



Topsector HTSM

Roadmap High Tech Materials
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Roadmap High Tech Materials

Societal and economic relevance

Connection with the key societal themes (Climate, Energy, Health, Mobility, Security, Material Resources)

The trend of “greening” our society demonstrates that economic prosperity and a sustainable society go hand in hand. The ultimate goal of the TKI High Tech Materials is to provide long-term competitive breakthroughs in materials technology to challenges posed by concerns such as energy consumption, environment, health care and climate change. Many issues cannot be solved without smart materials with new functionalities, like the environmental burden of greenhouse gases, the further exhaustion of our fossil fuel reserves, biocompatible devices and implants, safe and environmentally friendly transport, electronic devices for health and safety, and last but not least the availability of scarce materials.

Global market size addressed (2012-2020)

The materials sector in the Netherlands impacts 27% of the total production value (€ 292 billion), 61% of the export of all industry branches (€ 107 billion) and 55% of the industrially added value (€ 38 billion). The business of materials production in the Netherlands is more than € 20 billion with an average annual growth target of 5% during the period 2012-2020.^{1,2} The rapidly growing world population will boost the demand for materials considerably due to millions of new consumers in rising economies.

Competitive position of Dutch industry, total R&D investments

The R&D spending on materials by the Dutch industry is about € 1 billion annually and the knowledge base is at world-class level. This allows companies to develop and implement the latest cutting-edge technologies and to hold top positions in highly sophisticated products like ultra strong fibers, high performance coatings, ultra light composites, superior fiber metal laminates, high strength steels, and bio- and nanomaterials. This explains the high export value of these companies. On top of that, the global ranking of Dutch knowledge institutes and universities is excellent with convergence in the fields of physics, chemistry and microbiology with materials sciences. The strong combination of world-class industries and knowledge institutes, together with the national government, provides an outstanding basis for public private partnerships (triple helix).³

Application and technology challenges

State of the art for industry and science

The Roadmap High Tech Materials consists of nine industrial sectors: Aerospace, Automotive, Maritime, Materials production, Professional and consumer products, Energy, Security, Medical and Civil. Research will be based on industrial needs as well as academic curiosity in order to create new functionalities.

- One of the main drivers in the transport sector is the availability of ultra light and very strong materials with sophisticated functionalities under extreme conditions. This requires the further optimization of the (strong) link between processing conditions and final product properties of hybrid and composite materials. One of these optimizations is the strength over weight ratio which is extremely important in the **aerospace** industry together with the design freedom of the product.⁴ The Dutch **automotive** industry has a strong supplier base as well as OEMs. Key drivers are coatings, mechatronics, embedded systems, environmental issues (“Euro 6”), energy storage systems, and safety and comfort related topics.⁵ The Dutch **maritime** industry is leading in product innovations for winning raw materials and energy in deep sea and/or under arctic conditions. The Netherlands are also leading in ships with anti-fouling coatings to reduce drag and thus energy consumption and CO₂ emission.⁶ Another topic is to create a Dutch hub for international distribution in the LNG supply chain.
- The **materials production** sector comprises hybrids, composites and thin films, multifunctional textiles and advanced metals. *Hybrids and composites* are able to replace traditional materials based on their low weight, high strength, low maintenance and high durability (lower CO₂ footprint during production and during the use of the product). Strong growth is foreseen in the areas of transport (electric vehicles) and wind energy (longer blades). *Multifunctional textiles* offer high impact resistance at low density, giving solutions to anti ballistic applications and light weight systems for ships and tanks. Other solutions are the integration of (micro) electronics and nanotechnology in personal protective clothing to enable sensor reactive surfaces (alarming for chemicals) or conductive polymers that can harvest energy from the sun.⁷ In the *advanced*

¹ Bruggen bouwen in materiaalinnovatie, het succes van Publiek-Private Samenwerking, 2011

² Vision document HTSM, May 2010

³ M2i innovation program on high tech materials, September 2007

⁴ Visie luchtvaart 2020, vliegtuigbouw en instandhouding, Secretariaat Lucht en Ruimtevaart Nederland, 2011

⁵ Vision for the Dutch automotive sector 2010 – 2020, Federate Holland Automotive, September 2010

⁶ Nederland, de maritieme wereldtop, November 2010

⁷ Technology Roadmap Personal Protective Equipment, the Foundation of Engineering Fibrous Smart Materials, 2008

metals industry fundamental insight in the metallurgical and physical background of metals production is required to optimise and adequately control the process conditions in order to obtain desired microstructures and (combinations of) properties. Other challenges arise from low labor countries, environmental legislation, recycling requirements and increased costs of energy and raw materials. To remain competitive the sector has to produce high quality products with low life cycle costs.

- The core business of **professional and consumer products** (semiconductors, instruments, printing, and electronics) is the high tech systems and nanoelectronics industry. This sector is driven by cheap, durable, reliable, predictable, and maintenance-free functionalities with low energy consumption.^{8,9,10,11} As in other fields, new materials (like graphene and multifunctional oxides) have to be developed for function integration in intelligent devices at several length scales (macro, meso, micro and nano).
- Renewable **energy** techniques like solar photovoltaic (PV), wind and possibly nuclear fusion have to be implemented quickly to solve the growing energy demand. In *PV* the emphasis will be on further reducing the costs of solar energy (€/Wp), prolonging technical life and increasing energy yield.^{12,13} For *wind* energy cost reduction through lower capital investment and maintenance costs is a key element.¹⁴ The challenge of *nuclear* fission/fusion is to develop creep resistant steel alloys and high temperature barrier coatings that resist high temperatures / radiation. Magneto caloric materials can substantially reduce (>50%) the energy consumption of heat-pumping devices as refrigerators and air conditioners. They can also convert (waste) heat into electricity. Self healing materials can increase the time to failure of turbine blades to reduce maintenance and repair costs. And last but not least, by 2025 the global energy used for lighting (19% of the global energy production) can be reduced by 50 % when replacing the current 30 billion electrical bulbs by Solid State Lighting (SSL). Another advantage of SSL is that it requires less toxic and scarce materials.¹⁵
- In the past decade, increased activity in the prevention of, protection against and response to **security** threats has been observed, ranging from small scale security issues in the private and public domains effecting individuals, to the protection of critical (national or international) infrastructure. The wide scope of issues is reflected in the large variety of technologies ranging from sensor and communication technology, image processing and video analysis technology to materials for physical protection.¹¹
- The Dutch industry is a global player in the field of **medical** devices for hospitals, laboratories, dentists and homecare. Medical technology can help to tackle the major societal challenge of an aging population. Research is conducted to imaging technologies for hospitals allowing earlier diagnoses and thus more successful and less costly treatment, home care equipment allowing patients to live and work in their own environment longer and new implants ranging from intelligent bio-devices for diagnosis, or invasive devices like stents, to new prostheses and joint replacements materials.
- The **civil** sector consumes about 40% of Europe's primary energy, produces ca 33% of CO₂ emission and more than 450 million tons of waste per year. Securing resource and energy efficiency are main key drivers, addressing sustainability of both buildings and civil infrastructures. Advanced materials like glass, concrete and asphalt are needed to yield added functionality at minimized embodied energy, including implementation of bio-based principles, compact energy efficiency solutions and multifunctional responsive materials. In 2020 new buildings should be energy neutral (or use 60% demolition waste in construction materials).¹⁶

Additional challenges

- A major scientific challenge is to understand the structure-property relations at all relevant length scales of existing, modified and new materials, as well as the design (modeling, computational science) and development (synthesis and processing) of materials. Furthermore a transition has to be made from the current rather descriptive models to predictive modeling.
- Materials research needs to provide industry with tools for production, processing and manufacturing of high-tech materials, as well as for adequate testing and characterization. This requires the protection and expansion of the advanced physical material characterization facilities in the Netherlands. Concentration of activities on a few locations will help to create focus and mass.
- Life-cycle considerations, such as aging of production equipment and infrastructure, environmental impact, decommissioning, reliability, hazards, risks and recyclability need fundamental understanding and predictive modeling of degradation mechanisms of materials in often extreme conditions.
- In industrialized countries some 20% of all energy generated is ultimately lost through friction and wear. Therefore these phenomena should be understood from a fundamental point of view and controlled by high-tech surface engineering like texturing, coatings and thin films.

⁸ International technology Roadmap for semiconductors 2007

⁹ International technology roadmap for semiconductors 2009 Update System Drivers

¹⁰ International technology Roadmap for semiconductors 2009 Update Lithography

¹¹ Point-One Phase2 Multi-annual Roadmap and Annual Plan 2011

¹² Roadmap "Zon op Nederland", 2011

¹³ A Strategic Research Agenda for Photovoltaic Solar Energy Technology, European photovoltaic Technology platform, European Union, September 2011

¹⁴ Pure Power, Wind energy targets for 2020 and 2030, European Wind Energy Association – 2011

¹⁵ ISA (International Solid State Lighting Alliance) SRA, October 2011

¹⁶ Energy-efficient Buildings (EeB) PPP, Research Priorities for the definition of a multi-annual roadmap and longer term strategy, European Union, 2010

- An interdisciplinary approach in materials science means that fundamental research will be linked to materials questions from industry. Those questions are directly related to products, and therefore linked to several other issues, such as hazards, risks, environment and sustainability.
- Research and use of high tech materials in industry will require highly educated employees, not only in existing companies but also to increase the number of start-up companies active in materials. Materials research and technology needs young talent entering the field. This can only be achieved if the field is “attractive”. The image of materials science and technology needs improvement by including its vital contributions in several disciplines.

Future outlook, in present and emerging markets

Many companies focus increasingly on “green growth by innovation” demonstrating that economy and society go hand in hand. Societal themes will stimulate material innovation initiating new green products.

- **Climate.** To reduce CO₂ and NO_x emissions, light-weight / high-strength hybrid and composite materials will play a key role in the transport and wind energy sectors.^{4,5,14} European emission regulations (Euro 6) require improved catalyst materials and new high-temperature / low-friction barrier coatings to increase turbine and engine efficiency (fuel saving). Furthermore, high tech materials are urgently needed in the construction and building sector due to the high level of waste and energy use.¹⁶
- **Energy.** The exhaustion of fossil fuel reserves and increasing CO₂ emissions drive the transition towards alternative energy sources. For PV, piezoelectrics and SSL extensive research is needed on substrates, barrier layers, glues, TCOs, and reliable joints. Low cost processing steps have to be developed to apply materials on a large scale, e.g. in roll to roll technologies, printing and non-vacuum processes.^{12,13} The materials should be sustainable and C2C concepts should be applied. Enhanced oil recovery is an important subject in conventional oil winning.
- **Health.** To help controlling the rising health care costs of an aging population many materials related issues have to be tackled. Examples are new biocompatible materials for devices (e.g. catheters, stents and implants), material innovations to allow miniaturization and function integration in electronic devices (e.g. MEMS and SiP), biocompatible materials with low friction for prostheses and joint replacements, (bio)chemical modification of surfaces and interfaces for controlled drug delivery, and early detection and diagnostic devices using compatible functional materials.
- **Mobility.** Multifunctional textiles and other materials offer solutions for roads, railways, and marine constructions. Crashworthiness of high-strength / low-weight materials is an ongoing research topic in the transport sector to make cars and ships safer and more reliable. The dredging industry needs abrasion resistant coatings and materials leading to increased durability of ships, pipes and tooling.^{5,6}
- **Security.** In many aspects materials need to be failure resistant in order to protect people and their environment. Examples are protective clothing, coatings/materials with de-icing properties, reliable electronic connections and packaging, materials resistant against blast and impact loading, development of new inspection techniques, and fire resistant, shielding and self healing materials.¹¹
- **Material resources.** The availability of materials is influenced by either physical scarcity, political unstable regions or they place an intolerable strain on the environment. These factors drive the development of alternative solutions like using materials more efficient (*reduce*), using alternative materials (*replace*) and/or re-using materials according to the C2C concept (*recycle*).¹⁷

Priorities and programs

Selected items from roadmap

The nine industrial sectors of the Roadmap Advanced Materials represent nine sub-roadmaps with many project items related to materials innovation. A selection is made by focusing on different application categories highlighting a number of new material developments that are relevant for industry and society:

- **Hybrids and composites.** The potential is huge by further increasing the strength over weight ratio in combination with cost reductions. Important research issues are: improved toughness, impact, fatigue and corrosion behavior, short curing times and minimum shrinkage, improved resins and resin injection techniques, 3D composites to further increase design freedom, automated fiber placement and steering, visco-elasticity of elastomer-based nanocomposites, improved mechanical properties at high temperatures, joining, inspection and repair methods, and recycling (green production).
- **Advanced metals.** Value chain optimization in metals production based on total life cycle costs has many aspects of materials innovation. Key issues are: blast furnace technology, extraction of raw materials from waste streams and products, CO₂ capture and storage technology, waste heat recovery, ultra low CO₂ steelmaking, high performance aluminum, magnesium and titanium technology, laser additive manufacturing of metals, Electron Beam Direct Manufacturing, advanced joining and forming, recycling of rare earth metals from waste and end-of-life products, processing of high temperature materials, and safety aspects of metals.

¹⁷ Sustainable Process Industry, European Industrial Competitiveness through Resource and Energy Efficiency, 2011

- **Multifunctional textiles.** Nanotechnology is one of the drivers for improved multifunctional textiles. Nanofibers, nanoparticles and nanosurface engineering will add new functionalities to many applications. This needs further development of advanced production technologies. For example plasma and laser treatment, pick and place robotics and inkjet technology will play a key role in the introduction of new products to the market. MEMS and conductive polymers are another example in this respect. New technologies will also enable tailoring of strength, endurance, water repellence, etc.
- **Surface and interface engineering.** Friction and wear should be understood from a fundamental point of view and controlled by high-tech surface engineering and modification. Many surface modification techniques are available in this respect. Apart from coating, cladding and thin film techniques, surfaces can also be modified by direct laser treatment (e.g. 3D micromachining) or the implantation of nanoparticles. A variety of these surface modification techniques is included in the various sub-roadmaps. A high tech application can be found in extreme UV multilayer optics.
- **Nanosized and nanostructured materials.** Tuning materials at the nanoscale allows obtaining the materials of the future with astonishing optical, mechanical or surface properties in almost any (industrial) domain. Main research areas are new materials-specific theories for atomic and molecular interface physics and nanophysics, control over functional nanoparticle solids and graphene-based electronics. Other examples include nanostructured materials for nanocatalysis and photocatalysis, plasmonics for PV, graded thin films for SSL, phase change materials and battery/thermoelectric energy management.
- **Smart materials.** Smart or intelligent materials, like nanomaterials, show a great development in new applications. The challenge of these materials lies in controlling the macroscopic properties and behavior from the micro- or even nanoscopic structure of the building blocks. On different length scales (nano, micro, meso, macro) all kind of smart functionalities can be added to materials to create special properties. Examples are drug delivery on demand, selective measure and sensor techniques in the personal healthcare domain (e.g. lab-on-a-chip technology), photonic sensor materials for process control and monitoring of ageing, self-healing and debond-on-command materials, flexible foils for electronic devices like OLED and PV, next generation organic PV, printable electronics and switchable optical materials.
- **Soft materials.** Roughly 10% of the world energy consumption is used for the transport and handling of granular materials. Also many foodstuffs, cosmetics and industrial materials (oil drilling mud, coatings) are soft materials in the sense that large deformations result from small forces. The challenge for all these materials lies in understanding and engineering their behavior at large scales from the organization of the building blocks at much smaller scales. Research subjects are physics of colloidal dispersions in external fields, physics of granular matter, innovative physics for oil and gas, and bio (related) materials.

Proposed implementation (NWO, TNO/GTI, international R&D, regional, other)

High tech materials are one of the Key Enabling Technologies (KET) as defined by the European Commission.¹⁸ The broad application fields of materials enable excellent alignments with NWO, IOP, TNO/GTI, EU and other programs. Examples in the more fundamental field are the advanced material programs of STW, FOM and other NWO disciplines, the EU programs ENIAC, FP7, FP8, Eureka and RFCS. The running FOM-IPP program with M2i on Size Dependent Material Properties is a good example of fundamental research linked with industry. The more applied or valorization projects will be carried out together with TNO/GTIs including projects with SMEs and links with IPCs and other Innovation Funds. The current valorization program of M2i consisting of six valorization modules is a very good starting point in this respect.

Collaboration activities qualifying for TKI

The current materials program of M2i will serve as a first building block for TKI based on a transparent long-term collaboration between industry, knowledge institutes and government. In this collaboration industry contributes 44% of the total activity level (cash and in kind). During 2012 and 2013 a transition from TTI towards TKI will be initiated by involving NWO and TNO/GTI in the TKI. The governance of such collaboration is not clear yet but discussions with NWO and TNO are ongoing to create a workable set-up.

Engaged partners from industry and science

Due to the broad materials scope of the TKI High Tech Materials there are strong links with other top sectors like chemistry, energy and water. Since already several years projects are carried out together with other TTIs and innovation programs, of which some of them now apply for a TKI in several top sectors. The Roadmap High Tech Materials has been sent to about 1700 industrial contact persons. Their feedback consisted of many ideas for additional projects and programs. About 70 companies have been asked to sign an LOI. The first ones have already been sent back and represent a significant value. This is on top of the existing commitments of about 60 industrial and scientific partners active in M2i. Their collaboration with M2i is based on ongoing commitments represented by their logos on the last but one page. In the framework of the TKI this will grow further as has been indicated in the budget tables shown in the next paragraph. The first signed LOIs will initiate this process.

¹⁸ KET final document, July 2011

Investments

Public-private partnership R&D (budget tables 2012-13 and 2014-16)

The size of the current M2i organization is included in the figures of the tables shown below. In the transition year 2012 the growth of the TKI High Tech Materials is relatively low but will speed up from 2013 onwards, partly due to the introduction of the RDA⁺ tax deduction possibilities for companies participating in TKIs.

2012 (alle bedragen in M€ per jaar)

Financiers → ↓ Uitvoerders	Bedrijven	Rijk TNO/NLR	Rijk NWO	Rijk overig **)	Universiteit (matching)	EC	Anders ***)
Universiteit TKI	6,50	1,70	6,00	6,70	6,60	-	-
Universiteit niet-TKI	-	0,30	-	-	-	-	-
TNO/NLR TKI	0,50	0,30	-	-	-	-	-
TNO/NLR niet-TKI	-	1,40	-	-	-	-	-
Bedrijven TKI	4,00	-	-	-	-	-	-
Bedrijven niet-TKI	-	-	-	-	-	-	-
Internationale R&D consortia	-	-	-	-	-	0,15	-
Totaal	11,00	3,70	6,00	6,70	6,60	0,15	-

2013 (alle bedragen in M€ per jaar)

Financiers → ↓ Uitvoerders	Bedrijven	Rijk TNO/NLR	Rijk NWO	Rijk overig **)	Universiteit (matching)	EC	Anders ***)
Universiteit TKI	12,00	3,30	10,00	6,70	8,00	-	-
Universiteit niet-TKI	-	0,30	-	-	-	-	-
TNO/NLR TKI	-	-	-	-	-	-	-
TNO/NLR niet-TKI	-	1,30	-	-	-	-	-
Bedrijven TKI	8,00	-	-	-	-	-	-
Bedrijven niet-TKI	-	-	-	-	-	-	-
Internationale R&D consortia	-	-	-	-	-	0,50	-
Totaal	20,00	4,90	10,00	6,70	8,00	0,50	-

2014 – 2016 (alle bedragen in M€ per jaar)

Financiers → ↓ Uitvoerders	Bedrijven	Rijk TNO/NLR	Rijk NWO	Rijk overig **)	Universiteit (matching)	EC	Anders ***)
Universiteit TKI	15,00	3,30	17,00	-	11,00	-	-
Universiteit niet-TKI	-	0,30	-	-	-	-	-
TNO/NLR TKI	-	2,00	-	-	-	-	-
TNO/NLR niet-TKI	-	1,20	-	-	-	-	-
Bedrijven TKI	9,00	-	-	-	-	-	-
Bedrijven niet-TKI	-	-	-	-	-	-	-
Internationale R&D consortia	-	-	-	-	-	1,00	-
Totaal	24,00	6,80	17,00	-	11,00	1,00	-

Other innovation instruments (such as IPC, Innovation Funds, SBIR, valorization grants)

As stated earlier, the more applied and/or valorization projects, particularly meant for SMEs, will be carried out together with TNO/NLR, other GTIs, associations in several disciplines, and TKIs in other top sectors like DPI and DPI Value Center. These types of projects can be excellently linked to IPCs, Innovation Funds, SBIR and valorization grants. This is one of the possibilities to grow the TKI in the coming years to the levels indicated above, next to a growing volume of fundamental research projects together with NWO and universities.

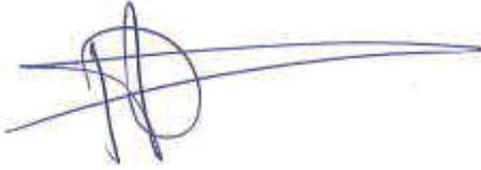
Industriële partners



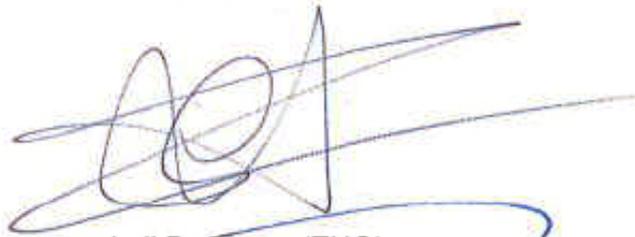
Universitaire partners



Signed by:

A handwritten signature in blue ink, consisting of a large, stylized 'D' followed by a horizontal line.

Daniel Bonn (UvA)

A handwritten signature in blue ink, featuring a large, stylized 'A' followed by a horizontal line.

Ardi Dortmans (TNO)

A handwritten signature in blue ink, appearing to read 'T. Palstra'.

Thom Palstra (RUG)

A handwritten signature in blue ink, appearing to read 'M. Peters'.

Michel Peters (NLR)

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Guus Rijnders (UT)

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Bert van Haastrecht (M2i)

A handwritten signature in blue ink, appearing to read 'Sybrand van der Zwaag'.

Sybrand van der Zwaag (TUD)

A handwritten signature in blue ink, appearing to read 'Sibbe Hoekstra'.

Sibbe Hoekstra (M2i)

Delft, 1 december 2011