national space ecosystem, and the position of the Netherlands in the international field of remote sensing and science missions.

The technology development program is focused at enabling a relevant contribution to specific applications (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. The following technology areas will be covered by VP research (SMO) and TKI projects:

- Measuring techniques
  - Spectrometry, Interferometry, Polarimetry
- Components
  - Free form optics
  - Deformable mirrors and adaptive optics systems
  - High accuracy mechanisms, High stability optomechanics
  - Super gratings, Diffusers for in orbit calibration
  - Fiber sensors, Metamaterials for radar and optical range (e.g. hyperlenses)

15.4 Demand driven interaction

TNO aims for intense interaction with both scientific and industrial partners, driven 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 cooperations are:

- R&D partner of SRON. We primarily work together in the research lines Earth Observation Instrumentation and Space Science Instrumentation.

- SpaceNed: TNO is member of SpaceNed and works together with SpaceNed partners in merely all research lines.
- Cooperation with Dutch Space for TROPOMI, and future instruments (e.g. Sentienel-5).
- We cooperate with the National Aerospace Laboratory NLR in the sense that we make sure that our activities are and remain complementary, leading to collaboration in actual projects.
- TU Delft. We work together in the area of microsatellites and their applications.
- Cooperation with ISIS and Systematix in the area of small instruments and nanosatellites.
- In the downstream domain (Space Data Utilization) we have established relationships with Universities and Institutes:
  - NL: TU Delft (DEOS), Universiteit Utrecht (IMAU), WUR, Universiteit Twente (ITC), Vrije Universiteit, Wageningen Universiteit (WUR), SRON, KNMI, Deltares, Alterra, ECN.
  - International: FRIUUK, Politecnico Milano, Universiteit Bologna, Universiteit Krakow, Paris-Loudron Universiteit, Universiteit Helsinki and with Research & Technology Organisations (RTO's) ARMINES, DLR, VITO, BGS, EMEP, INERIS, FMI, FOI, FFI, ISDEFE, JRC, FRONTEX.

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 Antenna Roadmap and the Roadmap on Optical Instrumentation.
For international contacts (e.g. from China) TNO has a growing role as gatekeeper for contacts with Dutch industry and institutes.

15.5 Program 2015

The Roadmap Space will focused on:

- Space Instruments:
  - Excellence in (space) science determines the technological demands. The main focal points are: Instruments for Astrophysics and Exoplanet research, such as GAIA at present, and LISA and ATHENA in the future, depend on high precision optomechatronics (sub)systems; these are VP topics for the coming period. Most of them have links with groundbased astronomy and other Big Science applications.
  - Atmosphere, for climate and air quality. Further innovation is required for EO instruments in order to meet the increasing demands for resolution and sensitivity for the ESA missions; for other end-users dedicated efficient compact instruments are required. Both of these developments are incorporated in the VP.
- Space Systems and Components:
  - Relevant topics for TNO: AOCS, Propulsion, Materials for structures, Igniters, Satellite cluster technology.
- Downstream Applications and Services:
  - TNO is taking the role of coordination of further application of scientific data, with focus on Combination of space and in-situ data, Commercialization (driven by Dutch SME's), and supported by Big data technology 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.

Match with Horizon 2020:
The European themes of Commercial imaging, EU Non-dependence, Innovative concepts, Mini-satellites, and New Mission concepts match very well with the ambitions, and partners, for new EO instruments.
The themes EO apps, and Cimate change data (re)processing show an excellent fit with the Space Data Utilisation activities.
Space debris could also be a topic for cooperation with European partners.

The impact of these activities is aimed at obtaining an increased level of application of information collected from Space in the Dutch and European society, and an increased level of economic activity of Dutch companies in both upsteam and downstream products.

The Earth Observation Program will specifically focus on:
- Compact Optical Instruments; end-to-end conceptual design & breadboarding of critical subsystems.
- Innovative subsystems/components for Radar missions.
- Calibration services for slit function stimulus, sun simulator, feasibility of accurate polarization calibration and diffusers.
- Space Data Utilization for OSSE's (Observation System Simulation Experiments) for compact optical instruments.
- Components for diffusers with accurately predictable Spectral Features and BRDF, Super Gratings, in close cooperation with SRON.

The Scientific Instrumentation Program will specifically focus on:
- Assessment of ESA science missions and teaming opportunities with the;
- Selection and first development steps of key technologies for the relevant missions.

The Optical Satellite Communication Program will specifically focus on:
- High stability optomechanical systems and Adaptive Optics.

16 TNO applied research in HTSM Roadmap Advanced Instrumentation

16.1 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, KM3net, and ESS (European Spallation Source). It should be mentioned that there is strong synergy with activities outlined in the HTSM Roadmap Space.

16.2 Program 2015-2018

For Scientific Instrumentation it is crucial for TNO to cooperate with a network of scientific organizations and industry. Scientific institutes (for instance 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. The combination of these three entities has proven to be a powerful one and we definitely jointly see possibilities for more projects in this area. NWO defines the Roadmap for the Dutch participation in the European Big Science programs, and the VP priorities of the joint developments for Scientific Instrumentation are synchronized with this Roadmap.

16.2.1 Background, context, definitions and long term visions

The main telescope programs under development by **ESO** are the European Extremely Large Telescope (**E-ELT**) and Atacama Large Millimeter/submillimeter Array (**ALMA**).

The VLT (Interferometer) is being upgraded in the coming years.
The VLT(I) and E-ELT programs allowed TNO to enter the ESO programs as industrial partner roughly since 1995. Over these years TNO provided items that cannot be delivered by scientific institutions and regular industry. Over these years TNO has been involved in programs such as the VLTI Delay Lines to start with, until the still running programs on the E-ELT nano-actuators and the VLTI PRIMA Star Separators. TNO is ESO’s only non-academic partner with continuous contracts over these years.
In the context of ESO programs, currently the most relevant topics for TNO are adaptive mirrors, control for adaptive optics, laser-launch telescopes, and precision actuated support structures (E-ELT M1 Support). Cooperation with industrial partners, e.g. VDL and Dutch Space, is crucial in these projects, with TNO acting as developer of prototypes, and as an interface to the scientific end-user community of astronomers. These subsystems are needed for other big telescopes, and we have been approached by telescope development teams from around the world (GMT, TMT, VLT) with request for information, possibly leading to participation in their projects.

A science oriented area outside astronomy is at present mainly related to **ITER** and **particle accelerators**.

In the framework of ITER a successful joint program is set up by TNO, knowledge institutes and industry called ITER-NL. We are convinced that this concept of cooperation can work for other Big Science facilities as well, increasing the strategic collaboration between TNO, industry and academia. To facilitate this “Het Huygens Huis” has been started by TNO together with partners.
Regarding accelerators a collaboration is being set up with VDL and TU/e. These accelerators are targeted to the scientific “market” (e.g. CERN-CLIC), but also towards other areas (e.g. medical instrumentation and Free Electron Lasers for EUV lithography. Obviously the latter implies a strong tie to the Semicon Roadmap.

16.3 Ambition and Impact

It is clearly visible that the type of technologies, the development approach and the network of high-tech industries are almost identical for the different Big Science applications, including ground-based astronomy, and even Space projects. The return on investment of Dutch governmental funds as contribution to Big Science facilities has room for improvement A collaborative approach, based on added value of all parties involved, should result in more work (possibly for tens of millions of euros) for Dutch high-tech companies, and an even more prominent role for Dutch scientists. This will also boost the valorization of scientific results.
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.

16.4 Demand driven interaction

For astronomy many of the developments are carried out with the goal to position Dutch industry for obtaining the production of hardware (e.g., E-ELT mirror supports with VDL). Het Huygens Huis will be a platform for demand driven interaction: requests from the scientific community will lead to innovations from industry, and new industrial products can be created from knowledge gained at the scientific institutes; in both of these processes TNO will not only act as interface, broker for spin-off applications and coordinator, but also contribute with its own know-how and expertise. TNO is experienced in the design of scientific instrumentation and prototyping; this can help to bridge the “valley of death” between scientific knowledge and industrial application.
SMEs are key players in Advanced Instrumentation. TNO, and NWO, have several instruments in place to stimulate the collaboration with SMEs and search for synergy with organizations, such as FME, representing employers and businesses in the technological industry.

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.

16.5 Program 2015

The priorities of the Roadmap Advanced Instrumentation are:
- Optical instrumentation, including enabling optics and optomechatronics.
- Sensor system technology, including detector development and microwave technology.
- Precision technology, including mechatronics and robotics/remote handling.
- Customized micro-electronics and nanophotonics (resistant to extreme conditions, miniaturized).
- ICT infrastructures, data management and interpretation tools.

The VP Scientific Instrumentation covers many of these topics, with a focus on optical instrumentation, sensor technology, and precision technology.
In the ITER-NL program (e.g., during the Big Science Industry days) a strong interaction within the network has been achieved; the implementation of Het Huygens Huis will further strengthen this.
The ambition is to increase the integration of the activities of the partners: scientists will involve industry in tenders for instrumentation for Big Science, and industry will provide the scientists with cutting edge research tools.

For ground based astronomy the main topics are:
- Segmented Mirrors
- Deformable Mirrors for Adaptive Optics
- Laser Guide Star technology

The workpackages planned (pending the joint funding) for Het Huygens Huis are:
- Big Science Business Case development:
  Networking with national stakeholders and aiming at Big Science facilities (exhibitions & conferences, industry day, leaflets, websites, contact database).

Opportunity selection and organization
- Technology predevelopment

In industrial projects for technology demonstrators
- Initiating proposals: the actual proposals are produced by industrial consortia
- Coordination and dissemination

17 TNO applied research in HTSM Roadmap Mechatronics and Manufacturing

17.1 Introduction

The Topsector HTSM Roadmap 2012-2014 Mechatronics and Manufacturing (M&M) had three parts: mechatronics, manufacturing and instrumentation. The instrumentation part, mainly scientific instrumentation was set apart in a Roadmap of its own in 2013. Given the developments of the Smart Industry initiative we propose to restructure for 2015 the other parts.

The mechatronics part deals with advanced mechatronics as needed in ultra precise waferstages as well as more generic mechatronics as used in robotics. In our vision today's faster control loops and stiffer constructions are not enough to maintain a leading edge competitive position for Dutch companies. Mechatronics should be extended to non-linear & predicted deformations due to much lighter and less stiff constructions. This development requires a huge effort of its own. It will interface intensively with the HTSM Semicon Equipment and Advanced Instrumentation Roadmap. In this context it is worth to mention that the adaptive optics TKI project was not placed in the current M&M Roadmap, but in the Semicon Equipment Roadmap. In this HTSM Roadmap M&M we will deal with Mechatronics as a separate chapter with its own subgroup, originating still from the Point One days and focus the main part of the Roadmap on Manufacturing.

A similar development takes place with respect to Additive Manufacturing (AM). Originally seen as a new manufacturing technology, it is now more dealt with in the printing Roadmap as 3D printing. Therefore the TNO activities in AM will be put in the Topsector HTSM Roadmap Printing (and Additive Manufacturing).

With this 2015 adaption the TNO HTSM M&M Roadmap could be rename as HTSM Manufacturing Roadmap with a focus on the Smart Industry initiative. Although this initiative has been broaded next to HTSM to include the chemical process, the agro/food industry and logistics, the focus is on the changes in manufacturing due to all kind of changes as caused by the Internet of (every) Thing evolution in processes on the shopfloor or plant.

17.2 Program 2015-2018

The TNO contribution to the HTSM Roadmap manufacturing will focus on the current (re-)industrialization project in the Netherlands within the Smart Industry initiative and at European level called “Factory of the Future” (and in Germany “Industrie 4.0”, in the UK as catapult program “high-value manufacturing” or MADE in Denmark, SOC maakindustrie in België and “made in US” in the USA). The goal of these programs is to maintain and create jobs in industry as well as to maintain and built a strong (national/EU) and competitive capability for the production of goods in the long run. In the German “Industrie 4.0” and even more in our own Smart Industry initiative we focus on the consequences of a much further digitalization of all processes in the factory and the changes that will have on manufacturing and on the total business value chain. What will happen once all processes are made “smart” and can communicate and exchange information without human intervention? What happens when we have robots working 24h/7d with zero defect? What kind of urban manufacturing will we see once users order any parts by 3D printing around the corner and have them delivered within hours?

For the 2015-2018 plan period of TNO, we decided to focus on the new manufacturing industry. Established by law TNO has to support the innovation capability of the Dutch society and industry. For this period we merge TNO Industrial Innovation and TNO ICT into one “TNO Industry” organization, as ICT is seen key for the evolution to “Smart Industry”.

Note that the “Smart Industry” (SI) initiative is led by FME, VNO/NCW, TNO and the Ministry of Economic Affairs. It was started at the 2014 Hannover Messe and is expected to hand over to the Minister an action plan by mid-October. The text in this “speurwerkprogramma TNO” has been written in July-September 2014 for submission to the Ministry in September and consultation with the HTSM Roadmap council in October. Based upon comments by the Topsector and the SI plan adaptation of this version might take place to align the TNO activities with the selected SI action plan.

17.2.1 Visions

Internet of (any)things is a concept that exists since 2000. At that time the Internet broke loss from implemented on computers only and appeared on the initial smart phones. Suddenly the Internet would not interconnect millions of computers, but billions of devices. Any device could be equipped with a computer chip and (mobile/wireless) interface. It took another 15 (10-20) years before an affordable and widespread adaptation of this technological possibility has been realized and starts to impact real use and businesses. Today all kinds of applications are in discussion: smart cities, smart mobility, smart health, smart grid and now too, smart industry. In essence it is not the technology as such, but the use of it.

Making your processes, machines, logistics “smart” implies that in manufacturing next to humans and machines, also the often not visible computers, databases, networks and software become key components in successful businesses. You can do the same things differently, faster and/or cheaper, but you can also do new things. “Industrie 4.0” talks about cyber-physical systems, doing the same things better as robotizing the whole factory. In Smart Industry the ambition is to catch up with Germany and jump over by doing new things in the sense of chaining business value chains.

Today vendors are changing towards solution providers and move more and more of the manufacturing of the goods toward suppliers. E.g. Canon/Océ sell a lease contract with a pay per copy/print and monitors the copy/printer. The customers does not own the equipment, it is replaced and recycled/refurbished without his concern. Thanks to the Internet of things the hardware part of their solutions can be remote monitored and making this pay per use possible. This shift from the classical manufacturer to solution providers involved a change for suppliers. They will do more design and engineering as well as produce in smaller series more complete subassemblies/complete products (e.g. Flextronics, but also Dutch suppliers as VDL, NTS, Frencken, KMWE, etc.). And they have to do it for the same lowest costs and from day one with zero defect. This is becoming possible using the same Internet of things possibilities to make the processes and their control/logistics smarter too. In this sense new technology has a large impact on the way businesses are organized. It is this change the Smart Industry initiative intent to spread out in Dutch industry as rapid and effective as possible. In the TNO contribution to the HTSM Manufacturing Roadmap we will focus on the manufacturing aspects of Smart Industry and in particular on the support of fieldlabs with a dominant manufacturing aspect.

It is our vision that a factory is a continuous changing environment, always on the move to lower costs, improve productivity and introducing new products (the continuous learning curve of a factory). To make manufacturing processes smart we need to equip and/or improve each manufacturing step with the proper sensing (and actuation) means for zero defect manufacturing. As production might be fully robotized and work 24h/7d, we expect that there are (during day time) engineers active to implement the changes and operators to monitor the processes and equipment. The smart factory will always contain humans with skills that have to improve and adapt continuously too. Therefore training/learning is an integral part of the fieldlabs.

17.3 Ambition and Impact

To realize the Smart Industry ambition fieldlabs, pilot environments or shared facilities to implement, demonstrate and train people we be established. To have a significant impact however we expect that for different manufacturing environment we need different pilot environment, “proeftuinen”, shared centra or whatever name an environment might choose[11].

Next to the support and organization of the fieldlabs, the TNO program with respect to the HTSM Roadmap Manufacturing will focus on **industrial physics and the mechatronics/robotics** part of these environments. (Of course other parts of TNO will focus on ICT, labor issues or other technologies as the earlier mentioned additive manufacturing). To make all kind of equipment smart we need more sensing capabilities than ever before. To enable 24h/7d zero defect manufacturing possible, without continuous and sample inspection by operators, one need to measure several physical process parameters and process them within the process cycle time during all process steps. Or for predictive instead of prescribed/preventive maintenance where the equipment is continuously monitored to determine the right moment for maintenance. For such maintenance based upon the actual condition and not a regular scheduled shutdown we will also need to implement new sensing technologies. Or for manufacturing orders down to series of one (with the same costs as large series) we need reliable processes that can handle the changes automatically and with zero defect. Even 3D printing or additive manufacturing with absolute reliable process conditions will become the norm and will require all kind of industrial physics monitoring of the process too. In all cases it is our ambition to demonstrate that more automation is possible due to the lower costs of electronics in combination with all kind of industrial physics and industrial robotics/mechatronics.

[11] Pilot lines or environments are owned by an industrial player, close to production (TRL 7-9). Shared facilities or technological infrastructures focus on the production of prototypes (TRL 4-7) and are in general more often owned or run by RTO’s as TNO. In the pilot line case the (private) owner can restrict access to the line. In the case of infrastructure own by public organization access is open to all interested and paying customers. These shared environments are also more used for teaching purposes. In general we talk about fieldlabs as the collection of pilot lines and shared facilities.

17.4 Demand driven interaction

During the year 2014, starting already in January tenths of interviews with the industry have been taken place in the context of initial the Smart Industry report (April 2014), followed but again tenths of discussion in all regions with hundreds of people involved and with many manufacturing domains or “ecosystems”. This work has been conducted in full cooperation with FME and VNO/NCW but also with the regional development organizations (InnovationQuarter, Brainport Development, BOM, NOM, NV Oost, …) and the Chambers of Commerce. In all cases with these organizations also larger meetings in 4 regions (Delft, Eindhoven, Groningen, Enschede) with representatives of multiple organization were held. Out of these discussion 50+ ideas and proposals for Smart Industry fieldlabs are born. A significant is related to manufacturing, but no detailed selection has been made yet. Nevertheless we foresee at the moment support with industrial physics for zero defect initiatives around the smart factory initiatives in Drachten en Hoogeveen (shaver heads-Philips and composite constructions – Fokker/ten Cate) and robotic loading of machining centre in Brainport Industry context. But also other issues as streamlining product information standard are in discussion.

As noted we will also continue the discussion on mechatronics, organized within the mechatronics workgroup with representatives from several companies and the 3TU, in particular the TU/e HTSC. But, except for the TKI project no concrete project with TNO contributions are running at present under the HTSM M&M context.

17.5 Cooperation

Smart Industry is a FME, VNO/NCW, Ministry of EZ and TNO initiative in which we cooperated in the preparation phase also with universities and higher education institutes (HBO) representatives (Tafel 2), see above. At the same time we cooperate with EFFRA, the European Factory of the Future Research Association, at EU/H2020/Cohesion Program level. At that level we are participating in the preparation of the next H2020 call text, project proposals as the Vanguard initiative and the initial talks on a EIT KIC Manufacturing. The last topic should lead to a NL participation in the EIT 2016 call. At present that proposal will include teaching factories similar to the Smart Industry fieldlabs we propose within the SI action plan.

Note that in both cases, SI and EU, consider access to these environments for SME as of utmost importance. At EU level the Solliance example where several SMEs and a few large enterprises cooperate to prototype a complete thin-film solar PV line. None of the SMEs never could have create itself. It is hoped that under the SI umbrella such environment in other ecosystems might provide new opportunities for SME that are currently not possible. For them the cooperation with others and in most cases large vendors in a goal oriented program provides new business chances. For this reason we will define in the SI action plan different manufacturing ecosystems where large and small players can interact. Note that proximity helps and that such ecosystems in many cases will have initial a regional trigger, but are not regional only. In case of EU or Interreg funding international partners are even welcome.

17.6 Program 2015 – TO2-2015 Smart Industry

The 2015 program will be one-to-one based upon the Smart Industry action plan as submitted mid-October to the Minister of Economic Affairs and the reaction on this plan. TNO will participate in as much ecosystems as sensible and depending on the requested capabilities. Several contributions as e.g. ICT and workplace innovation are funded from other TNO programs. In particular we will also use the TO2 contribution for this program means and it is planned to distribute that contribution over strategy support, industrial physics, ICT, additive manufacturing and workplace innovation. This HTSM Manufacturing “speurwerk” program is however focused on the industrial physics part only.

For the TO2 900k is made available for TNO in general and 100k for DLO. TNO will use its funding as mentioned, DLO will use the funding to prepare their contributions in agro/food related fieldlabs. Note however that the additive manufacturing part is put separately in a 500k budget for TNO, ECN and NLR together.