# Integrated Research and Industrial Roadmap for European Nanotechnology

NANO*futures*, European Technology Integrating and Innovation Platform on Nanotechnology

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NANOfutures

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# Prefix

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This document aims at presenting the **NANO*futures* Integrated Research and Innovation Roadmap (2013-2025)**, including detailed implementation plan focusing more on actions up to 2020.

This roadmap represents an **open working document**, developed within the European Coordination and Support Action **NANO*futures*** (contract number NMP4-CA-2010-266789). This document will be further developed with all NANO*futures* Platform members and other stakeholders from the Nano related Community who would like to contribute.

**Version:** July 2012

# Executive Summary

# Executive Summary

***Chapter 1*** describes the roadmap background: NANO*futures* is a new generation cluster of ETPs and stakeholders operating on nanotechnology:

- It addresses cross-sectorial needs, joining the efforts of all the stakeholders;
- It aims at reducing fragmentation, aligning research and innovation efforts for the competitiveness of European nanotechnology;
- It aims at meeting grand societal and economical challenges through fostering the development of sustainable nano-enabled products

NANO*futures* Coordination and Support Action (CSA) project, funded by the European Commission (FP7) aimed at developing the NANO*futures* Roadmap.

NANO*futures* is steered by a Steering Committee, formed by 10 Chairs of Horizontal Working Groups and 11 European Technology Platforms from different industry sectors:

- Textiles ETP: ETP for the Future of Textile and Clothings
- NANOMEDICINE ETP
- SusChem: ETP on Sustainable chemistry
- ECTP: European Construction Technology Platform
- ENIAC: Joint Undertaking in Nanoelectronics
- MANUFUTURE: ETP on Advanced manufacturing
- MINAM: ETP on micro and nanomanufacturing
- ERTRAC: ETP Transportation
- EUMAT: ETP on Advanced Engineering Materials and Technologies
- PHOTONICS21: European Technology Platform for photonics
- ETPIS: ETP on Industrial Safety

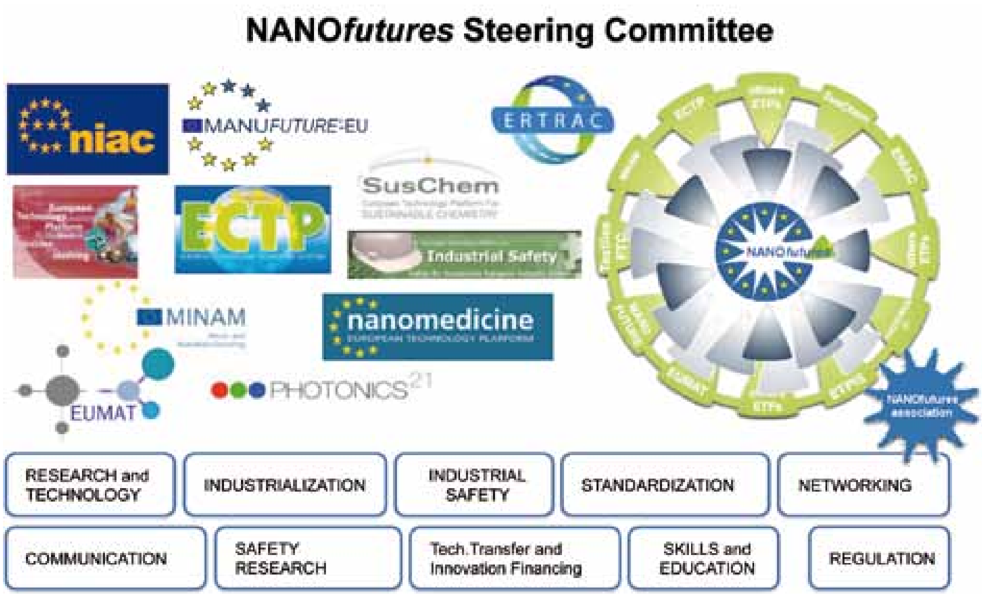



**Figure 0-1: NANO*futures* Steering Committee**

The wide participation of European experts and stakeholders (around 700 participants up to march 2012) is guaranteed by an online web platform (www.nanofutures.eu) as well as by the organization of several expert workshop and dissemination meetings. The experts involved in the different roadmapping groups are listed in the website.

***Chapter 2*** describes NANO*futures* vision and objectives. NANO*futures* Vision towards 2025 can be summarised as follows:

- **By 2015**, Nanotechnology World Market Size would hit 3 trillion Euros in a broad range of sectors (chemical manufacturing, pharmaceuticals, aerospace, electronics, materials etc.)[1 2].
- **By 2025**, nanotechnology is expected to be a mature yet still growing industry, with countless mainstream products in all different industrial sectors.
- In this context, Europe aims to play a **market leader position**, increasing its competitiveness in all different sectors where nanotechnology may have a strong added value.
- The growth and commercialization of nanotechnology must be guided and fostered by taking care of social and **sustainability** aspects.

If effective alignment of private and public efforts over promising areas is guaranteed from short to long term, European Nanotechnology is expected to promote *Excellent Science*, increase the *European Industrial Leadership*, as well as give an outstanding contribution to major Societal Challenges of our time[3]:

In this framework, **NANO*futures* integrated Industrial and Research Roadmap** aims to:

- deliver a focused **implementation plan** until 2020, within a longer term horizon of actions (>2025);
- address **European cross-cutting key nodes in terms of cross-sectorial research, technology and innovation issues**;
- cover broad **socio-economic challenges** to the implementation and commercialisation of sustainable and safe nanotechnology enabled solutions;
- Have a **market-driven value chain approach** with a set of tech and non-tech actions along the identified nano-enabled value chains.

The Roadmapping approach, described in ***Chapter 3***, may be summarized by the figure below, showing that the Roadmap has an industry driven approach: it started from ETP needs, involved different expert communities (WGs, KNs) and come back to ETPs for validation purposes.

1 Cientifica Ltd 2007. Halfway to the trillion dollar market?, available at http://cientifica.eu.

2 Lux Research Inc. (2009): “Nanomaterials of the Market Q1 2009:Cleantech’s Dollar Investments, Penny Returns”

3 As listed in COM (2011) 808 Final: “Horizon 2020 - The Framework Programme for Research and Innovation - Communication from the Commission”

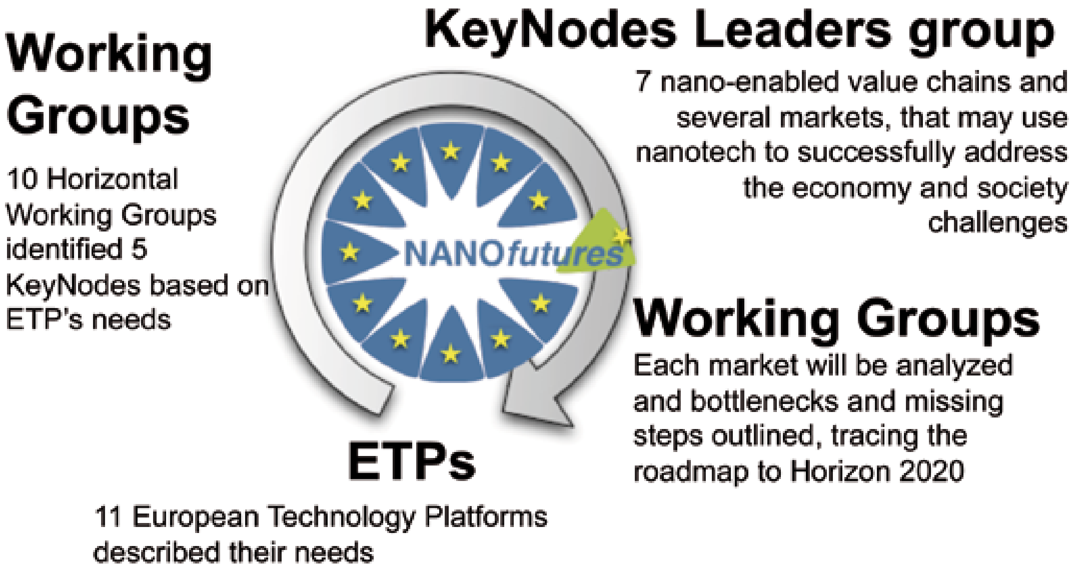



**Figure 0-2: NANO*futures* Roadmapping loop**

**NANO*futures*** decided to have a **value chain approach**, in order to contribute to **bridge the current gap between nanotechnology knowledge and successful commercialization** of nano-enabled products.

The approach resulted in three roadmapping layers as shown in Figure 0-3: 5 key nodes and 7 nano-enabled value chains, 27 examples of lead markets and a set of final nano-enabled products (production chains), cross- cutting actions that overarch the roadmap (societal chains).

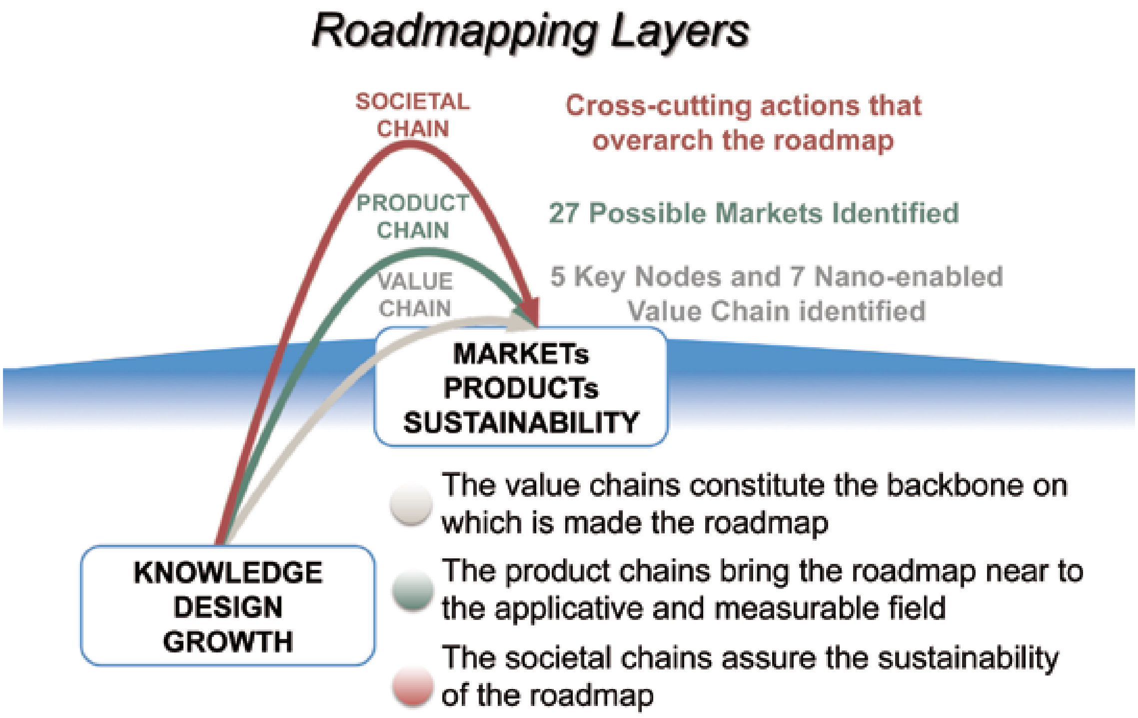



**Figure 0-3: NANO*futures* Roadmapping layers**

A schematic figure representing the value chain, which includes production aspects (the "Production Chain") as well as societal aspects (the "Societal Chain") is represented below.

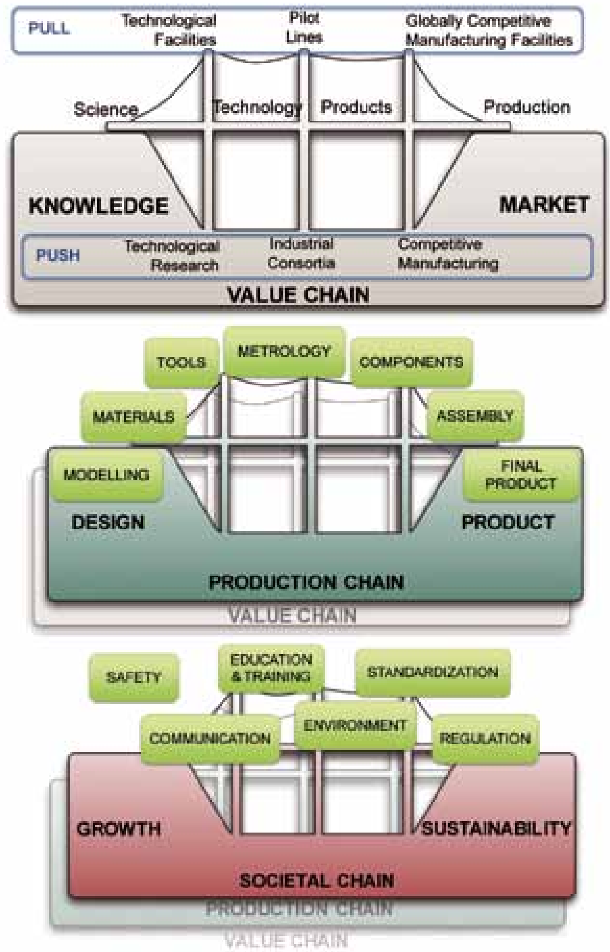



**Figure 0-4: Overview of the NANO*futures* value chain approach**

***Chapter 4*** describes the roadmap content: for example, the link between the 5 keynodes and the **7 nano-enabled value chains and the set of target markets and final nano-enabled products** of the NANO*futures* Roadmap is given below. The grey areas in the figure below are the nano-enabled the value chains, i.e. the set of actions along the value chains that are feasible thanks to nano-enabled materials and technologies.

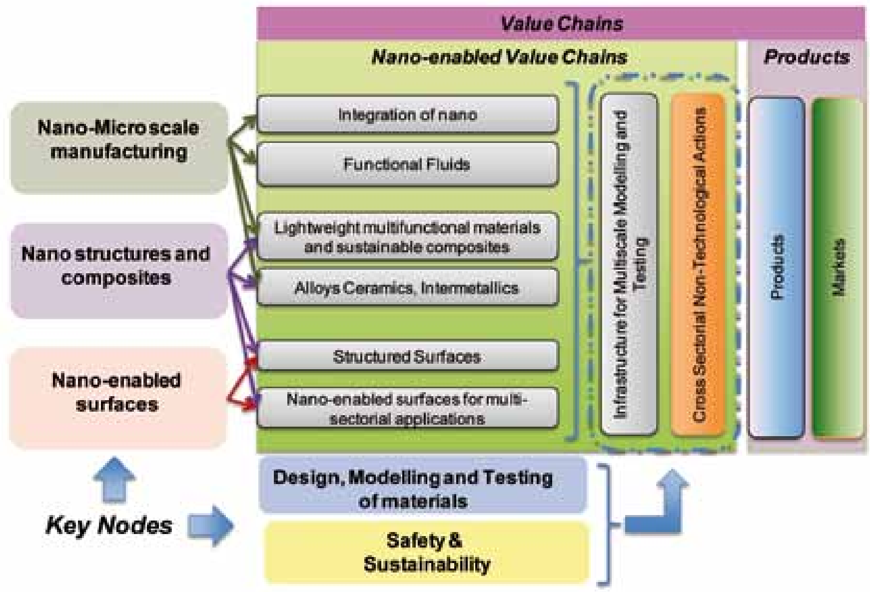



**Figure 0-5: From Keynode groups to NANO*futures* Value Chains**

Figure 0-6 shows an overview of NANO*futures* Roadmap, focused on nano-enabled value chains (grey boxes), which include actions to address industrial needs and research and innovation challenges for the successful development of safe and sustainable nano-enabled products. For each nano-enabled value chain, **one or more production chains** were detailed, identifying examples of possible lead markets. Actions at different steps in the value chain, at different TRL level and at different timeline were identified. Examples of resulting **nano-enabled final products** are included in ***Chapter 5***.

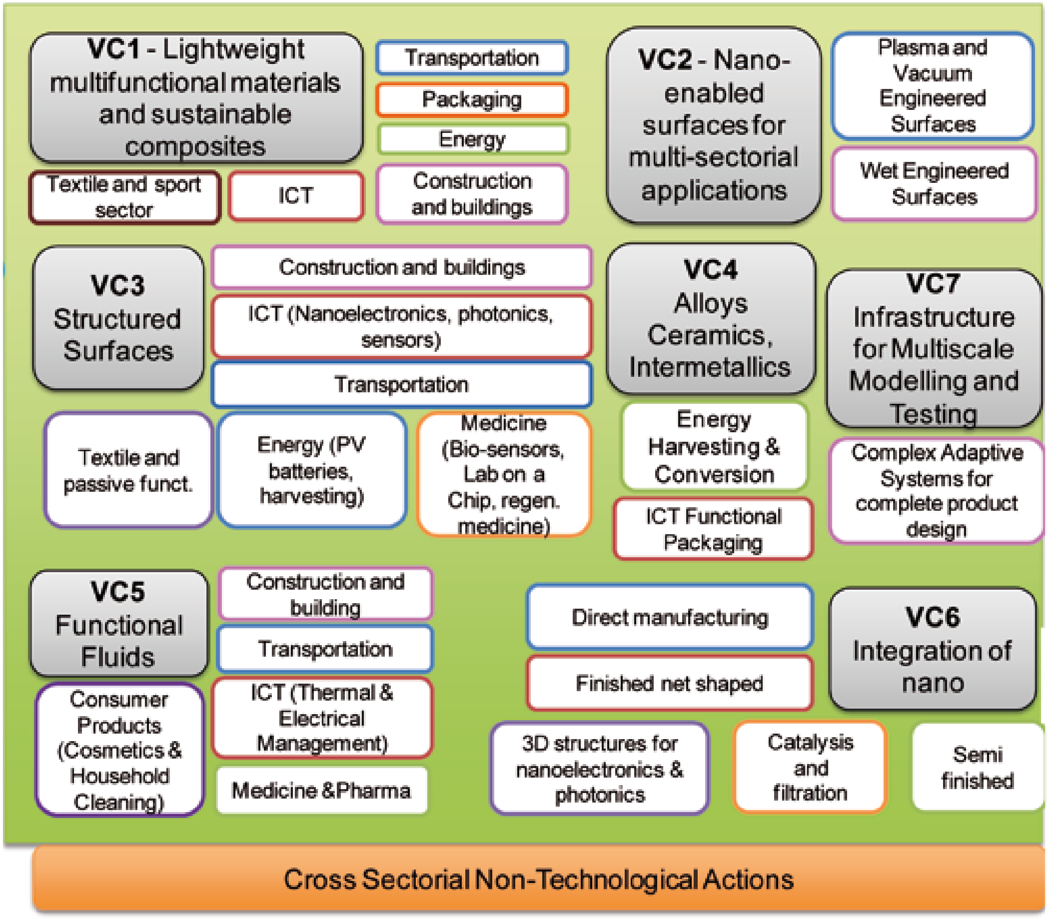
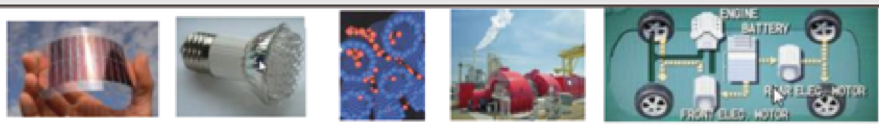
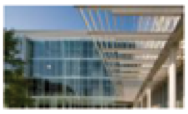
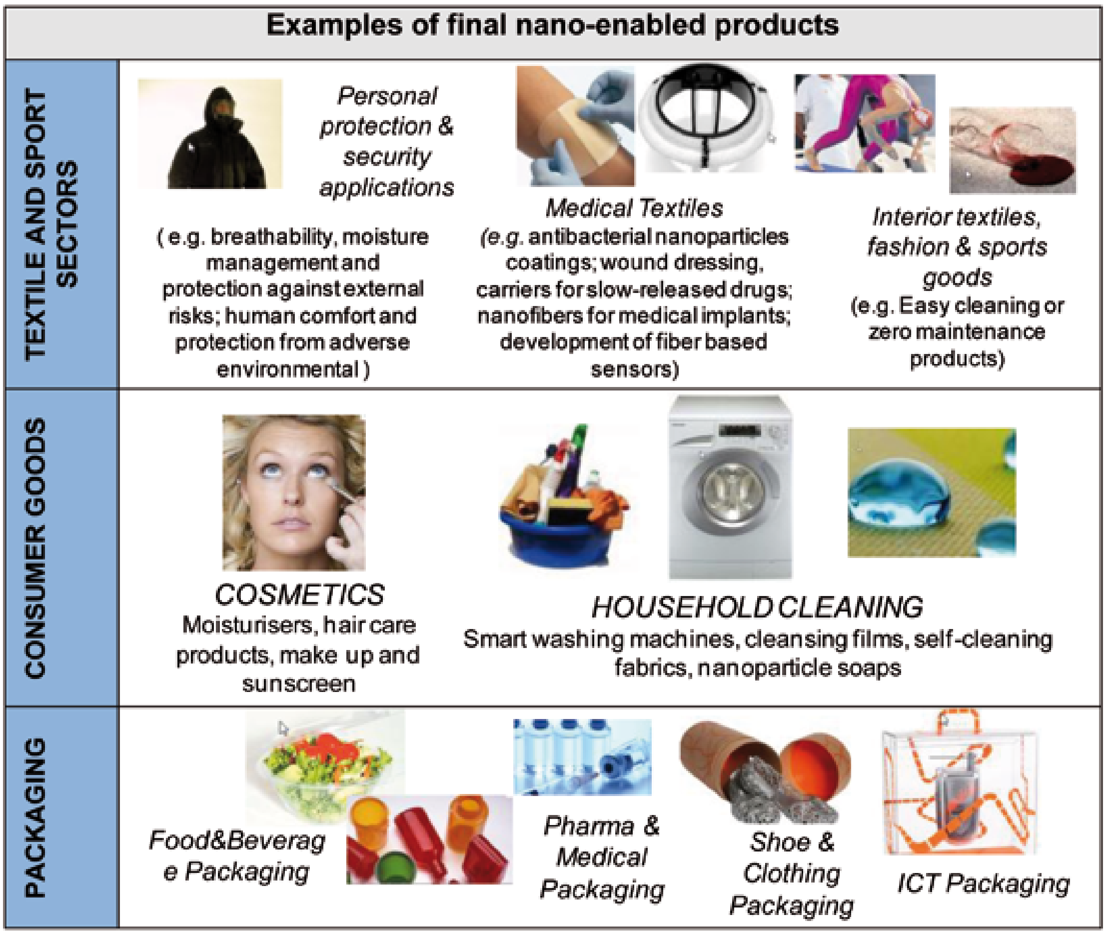



**Figure 0-6: Overview of the NANO*futures* nano-enabled value chains and lead markets**

***Chapter 5*** describes the impact of the roadmap: the following table summarizes the impact in terms of examples of final **nano-enabled products** for each industrial sector.

**Table 0-1: NANO*futures* Impact – examples of final nano-enabled products, for each target market**

| | Examples of final nano-enabled products |
|---|---|
| **ENERGY** |  Advanced Solar cells (Including organic & hybrid PV); solid state lighting (LED, OLED, PLED); Efficient catalysis & carbon capture and storage -CCS (pollution control in fuels, in geothermal etc.); Storage technologies (hybrid batteries, gas, hydrogen). Power electronics for industrial applications and engine management) |
| **TRASPORTATION** |  Long time, low cost fuel cell membranes and batteries; Low friction engines & lubricants; Smart glass surfaces; Lightweight metal or plastic sheet for chassis; efficient tires, wiper blades, seals; sustainable lightings and heating systems; smart sensors and radar systems |
| **CONSTRUCTION & BUILDINGS** |  High durability & high productivity infrastructure; Self-cleaning/Anti-microbial/solar reflective paints for building envelopes or indoor environment (e.g. HVAC) ;  Advanced insulating systems for new and existing building envelopes;  Green high performance concrete (CO2 trapping) & recycled building composites; Smart integration of technologies (incl. Sensors) at building level  |
| **MEDICINE & PHARMA** |  Scaffolds and coatings for regenerative medicine (implants, engineered cartilage, vessels, bone); biosensors, like lab-on-chip and micro-TAS, smart pills; Nano-pharmaceuticals, biomarkers and contrast agents for theranostics; Diagnostic tools (CT, NMR, PET, optical), portable point-of-care devices and nano-imaging |
| **ICT** |  Lasers (optical communications, medical diagnostics and treatments, manufacturing tools, printers); ink-jet printers; LCD-, silicon-, LED- and OLED-based Displays and Photovoltaics; Consumer Electronics (smart phones, TV set, digital cameras etc.) |




The path from Societal Challenges to NANO*futures* markets and products towards implementation of specific actions is shown in the following figure.

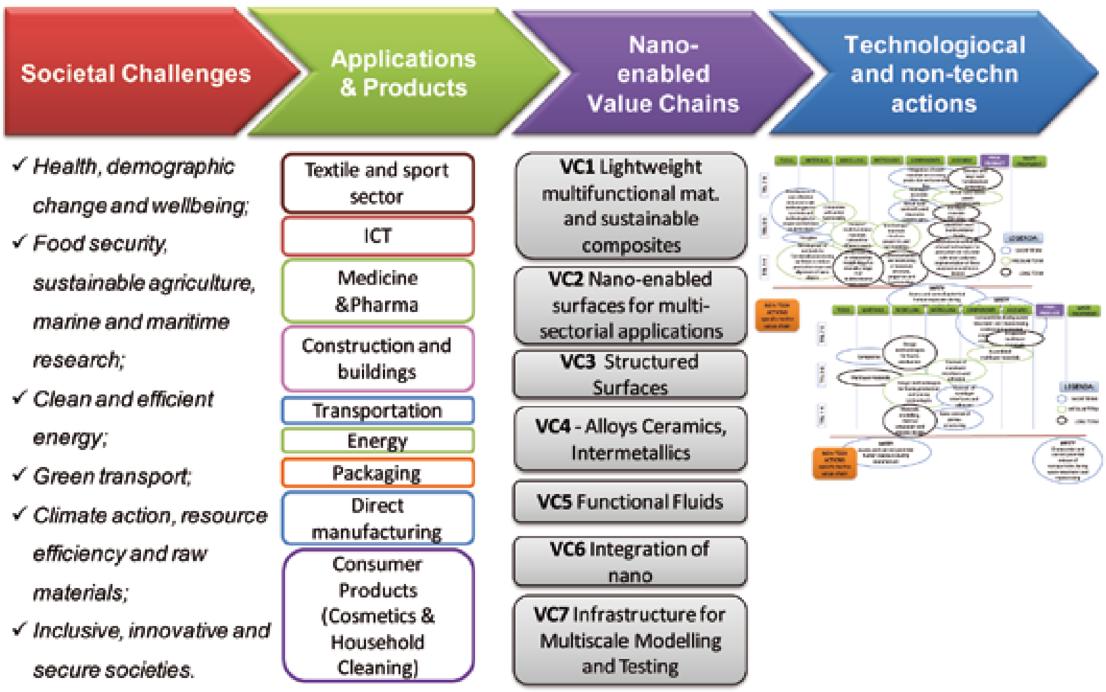



**Figure 0-7: From Societal Challenges to NANO*futures* products towards NANO*futures* proposed actions**

The actions included in the NANO*futures* Roadmap are introduced in the **Implementation Plan**, reported in ***Chapter 6***. Each action, with special care to short term actions, is deeply analyzed in Annexes A, B and C.

Finally some budget considerations were given, drafting an overall distribution of expected costs among the value chains and considering an overall cost of 1.5 Billion Euros. The cost of cross-cutting non technological actions was distributed equally in all value chains. Such consideration is only the starting point for future discussion among European stakeholders. A summary figure is described below.

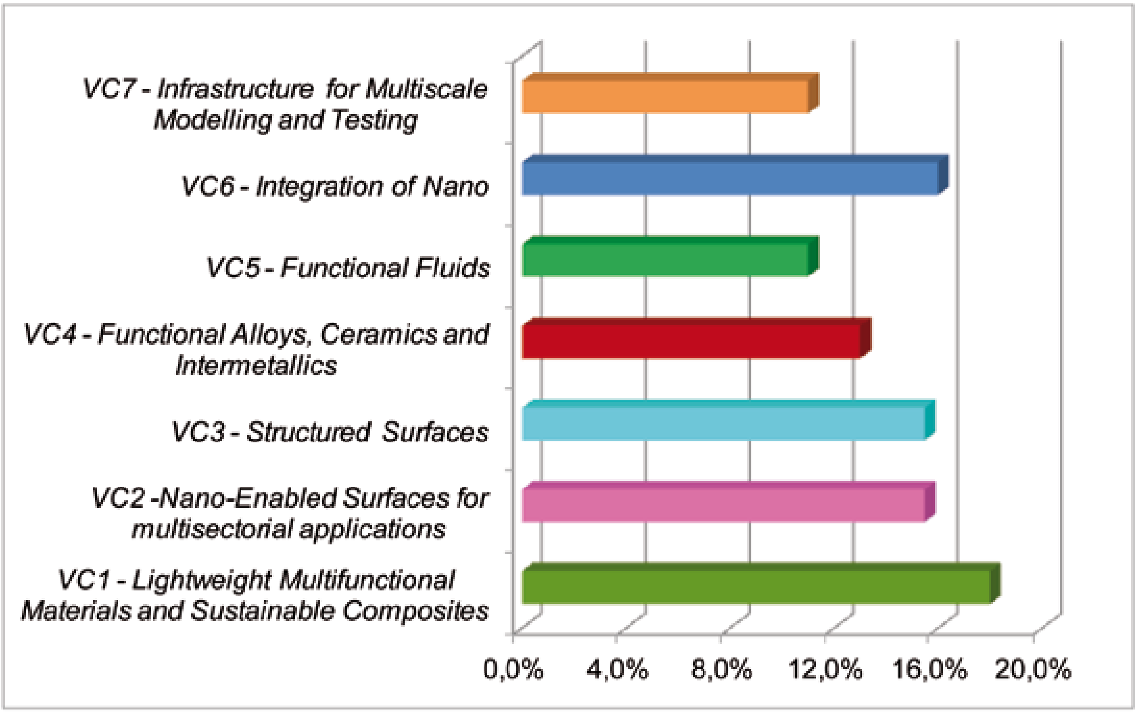



**Figure 0-8: Estimation of % cost distribution among VCs, considering a total funding (100%) of 1.5 Billion Euros**

***Chapter 7*** includes the conclusion and future activity: the Roadmap is conceived to be a live document, to be continuously disseminated, discussed and improved by the NANO*futures* Community, the European Commission and all nanotechnology stakeholders.

As anticipated in ***Annexes A, B and C***, all the actions are deeply described and the following details are reported: a description of the action content in terms of research and innovation challenges with respect to the state of the art, the technologies to be further developed and some examples of possible type of funding to be used to implement the action.

# Acronyms

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| | |
|---|---|
| CA | Coordination Action |
| CCS | Carbon Capture and Storage |
| CEO | Chief Executive Officer |
| CSA | Coordination and Support Action |
| CT | Computed Tomography |
| DoW | Description of Work |
| ETP | European Technology Platform |
| EU | European Union |
| HVAC | Heating, ventilation, and air conditioning (system) |
| KN | KeyNode |
| LED | Light Emitting Diode |
| Micro-TAS | Micro(μ) total analysis systems |
| MNR | Magnetic Nuclear Resonance |
| Nf | NANO*futures* |
| NfA | NANO Association |
| OLED | Organic Light Emitting Diode |
| PET | Positron Emission Tomography |
| PLED | Polymer light-emitting diodes |
| PPP | Public Private Partnership |
| PV | Photovoltaics |
| TRL | Technology Readiness Level |
| VC | Value Chain |
| WG | Working Group |

# 1 Background

# 1 Background

Interest in Nanotechnology has increased enormously in the last years due to the technology revolution potential it holds. Worldwide spending on research and development in Europe and the US exceeds 3 billion Euros per year and accounts for half of total funding.

However, economic and social benefits from these large investments in research are nevertheless not appearing, as it would be expected, probably due to:

- gap between research efforts and industrial and user needs: more market driven efforts should be made to bridge the existing “valley of death” between the knowledge-base science and the successful commercial nano-enabled products.
- dispersion and fragmentation of efforts: European public and private spending in nanotechnology is currently dispersed in a large number of EU, national and regional projects and initiatives.
- broader challenges going beyond sectorial technological gaps which hinder the nanotechnology development and commercialization. Among these there are safety, regulation, standardization, innovation financing and technology transfer issues.
- Poor focus of nano research and innovation to develop products and services able to address the social and economic Grand Challenges of our time.

Although several ETPs were capable of addressing the specific needs and challenges of their sector or technology areas effectively, addressing such broader challenges requires an **unusual multidisciplinary and cross-sectorial collaboration within the value and innovation chains**, including an international approach for future regulation.

**NANO*futures* European Technology Integrating and Innovation Platform (ETIP)** was created to help remedy this situation and accelerate the safe and responsible uptake and use of nanotechnology.

## 1.1 NANO*futures* at glance

NANO*futures* is a new generation cluster of ETPs operating on nanotechnology:

- It addresses cross-sectorial needs, joining the efforts of all the stakeholders;
- It aims at reducing fragmentation, aligning research and innovation efforts for the competitiveness of European nanotechnology;
- it aims at meeting grand societal and economical challenges through fostering the development of sustainable nano-enabled products


**Figure 1-1: NANO*futures* interactions**

The Platform started as a voluntary initiative in 2009 and was officially launched in NANO*futures* Launching event in Gijon (Spain, 15-16 June 2010). It was conceived to be a “Nano-Hub” able to link:

- large industries, SMEs and industrial associations and networks from different sectors;
- research institutions and universities
- non-Governmental Organisations
- European and national authorities and financial institutions,
- civil society with an involvement of national and regional networks

in close collaboration with 11 European Technology Platforms **from different industry sectors**:

- Textiles ETP: ETP for the Future of Textile and Clothings
- NANOMEDICINE ETP
- SusChem: ETP on Sustainable chemistry
- ECTP: European Construction Technology Platform
- ENIAC: Joint Undertaking in Nanoelectronics
- MANUFUTURE: ETP on Advanced manufacturing
- MINAM: ETP on micro and nanomanufacturing

- ERTRAC: ETP Transportation
- EUMAT: ETP on Advanced Engineering Materials and Technologies
- PHOTONICS21: European Technology Platform for photonics
- ETPIS: ETP on Industrial Safety

**The Steering Committee includes 11 ETP representatives** and **10 nanotechnology experts** who chair the working groups on cross-sectional “horizontal” issues within the NANO*futures* Co-ordination Action (CA) project, funded by the European Commission (FP7). This Committee was officially constituted in Brussels, during the meeting of January 14th 2010.

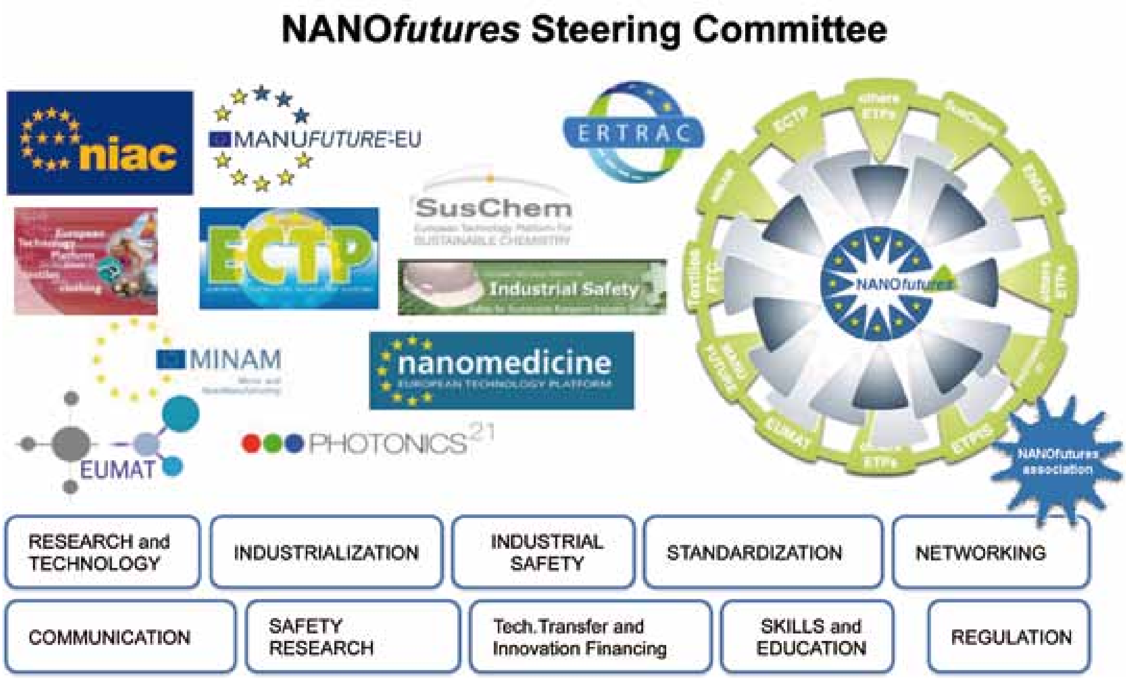


**Figure 1-2: NANO*futures* Steering Committee**

The Steering Committee is chaired by Paolo Matteazzi (MBN Nanomaterialia SpA, IT and MINAM ETP chair), supported by two co-chairs: Prof. Costas Kiparissides (CERTH, GR) and Peter Krüger (Bayer Material Science, DE).

The wide participation of European experts and stakeholders (around 700 participants up to march 2012) is guaranteed an online web platform (www.nanofutures.eu) as well as by the organization of several expert workshop and dissemination meetings. The experts involved in the different roadmapping groups are listed in the website.

### 1.1.1 Link between NANO*futures* and MINAM 2.0

MINAM 2.0 and NANO*futures* CSA projects have collaborated on roadmapping activities related to micro-nano manufacturing. MINAM 2.0 is a CSA which focuses on manufacturing technologies, scale-up and industrialization issues, while NANO*futures* has a wide cross-sectorial approach which cover the whole value chain from material development to end of life treatment, considering also non technological targets (safety, regulation, education etc.).

A representation of MINAM 2.0 was involved in the keynode Nano-micro Manufacturing workshops. MINAM 2.0 experts gave their suggestions in terms of required actions at short, medium, long term on technological industrialization aspects. Further details on such aspects, with a detailed description of current bottlenecks and some best practices, will be available in the MINAM 2.0 roadmap that will be released approximately by October 2012 at http://www.minamwebportal.eu/index.php?m1=Public-Area&l1=MINAM-2.0.

Conversely, NANO*futures* made available to MINAM 2.0 the overall picture of NANO*futures* nano-enabled value chains and corresponding nano-enabled materials and products.

### 1.1.2 Link between NANO*futures* and other initiatives

NANO*futures* collaborates also with other CSA projects (for example NANOCOM, PRONANO, ObservatoryNANO and Nano2Market) and other initiatives (e.g. the NanoSafetyCluster, SIINN Eranet etc.). These initiatives provided NANO*futures* with nanotechnology desk research and survey results (e.g. ObservatoryNANO), their studies on their barriers to commercialization of nano-enabled products (e.g. NANOCOM), their public analysis of nano projects and best practices (Pronano, Nano2Market). Such documentation was used as background for working groups and roadmapping activities. A representation of experts from such initiatives was invited to participate to roadmapping workshops and other Platform events. In turn NANO*futures* helped to promote participation to their surveys, their events and to disseminate their reports and news to a wider audience of nanotechnology stakeholders.

# 2 Vision and Objectives

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NANO*futures* Vision towards 2025 can be summarised as follows:

- **By 2015,** Nanotechnology World Market Size would hit 3 trillion Euros in a broad range of sectors (chemical manufacturing, pharmaceuticals, aerospace, electronics, materials etc.)[4 5].
- **By 2025**, nanotechnology is expected to be a mature yet still growing industry, with countless mainstream products in all different industrial sectors.
- In this context, Europe aims to play a **market leader position**, increasing its competitiveness in all different sectors where nanotechnology may have a strong added value.
- The growth and commercialization of nanotechnology must be guided and fostered by taking care of social and **sustainability** aspects.

If effective alignment of private and public efforts over promising areas is guaranteed from short to long term, European Nanotechnology is expected to promote *Excellent Science*, increase the *European Industrial leadership*, as well as give an outstanding contribution to major *Societal Challenges of our time*[6]:

- Health, demographic change and wellbeing;
- Food security, sustainable agriculture, marine and maritime research and the bio-economy;
- Secure, clean and efficient energy;
- Smart, green and integrated transport;
- Climate action, resource efficiency and raw materials;
- Inclusive, innovative and secure societies.

In this framework, NANO*futures* integrated Industrial and Research Roadmap aims to:

- deliver a focused **implementation plan** up to 2020 within a longer term horizon of actions (>2025);
- address **European cross-cutting key nodes in terms of cross-sectorial research, technology and innovation issue**s;
- cover broad **socio-economic challenges** to the implementation and commercialisation of sustainable and safe nanotechnology enabled solutions;
- have a **market-driven value chain approach** with a set of tech and non-tech actions along the identified value chains.

4 Cientifica Ltd 2007. Halfway to the trillion dollar market?, available at http://cientifica.eu.

5 Lux Research Inc. (2009): "Nanomaterials of the Market Q1 2009:Cleantech's Dollar Investments, Penny Returns"

6 COM (2011) 808 Final: "Horizon 2020 - The Framework Programme for Research and Innovation - Communication from the Commission"

# 3 Roadmapping Approach

# 3 Roadmapping Approach

## 3.1 The Roadmapping Process in NANO*futures*

NANO*futures* is a hub for nanotechnologies and the roadmapping activity reflects this structure:

- The starting point of roadmapping was based on contributions from **11 ETPs** and from the NANO*futures* members (industries, universities, Technology centers, Development Agencies,…) divided in **10 Horizontal Working Groups (around 600 entities involved in total)**.
- The **ETPs** provided the **needs (50) for their economical growth**.
- The **Working groups (WGs)** analyzed the ETP needs, based on **common horizontal issues** from industry to safety, from research to communication.
- From the clustering of the ETP needs with the horizontal issues emerged 5 Key **Nodes (KNs) (around 80 entities involved in total)**.
- For each of them a leading expert and a group of experts were appointed in order to translate backward the KNs in Actions and Markets.
- **7 Nano-enabled Value Chains (VC)** were identified by the experts. The VCs constitute the backbone of the roadmap
- Several **Markets and a set of final nano-enabled products** were outlined: the **WGs** analyzed them in order to provide specific guidelines for the development of nanotechnologies.
- ETPs validated the roadmap results.

The loop (shown in the Figure below) is almost closed and will be the basis for next activities of the NANO*futures* environment. Complete validation and dissemination of the Roadmap will be achieved during a NANO*futures* CSA final event, where different stakeholders will be invited.

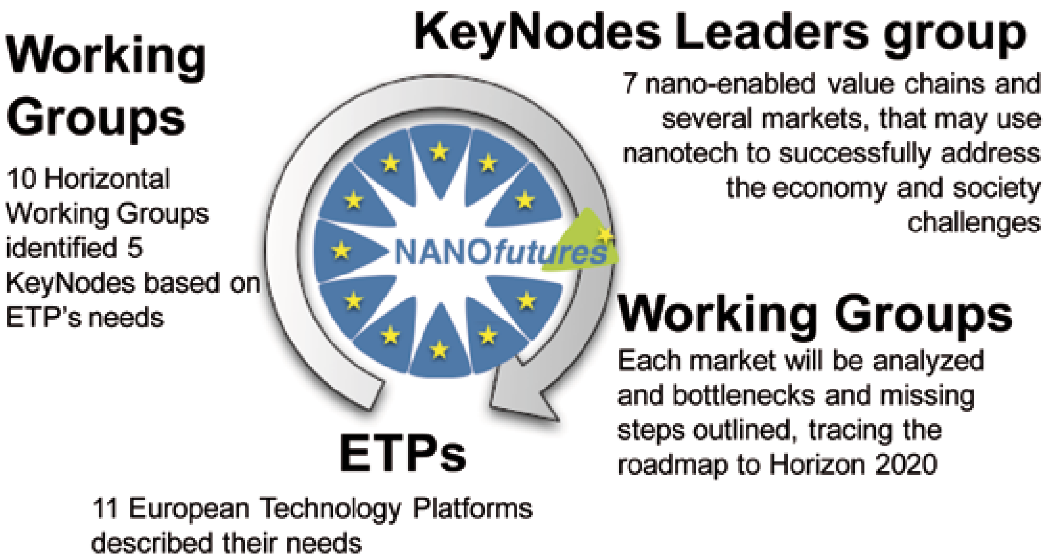



**Figure 3-1: NANO*futures* Roadmapping loop**

The approach resulted in three roadmapping layers as shown in Figure 3-2: 5 key nodes (value chains), 27 examples of lead markets (production chains), cross- cutting actions that overarch the roadmap (societal chains).

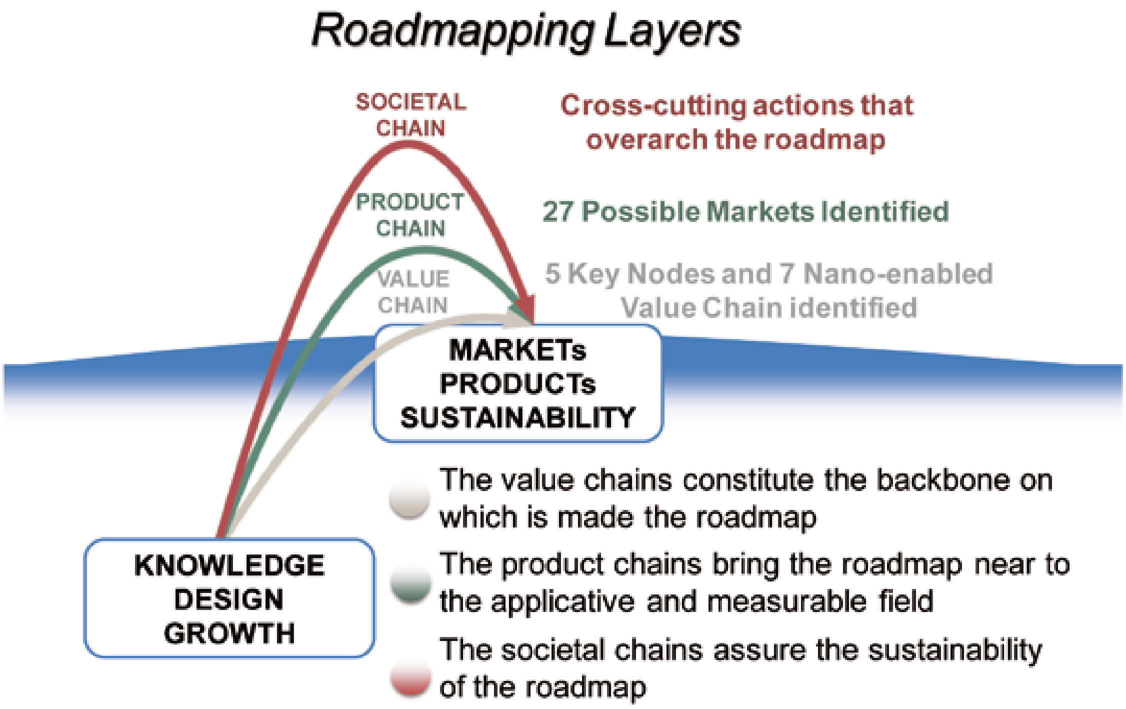



**Figure 3-2: NANO*futures* Roadmapping layers**

## 3.2 Description of Key Node Areas

The five keynodes, with their respective leaders are listed in the following table.

**Table 3-1: List of Keynodes**

| Keynode Title | Keynode Leader | Affiliation |
|---|---|---|
| Design, Modelling and Testing of Materials (including analytical techniques, knowledge sharing and intellectual properties) | David Cebon | University of Cambridge & Granta Design Ltd |
| Nano-Micro Scale Manufacturing | Vito Lambertini | Centro Ricerche FIAT (CRF) |
| Safety & Sustainability | Rob Aitken | Institute of Occupational Medicine (IOM) |
| NanoStructures & Composites | Bertrand Fillon | Commissariat à l'énergie atomique (CEA) |
| Nano-Enabled Surfaces | Jean-Pierre Celis | Katholieke Universiteit (KU) Leuven |

The key node are broad knowledge areas able to link several high level industrial and research experts and let them roadmap on cross-sectorial topics of interest for several ETPs. Such keynodes may be described as follows:

- **Design, Modelling and Testing of Materials:** this key node deals with methods, tools and research and innovation actions related to the design, modelling and simulation of nano-enabled materials and products as well as their effective testing (in vitro, in vivo, on site, analytical techniques etc.). The key node includes also knowledge management and sharing and intellectual properties issues. Regarding the latter issues, the group received inputs and/or documentation from supporting CSAs like Nano2Market and Pronano.
- **Nano-Micro Scale Manufacturing:** this keynode deals with industrial oriented issues related to the manufacturing of nano-enabled products from prototyping to large scale and at different scales (from nano-micro to macro). Current barriers to commercialization of nano-enabled products were considered, thanks to the supporting CSAs NANOCOM. Moreover, MINAM 2.0 representatives, invited in the keynode workshops, contributed with inputs on technical actions related to nano-micro manufacturing.
- **Safety and Sustainability:** this keynode relates to all issues related to the sustainability and safety of nanomaterials and nano-enabled products. This includes suggested actions on standards & best practice guidelines for handling nanomaterials(nanoparticles, nanopowders); measurement protocols for nanomaterials; risk assessment and risk management; environmentally friendly and sustainable nanomaterials production and processes. The participations to several experts involved in the NanoSafety Cluster and other initiatives guarantees extensive knowledge of past actions and alignment with ongoing EU initiatives.
- **Nanostructured and Composites:** this keynode includes issues on accuracy, high yield 2D control and of composites and substrates for nanotexturing as well as integration of source materials for nanostructures and composites. This keynode links with MINAM 2.0 roadmapping action through the key node leader.
- **Nano-Enabled Surfaces:** this keynode includes issues on development, functionalization and production of high performance coatings, printed functionalities and sensors. Nano-enabled surface properties such as: low friction, corrosion, anti-fouling, anti-ice, wear resistance; topography, printed intelligence (roll to roll) are taken into account.

## 3.3 The meaning of Value Chains

**NANO*futures*** decided to have a **value chain approach**, in order to contribute to **bridge the current gap between nanotechnology knowledge and successful commercialization** of nano-enabled products. In this framework, the NANO*futures* collaborative environment has a great potential for development of such value chains because it is a hub for all the necessary actors to complete the bridge. Within this approach:

- The value chains constitute the backbone on which is made the roadmap (Figure 3-3). The Key Node Leaders and experts defined **Nano-enabled Value Chains** in order to address the NANO*futures* roadmap (Figure 3-4).

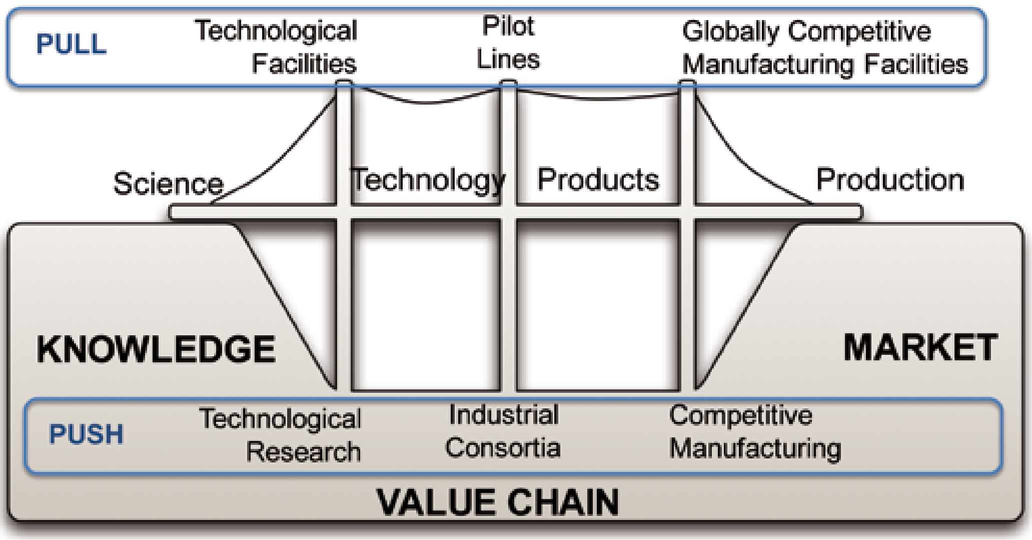



**Figure 3-3: Scheme of a value chain**

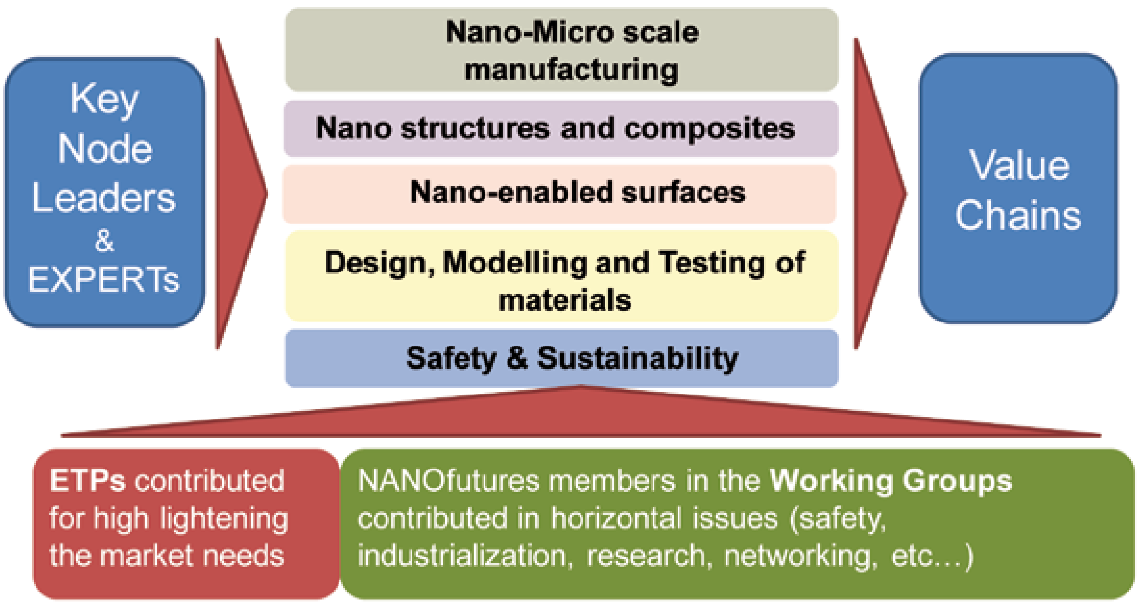



**Figure 3-4: Identification and development of NANO*futures* value chains**

- The value chain actions are aligned with Horizon 2020 structure: Excellent Science (the first steps of the value chain), Societal Challenges (a broad view on the non-technological issues), Industrial Leadership (a market driven perspective for the development of successful and sustainable nanotechnology) (Figure 3-5).

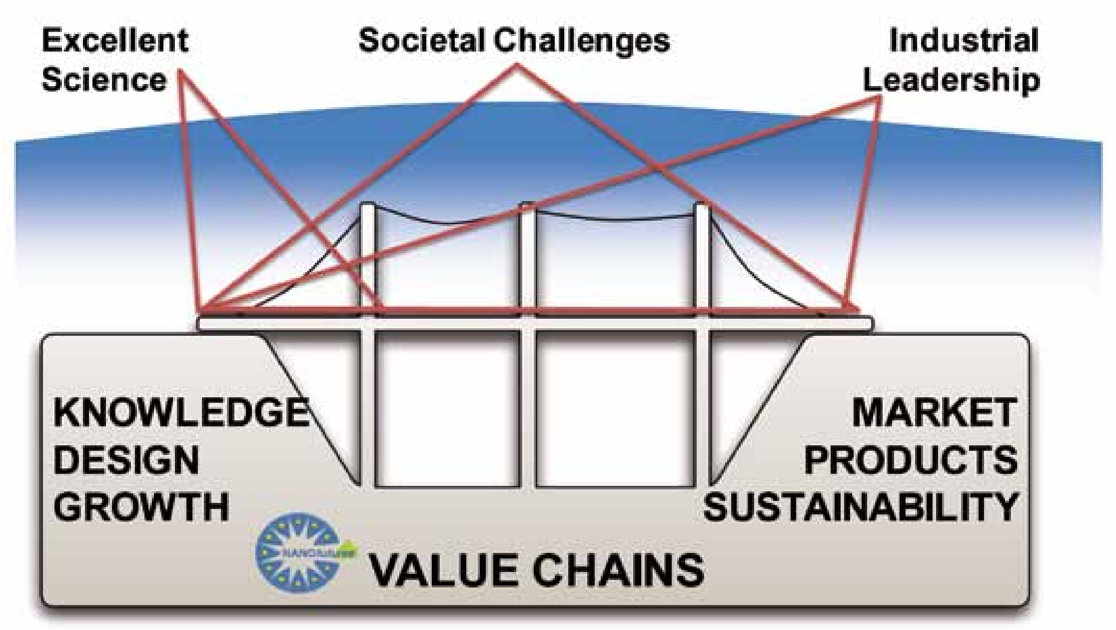



**Figure 3-5: Alignment between NANO*futures* value chain approach and Horizon 2020 (Excellent Science, Societal Challenges, Industrial Leadership)**

- Within a Value Chain the **Production Chain** was highlighted, in order to evidence the missing steps in order to have the product. The production chains bring the roadmap near to the applicative and measurable field, focusing on some example of **lead markets and final nano-enabled products** (Figure 3-6).

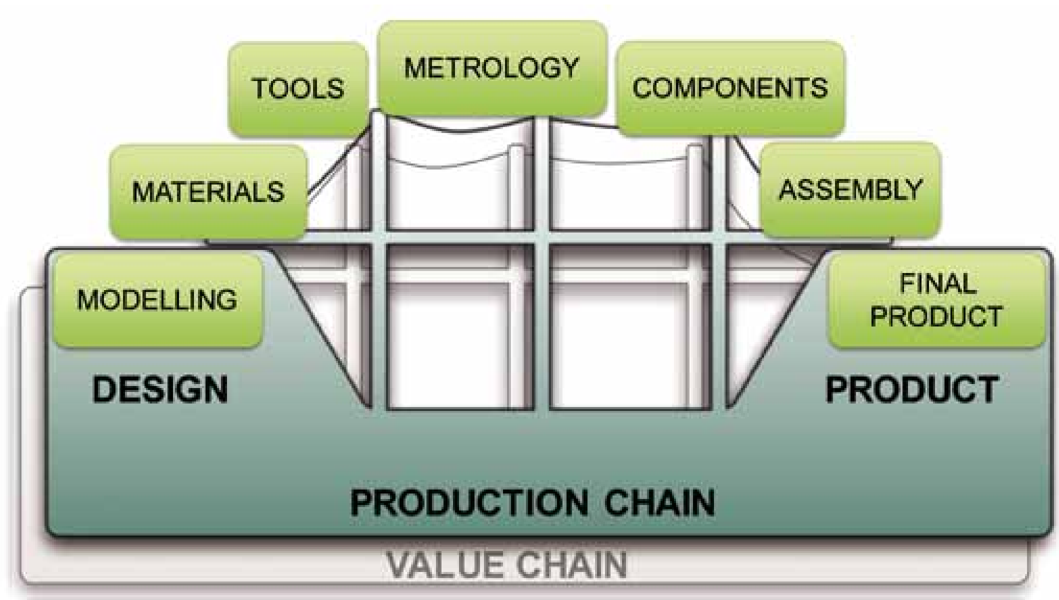



**Figure 3-6: Scheme of a Production Chain**

- **The societal chains assure the sustainability of the roadmap:** non-technical and technical actions specific to one value chain as well as overarching all the chains address the societal challenges (Figure 3-7).

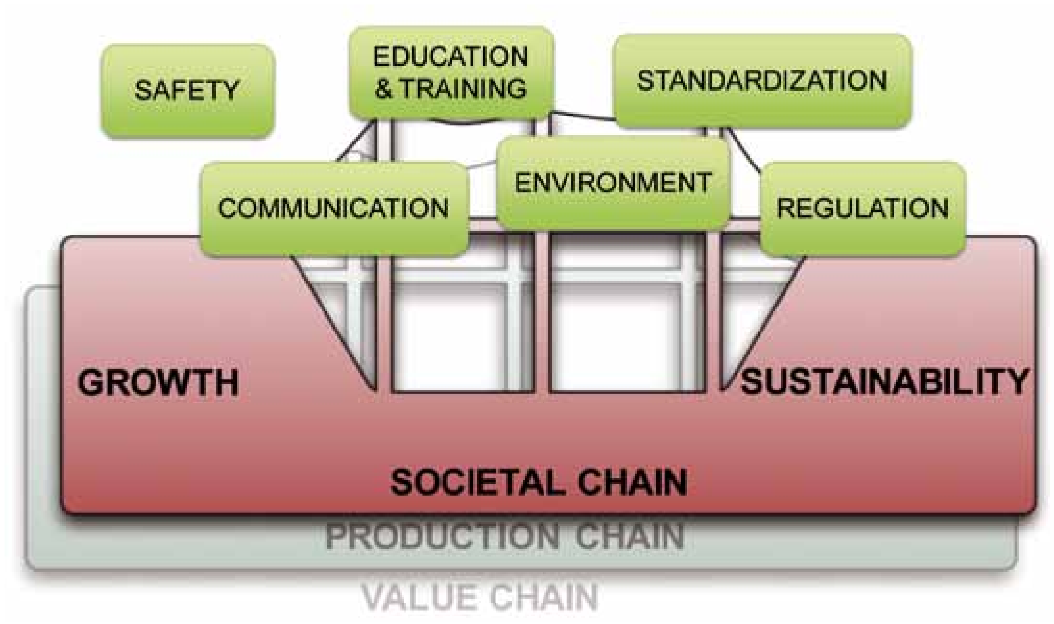



**Figure 3-7: Scheme of a Societal Chain**

# 4 The roadmap - industrial needs & research and innovation challenges in key value chains

# 4 The roadmap - industrial needs & research and innovation challenges in key value chains

## 4.1 Overview of the NANO*futures* Roadmap

NANO*futures* Roadmap focuses on a value chain approach: the figure below explains the link between the 5 keynodes and the **7 nano-enabled value chains and the set of target markets and final nano-enabled products** of the NANO*futures* Roadmap. The grey areas in the figure refer to the nano-enabled the value chains, i.e. the set of actions along the general value chains that are feasible thanks to nano-enabled materials and technologies.

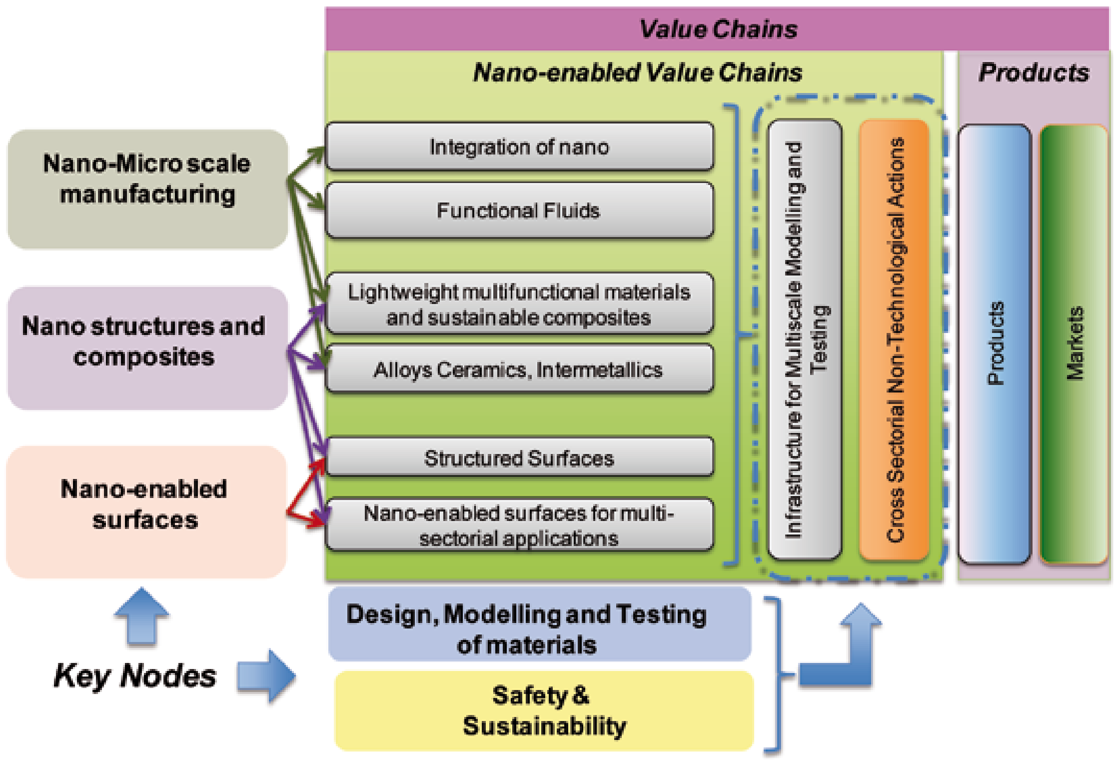



**Figure 4-1: From Keynode groups to NANO*futures* Value Chains**

Figure 4-2 shows an overview of NANO*futures* Roadmap which includes actions to address industrial needs and research and innovation challenges for the successful development of safe and sustainable nano-enabled products. For each nano-enabled value chain (grey boxes), **one or more production chains** were detailed, identifying examples of possible **lead markets**. Examples of final nano-enabled products are shown in Chapter 5.

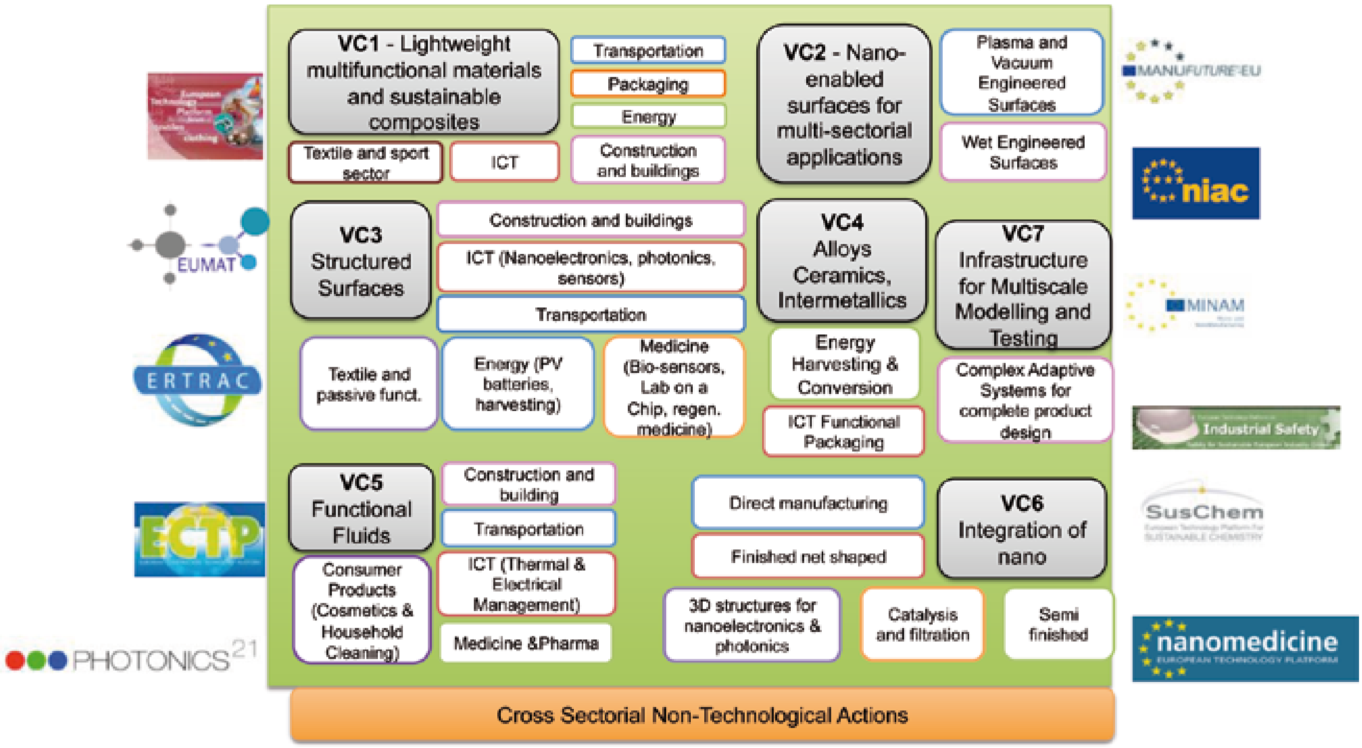



**Figure 4-2: Overview of the NANO*futures* Nano-enabled Value chains and Lead Markets**

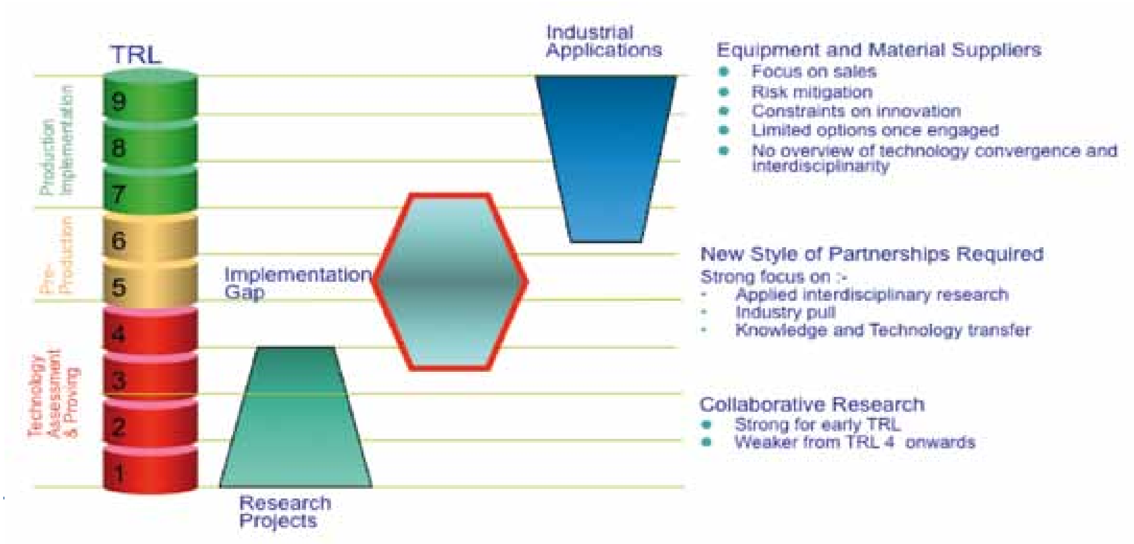
In all the value chains:

- Timeline for proposed actions is:
  - Short Term: 2013-2016;
  - Medium Term: 2017-2020;
  - Long Term: 2020-2025 and beyond.

- Two types of actions were proposed:
  - Cross-cutting Tech and non Tech Actions relevant for ALL value chains;
  - Specific Tech and non Tech Actions for one market-driven value chain.

- For technical actions, the Technology Readiness Level (TRL) was added, from 1 to 9, i.e. from technological assessment to production implementation, according to most widely used TRL scales (example in Figure 4-3).

It is important to note that there are actions at different TRL are foreseen at different time scale. In fact, it may be that at short term there are demonstrations actions for certain type of technologies/products at high TRL, while having also some applied research actions at low TRL on other materials/technologies. Therefore, for a given timeframe there can be actions at different TRL.




## 4.2 ETP interest in market-driven value chains

The Roadmap was developed to guarantee a broad interest from the ETPs and the European Nanotechnology Community. In fact each market-driven value chain considers the needs from several ETPs and each ETP was interested in different nano-enabled value chains and markets. Reliability of the system was guaranteed by integration and complementarities of the actions, as shown in the subsequent chapters.

In the following image, for each value chain, the logos of interested ETPs are reported.

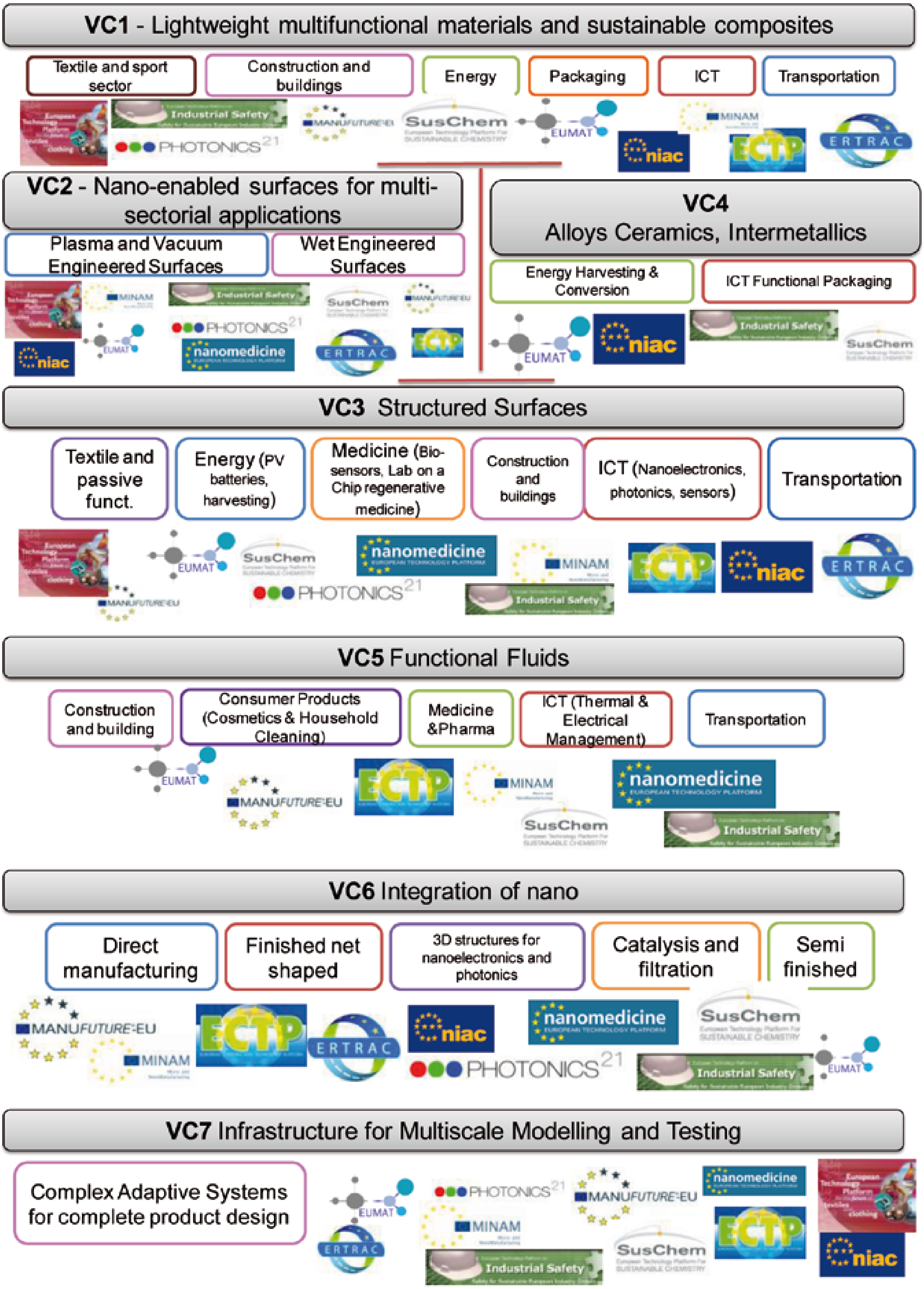



**Figure 4-4: ETP interest in nano-enabled value chains and mark**

## 4.3 Non technological cross-cutting actions for ALL value chains

Cross-sectorial non-technological actions for all value chains have been identified: such horizontal actions related to:

- Safety;
- Environment;
- Standardization;
- Regulation;
- Communication and networking;
- Skills and education;
- Technology transfer and innovation financing.

The following figures show the proposed actions along a typical value chain, including the timeline for each action. A detailed description of the actions is included in Chapter 6.

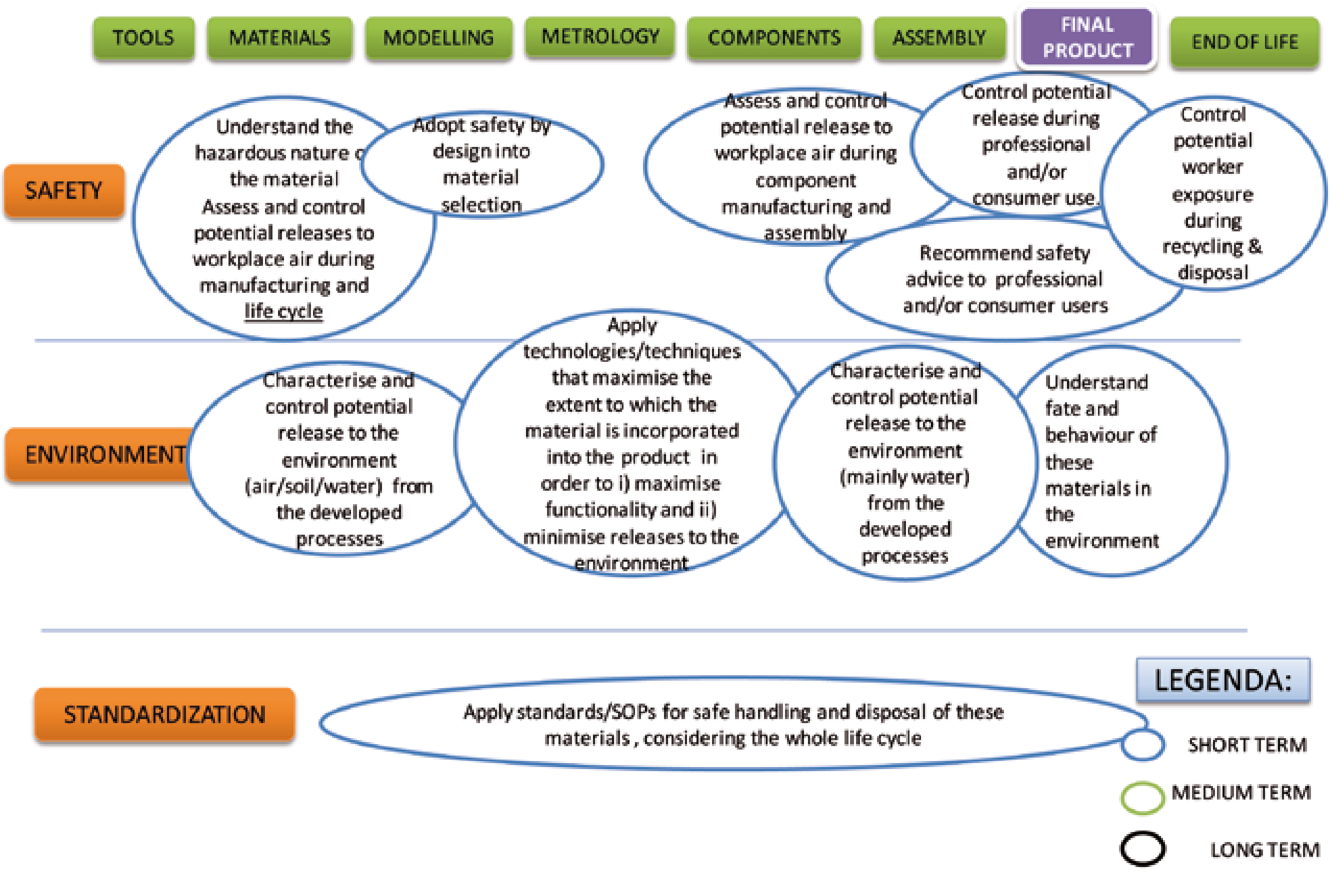



**Figure 4-5: Non-technological cross-cutting actions for all value chains/1**

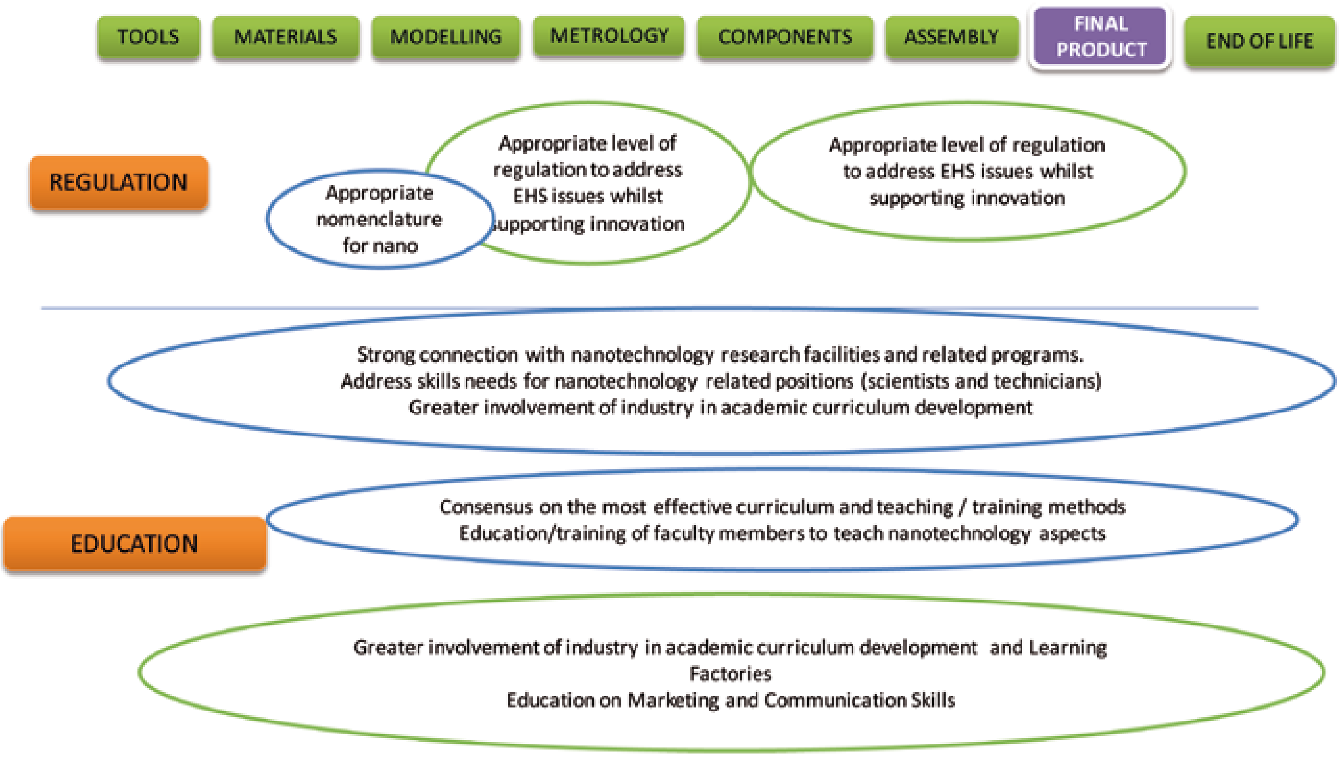



**Figure 4-6: Non-technological cross-cutting actions for all value chains/2**

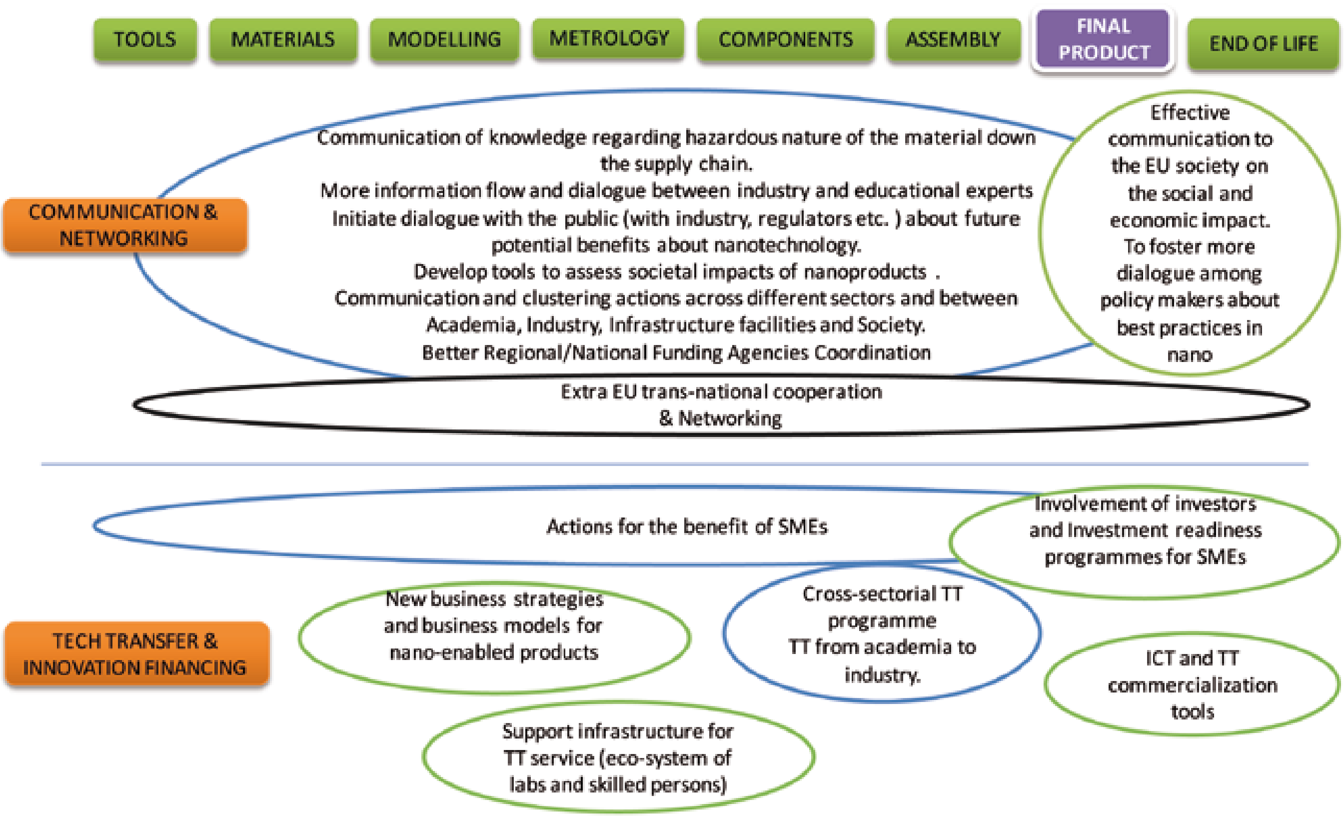



**Figure 4-7: Non-technological cross-cutting actions for all value chains/3**

## 4.4 VC1 - Lightweight Multifunctional Materials and Sustainable Composites

The Nano-enabled Value Chain 1 (VC1), named “Lightweight Multifunctional Materials and Sustainable Composites” includes lightweight, multifunctional, economic and environmental materials for different applications. Examples of such materials are: polymer composites including fibers; nanoporous materials, nanolayered materials with optimal barrier properties (to moisture, oxygen etc.); advanced thin glass; metal foams and ceramic composites. VC1 manufacturing technologies include dispersion/exfoliation, extrusion, spinning, functionalization during synthesis in order to ease the alignment/controlled positioning of nano-objects.

Examples of lead markets for such nano-enabled value chain may be:

- TEXTILE and SPORT SECTORS;
- PACKAGING;
- TRANSPORTATION;
- ENERGY (structuring materials, surface materials, nanoporous materials);
- ICT (structuring materials, surface materials, nanoporous materials).
- CONSTRUCTION & BUILDINGS.

For each of the market above a production chain has been developed, as shown in the following figures.

A detailed description of the actions is included in Chapter 6.

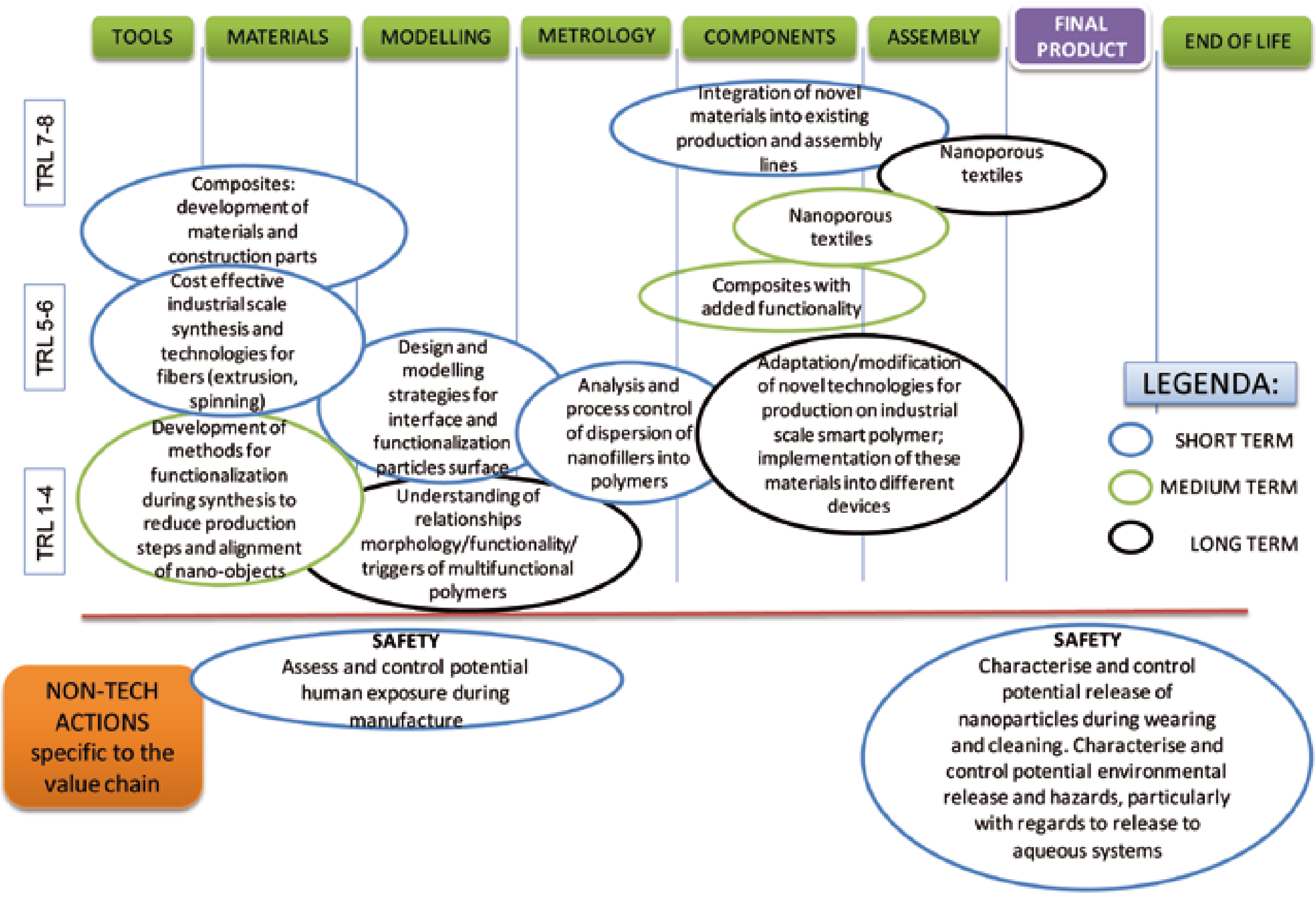



**Figure 4-8: Production chain on Lightweight Multifunctional Materials and Sustainable Composites for TEXTILE and SPORT SECTORS**

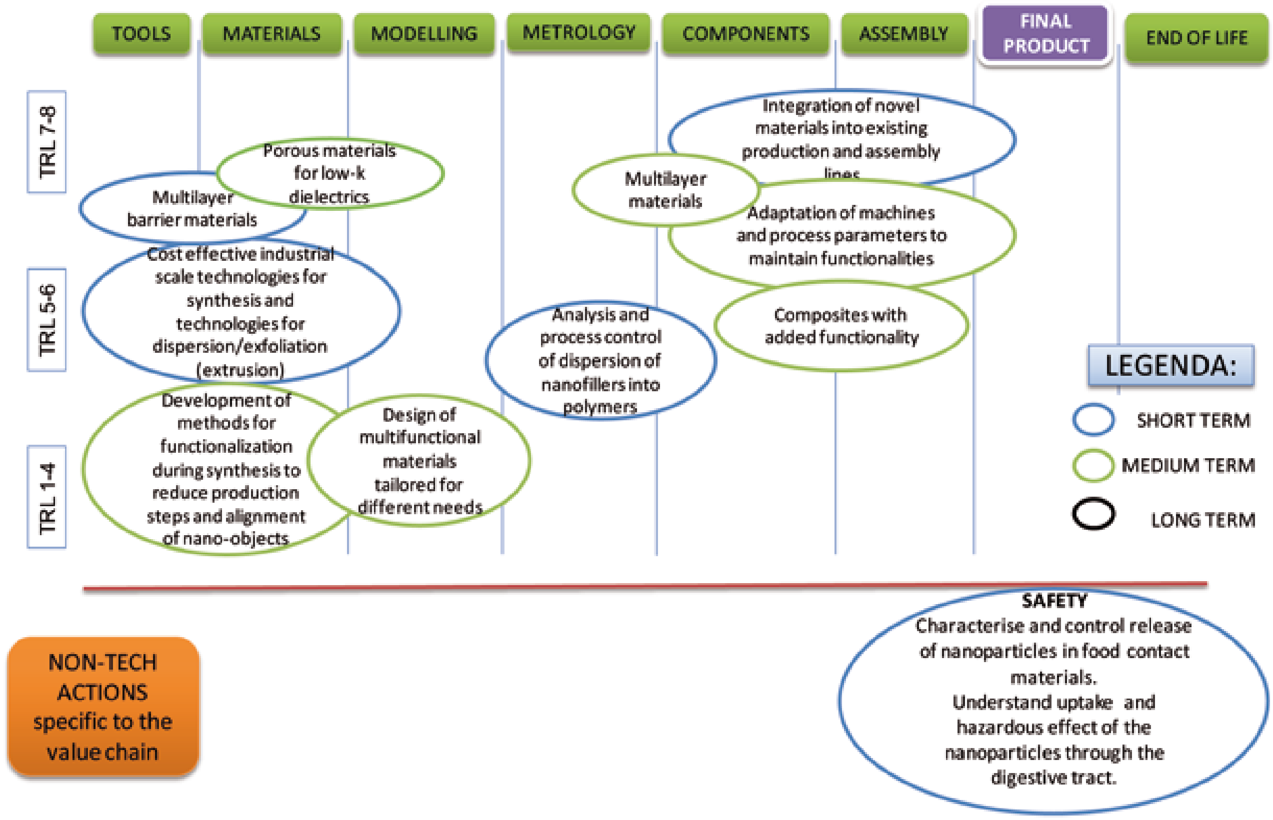



**Figure 4-9: Production chain on Lightweight Multifunctional Materials and Sustainable Composites for PACKAGING**

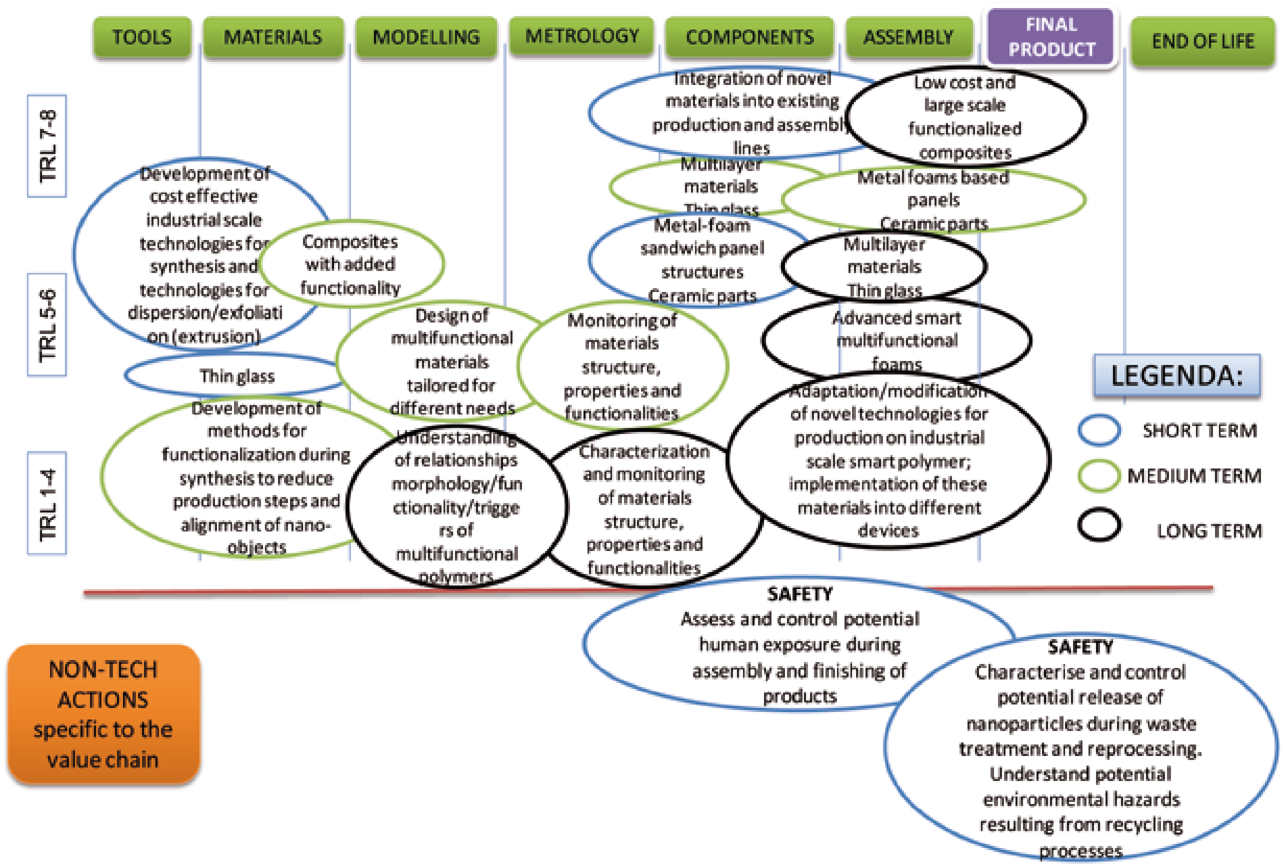



**Figure 4-10: Production chain on Lightweight Multifunctional Materials and Sustainable Composites for TRASPORTATION**

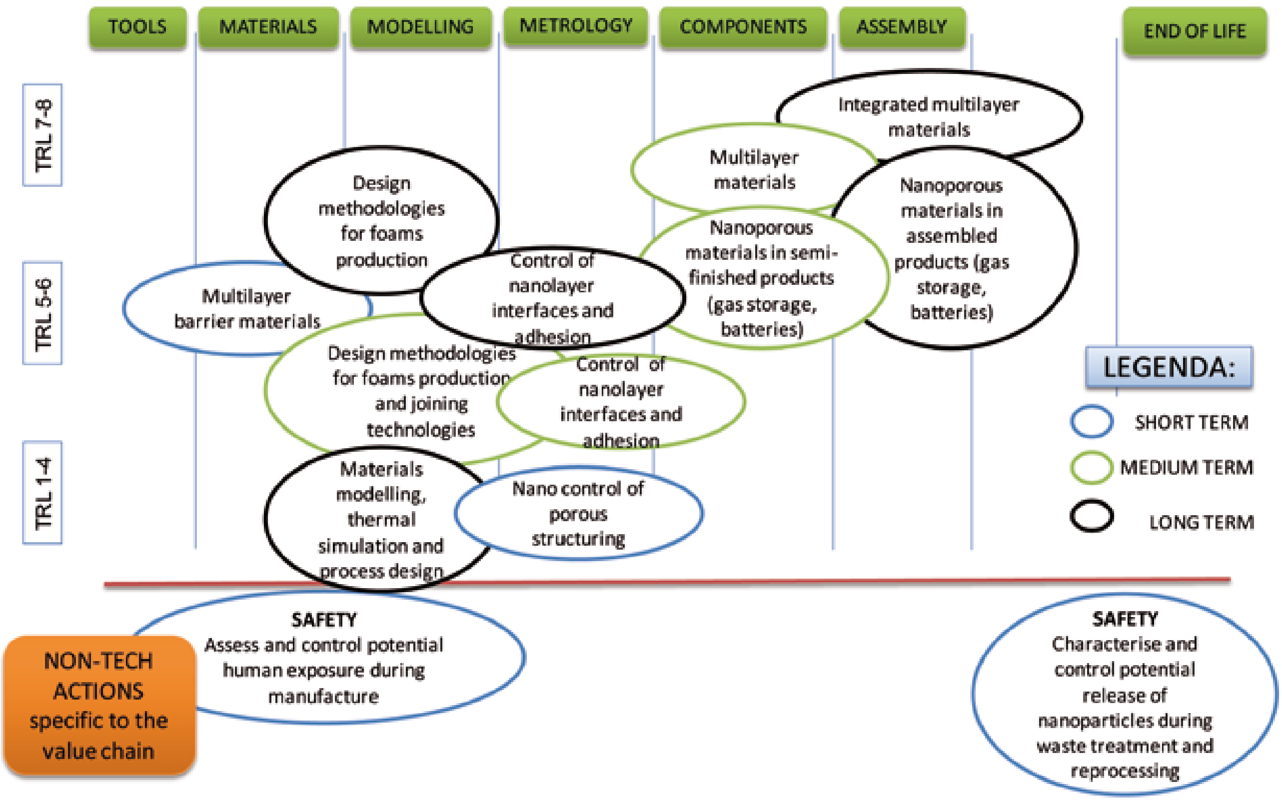



**Figure 4-11: Production chain on Lightweight Multifunctional Materials and Sustainable Composites for ENERGY (structuring materials, surface materials, nanoporous materials)**

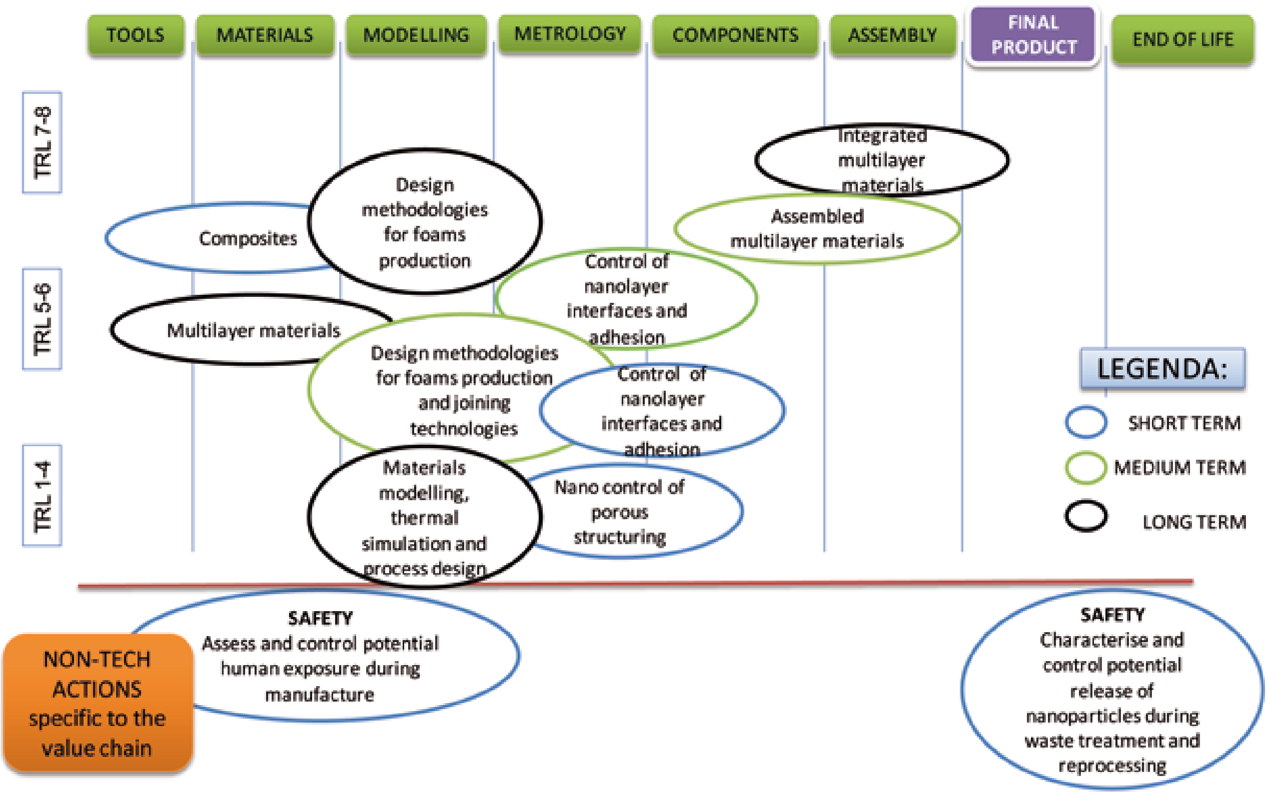



**Figure 4-12: Production chain on Lightweight Multifunctional Materials and Sustainable Composites for ICT (structuring materials, surface materials, nanoporous materials)**

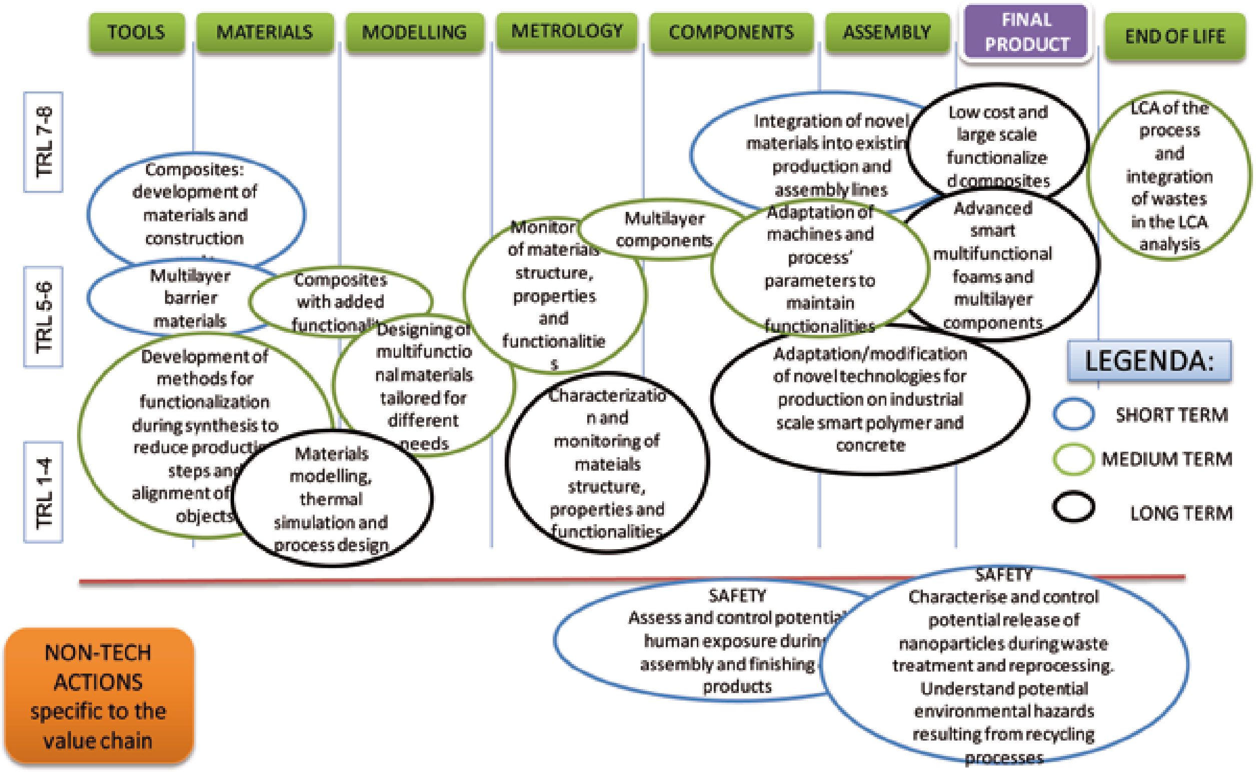



**Figure 4-13: Production chain on Lightweight Multifunctional Materials and Sustainable Composites for CONSTRUCTION & BUILDING**

## 4.5 VC2 –Nano-Enabled Surfaces for multisectorial applications

The Nano-enabled Value Chain 2, named “Nano-Enabled Surfaces for multisectorial applications” is focused on surfaces obtained by liquid-based deposition processes or by plasma or vacuum based deposition processes of nano-films. The related technologies, characterization and upscaling processes present several common issues, regardless of specific sectorial application. The VC deals with such cross-sectorial actions.

Therefore, example of production chains for this nano-enabled value chain may be:

- Wet Engineered Nano-Enabled Surfaces for multisectorial applications;
- Plasma and Vacuum Engineered Nano-Enabled Surfaces for Multi-Sectorial Applications.

The following figures show all the related actions of these production chains.
A detailed description of the actions is included in Chapter 6.

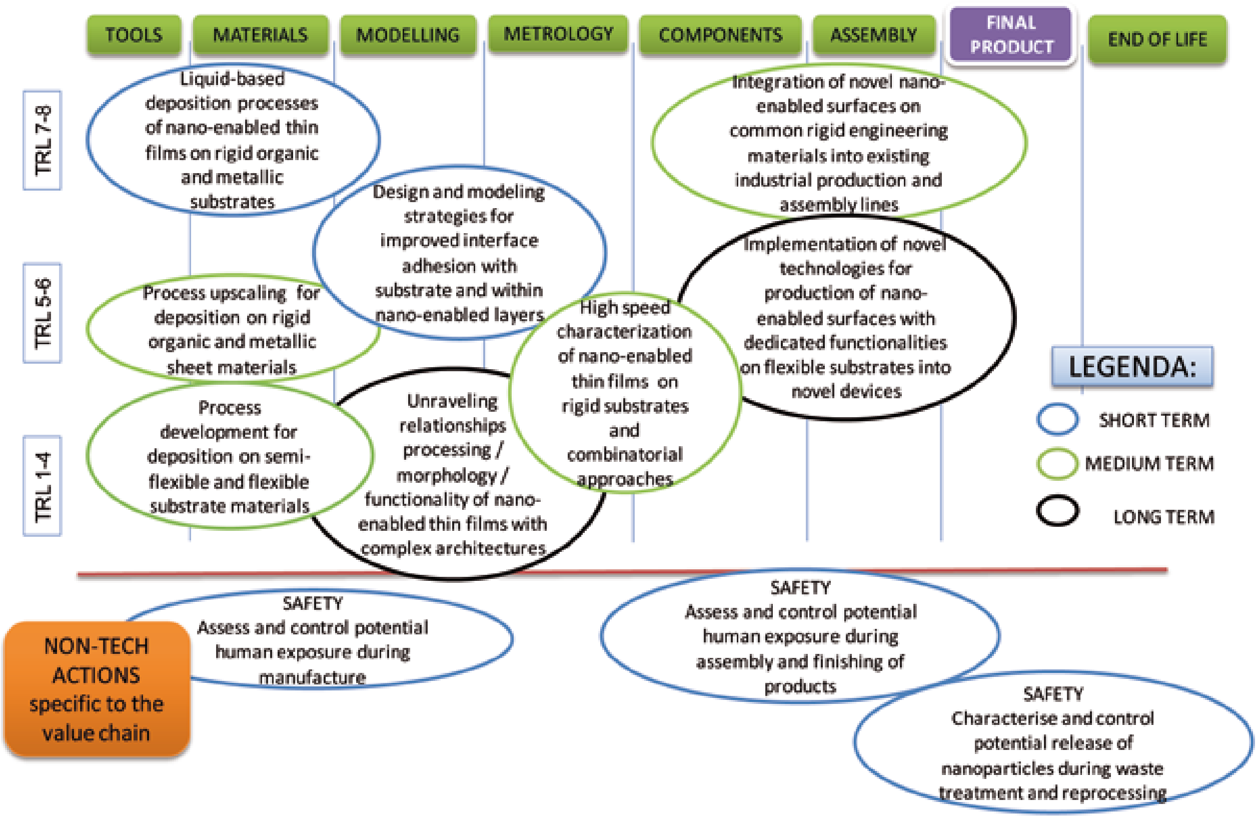



**Figure 4-14: Production chain on Wet Engineered Nano-Enabled Surfaces for multisectorial applications**

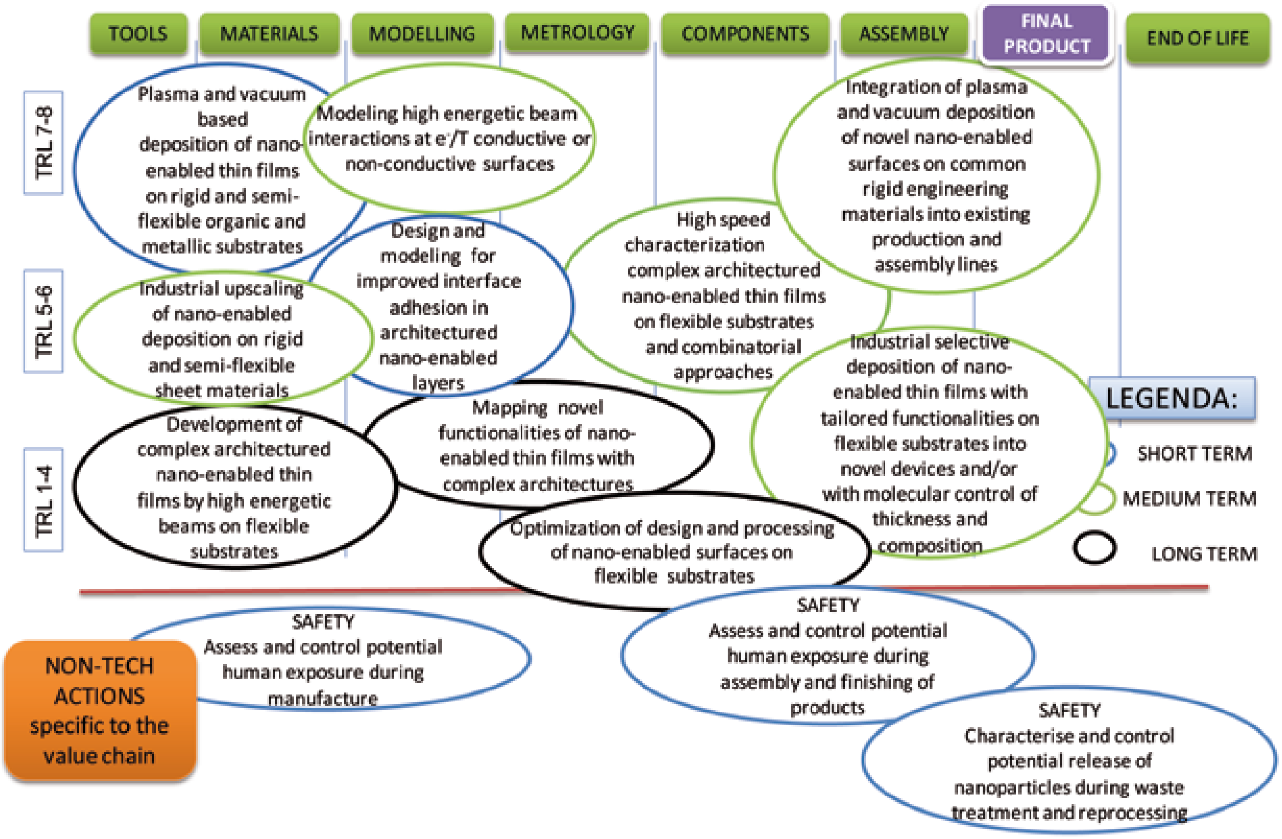



**Figure 4-15: Production chain on Plasma and Vacuum Engineered Nano-Enabled Surfaces for Multi-Sectorial Applications**

## 4.6 VC3 – Structured Surfaces

The Nano-enabled Value Chain 3, named “Structured Surfaces”, includes surfaces obtained by 2-D printing (sheet to sheet), high throughput and high definition technologies (nanoimprint lithography, litho and laser ablation and writing); molecular lithograpy and self assembling process; large area metal and selective etching; 3D methods, including plasma treatment optimization and integration in plastics. Issues related to the integration of active and passive films into 3D parts with in-line process development (In-Mould Labelling, thermoforming, lamination) have been also taken into account.

Examples of lead markets for such nano-enabled value chain may be:

- ENERGY (PV, batteries, energy harvesting);
- ICT (Nanoelectronics, photonics, sensors);
- TEXTILE passive functionalities;
- MEDICINE (bio-sensors, Lab on a Chip, regenerative medicine);
- TRANSPORTATION (2D & 3D low cost parts);
- CONSTRUCTION & BUILDINGS.

For each of the market above a production chain has been developed, as shown in the following figures.
A detailed description of the actions is included in Chapter 6.

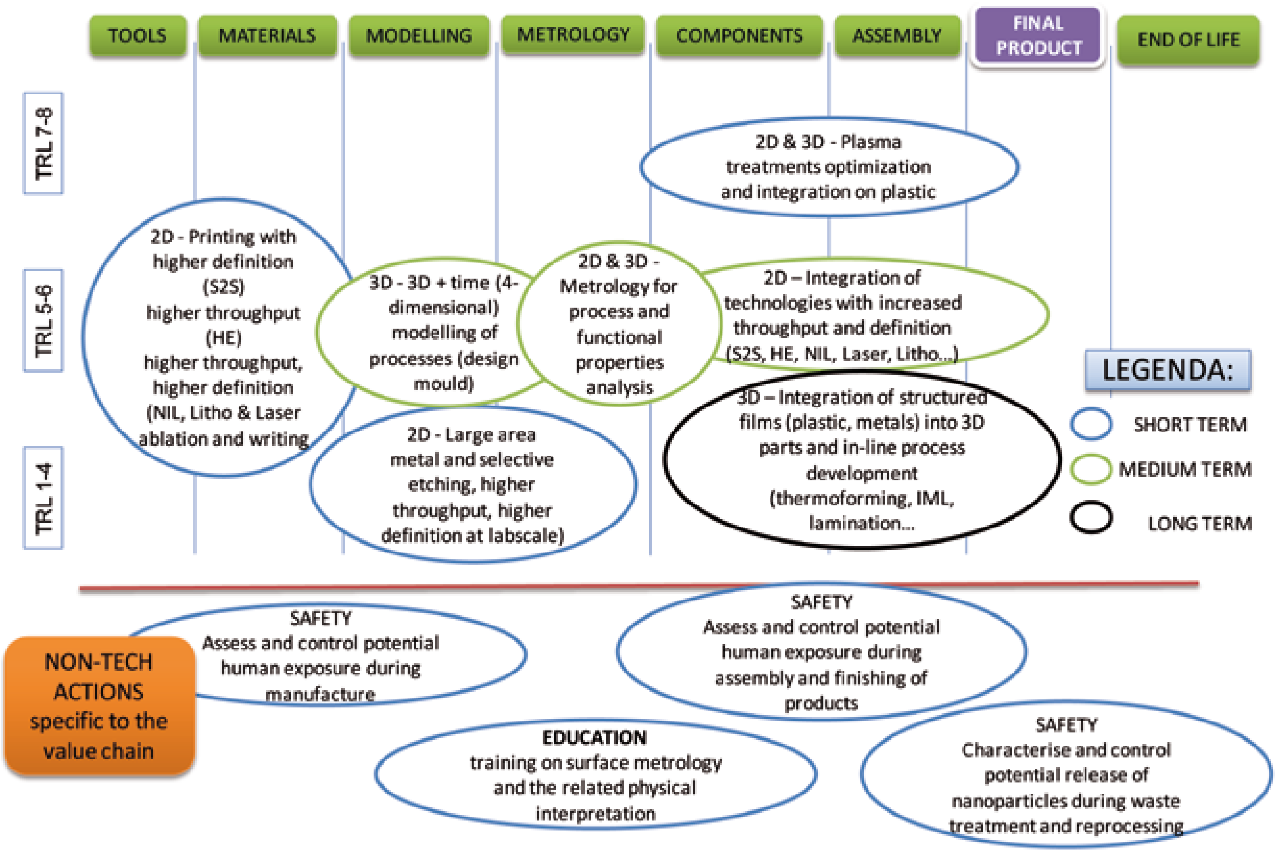



**Figure 4-16: Production chain on Structured Surfaces for ENERGY**

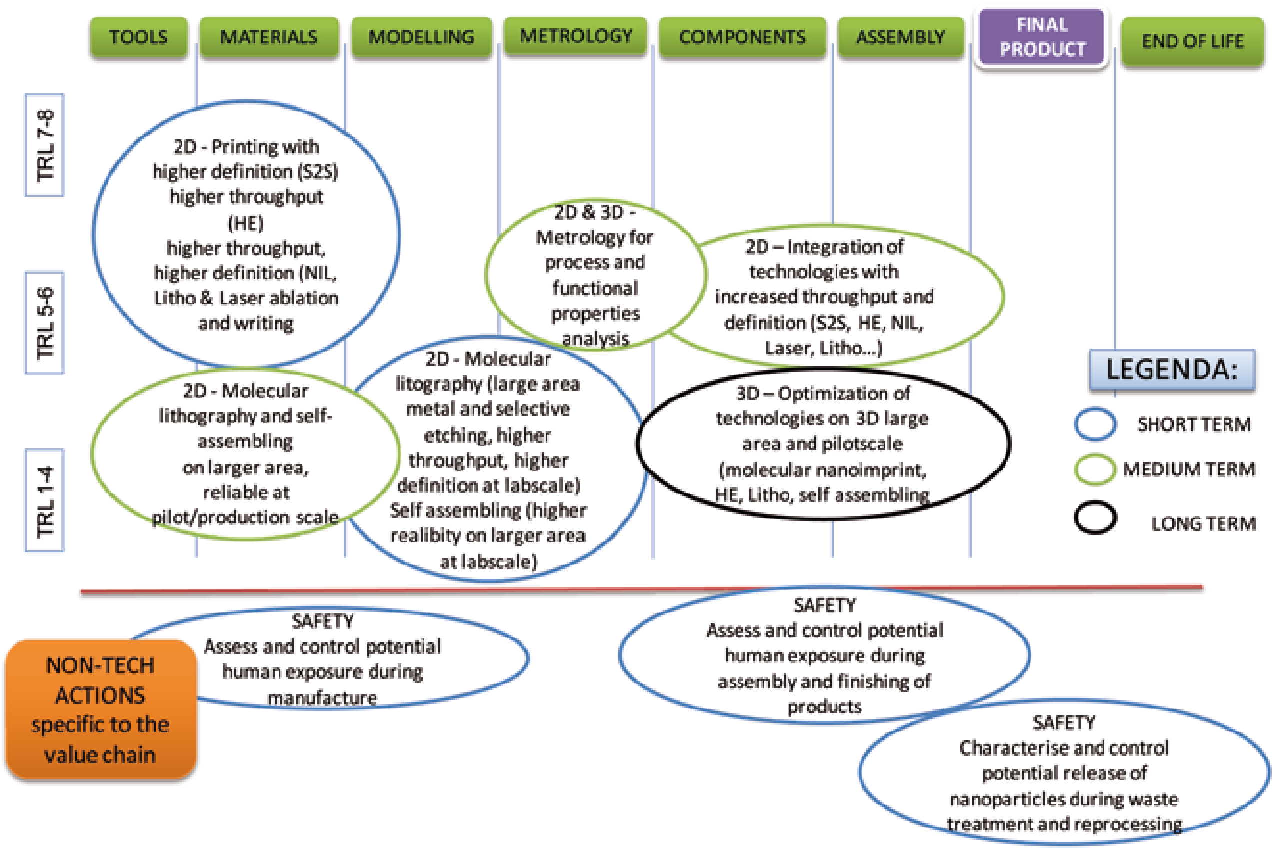



**Figure 4-17: Production chain on Structured Surfaces for ICT (nanoelectronics, photonics, sensors)**

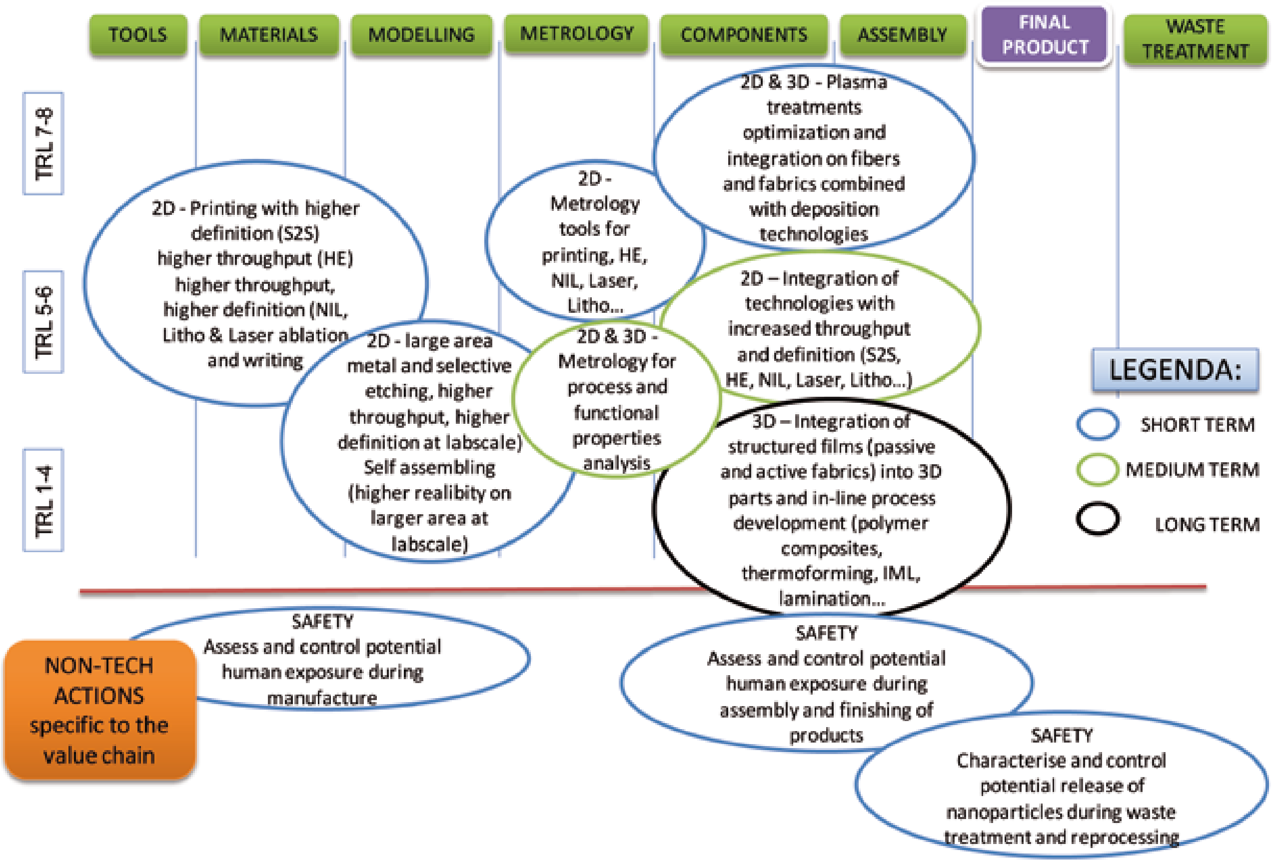



**Figure 4-18: Production chain on Structured Surfaces for TEXTILE passive functionalities**

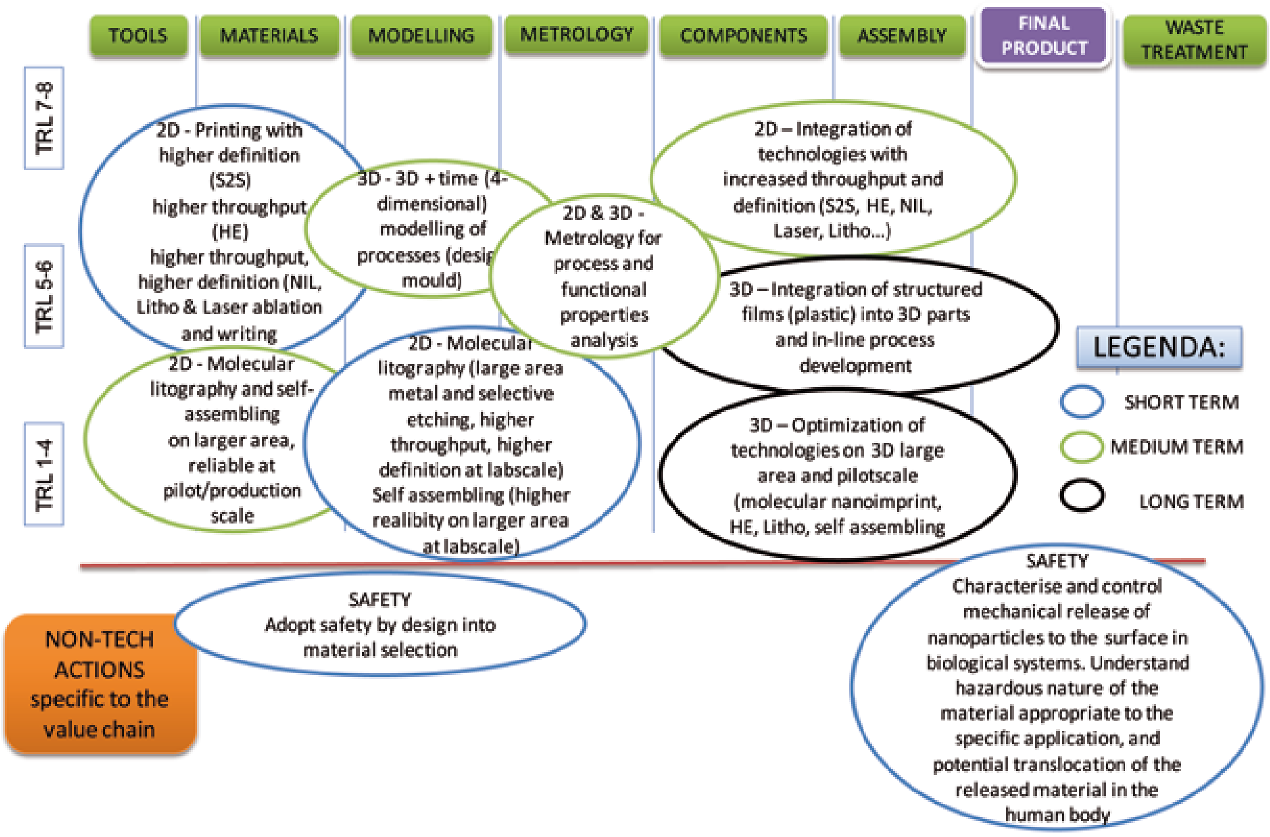



**Figure 4-19: Production chain on Structured Surfaces for MEDICINE (biosensors, Lab on a Chip, regenerative medicine)**

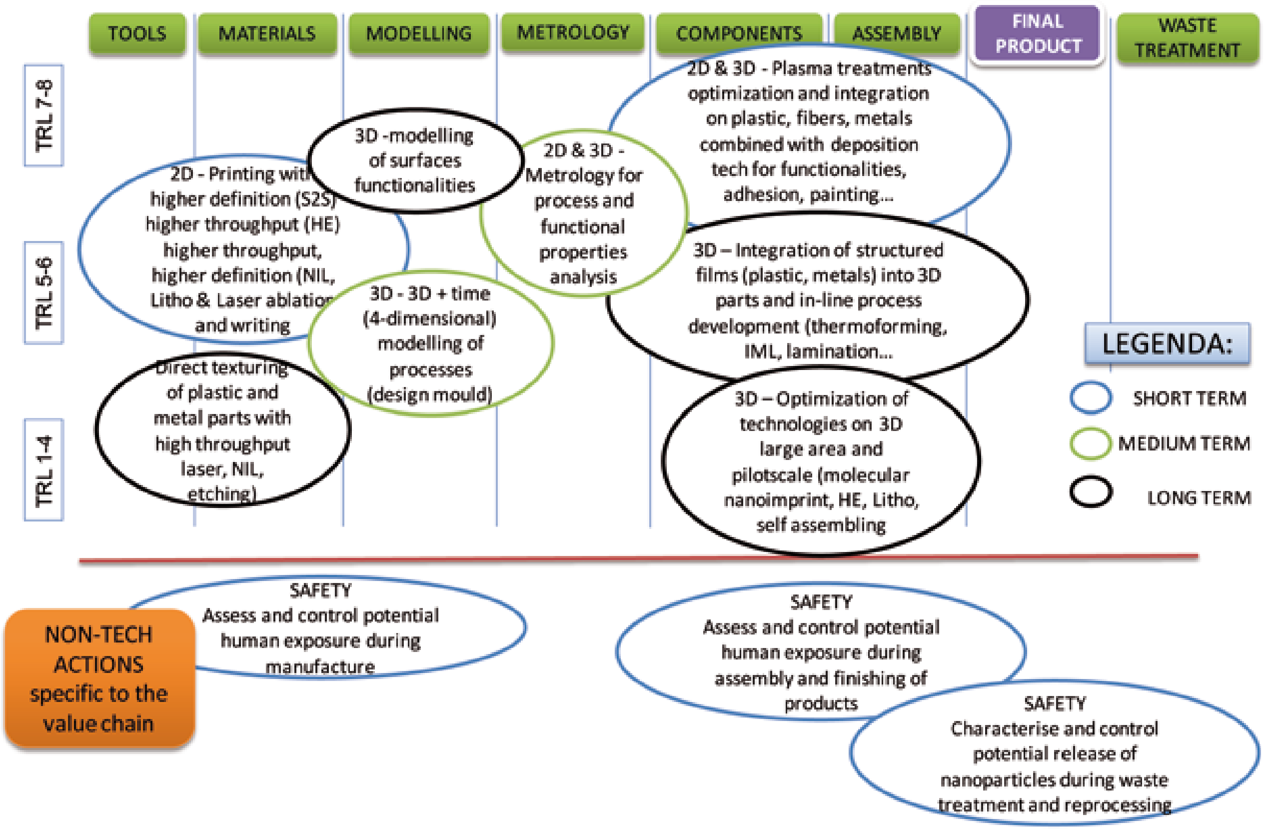



**Figure 4-20: Production chain on Structured Surfaces for TRANSPORTATION**

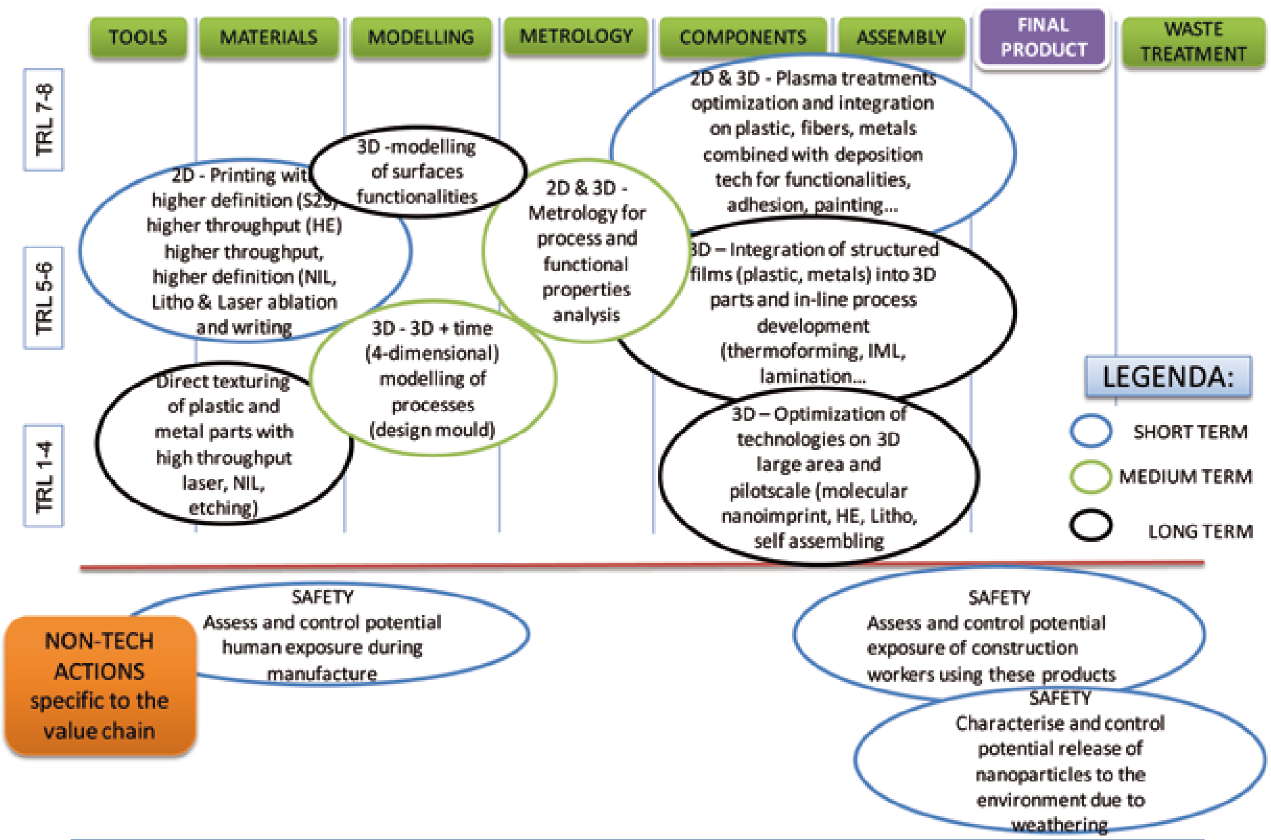



**Figure 4-21: Production chain on Structured Surfaces for CONSTRUCTION & BUILDINGS**

## 4.7 VC4 – Functional Alloys, Ceramics and Intermetallics

The Nano-enabled Value Chain 4, named “Functional Alloys, Ceramics and Intermetallics” is focused on the development of controlled synthesis of hosted nano-particle and nano-aggregate systems which form advanced alloys, ceramics and intermetallics. Moreover, issues on design, metrology and process upscaling are included in the VC.

Example of lead market for such nano-enabled value chain may be:

- Energy Harvesting and Energy Conversion;
- ICT Functional Packaging.

For this market a production chain has been developed, as shown in the following figure.

A detailed description of the actions is included in Chapter 6.

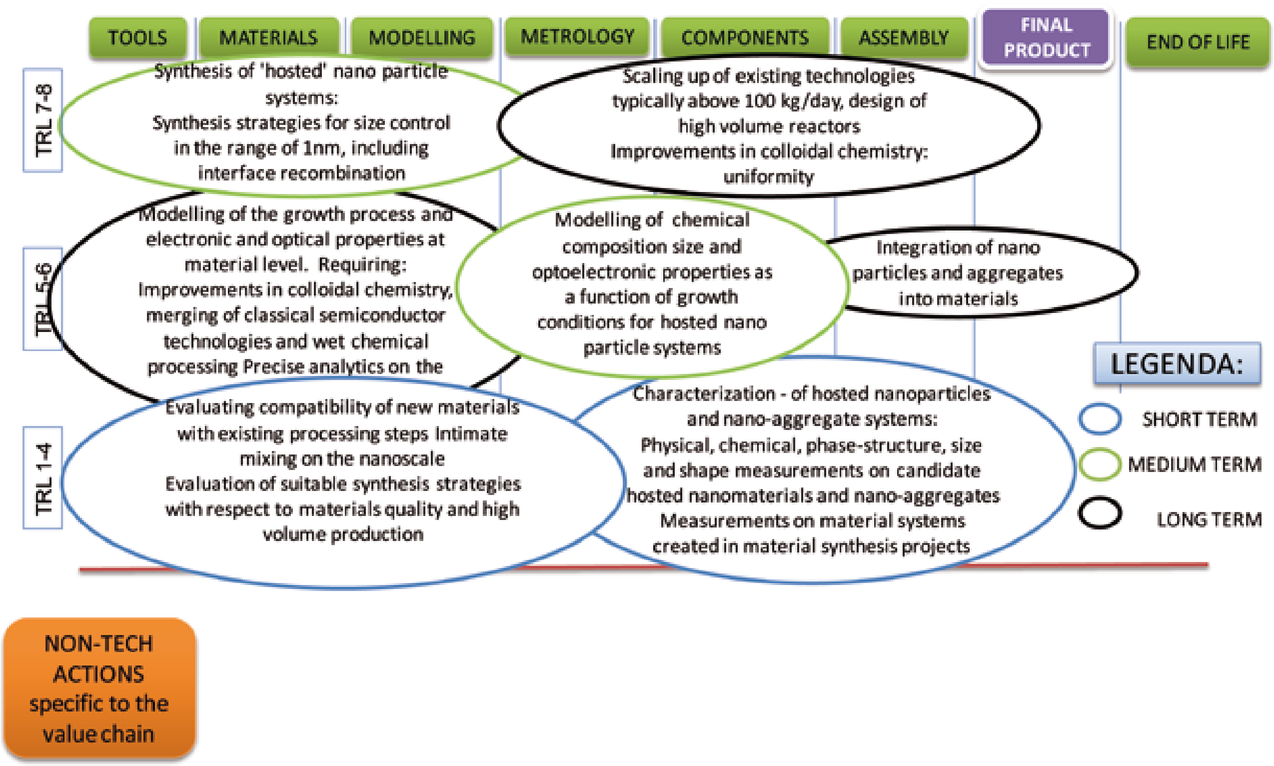



**Figure 4-22: Production chain on Functional Alloys, Ceramics and Intermetallics for ENERGY HARVESTING & CONVERSION**

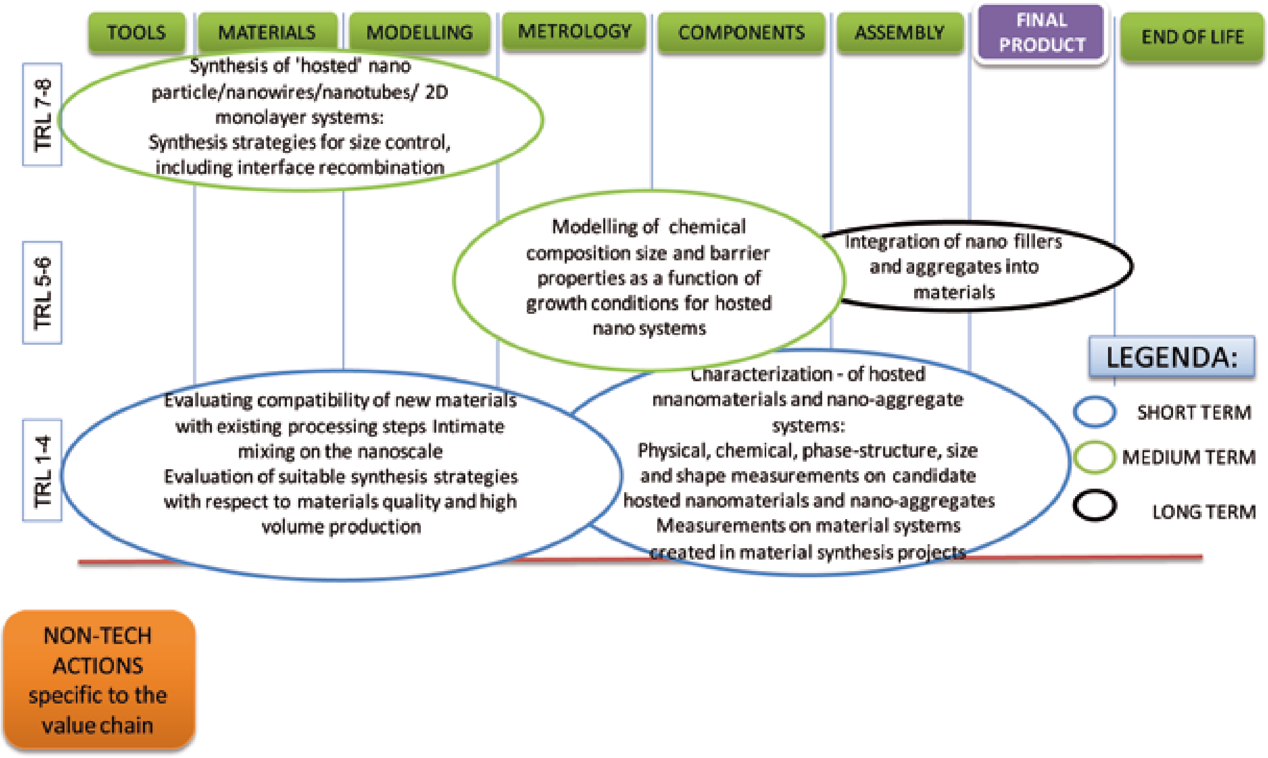



**Figure 4-23: Production chain on Functional Alloys, Ceramics and Intermetallics for ICT FUNCTIONAL PACKAGING**

## 4.8 VC5 – Functional Fluids

The Nano-enabled Value Chain 5, named "Functional Fluids" includes nanofiller synthesis, control and characterization as well integration issues related to nanofluids: for example integration of novel materials in existing production or assembly lines (blending, inkjet, Roll-to-Roll) or integration of novel multi-fluids or smart fluids in devices.

Example of lead market for such value chain may be:

- TRANSPORTATION;
- CONSTRUCTION & BUILDINGS;
- MEDICINE & PHARMA;
- CONSUMER PRODUCTS (Cosmetics & Household Cleaning);
- ICT (Thermal & Electrical Management).

For each of the above markets a production chain has been developed, as shown in the following figures.

A detailed description of the actions is included in Chapter 6.

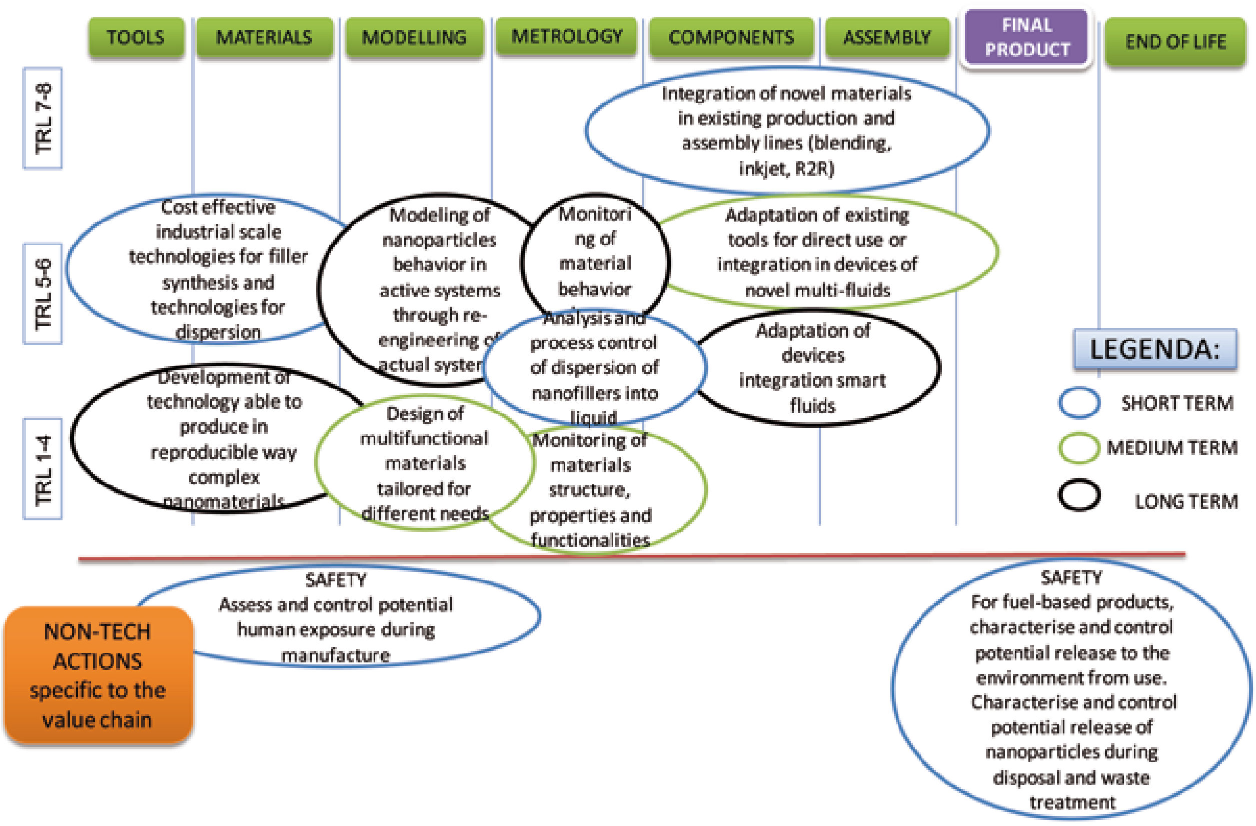



**Figure 4-24: Production chain on Functional Fluids for TRANSPORTATION**

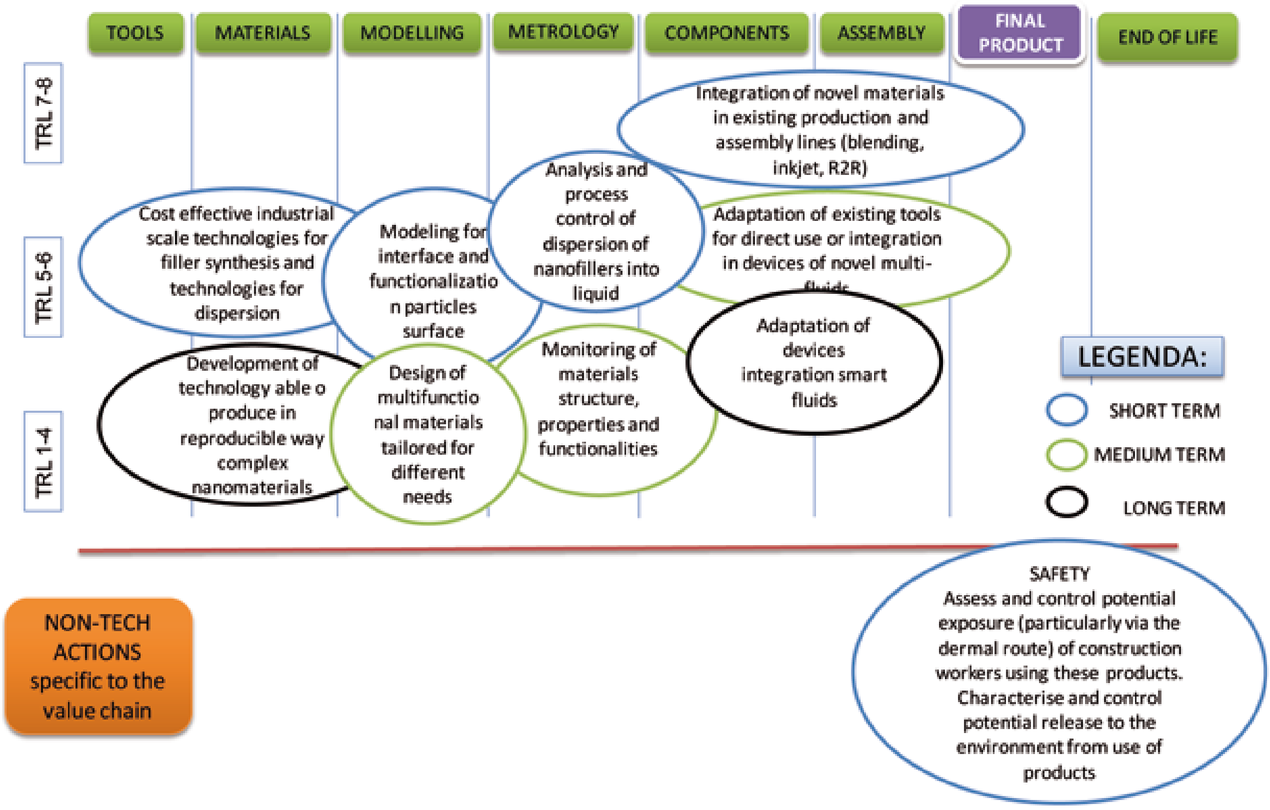



**Figure 4-25: Production chain on Functional Fluids for CONSTRUCTION and BUILDINGS**

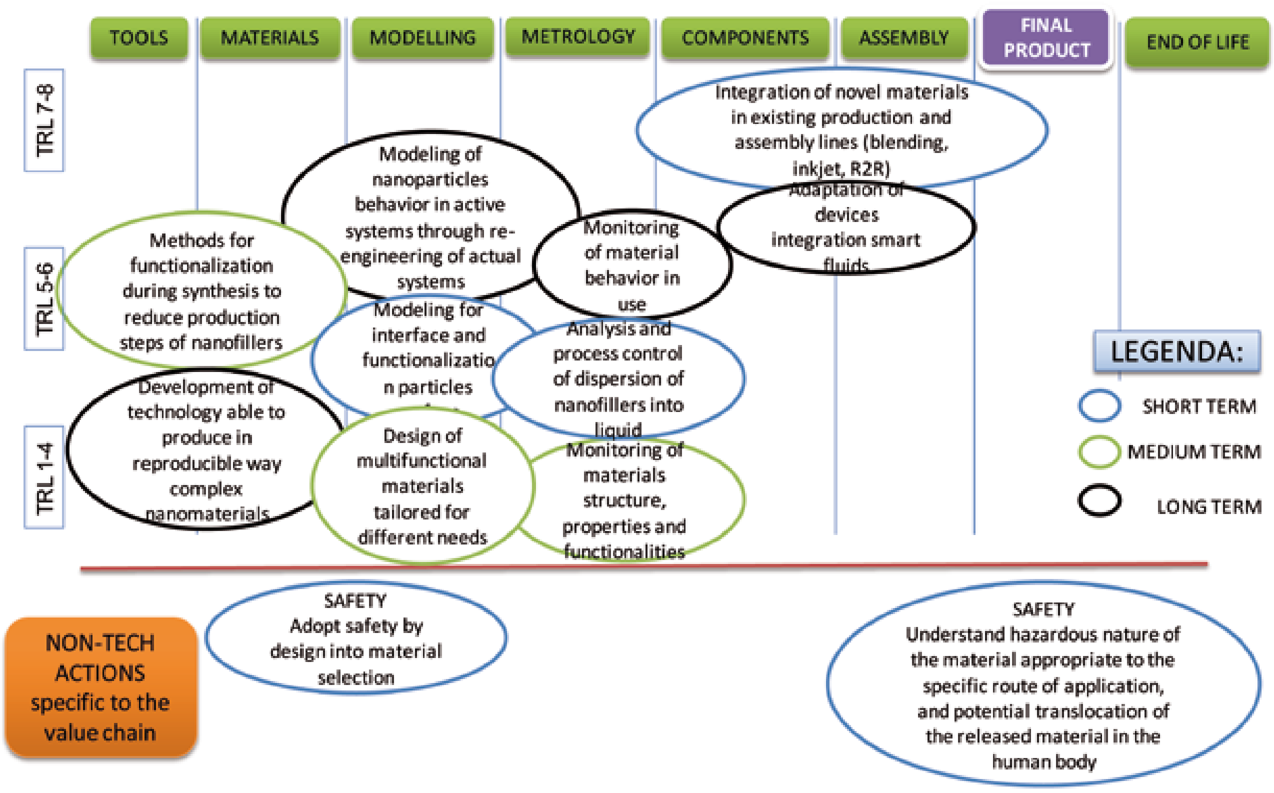



**Figure 4-26: Production chain on Functional Fluids for MEDICINE & PHARMA**

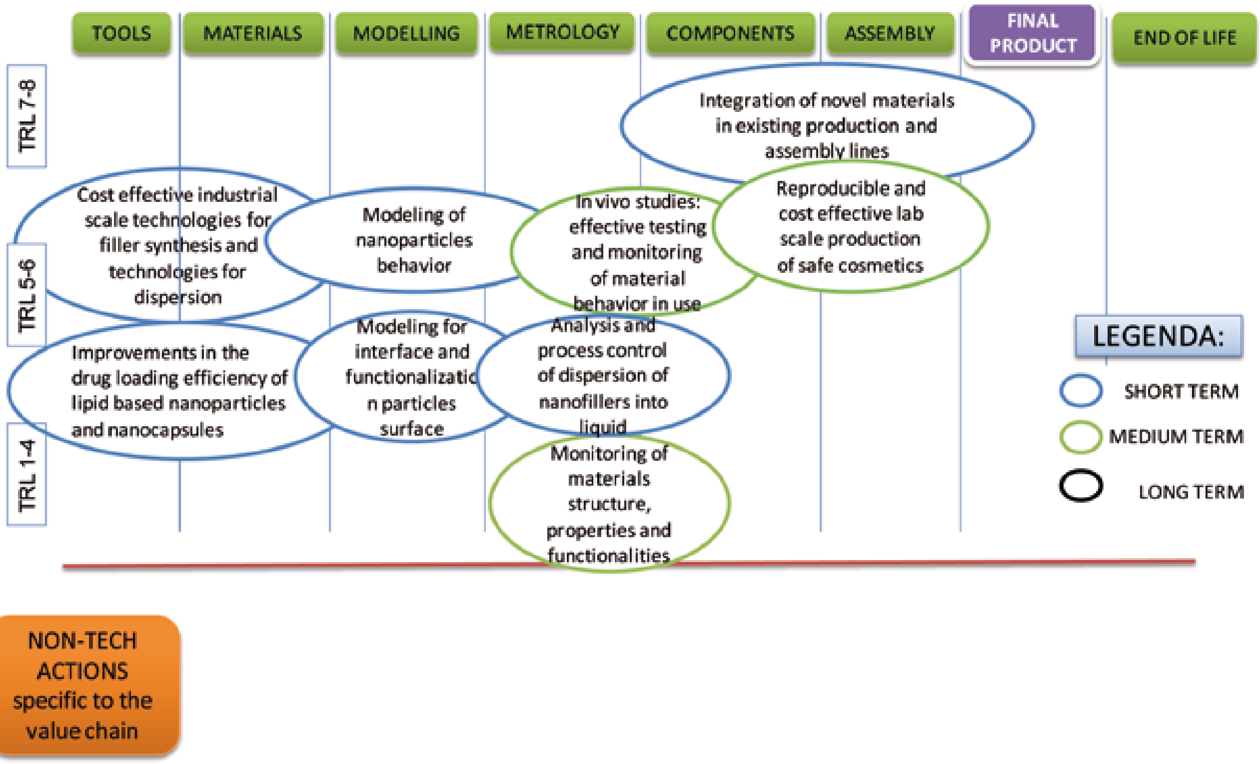



**Figure 4-27: Production chain on Functional Fluids for CONSUMER PRODUCTS (Cosmetics & Household Cleaning)**

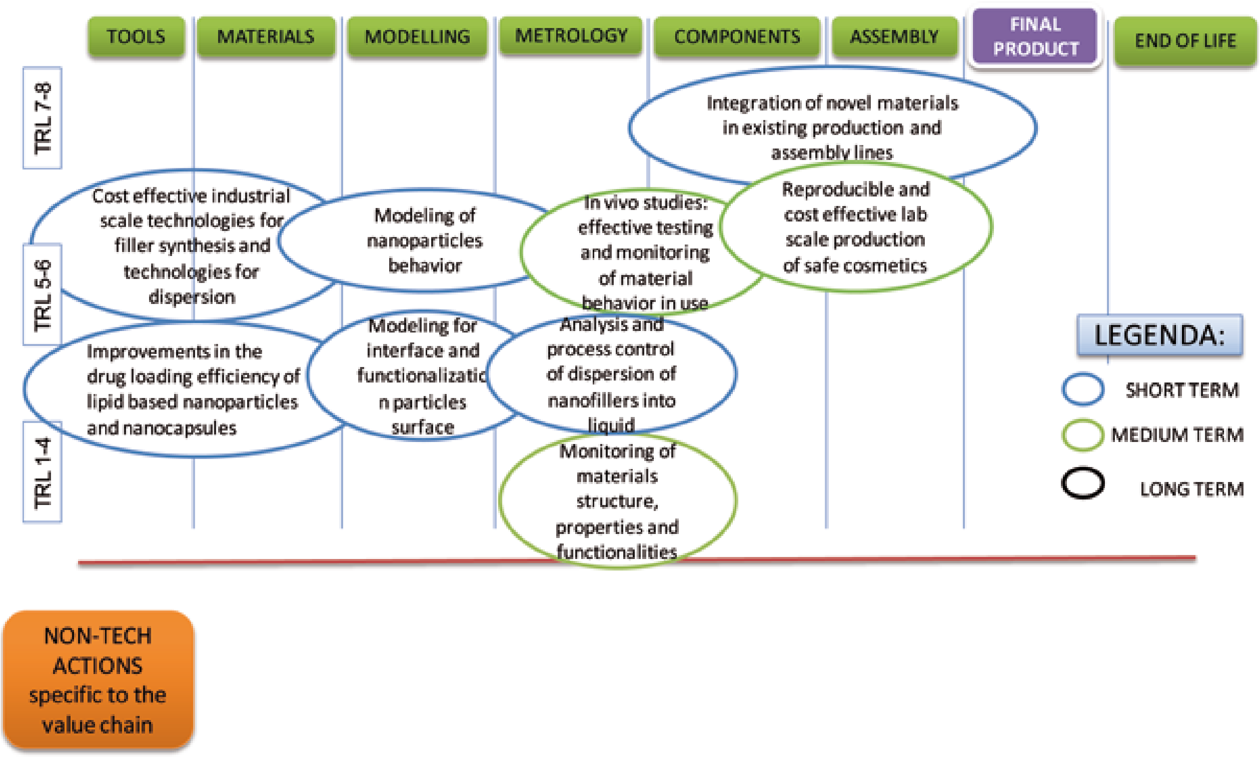



**Figure 4-28: Production chain on Functional Fluids for ICT (Thermal & Electrical Management)**

## 4.9 VC6 – Integration of Nano

The Nano-enabled Value Chain 6, named “Integration on nano” focuses on integration of nanomaterials into micro and macro products. This value chain deals with industrial needs related to low cost, large scale source nanomaterials, obtained by friction, plastic deformation, supercool laser, self-assembly, phase separation, in situ crystallization, colloidal chemistry, plasma sintering, net shaped rapid reforming. The VC includes several issues related to modelling, characterization and integration of nanomaterials to build components and products, by using for instance nanomaterial extrusion, rapid solidification, electrochemical deposition, tape casting, block co-polymerization etc.

Example of lead market for such value chain may be:

- SEMIFINISHED;
- FINISHED NET SHAPED;
- DIRECT MANUFACTURING;
- 3D STRUCTURES FOR NANOELECTRONICS & PHOTONICS;
- CATALYSIS AND FILTRATION.

For each of the above markets a production chain has been developed, as shown in the following figures.

A detailed description of the actions is included in Chapter 6.

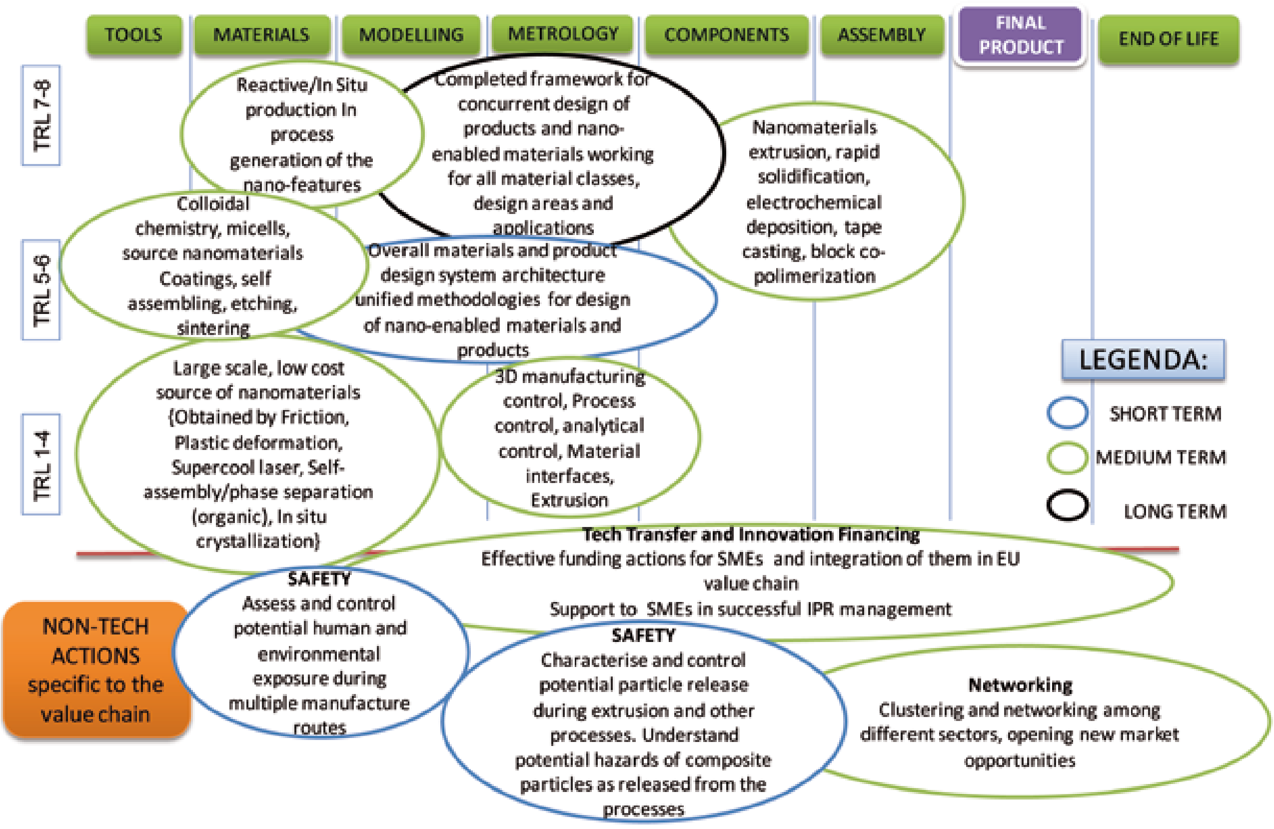



**Figure 4-29: Production chain on Integration of nano: SEMIFINISHED**

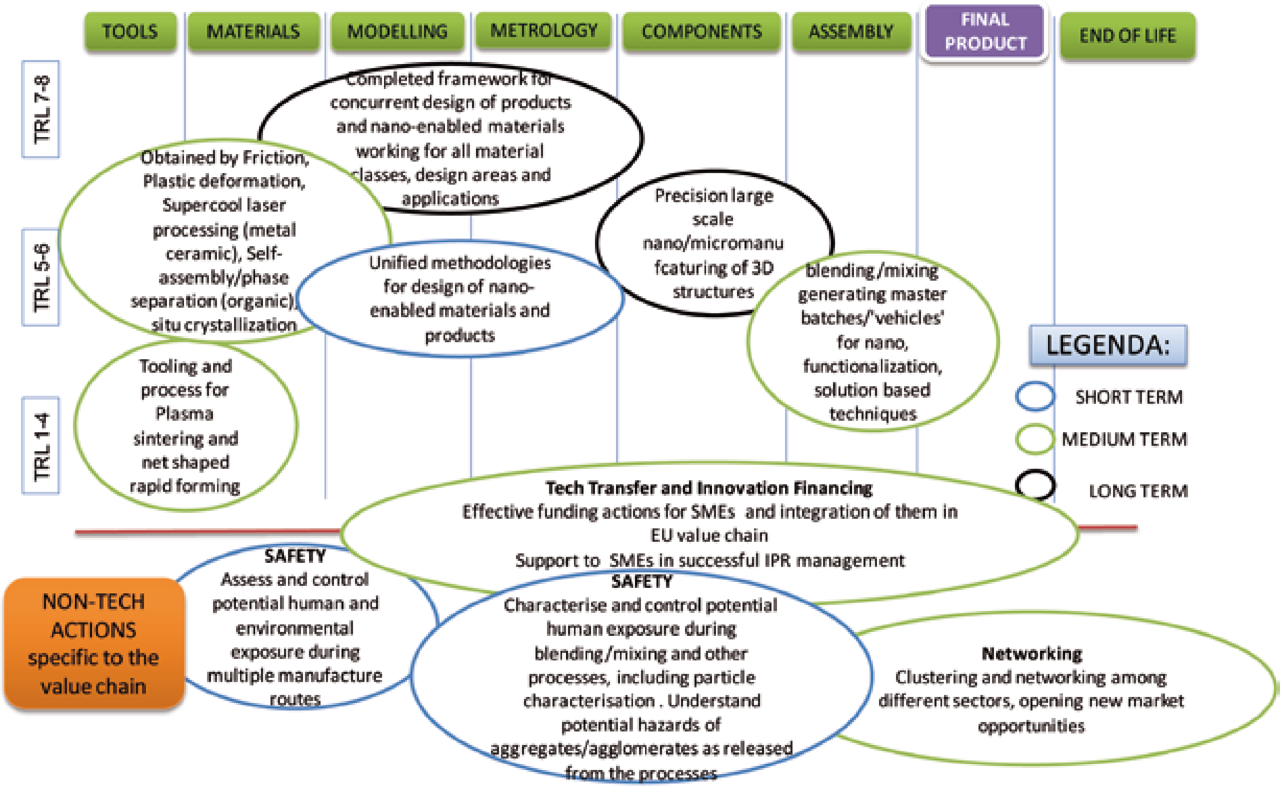



**Figure 4-30: Production chain on Integration of nano: FINISHED NET SHAPES**

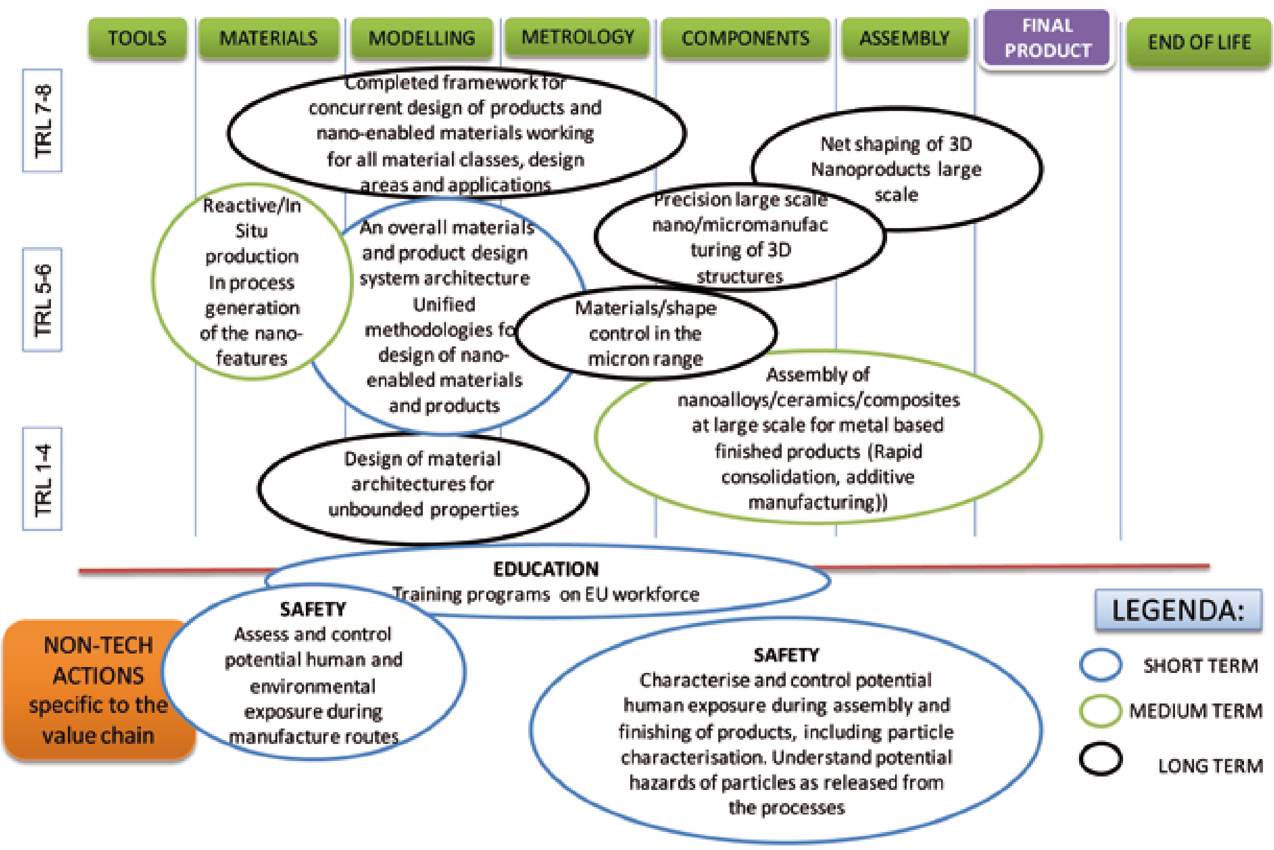



**Figure 4-31: Production chain on Integration of nano: DIRECT MANUFACTURING**

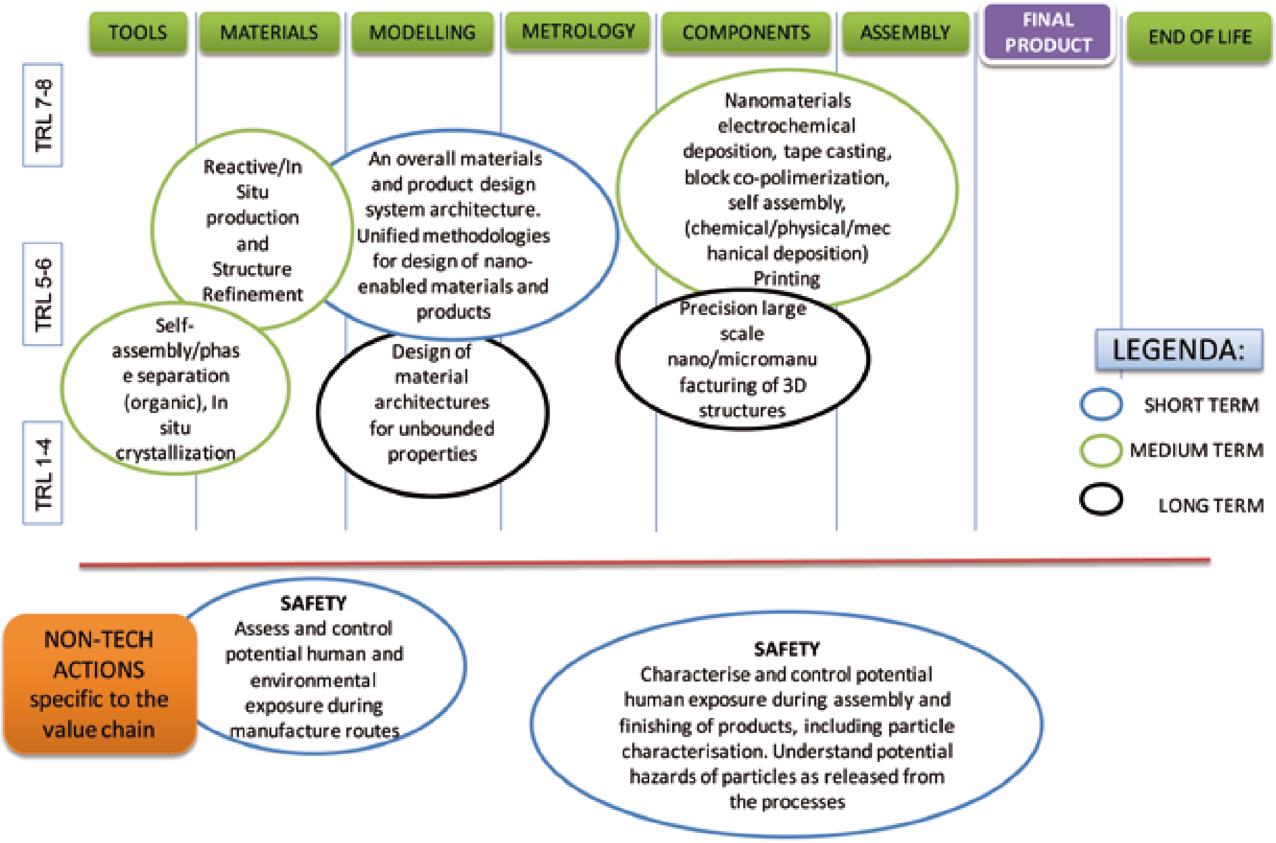



**Figure 4-32: Production chain on Integration of nano: 3D STRUCTURES for NANOELECTRONICS & PHOTONICS**

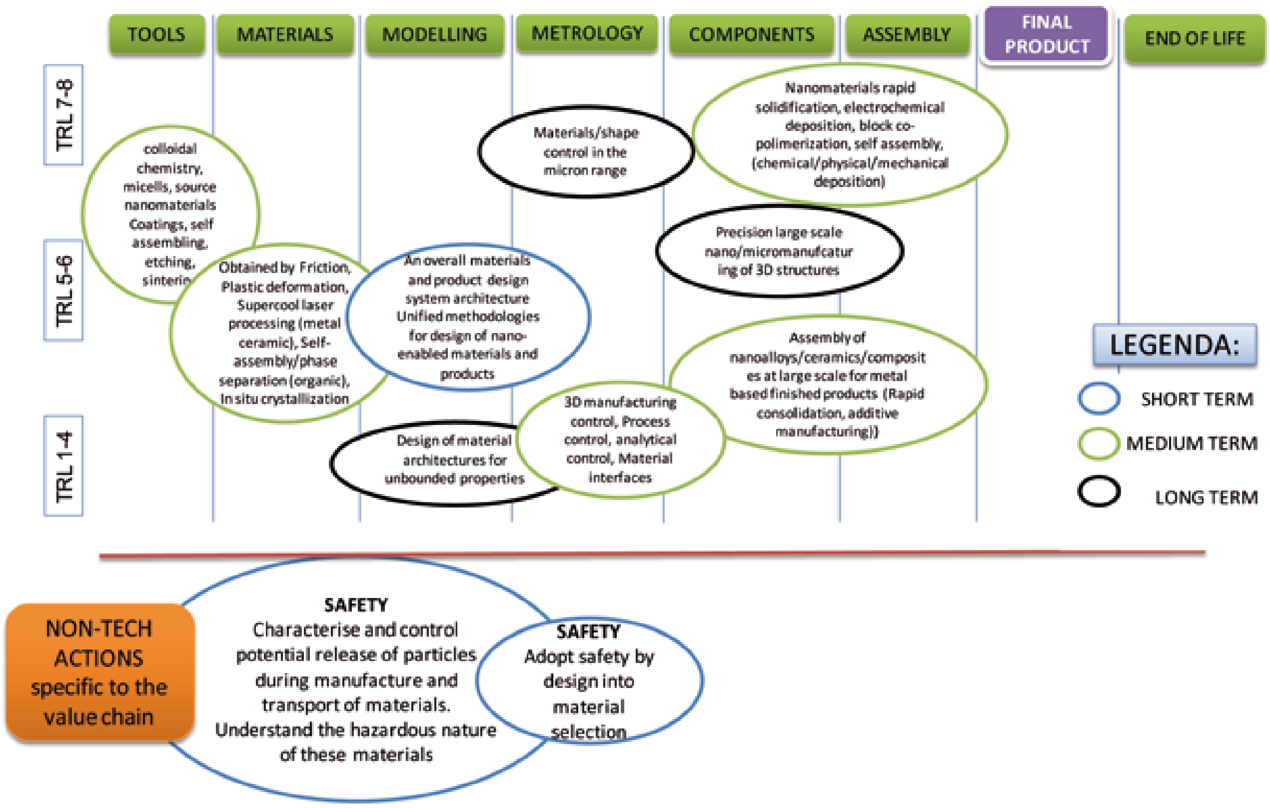



**Figure 4-33: Production chain on Integration of nano: CATALYSIS and FILTRATION**

# VC7 – Infrastructure for Multiscale Modelling and Testing

The Nano-enabled Value Chain 7, named "Infrastructure for Multiscale Modelling and Testing" focuses on an integrated approach to modelling, design and characterization at the nano-scale for the development and monitoring of passive and active nanostructures and nanosystems.

An example of possible application is:

- Complex Adaptive Systems for complete product design

The following figure shows all the related actions of this production chain.

A detailed description of the actions is included in Chapter 6.

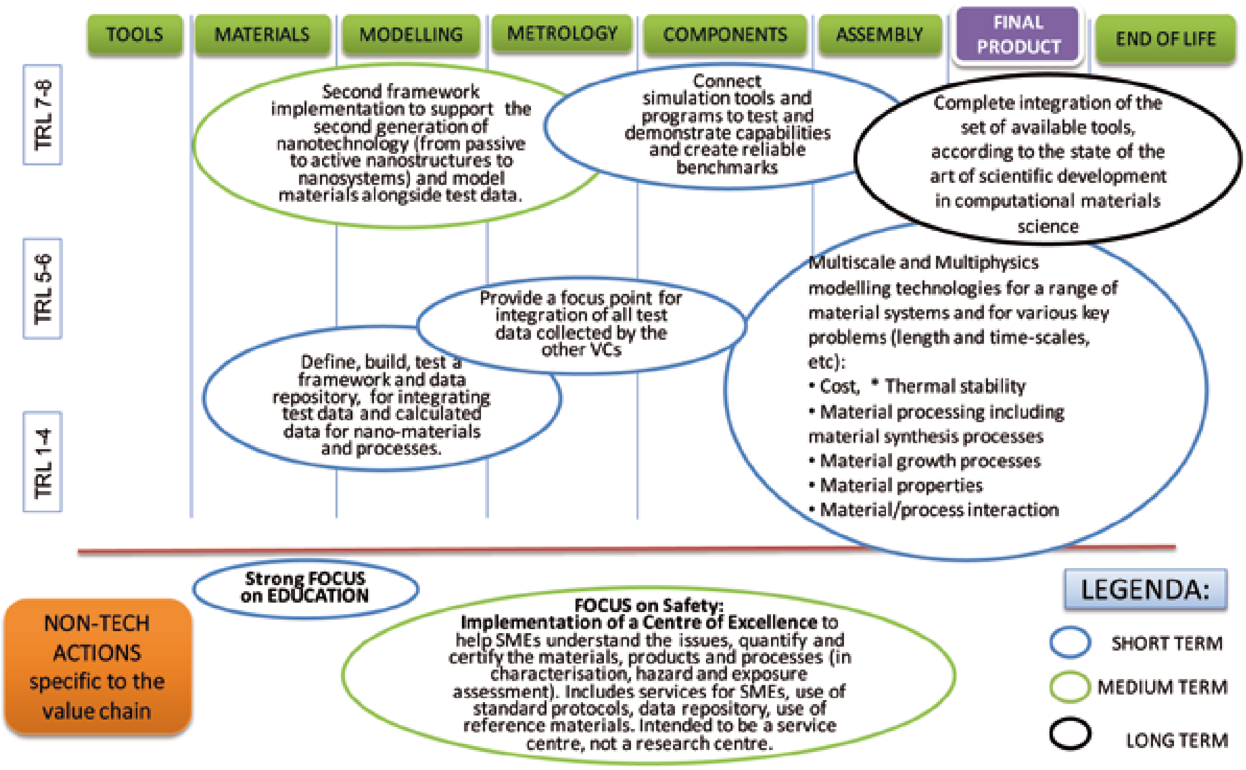



**Figure 4- 34: Production chain on Infrastructure for Multiscale Modelling and Testing: Complex Adaptive Systems for complete product design**

# 5 Expected Impact

# 5 Expected Impact

NANO*futures* Roadmap is expected to develop and broadly disseminate a **cross-ETP vision of European nanotechnology**. This strategy will have a great impact on the ability of Europe to address cross-sectional needs that currently hinder nanotechnology full development and commercialization.

In fact NANO*futures* is strongly aligned with **Horizon 2020 goals**:

- The NANO*futures* industrial roadmap will highly boost ***European Industrial Leadership*** in different sectors.
- NANO*futures* open environment, that aims to involve all relevant private and public nanotechnology stakeholders, will contribute to align European strategies on nanotechnology to meet the ***Societal Challenges*** of our time, which cannot be addressed with a limited sectorial approach.
- Finally, the presence of a coherent roadmap from research to demonstration, will also contribute to promote ***Excellent Science*** in Europe.

## 5.1 Promoting European Industrial Leadership

The market size for nanotechnology amounted to 103 billion Euros in 2007 and it is expected to grow over 3 trillion dollars by 2015[7] [8], considering the whole nanotechnology value chain. By then, about 2 million of nanotechnology workers are needed, with a European share amounting for approximately 25%.

Current private investment in nanotechnology amounts only to 1.2 billion €, compared to 1.9 billion €, in US. Moreover, funds from venture capitalists account only for less than 7% of total European funding[9].

In this framework, the implementation of NANO*futures* Roadmap is expected to:

- **Improve the competitiveness and leading position of Europe** and its industries in nanotechnology related markets by overcoming the current barriers to commercialization of nano-enabled products.
- **Promote private investments on nanotechnology** through the definition of clear market driven value chains, able to involve SMEs, large industries, innovative associations and clusters and financial investors on the same target.

[7] Lux Research Inc. (2009): "Nanomaterials of the Market Q1 2009: Cleantech's Dollar Investments, Penny Returns

[8] Cientifica Ltd 2007. Halfway to the trillion dollar market?, available at http://cientifica.eu.

[9] Lux Research Inc. (2009): "Nanomaterials of the Market Q1 2009:Cleantech's Dollar Investments, Penny Returns".

- **Support European Commission in proposing co-funding as well as corrective actions** (e.g. fiscal incentives, innovation and education polices etc.) that can promote investments and technology transfer in nanotechnology.
- **Contribute to improve the quantity and quality of jobs**, through the development of value chains as well as the improvement and dissemination of knowledge for risk assessment and management related to nanotechnology.
- Effective communication to the EU society on the social and economic impact of nanotechnology and their benefits for consumers and society at large. This includes careful and scientific communication on safety research results, targeting the dissemination approach to the type of audience (e.g. scientists, workers, general public, students etc.).

### 5.1.1 Target markets and products

The implementation of NANO*futures* Roadmap is expected to bring nano-enabled products to several markets and sectors. The following table gives a brief description of target markets in terms of estimation of market size and list of the ETPs interested in such markets.

**Table 5-1: Target market description and interested ETPs**

| Market Description | Interested ETPs |
|---|---|
| **ENERGY**<br>Estimation of target market size:<br>• In 2030, at least 30% shares of renewables in gross final energy consumption[10]<br>• In 2035 renewables, including hydro, produce roughly 15000 terawatthours (TWh) in the world[11] | niac, EUMAT, Industrial Safety, MANUFUTURE-EU, MINAM, nanomedicine, PHOTONICS21, SusChem, [illegible] |
| **TRASPORTATION**<br>Estimation of target market size:<br>• Passenger cars & LCVs market in 2011 WW ~75mn units (around 18mn in EU | niac, ERTRAC, EUMAT, Industrial Safety, MANUFUTURE-EU, MINAM, nanomedicine, PHOTONICS21, SusChem, [illegible] |
| **CONSTRUCTION & BUILDINGS**<br>Estimation of target market size:<br>• EU construction market: >10% of GDP, >2.5 million enterprises; >13 million workers. Buildings account for around 40% of total energy consumption and 36% of CO2 emissions in Europe[12]. | EUMAT, Industrial Safety, MANUFUTURE-EU, MINAM, nanomedicine, PHOTONICS21, SusChem, [illegible] |

[10] http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf

[11] http://www.iea.org/IEAEnergy/Issue2_Renewables.pdf

[12] Optech Consulting at http://spie.org/x38563.xml

| Market Description | Interested ETPs |
| --- | --- |
| **MEDICINE & PHARMA**<br>Estimation of target market size:<br>• Worldwide Nanomedicine market by 2025: Drug Delivery (including nanopharmaceuticals) >50 billion €; Regenerative Medicine (including biomaterials) > 50 billion €; Diagnostics : ~10 billion €[13] | ECTP, niac, ERTRAC, EUMAT, Industrial Safety, MANUFUTURE-EU, MINAM, PHOTONICS21, SusChem |
| **ICT (Nanoelectronics & Photonics)**<br>Estimation of target market size:<br>• Total Semiconductor market is expected to exceed 320B$ in 2012[14]<br>• Total Photovoltaics market was more than 83B$ in 2010[15]<br>• For solid state lighting the market in 2013 is expected to be 14.9B$[16]<br>• For Flat Panel Displays it is quoted around 100B$ flat[17 18 19]. | niac, ERTRAC, EUMAT, Industrial Safety, MANUFUTURE-EU, MINAM, PHOTONICS21, SusChem |
| **TEXTILE AND SPORT SECTORS**<br>Estimation of target market size:<br>• Market for Technical Textiles in Western Europe: 35,6 Billion Euro in 2004[20] | ECTP, niac, EUMAT, Industrial Safety, MANUFUTURE-EU, MINAM, PHOTONICS21, SusChem |

[13] Synthesis from “Roadmap in Nanomedicine towards 2020” (2009) available at http://www.etp-nanomedicine.eu/public/press-documents/publications/etpn-publications

[14] Source: IHS-i-supply

[15] Analysis of data taken from: http://files.epia.org/files/Global-Market-Outlook-2016.pdf and (http://www.eetimes.com/electronics-news/4376076/PV-gross-margins-fell-75--in-Q1

[16] Strategies Unlimited, “High-Brightness LED Market Review and Forecast 2009”, Report OM-50,2009, citato nella edizione 2010 della Strategic Research Agenda di Photonics 2020

[17] http://www.displayforum.de/market.htm;

[18] http://www.prweb.com/releases/flat_panel_displays_FPDs/liquid_crystal_displays/prweb8117763.htm

[19] http://www.photonics21.org/download/SRA_2010.pdf

[20] Euratex – ETP Textiles Vision for 2020

| Market Description | Interested ETPs |
|---|---|
| **CONSUMER GOODS (e.g. houlsehold cleaning and cosmetics)**<br>Estimation of target market size:<br>• Global Household Cleaning market: 83 billion € by 2015[21]<br>• Global Cosmetic market: €136.2 billion (EU almost 60%) in 2006[22] | niac, EUMAT, Industrial Safety, MANUFUTURE-EU, MINAM, PHOTONICS21, SusChem |
| **PACKAGING**<br>Estimation of target market size:<br>• ICT packaging market: $ 60 Billion worldwide in 2008[23];<br>• food&beverage industry: $103 Billion worldwide in 2010[24];<br>• medical/pharmaceutical packaging: $ 62.3 billion U.S worldwide in 2013[25] | niac, EUMAT, Industrial Safety, MANUFUTURE-EU, MINAM, nanomedicine, SusChem |

NANO*futures* Roadmap will greatly impact on those markets through the development of research and innovation actions included in VCs, which, using key enabling materials, technologies and processes, will develop final nano-enabled products.

[21] http://sanitationupdates.wordpress.com/2012/02/08/global-market-for-household-cleaning-agents-to-reach-us-83-23-billion-by-2015-according-to-business-analysts/

[22] http://ec.europa.eu/enterprise/newsroom/cf/_getdocument.cfm?doc_id=4561

[23] http://thor.inemi.org/webdownload/Industry_Forums/Productronica_2005/2007_Roadmap_Kickoff/2005_Packaging_Roadmap.pdf

[24] http://www.freedoniagroup.com/World-Food-Containers.html

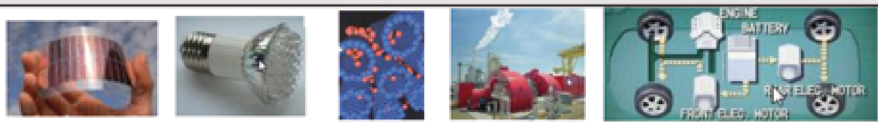
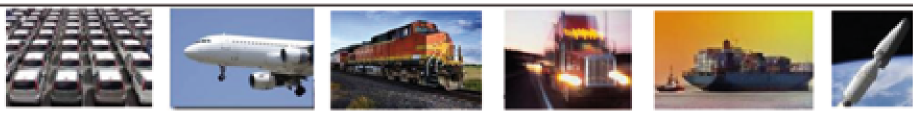
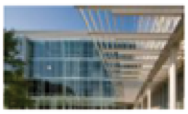
[25] http://www.vacuum-thermoforming.com/News-88.htm

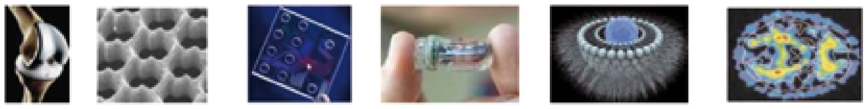
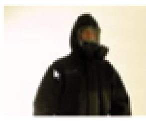
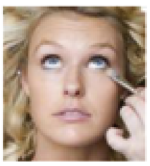
Table 5-2 lists the VCs and examples of key enabling materials, technologies and processes for each target market and Table 53 lists some examples of nano-enabled products foreseen for each target market.

**Table 5-2: NANO*futures* Impact – VCs and examples key enabling materials, technologies and processes for each target market**

| Nano-enabled VALUE CHAINS | | Examples of Key Enabling Materials, Technologies and Processes |
|---|---|---|
| **ENERGY** | **VC1, VC2, VC3, VC4, VC6 and VC7** | Multifunctional and smart polymer nanocomposites, multilayer structures, porous structures, metal alloy, ceramics, intermetallics, nanostructured surfaces, coatings and paints for energy generation, harversting, storage and distribution/management needs (high barrier properties for energy cell, enhanced gas absorption and trapping, efficient energy transmission, magnetic storage, catalytic structures and coatings, power electronics). |
| **TRASPORTATION** | **VC1, VC2, VC3, VC4, VC5, VC6 and VC7** | Nanocomposites, nano-enabled thin glasses, metal-foams sandwitch panels, ceramic structures, nanoporous structures, coatings, structured surfaces and functional fluids tuned for transportation. |
| **CONSTRUCTION & BUILDINGS** | **VC1, VC2, VC3, VC5, VC6 and VC7** | Integration of nanoparticles and nanostructures in building materials and components to improve their aesthetic (color), optical (near infra red reflection; overall energy efficiency), mechanical, durability (self-healing), safety (safe resistance, catalytic/anti-microbial activity) properties; new nanoporous structures for pollution trapping, new coatings, integrations of sensors and active components; new nano-enabled treatments for increasing the re-use of waste in composites for construction and buildings. |
| **MEDICINE & PHARMA** | **VC2, VC3, VC5 and VC7** | Nanotechnology in medicine & pharma for regenerative medicine, diagnostics and drug delivery: for example nanoporous and nano-enabled textiles structures and surfaces for smart biomaterials, nanoparticles/capsules/nanofluids for to be used as nanopharmaceuticals and/or contrast agents, surface treatments for high-throughput, microfluidic advanced systems for in vitro diagnostics, smart chemical and bio sensors for multi-parameter measurements (multiplexing). |
| **ICT** | **VC1, VC2, VC3, VC5, VC6 and VC7** | Multilayer sandwitch structures, organic structures, porous structures, nano-structured obtained by technologies such as 2D & 3D printing, self assembly, in situ production, molecular lithography and coating technology for ICT, with particular reference with nanoelectronics, photonics and their integration. |
| **TEXTILE AND SPORT SECTORS** | **VC1, VC2, VC3, VC4, VC6 and VC7** | Technical, sustainable passive and active textiles with: self-cleaning, fire-retardant, hydrophobic /hydrophilic, antibacterial, anti-odour, UV protection, conductive properties and integrating sensors. Examples of application areas: Personal protection & security applications, medical textiles, interior textiles, fashion and sports, construction and Industrial applications, transport and mobility. |
| **CONSUMER GOODS** | **VC2, VC5 and VC7** | Safe, effective and environmentally sustainable nanoparticles and nanofluids for consumer products: household cleaning and cosmetics. Examples in cosmetics are: nanotechnology for delivery (liposomes, niosomes, solid lipid nanoparticles, nanocapsules as delivery vehicles), nano-emulsions, metal oxide nanoparticles (Titanium dioxide and Zinc Oxide), fullerenes, dendrimers. Examples in household cleaning are: silver particles and nanoemulsion, catalythic coatings and nanofilms. |
| **PACKAGING** | **VC1, VC2, VC4, VC6 and VC7** | Nano-particles and structures, polymer nanocomposites, multilayer laminates, surface treatments for smart packaging in different sectors (e.g. improved barrier properties, lightweight, recyclability, biodegradability, efficient catalysts) and encapsulation (e.g. in medicine and food & beverage industry). |

**Table 5-3: NANO*futures* Impact – examples of final nano-enabled products, for each target market**

| | Examples of final nano-enabled products |
|---|---|
| **ENERGY** |  *Advanced Solar cells (Including organic & hybrid PV)*; *solid state lighting (LED, OLED, PLED)*; *Efficient catalysis & carbon capture and storage -CCS (pollution control in fuels, in geothermal etc.)*; *Storage technologies (hybrid batteries, gas, hydrogen). Power electronics for industrial applications and engine management)* |
| **TRASPORTATION** |  *Long time, low cost fuel cell membranes and batteries; Low friction engines & lubricants; Smart glass surfaces; Lightweight metal or plastic sheet for chassis; efficient tires, wiper blades, seals; sustainable lightings and heating systems; smart sensors and radar systems* |
| **CONSTRUCTION & BUILDINGS** |  *High durability & high productivity infrastructure*; *Self-cleaning/Anti-microbial/solar reflective paints for building envelopes or indoor environment (e.g. HVAC)* ;  *Advanced insulating systems for new and existing building envelopes*;  *Green high performance concrete (CO2 trapping) & recycled building composites*; *Smart integration of technologies (incl. Sensors) at building level*  |

| Examples of final nano-enabled products | |
|---|---|
| MEDICINE & PHARMA |  *Scaffolds and coatings for regenerative medicine (implants, engineered cartilage, vessels, bone)*; *biosensors, like lab-on-chip and micro-TAS, smart pills*; *Nano-pharmaceuticals, biomarkers and contrast agents for theranostics*; *Diagnostic tools (CT, NMR, PET, optical), portable point-of-care devices and nano-imaging* |
| ICT |  *Lasers (optical communications, medical diagnostics and treatments, manufacturing tools, printers)*; *ink-jet printers*; *LCD-, silicon-, LED- and OLED-based Displays and Photovoltaics*; *Consumer Electronics (smart phones, TV set, digital cameras etc.)* |
| TEXTILE AND SPORT SECTORS |  *Personal protection & security applications* ( e.g. breathability, moisture management and protection against external risks; human comfort and protection from adverse environmental );  *Medical Textiles* (*e.g.* antibacterial nanoparticles coatings; wound dressing, carriers for slow-released drugs; nanofibers for medical implants; development of fiber based sensors); *Interior textiles, fashion & sports goods* (e.g. Easy cleaning or zero maintenance products) |
| CONSUMER GOODS |  *COSMETICS* Moisturisers, hair care products, make up and sunscreen;  *HOUSEHOLD CLEANING* Smart washing machines, cleansing films, self-cleaning fabrics, nanoparticle soaps |
| PACKAGING |   *Food&Beverage Packaging*;  *Pharma & Medical Packaging*;  *Shoe & Clothing Packaging*;  *ICT Packaging* |

## 5.2 Addressing the Societal Challenges

NANO*futures* Roadmap will contribute to address the Societal Challenges as mentioned in the Horizon 2020. The path from Societal Challenges to NANO*futures* markets and products towards implementation of specific actions is shown in Figure 5-1.

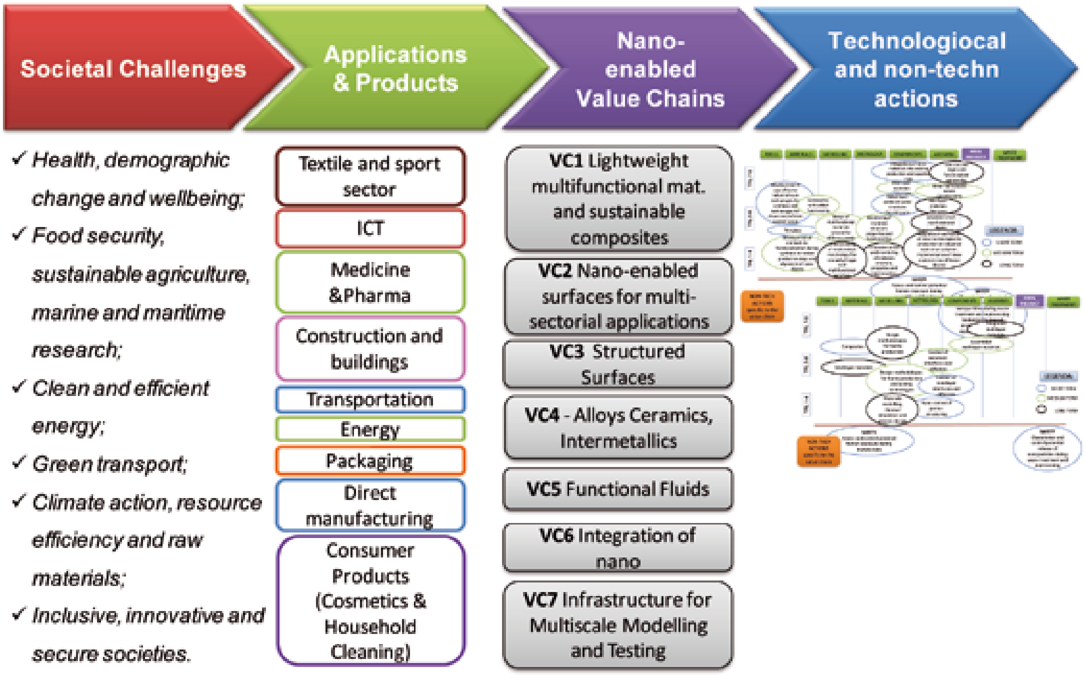



**Figure 5-1: From Societal Challenges to NANO*futures* products towards NANO*futures* proposed actions**

An example of possible path to address the Societal Challenges called “Smart, green and integrated transport” and “Climate action, resource efficiency and raw materials” is given in Figure 5-2.

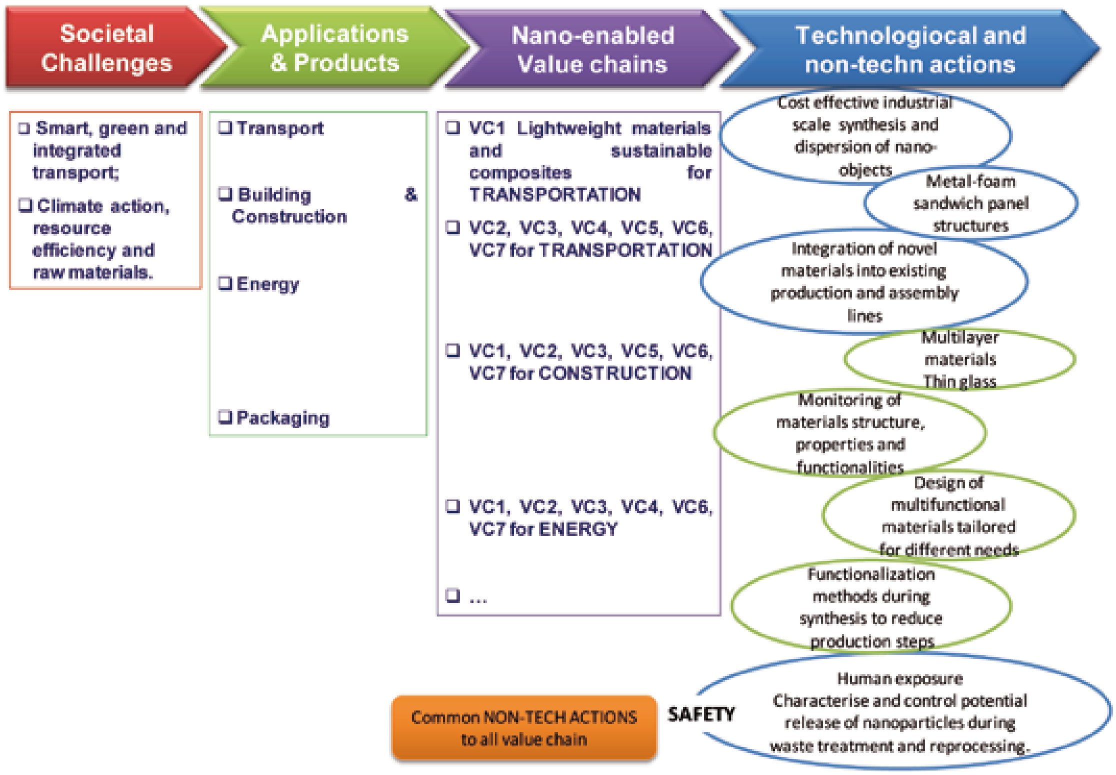



**Figure 5-2: Example of path towards addressing “Smart Transport” and “Climate Action” Societal Challenges**

It must be noted that in the above figure only the short-medium actions (i.e. up to 2020) are included, in alignment with Horizon 2020 life span.

Table 5-4 shows the main societal challenges addressed by each target market.

**Table 5-4: NANO*futures* impact: Main Societal Challenges addressed by market**

| Main Societal Challenges by market | |
|---|---|
| **ENERGY** | • Secure, clean and efficient energy;<br>• Smart, green and integrated transport;<br>• Climate action, resource efficiency and raw materials |
| **TRASPORTATION** | • Smart, green and integrated transport;<br>• Climate action, resource efficiency and raw materials |
| **CONSTRUCTION & BUILDINGS** | • Secure, clean and efficient energy;<br>• Climate action, resource efficiency and raw materials. |
| **MEDICINE & PHARMA** | • Health, demographic change and wellbeing |
| **ICT** | • Health, demographic change and wellbeing;<br>• Inclusive, innovative and secure societies. |
| **TEXTILE AND SPORT SECTORS** | • Health, demographic change and wellbeing;<br>• Inclusive, innovative and secure societies. |
| **CONSUMER GOODS** | • Health, demographic change and wellbeing |
| **PACKAGING** | • Health, demographic change and wellbeing;<br>• Food security<br>• Climate action, resource efficiency and raw materials |

## 5.3 Promoting Excellent Science

Although NANO*futures* roadmapping activity had a strong industry-driven and application-oriented approach, there are several proposed actions included in the Roadmap that will highly contribute the development of excellent scientific expertises in Europe. Such priorities are given in each Value Chain at the beginning of the value chain, in the steps called “material”, “metrology” and “design”. In fact, extensive efforts are needed from short to long term for a complete understanding of nanomaterial and nanotechnology intrinsic properties, through lab synthesis and manufacturing as well by means of deep testing and modelling campaigns.

## 5.4 Impact on horizontal issues

One of the pillars of the NANO*futures* Roadmap is the focus on horizontal cross-sectorial issues, discussed within the Platform Working Groups. Therefore the impact of the Roadmap on such issue may be also summarized in the table below.

**Table 5-5: Expected impact on horizontal issues**

| Topics | NANO*futures* Roadmap impact |
|---|---|
| **SAFETY RESEARCH & INDUSTRIAL STRATEGY** | NANO*futures* will reduce knowledge fragmentation about risks exposure / toxicology/ safety/ impact, particularly in relation to risk assessment. Nf supports responsible industrial development of nanotechnologies and nanomaterials. In fact, Nf actions will contribute to promote safe, sustainable and socially responsible nanotechnology by addressing current research safety needs as well as well as knowledge gaps with respect to industrial safety management of nanotechnologies and nanomaterials. |
| **STANDARDISATION** | Standardization is critical to scientific communication and commerce because, in order to build on lessons learned, researchers need to quickly convey scientific discoveries across disciplines. NANO*futures* includes standardization priorities coming from researchers, industries and authorities. |
| **TECHNOLOGY TRANSFER & INNOVATION FINANCING** | Europe cannot compete unless it becomes more inventive and innovative. Synergies between stakeholders from different sectors and regional, national and European and international bodies will be established.<br>NANO*futures* includes actions that encourage the set up on new initiatives bringing the results of research projects into products. |
| **INDUSTRIALIZATION & nanoMANUFACTURING** | NANO*futures* roadmap will support: the establishment of a new industry for the manufacturing of products based on emerging micro and nanotechnologies, in collaboration with MINAM and MANOFUTURE; the development of Europe as the leading location for the production of nanoparticles, micro- and nanostructures and components with “micro/nano inside”; the creation of the complete value chains leading to the manufacturing of European micro- and nanotechnology products; the production of the new micro- and nanoproducts at European facilities using equipment and systems of European origin, thus overcoming the current situation in which only R&D, pilot cases and first production lines are set in Europe. |

<table>
<tr><th>Topics</th><th>NANOfutures Roadmap impact</th></tr>
<tr><td>SKILLS AND EDUCATION</td><td>The competitiveness of the EU nanotechnology industry is dependent on several factors. A key requirement for success is the availability of a skilled workforce. Education and training issues are critical and young peoples' interest in science (nenotechnology) careers needs to be raised by improving the image of the nanotechnology. NANOfutures Roadmap will promote a culture change that includes information sharing - among government, universities, and companies - to help the community to build a common knowledge on nanotechnology and focus on developing and commercializing nanotechnologies in the near term.</td></tr>
<tr><td>RESEARCH AND TECHNOLOGY</td><td>Europe is spending up to 3 billion Euros per year on nanotechnologies and yet competing powers such as the USA and Japan are taking the lead in patenting nanotechnology developments and commercializing nano (enabled) products. One of the reasons for it may reside in the fragmentation of European Research and in the missing link between academic interests and industrial needs.<br>NANOfutures will contribute to align European research to industry needs, ensuring that R&D is translated into affordable and safe wealth-generating products and processes.</td></tr>
<tr><td>REGULATION</td><td>NANOfutures Roadmap actions will contribute in addressing the current gaps in current regulatory framework and governance of nanotechnology.</td></tr>
<tr><td>NETWORKING and COMMUNICATION</td><td>Networking and communication is should applied in daily work if the overall nanotechnology development is to be accomplished.<br>NANOfutures ensures effective networking among the different stakeholders all along the value chain facilitating technology transfer to the market. Roadmap actions will facilitate the trans-sectorial and trans-national cooperation within and outside Europe for R&D consortiums establishment or direct business to business collaborations and will contribute to coordination of regional, national and European funding agencies to avoid dispersion of efforts.<br>Complete adoption of nanotechnology depends on public acceptance. In this sense, proposed communication actions will pay special attention to society in order to transmit the social and economic impact of nanotechnology developments. Also, special efforts will be put in communication of safety strategies and risks assessment in order to assure safe and sustainable fabrication and commercialization of nanoproducts. Moreover, the networking and communication groups are helping offering tools, widen the channels and supporting the EC-local communication flow.</td></tr>
</table>

# 6 Budget considerations & Implementation Plan

# 6 Budget considerations & Implementation Plan

## 6.1 Implementation Plan

The actions included in the NANO*futures* Roadmap are described in details in Annexes A, B and C, providing a short description of the state of the art, a description of the action content in terms of challenges to be addressed, technologies to be further developed etc. and some example of possible type of funding to be used to implement the action.

Actions are divided in three sections, for short, medium and long term actions. In each of these sections, for each nano-enabled value chain a table of related actions is provided:

- Short term actions are presented in Annex A,
- Medium term actions are presented in Annex B,
- Long term actions are presented in Annex C.

Short-term actions are described in more details.

## 6.2 Budget considerations

This chapter includes an overall estimation of total costs foreseen for the short and medium term actions (up to 2020) with a percentage distribution among the value chains.

The following assumptions have been made:

- actions that are repeated in different production chains are considered to be funded only once with their budget is distributed equally in the relevant value chains;
- the costs of non-technological cross-cutting actions were distributed with the same percentage in all the value chains.

The total cost, including private and public funding, is estimated to be 1.5 Billion Euros, with the approximate distribution shown in the figure below. Such consideration is only the starting point for future discussion among European stakeholders.

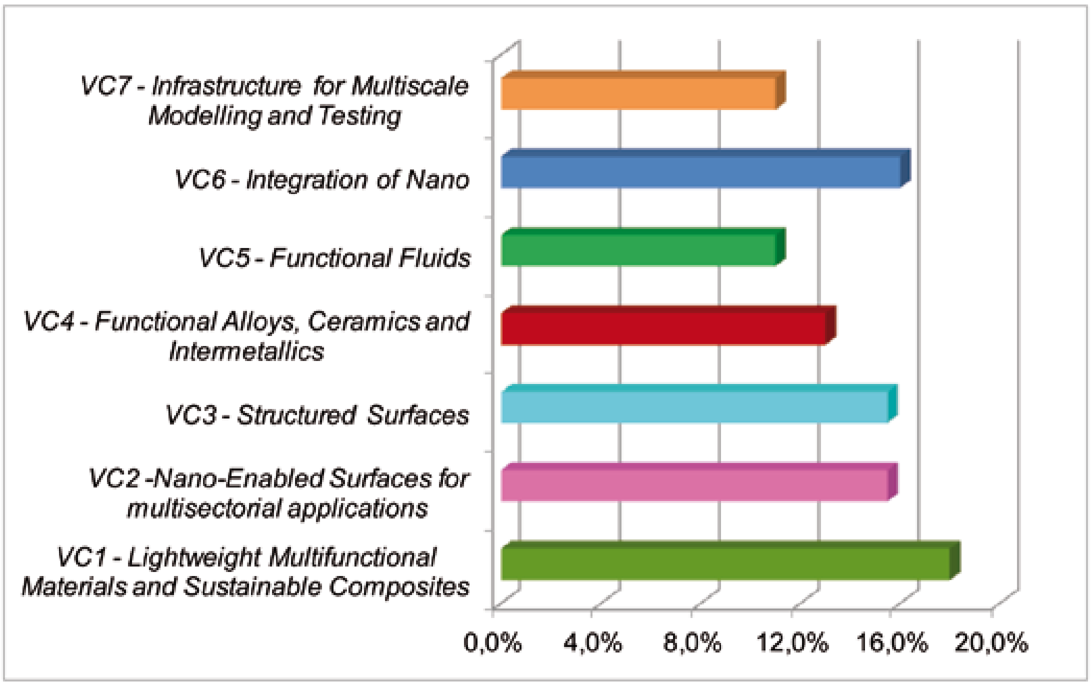



**Figure 6-1: Estimation of % cost distribution among VCs, considering a total funding (100%) of 1.5 Billion Euros**

# 7 Conclusion and Future Activities

# 7 Conclusion and Future Activities

The NANO*futures* Roadmap was here described, focusing on several value chains where technological and non-technological actions were included. Examples of lead markets were given. Moreover, cross-cutting actions, relevant for all value chains were also added. A detailed implementation plan, focusing on action at short-medium terms (up to 2020) but including also a brief description of long term actions was provided. The vision behind the roadmap, the roadmapping methodology and expected impact were also described.

The Roadmap is conceived to be a live document, to be continuously disseminated, discussed and improved by the NANO*futures* Community, the European Commission and all nanotechnology stakeholders.

# Annex A Short Term Actions

# Annex A Short Term Actions

## Non- Technological Cross- Cutting Actions

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| NT1 -short | Safety | Understand the hazardous nature of the material Assess and control potential releases to workplace air during manufacturing and life cycle | Materials | **Challenges with respect to the state of the art:** In order to evaluate the **dangerousness of material**, complete and satisfying material datasheets need to be provided where information on handling, using and disposing them need to be included. Further efforts are needed in the development and sharing of test and emergency procedures in order to manage correctly every happening. The use of adequate PPE (Personal Protective Equipment) is also an important feature.<br>**Type of needed action:**<br>There is a need a consistent set of actions in short term covering different industrial sectors. ***Collaborative as well as supporting actions*** are required, connecting industrial and research experts from different sectors, covering all possible safety issues during production, processing, final use and end-of-life treatment. Good coordination needs to be put in place with past and existing nanosafety projects, initiatives and relevant networks (e.g. Nanosafety Cluster, SIINN Eranet, ETP of Industrial Safety). |
| NT2- short | Safety | Adopt safety by design into material selection | Modelling | **Challenges with respect to the state of the art:**<br>Construction or product designers are encouraged to consider **health and safety risks during design development**. The concept supports the view that along with quality, programme and cost; safety is determined during the design stage.<br>These concepts shall be included in material selection tools, providing also safety design solutions.<br>**Type of needed action:**<br>***Coordination and support actions linked to collaborative projects included in the other NTs*** involving stakeholders from the safety sector (occupational safety associations, safety research institutes etc.) as well from the design and manufacturing field. |
| NT3 - short | Safety | Assess and control potential release to workplace air during component manufacturing and assembly | Metrology Components | **Challenges with respect to the state of the art:**<br>**Regulation and standardization procedure**s are requested in order to avoid or at least to reduce major accidents, due to human errors or to negative circumstances.<br>In addition refresher courses should be periodically organized on occupational health issues and sensors and controls shall be installed in the manufacturing areas.<br>**Type of needed action:**<br>***Collaborative actions as well as supporting actions*** are required, covering different industrial sectors. Knowledge of and coordination with past initiatives and relevant networks is recommended. |

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| NT4 - short | Safety | Control potential release during professional and/or consumer use | Assembly Final Product | **Challenges with respect to the state of the art:**<br>**Health and safety procedures should be followed:**<br>- Use of PPE<br>- Definition of best practices<br>- Elaboration of an emergency plan<br>Deep instruction for handling and assembling products shall be provided.<br>**Type of needed action:**<br>For all these actions ***collaborative projects*** as well as ***capacity projects*** (e.g. Research for SMEs and SME-Ags) are needed: obtaining information of all existing risks will be useful to describe protocols to understand human exposure and will decrease the time to market. The presence of a good representation of industrial end users is fundamental to increase the impact of project results. |
| NT5-short | Safety | Control potential worker exposure during recycling & disposal | End of Life | **Challenges with respect to the state of the art:**<br>Also in this phase, where maybe the attention decreases, it is important to **educate workers on risk** of handling dangerous products, that during dismantling operation can release (nano)particles<br>**Type of needed action:**<br>In order to control these phases ***collaborative actions*** as well as ***supporting actions*** are required. In particular, ***collaborative projects targeted to SMEs*** may be a good tool to connect people in from different sectors, covering especially waste treatment industries. |
| NT6 - short | Safety | Recommend safety advice to professional and/or consumer users | Assembly Final Product | **Challenges with respect to the state of the art:**<br>Refresher courses, handling manuals, risks list are the main instruments that producer has in order to s**ave and reduce safety problems due to nano material usage**.<br>The procedures should be made homogeneous across all Europe in order to make easy transnational trading.<br>**Type of needed action:**<br>***Coordination actions*** aiming at defining common procedures between EU stakeholders should be put in place, in cooperation with major safety and industrial networks. |
| NT7 - short | Environment | Characterise and control potential release to the environment (air/soil/water) from the developed processes | Materials | **Challenges with respect to the state of the art:**<br>A proper characterisation of material release during manufacturing, through **development of pollutants/material dispersion models**.<br>In addition periodical analysis on soil, air, water should be performed and an emergency plan in case of accidental releases of toxicity elements has to be prepared.<br>The ecotoxicity indicator should be easily assessed; a detailed data sheet of material should be written and attached to product packaging.<br>**Type of needed action:**<br>***Collaborative projects*** developing proper control systems are needed. Clustering activities among awarded environmental and safety project is important. |
| NT8 - short | Environment | Apply technologies/techniques that maximise the extent to which the material is incorporated into the product in order to i) maximise functionality and ii) minimise releases to the environment | Metrology | **Challenges with respect to the state of the art:**<br>**Best available technologies** have to be used for incorporating materials into products. Often an adequate environment respect is aligned with high value production.<br>Monitoring and control sensors applied on manufacturing chain will warrant the same objective.<br>**Type of needed action:**<br>***Coordination and support actions*** whose goal is to compensate production needs and environmental respect are needed and should involve industrial experts, industrial associations and end user associations in order to focusing toward a common objective. |

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| NT9 -short | Environment | Characterise and control potential release to the environment (mainly water) from the developed processes | Components Assembly | **Challenges with respect to the state of the art:** A proper characterisation of material release during assembly, through development of **pollutants/material dispersion models** is necessary. In addition, periodical analysis on water (but also soil, air) should be performed and an emergency plan in case of accidental releases of toxicity elements has to be prepared. **Type of needed action:** ***Collaborative projects*** involving the different actors of the value chain should be proposed with a strong focus on solution for minimizing impact on ecosystems. The ecotoxicity indicator should be easily assessable. A detailed data sheet of material should be written and attached to product packaging. Emergency and contingency plans should be elaborated in function of different industrial processes. |
| NT10 - short | Environment | Understand fate and behaviour of these materials in the environment | Final product | **Challenges with respect to the state of the art:** Proper models analyzing the materials dispersion in the environment should be provided. The producer as well as independent institutions should **test the product** before market release and in the meantime should provide indication to customers about a proper disposal. In case of accidental releases of materials, emergency procedures have to be fixed in order to protect specific ecosystems. **Type of needed action:** ***Tenders*** may be promoted with the aim of studying possible releases from a wide sset of nano enabled products or materials into environments (air, soil, water). |
| NT11 - short | Standardization/regulation | Apply standards/ SOPs for safe handling of these materials, considering the whole life cycle | All | **Challenges with respect to the state of the art:** Standardization is a technical solution to health and safety concerns that can potentially provide **legal certainty and consumer confidence in nanotechnology and nanomaterials**. Standards are useful for the entire product life cycle. Standards have to be applied also on end of life solutions, to reduce at minimum the impact on environment. The European Waste Catalogue has specific codes, which identifies particular waste categories. **Type of needed action:** One **CSA** should promote the plan between policy makers and stakeholders in order to have a shared point of view and proceed toward the standardization of nano enabled materials or products disposal. Cooperation with OECD, CEN and other safety, standardisation and regulation stakeholders are foreseen. |
| NT12 short | Regulation | Appropriate nomenclature for nano | Materials Modelling | **Type of needed action:** The nomenclature for nanotechnology and nanomaterials needs to be developed so that regulators, stakeholders, and consumers can work with a common vocabulary and a **common understanding** of terms and their implications. Networking and communication actions (e.g. **CSAs**) are foreseen. Link with safety and standardization related actions. |
| NT13 - short | Skills and Education | Apply standards/ SOPs for safe handling of these materials | Components | **Challenges with respect to the state of the art:** Standardization is a technical solution to health and safety concerns that can potentially provide **legal certainty and consumer confidence** in nanotechnology and nanomaterials. It is important to include standardization knowledge in educational programmes and involve graduated students and researchers in standardizations courses and activities. **Type of needed action:** An educational ***ERANET type of project*** (linked to action NT11) should involve also research institutions and universities with the task of performing standardization courses and including such expertise in their educational programmes. ***Marie-Curie Actions*** type of projects should also include standardization issues in their proposals. |

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| N14 - short | Skills and Education | Greater involvement of industry in academic curriculum development | ALL | **Challenges with respect to the state of the art:**<br>The process through which a degree program is added is lengthy and time-consuming, requiring commitment on the part of faculty, administrators and staff. The formal titles of the existing **nanotechnology degree programs** are mainly general (e.g., nanotechnology, nanosciences and nanotechnology, nanomolecular science, nanoengineering) and in some cases a little more specific (e.g., nanoelectronics, nanomaterials, nanobiotechnology, etc.). The approaches to the interdisciplinary aspects of nanotechnology vary among the different programs.<br>**Type of needed action:**<br>**CSAs** aiming to promote the collaboration of academic institutions at national / EU level towards the development of nanotechnology degree programs. Universities should set up schemes to encourage joint appointments, particularly between different engineering and science (biosciences, chemistry and physics) departments. New tools must be incorporated from other disciplines, and engineers must increasingly learn additional skills beyond those of physics and mathematics. In addition, since the state of the art in transdisciplinary nanoeducation is limited to cooperation between natural sciences and engineering, integrating EHS and ELSA aspects, as well as entrepreneurial skills, would be considered as a key challenge. This could be the focus of a CSA but also an activity funded under ERASMUS for all schemes of DG Education (new skills alliances): http://ec.europa.eu/education/calls/s0112_en.htm.<br>Finally, the development of a kind of "scientific social responsibility" attitude would be very good. Students at all levels should be able to explain how their work fit into a greater picture. |

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| NT15 - short | Skills and Education | Strong connection with nanotechnology research facilities and related programs. Address skills needs for nanotechnology related positions (scientists and technicians) | ALL | **Challenges with respect to the state of the art:**<br>• **Interdisciplinary curricula** relevant for nanosciences and nanotechnology need to be developed. A key issue could be the fast transfer of basic knowledge from research to application. To ensure this, greater opportunity and encouragement needs to be given to nanotechnology students in order for them to have research experiences.<br>• To provide **job opportunities** for all and create a more competitive and sustainable economy, Europe needs a highly skilled workforce able to meet current and future challenges. To ensure this, it is urgent to invest in the right skills and improve matching of jobs with these skills. A joint policy initiative carried out in cooperation between the European Commission and the EU Member States, (New Skills for New Jobs) aims to support EU countries and regions in developing more effective ways to analyze and predict which skills will be required in tomorrow's labour markets and, with this knowledge, developing and adapting education and training so that the workers gain the skills required.<br>**Type of needed action:**<br>• **Mobility programmes** should be established for the exchange of undergraduate and postgraduate students between both academic and industrial research laboratories in order to promote and transfer the knowledge and expertise and to increase the cooperation between academic institutions as well as between academia and industry. Training facilities and topics should be identified in order to organize training activities meeting nanotechnology needs. In addition, networking with European initiatives, projects, technology platforms and organizations in the field of nanotechnology should be pursued.<br>• **CSAs** to bring together academia, industry and relative organizations of EU countries in order i) to define skills needs for nanotechnology related positions (scientist and technicians), ii) provide answers to the following questions: How do we know which skills are important? Can we speak of general skills that apply in all or most places, contexts and cultures? How are knowledge and competence produced? What are the returns to knowledge and skills? What is the pattern of access to learning opportunities for different groups and regions? iii) Examine the success of nanotechnology programs graduates in the labour market and iv) help policymakers to identify program elements that are important to foster the development of particular types of program models in the future. |
| NT16 - short | Skills and Education | Consensus on the most effective curriculum and teaching / training methods Education/ training of faculty members to teach nanotechnology aspects | All | **Challenges with respect to the state of the art:**<br>• Currently, most nanotechnology postsecondary education is occurring informally in **lab environments**, as well as through elective courses and not within formal degree programs. However, there is no consensus yet on the best form or method to teach future nanotechnology.<br>• Other key barriers to establishing formal nanotechnology degree programs include the lack of faculty with the **interdisciplinary background** needed to teach effectively and the often, daunting degree requirements for nanotechnology which may add on to coursework in core disciplines.<br>**Type of needed action:**<br>• Discussion on these different approaches and exchange of best practices could be fostered in a CSA, but also through conferences, summer schools and teacher exchanges funded by DG Education, the European Science Foundation etc. A CSA could bring together scientists from academia and industry working in the field of nanotechnology with policy makers, in order to i) compare / evaluate existing nanotechnology degree programs, ii) develop / distribute / analyze surveys regarding the development of efficient nanotechnology curricula and teaching / training methods and iii) nominate the most efficient ones.<br>• **CSAs** for the development of nanotechnology educational material and organization of relevant training courses for faculty members. These courses could be sequentially organized in different European Countries. Encourage staff to take post doctoral training in diverse departments and/ or industry for a short period before taking an academic position in order to expand their range of research tools. |

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| NT17 - short | Tech Transfer & Innovation Financing | Actions for the benefit of SMEs | ALL | **Type of needed action**<br>Promote Research for the benefit of SMEs actions. The main goal is to **strengthen the innovation capacity** of small and medium-sized enterprises (SMEs) in Europe and their contribution to the development of new technology based products and markets in the nano-materials sector.<br>All the steps of a product can be covered by this kind of action, in function of SME proposal. |
| NT18 - short | Tech Transfer & Innovation Financing | Cross-sectorial TT programme TT from academia to industry. | Components Assembly | **Challenges with respect to the state of the art:**<br>Technology needs and technology solutions could be translated from different industrial sectors and from academia to industry: this will bring **new ideas, new power to research**.<br>**Type of needed action**<br>The EC should consider cross-sectorial technology transfer programmes similar to those already in place by the European Space Agency (www.esa.int/ttp/). |
| NT19 - short | Communication & Networking | Communication of knowledge regarding hazardous nature of the material down the supply chain.<br>More information flow and dialogue between industry and educational experts.<br>Initiate dialogue with the public (with industry, regulators etc.) about future potential benefits about nanotechnology.<br>Develop tools to assess societal impacts of nanoproducts.<br>Communication and clustering actions across different sectors and between Academia and Industry, Infrastructure facilities and Society.<br>Better Regional/ National Funding Agencies Coordination. | ALL | **Challenges with respect to the state of the art:**<br>Through **communication networks** (both standard and atypical), datasheets, safety instructions and so on need to spread across the different actors of the supply chain.<br>Moreover it is important to continue organizing events, shows, conferences, where presenting novelties on the world of “nano”, bringing examples of good collaborations, success stories, etc. using different communication channels according to different kinds of interlocutors.<br>As regards social Impact assessment tools and methods, there are different solutions that can be evaluated:<br>- Analytical tools<br>- Community-based methods<br>- Consultation methods<br>- Observation and interview tools<br>- Participatory methods<br>- Workshop-based methods<br>**Type of needed action:**<br>***CSAs*** where different stakeholders (policy makers, industries, R&D centres, technological platforms, end-users and consumer associations etc.) should develop a set of strategies to promote an effective dialogue on nano. |

# Technical Actions

## VC1 – LIGHTWEIGHT MULTIFUNCTIONAL MATERIALS AND SUSTAINABLE COMPOSITES

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC1-001-short | Composites: development of materials and construction parts | Textile and sport sectors | Tools Materials | **Challenges with respect to the state of the art:** Lightweight composite material has a long and successful track recording in **demanding and weight critical textile applications** where strength and stiffness are required, e.g. composites. The enabling technologies used to produce composite components are different and range from mixing, blending, sintering, synthesis (in situ/ex situ of/within polymers, self assembling).<br>**Type of needed action:**<br>Proposed funding scheme: ***Collaborative research activities*** among textile producers, polymer producers and end-users are needed. |
| VC1-002-short | Integration of novel materials into existing production and assembly lines | Textile and sport sectors/ Packaging/ Transportation/ Construction & Building | Components Assembly | **Challenges with respect to the state of the art:**<br>**Novel materials and new applications for nano materials** are continually being developed in university and commercial laboratories around the world. They are intended either to improve the performance of existing technologies, such as lightweight solutions for textile. Novel materials are used under controlled conditions in industrial processes (blending/mixing, etc.) to make everyday objects.<br>**Type of needed action:**<br>***Research and demonstration activities (including pilot lines)*** among producers (especially SMEs) from textile/packaging/ transportation/construction, R&D centres and end-users are needed. |
| VC1-003-short | Cost effective industrial scale synthesis and technologies for fibers (extrusion, spinning) | Textile and sport sectors | Tools Materials | **Challenges with respect to the state of the art:**<br>**Ceramic and carbon nanofibers** have been extensively researched and the outstanding properties have been heralded by advanced materials experts for quite some time. Commercialization, however, has been hampered by low yield and expensive manufacturing platforms.<br>**Type of needed action:**<br>Technologies using centrifugal force have been considered the most suitable. They make fibers in the nanoscale, which increases productivity by an order of magnitude at one quarter of the cost of other platforms such as electrospinning and extrusion.<br>***Large scale collaborative projects*** (linked to VC1-002-short) are needed to improve actual technologies and develop new solutions for warranting the cost effectiveness. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC1-004-short | Design and modelling strategies for interface and functionalization particles surface | Textile and sport sectors | Modelling | **Challenges with respect to the state of the art:**<br>Actually the research seems to be focused on: 1) improving the **biocompatibility and chemical stability**, and tailors the dispersibility and water solubility; 2) **endowing the nanoparticles new physic-chemical properties**; 3) Providing **new functional end groups** for the subsequent functionalized procedures or the subsequent applications, such as conjugation with the DNA, antibody, protein, etc.<br>**Type of needed action:**<br>Starting from these conditions and relative limits, large scale collaborative project should be focused on the research of the toxicity and degradability of nanoparticles, and preparing it via green chemistry for reducing the environmental pollution as much as possible. Successful development in this area will aid the growth of the various scientific researches or industrial applications as well as improving the quality of life in the population. |
| VC1-005-short | Analysis and process control of dispersion of nanofillers into polymers | Textile and sport sectors/ Packaging | Metrology | **Challenges with respect to the state of the art:**<br>Actually the main important techniques regard in-line analysis of the degree of dispersion of nanofillers in nanocomposites during extrusion through **ultrasonic measurements, near-infrared spectroscopy and light scattering**.<br>**Type of needed action:**<br>Thinking about new solutions ***through collaborative research projects*** among producers and end-users is needed. |
| VC1-006-short | Assess and control potential human exposure during manufacture | Textile and sport sectors/ Energy/ ICT | Materials<br>Modelling<br>Metrology | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC1-007-short | Characterise and control potential release of nanoparticles during wearing and cleaning. Characterise and control potential environmental release and hazards, particularly with regards to release to aqueous systems | Textile and sport sectors | Assembly<br>Final product<br>End of Life | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC1-008-short | Multilayer barrier materials | Packaging/ Energy/ Construction & Building | Tools Material | **Challenges with respect to the state of the art:** Nanocomposite materials currently used, or being developed, for the food packaging industry contains a **polymer plus a nano-additive**. Polymer nanocomposites containing nanoclay particulates are currently leading the food packaging market. However, bio-based nanocomposites (PLA clay, cellulose nanofibres) and metal (oxide)-polymer composites are also being developed for multiple purposes.<br>**Type of needed action:**<br>Chemical and biological processing techniques are needed for obtaining high value barrier materials. A way to develop new products and new manufacturing technologies are ***collaborative research projects (including those targeted to SMEs)***. Some research related to this topic may be included in ***FET-type projects going*** from short to long term actions on integrated multilayer materials (e.g. VC1-005-medium and VC-008 long). |
| VC1-009-short | Cost effective industrial scale technologies for synthesis and technologies for dispersion/ exfoliation (extrusion) | Packaging/ Transportation | Tools Materials | **Challenges with respect to the state of the art:** There are two main challenges in developing nanocomposite materials after the desired polymer has been selected for the purpose. First, the choice of nano-particles requires an interfacial interaction and/or compatibility with the polymer matrix. Second, the processing technique should address proper uniform dispersion and distribution of nano-particles or nano-particle aggregates within the polymer matrix. There is a need for **better understanding of formulation/ structure/ property relationships** to platelet exfoliation and dispersion etc.<br>**Type of needed action:**<br>***Collaborative projects and pilot lines*** on studying processes for improving the Exfoliation and Dispersion, involving machinery producers and their user are needed. |
| VC1-010-short | Characterise and control release of nanoparticles in food contact materials. Understand uptake and hazardous effect of the nanoparticles through the digestive tract. | Packaging | Final product Waste treatment | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC1-011-short | Metal-foam sandwich panel structures Ceramic parts | Transportation | Components | **Challenges with respect to the state of the art:** Metallic foams typically retain some physical properties of their base material. Foam made from non-flammable metal will remain non-flammable and the foam is generally recyclable back to its base material. The main goal of the use of metallic foams in vehicles is to **increase sound dampening, reduce the weight of the automobile, and increase energy absorption in case of crashes**, or in military applications, to combat the concussive force of IEDs. As an example, foam filled tubes can be used as anti-intrusion bars.<br>**Type of needed action:**<br>***Research for the benefit of the SMEs projects and demonstration actions*** are a good instrument to improve foaming technologies. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC1-012-short | Thin glass | Transportation | Materials | **Challenges with respect to the state of the art:**<br>Driven by the need to reduce vehicle weight, the desire for more design freedom, and for higher levels of safety, the automotive industry has been investigating the **substitution of mineral glass windows by polymer**s (more specifically polycarbonate) glazing for decades. However, until recently some key performance specifications had not been reached; scratch resistance and long term ultraviolet (UV) resistance remained challenges. Recent advances involving nanotechnology are helping polycarbonate window developers to overcome these challenges. Due to these advances the automotive sector expects that in 2020, 20% of automotive glazing will be produced from polycarbonate.<br>**Type of needed action:**<br>Different funding scheme are expected to create the basis for a further technology development (***collaborative projects, research for the benefit of SMEs***, etc). |
| VC1-013-short | Assess and control potential human exposure during assembly and finishing of products | Transportation/ Construction & Building | Components Assembly | These safety/standardization tasks need to e***mbedded in the projects of this VC***. Link with NT actions. |
| VC1-014-short | Characterise and control potential release of nanoparticles during waste treatment and reprocessing. Understand potential environmental hazards resulting from recycling processes | Transportation/ Energy/ ICT/ Construction & Building | Final product Waste treatment | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC1-015-short | Nano control of porous structuring | Energy/ ICT | Metrology | **Challenges with respect to the state of the art:**<br>Different parameters are responsible for the porosity of nanostructures: components ratio, process temperatures, etc.<br>**Type of needed action:**<br>For many advanced applications such as double layer supercapacitors the control of porosity at nano-level is very essential. This actions, coupled with medium to long term actions leading to nanoporous materials in assembled products (e.g. VC1-009-medium and VC-011-long), may represent a good example for ***FET-type of projects***. |
| VC1-016-short | Composites | ICT | Materials | **Challenges with respect to the state of the art:**<br>Inorganic materials for composite components are emerging as new class of materials that hold promise for several applications useful for low-cost, macro-scale electronics.<br>**Type of needed action:**<br>Much of this is in fairly mature markets - metal flake ink used for conductors in heated windscreens, membrane keyboards and circuit boards. But ***research projects (using for instance the research for the benefit of the SMEs scheme)*** are needed to improve actual technologies (mixing, blending, sintering. In-situ synthesis, etc.) and find new solutions. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC1-017-short | Control of nanolayer interfaces and adhesion | ICT | Metrology Components | **Challenges with respect to the state of the art:**<br>Molecular nanoglue for enhancing interface strength and toughness by utilizing self-assembling molecular nanolayers (MNL) and thin films within the interface are yet in an embryonic development phase.<br>When sandwiching the interfaces, the resulting structure is 5 times tougher than a classic sealant. Copper/Silica interface. Such high toughness values had previously only been achieved by using much thicker interface layers, which are less desirable for microelectronics. This characteristic could support **applications in extreme environments** like aerospace engines and power turbines, beyond energy production.<br>**Type of needed action:**<br>***Large scale collaborative projects*** can be the best funding scheme to improve adhesion features. |
| VC1-018-short | Composites: development of materials and construction parts | Construction & Building | Tools Materials | **Challenges with respect to the state of the art:**<br>Nano composite steel is more corrosion resistant than conventional steel, and can reduce installation costs and quantity needed. Nano Technology may take building enclosure material composites (coatings, panels and insulation) to dramatic **new levels of performance in terms of energy, light, security and intelligence**.<br>**Type of needed action:**<br>Actually the society is in great search for alternate materials and technology to develop buildings that save the material resources and promotes sustainable built environment. This can effectively be achieved through the emerging field of nano technology. There is wide scope of research for application of nanotechnology in the building industry and it shall help in conserving the material resources. ***Large collaborative projects*** can satisfy this need. |

## VC2 – NANO-ENABLED SURFACES FOR MULTI-SECTORIAL APPLICATIONS

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC2-001-short | Liquid-based deposition processes of nano-enabled thin films on rigid organic and metallic substrates | Wet Engineered | Tools<br>Materials | **Challenges with respect to the state of the art:**<br>Wet processes for the modification of surfaces are **largely applied in industries and numerous processes have been developed and are mature technologies** nowadays.<br>The development towards generating by such wet, nanostructured materials requires in first instance a deeper scientific insight into nucleation and growth processes coupled to advanced on-line process control tools. This is an atomistic process and thus allows a control of the nano-structuring of surfaces down to the scale of atoms. In that sense both types of processes deserve to be addressed in future R&D programs.<br>**Type of needed action:**<br>***Collaborative projects*** are needed, including a wide set of industries and SMEs involved in ***demonstration and pilots***. In fact, good research results are achieved it will be necessary to act intensively on the transfer of know how to SME and medium scale industries coupled to the development of appropriate technical tools allowing the up scaling of the processes in view of large scale applications. |
| VC2-002-short | Design and modelling strategies for improved interface adhesion with substrate and within nano-enabled layers | Wet Engineered/ Plasma and Vacuum Engineered | Modelling<br>Metrology | **Challenges with respect to the state of the art:**<br>The application of nanoenabled layers is **limited in different devices due to their poor adhesion** on substrates. Different methods have been elaborated and should be improved to enhance interfacial adhesion. Examples of solutions $TiCl_4$ treatment or interfacial modification for the.<br>**Type of needed action:**<br>***International collaborative projects*** aimed at providing the technical basis for drafting codes of practice and specifications for advanced materials are needed for providing correct strategies. |
| VC2-003-short | Assess and control potential human exposure during manufacture | Wet Engineered/ Plasma and Vacuum Engineered | Tools<br>Materials<br>Modelling | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC2-004-short | Assess and control potential human exposure during assembly and finishing of products | Wet Engineered/ Plasma and Vacuum Engineered | Components Assembly | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC2-005-short | Characterise and control potential release of nanoparticles during waste treatment and reprocessing | Wet Engineered/ Plasma and Vacuum Engineered | Assembly Final product End of Life | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC2-006-short | Plasma and vacuum based deposition of nano-enabled thin films on rigid and semi-flexible organic and metallic substrates | Plasma and Vacuum Engineered | Tools Materials | **Challenges with respect to the state of the art:**<br>Plasma and vacuum surface modification processes are largely applied in industries and numerous processes have been developed and are mature technologies nowadays.<br>The development towards generating by plasma or vacuum processes, nanostructured materials requires in first instance a deeper scientific insight into nucleation and growth processes coupled to advanced on-line process control tools. **The processes are atomistic processes and thus allow a control of the nano-structuring of surfaces down** to the scale of atoms. In that sense both types of processes deserve to be addressed in future R&D programs.<br>**Type of needed action:**<br>***Demonstration projects and pilot lines*** linked to the other actions of the VC can apply these techniques on large scale for relevant multi-sectorial applications, in close cooperation with designers, manufacturers and end-users. That will be a strong advertisement and an impulse towards further implementation of such materials in engineering. |

## VC3 – STRUCTURED SURFACES

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC3-001-short | 2D & 3D - Plasma treatments optimization and integration on plastic | Energy | Components Assembly | **Challenges with respect to the state of the art:** Surface modification technique uses **low temperature corona discharge plasma to etch and functionalize plastic surfaces to improve adhesion**. Plastics with chemically inert and nonporous surfaces have low surface tensions making them unreceptive to bonding with inks, coatings and adhesives. Plasma treatment of plastics is used in the energy, automotive, medical, packaging, assembly and many other industries. **Type of needed action:** ***Collaborative research actions***, small or medium, are needed. |
| VC3-002-short | 2D - Printing with higher definition (S2S) higher throughput (HE) higher throughput, higher definition (NIL, Litho & Laser ablation and writing | Energy/ ICT/ Textile/ Medicine/ Transportation | Tools Materials Modelling | **Challenges with respect to the state of the art:** Up to now, the technologies have been developed to a point where **demonstration of their use** in specific applications is needed to convince end-users in their applicability towards high throughput, large areas, etc... **Type of needed action:** Collaborative research actions (probably large if several applications should be addressed), ***including pilot lines*** should be proposed. The action should cover: - upscaling of the technology - standardization and metrology issues - prototypes fabrication |
| VC3-003-short | 2D - Large area metal and selective etching (higher throughput, higher definition at labscale) | Energy/ICT/ Textile/ Medicine | Modelling Metrology | **Challenges with respect to the state of the art:** Currently, magnetic nanodot arrays were prepared from **thin film templates** of cylinder-forming polystyrene-polylactide diblock copolymers to obtain cylinder that are etched by $O_2$-reactive ion etching. Metal (MgO, Al_2O_3, GaAs, Al, Cu, SiO_2) was then deposited by molecular beam deposition and finally the polymer mask was lifted off. **Type of needed action:** The generic nature of this methodology allows for the growth of magnetic nanostructures on single crystal substrates. The improvement of molecular lithography and self assembling technologies in order to have higher throughputs require strong research activities in order to evaluate reliability and products, like ***collaborative projects***. |
| VC3-004-short | Assess and control potential human exposure during manufacture | Energy/ ICT/ Textile/ Transportation/Constr.& Building | Tools Materials Modelling | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC3-005-short | Assess and control potential human exposure during assembly and finishing of products | Energy/ ICT/ Textile/ Transportation/ Constr.& Building | Components Assembly | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC3-006-short | Characterise and control potential release of nanoparticles during waste treatment and reprocessing | Energy/ ICT/ Textile/ Transportation/ Constr.& Building | Final product End of Life | These safety/standardization tasks need to ***embedded in the projects of this V***C. Link with NT actions. |
| VC3-007-short | Training on surface metrology and the related physical interpretation | Energy | Modelling Metrology Components | **Type of needed action:**<br>Courses, seminars, etc. should be organised by stakeholders to teach to technicians the instruments for modelling and measuring the nanostructured surfaces. ***This type of task can be embedded to collaborative projects*** of this VC and/ or ***to education actions (mobility programmes, CSAs etc)*** reported in the NTs. |
| VC3-008-short | 2D - Metrology tools for printing, HE, NIL, Laser, Litho… | Textile | Metrology | **Challenges with respect to the state of the art:**<br>The research is currently focused on **design of faster analytical tools for monitoring materials synthesis**, the development of robust and reproducible measurement techniques and sensors and fast online sensing during manufacture.<br>**Type of needed action:**<br>Research for the benefit of the SMEs projects are probably the most suitable funding scheme for continuing along these research areas. |
| VC3-009-short | 2D & 3D - Plasma treatments optimization and integration on fibers and fabrics combined with deposition technologies | Textile | Components Assembly | **Challenges with respect to the state of the art:**<br>Plasma treatment could allow modifying the chemical composition of the surface enabling to produce multifunctional surfaces that cannot easily produce by conventional finishing methods.<br>The new design and optimisation of atmospheric plasma in terms of **process versatility** (gas to be processed, effectiveness of aerosol dispersion of the reactive compounds) must be addressed in order to allow a significant spread of the technology at industrial level.<br>**Type of needed action:**<br>**Collaborative research actions**, small or medium, are needed for the development of novel technologies or processes to be able to combine them in order to demonstrate the potential of engineering surfaces into hierarchical structures, super-hydrophobicity, anti-fouling, drag reduction, etc.. especially controlling surface roughness through plasma parameters optimization. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC3-010-short | Adopt safety by design into material selection | Medicine | Materials Modelling | These safety tasks need to **embedded in the projects of this VC with focus on the medical sector**. Link with NT actions. |
| VC3-011-short | Characterise and control mechanical release of nanoparticles to the surface in biological systems. Understand hazardous nature of the material appropriate to the specific application, and potential translocation of the released material in the human body | Medicine | Final product End of Life | These safety tasks need to **embedded in the projects of this VC with focus on the medical sector**. Link with NT actions. |
| VC3-012-short | 2D & 3D - Plasma treatments optimization and integration on plastic, fibers, metals combined with deposition tech for functionalities, adhesion, painting… | Transportation/ Construction & Building | Components Assembly | **Challenges with respect to the state of the art:** Development of novel technologies or processes to be able to combine them in order to demonstrate the **potential of engineering surfaces into hierarchical structures** demonstrating super-hydrophobicity, anti-fouling, drag reduction, etc.. specially controlling surface roughness through plasma parameters optimization. **Type of needed action:** ***Collaborative research actions*** (probably small or medium) are a good usable funding scheme. |

## VC4 – FUNCTIONAL ALLOYS, CERAMICS and INTERMETALLICS

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC4-001-short | Evaluating compatibility of new materials with existing processing steps Intimate mixing on the nanoscale Evaluation of suitable synthesis strategies with respect to materials quality and high volume production | Energy Harvesting & Conversion/ ICT, Functional Packaging | Tools Material Modelling | **Challenges with respect to the state of the art:** The integration of nanomaterials with existing technologies can dramatically **enhance material performance**. In order to maximize nanomaterial-enhanced performance, nanomaterials must be integrated without destabilizing or agglomerating the material. **Type of needed action:** By understanding and controlling the physicochemical state of the nanomaterial through each step and carefully controlling the processing parameters, nanoparticles can be integrated into the final product and performance optimized. ***Collaborative projects as well as research for the benefit of the SMEs projects*** can be a good scheme to study and develop new integration solutions with existing semiconductor materials. Carbon nano-tubes or graphene-based transistors are unlikely to emerge commercially in few years. |
| VC4-002-short | Characterization - of hosted nanoparticles and nano-aggregate systems: Physical, chemical, phase-structure, size and shape measurements on candidate hosted nanomaterials and nano-aggregates Measurements on material systems created in material synthesis projects | Energy Harvesting & Conversion/ ICT, Functional Packaging | Metrology Components Assembly | **Challenges with respect to the state of the art:** Environmental/technological risk assessments of engineered nanoparticles require thorough characterization of nanoparticles and their aggregates. Furthermore, **quantitative analytical methods** are required to determine environmental concentrations and enable both effect and exposure assessments. Many methods still need optimization and development, especially for new types of nanoparticles in water, but extensive experience can be gained from the fields of environmental chemistry of natural nanomaterials and from fundamental colloid chemistry. Different methods are present in nanoecotoxicology for analysis and characterization of nanomaterials. **Type of needed action:** The strengths of single particle methods, such as electron microscopy and atomic force microscopy, with respect to imaging, shape determinations and application to particle process studies have to be improved, especially in terms of counting statistics and sample preparation. Methods based on the measurement of particle populations have to be improved in terms of their quantitative analyses, but the necessity of knowing their limitations in size range and concentration range should also be considered. ***Collaborative projects*** are the best funding scheme to be proposed. |

## VC5 – FUNCTIONAL FLUIDS

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC5-001-short | Integration of novel materials in existing production and assembly lines (blending, inkjet, R2R) | Transportation/ Constr. & Building/ Medicine & Pharma/ Consumer products/ ICT | Components Assembly | **Challenges with respect to the state of the art:**<br>Different technologies are studied for the deposition of nano liquid materials **into production and assembly lines**. Examples include lubricants for micromechanical parts, UV curable resins, etc. Several bottlenecks are yet evident like the surface compatibility, the creation of proper polymeric nanoarray and specially system integration.<br>**Type of needed action:**<br>***Research for the benefit of the SMEs*** projects ***(or collaborative projects targeted to SMEs)*** as well as ***demonstration projects*** are needed in order to involve highly specialized industries in the development of new solution for integration. |
| VC5-002-short | Cost effective industrial scale technologies for filler synthesis and technologies for dispersion | Transportation/ Constr. & Building/ Consumer products | Tools Materials | **Challenges with respect to the state of the art:**<br>During the last few years industrial scale production facilities for nanomaterials have been established by several manufacturers. The prices for industrial grade **carbon nanotubes** have reached such a level, that they have become realistic **functional filler in polymer (nano) composites for large volume productions**. While trying to realize these nanocomposite materials the experience suggests that for industrial application is much more difficult to disperse even in low viscosity solvents and they react differently to grafting chemistry.<br>**Type of needed action:**<br>Technology improvements are required and ***demo targeted collaborative projects*** can be the proper funding scheme to study and develop new synthesis and dispersion processes. |
| VC5-003-short | Analysis and process control of dispersion of nanofillers into liquid | Transportation/ Constr. & Building/ Medicine & Pharma/ Consumer products/ ICT | Metrology | **Challenges with respect to the state of the art:**<br>Averaged relative transmittance of the suspensions is applied to characterize the dispersion status and a model can be proposed to describe the dispersion behaviour. The **nanofillers in the suspensions typically underwent a procedure of aggregation, sedimentation and stabilization**, successively. The sedimentation period was determined by intrinsic attributes such as chemical composition and structure while the aggregation period was additionally affected by dispersion conditions.<br>**Type of needed action:**<br>***Collaborative projects (small or medium)*** are needed to study these models. |
| VC5-004-short | Assess and control potential human exposure during manufacture | Transportation | Tools Materials Modelling | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC5-005-short | For fuel-based products, characterise and control potential release to the environment from use.<br>Characterise and control potential release of nanoparticles during disposal and waste treatment | Transportation | Final product<br>End of Life | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC5-006-short | Modelling for interface and functionalization particles surface | Constr. & Building/ Medicine & Pharma/ Consumer products | Modelling | **Challenges with respect to the state of the art:**<br>Understanding and controlling the properties of fluid interfaces and functionalization particles is relevant to develop materials of industrial interest (food stuffs, personal care products, cosmetics, pharmaceuticals, painting or lubrication), to design engineering processes, and to understand fundamental scientific problems. There is a need to develop **methodologies to understand, explain and predict the structural and dynamical properties of fluid interfaces**.<br>Interfacial functionalization is important to tune the properties of materials. The possibility of functionalizing interfaces with particles of different sizes is opening a new route to control the interfacial properties and to make a new class of soft materials.<br>**Type of needed action:**<br>***Small collaborative projects*** should aim to bring together experts in computer simulation and theory of interfaces to establish the state of the art the theoretical investigation of the structure and dynamics of interfaces, as well as to delineate short-term objectives for the development of computational tools to assist in the design of functional interfaces. This action should be linked/collaborate with actions reported in VC7. |
| VC5-007-short | Assess and control potential exposure (particularly via the dermal route) of construction workers using these products.<br>Characterise and control potential release to the environment from use of products | Constr. & Building | Final product<br>End of Life | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC5-008-short | Adopt safety by design into material selection | Medicine & Pharma | Materials<br>Modelling | These safety tasks need to ***embedded in the projects of this VC with focus on the medical sector***. Link with NT actions. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC5-009-short | Understand hazardous nature of the material appropriate to the specific route of application, and potential translocation of the released material in the human body | Medicine & Pharma | Assembly<br>Final product<br>End of Life | These safety tasks need to ***embedded in the projects of this VC with focus on the medical sector***. Link with NT actions. |
| VC5-010-short | Modelling of nanoparticles behaviour | Consumer products | Modelling | **Challenges with respect to the state of the art:**<br>Actually there are different **experimental methods for the measurements of the transport of engineered nanoparticles through porous media** in the absence and presence of a non-aqueous phase liquid (NAPL).<br>For instance the transport, retention and accumulation of ferrite nanoparticles and quantum dots in the presence of NAPL (surrogate oil) are measured experimentally in one-dimensional (1-D) columns and two-dimensional (2D) cells.<br>**Type of needed action:**<br>***Collaborative projects*** are useful for re-engineering of current systems, ***including demonstration activities*** needed to implement these experimental methods. |
| VC5-011-short | Improvements in the drug loading efficiency of lipid based nanoparticles and nanocapsules | Consumer products | Tools<br>Materials | **Challenges with respect to the state of the art:**<br>Encapsulation technologies have been widely used for a long time in the pharmaceutical industry for drug delivery applications. **The emergence of nanotechnology and the availability of novel tools have paved the way for new type of particles which can be used for targeted delivery and that can carry drug payloads for localised action.**<br>Different types of nanocapsules are required depending on the nature of the material (hydrophobic or hydrophilic) to be incorporated. The release of the payload could be organised by an external trigger (ultrasound or magnetic field etc.) or the materials can be designed to release the payload depending on the environment (pH, temperature, light exposure etc.).<br>**Type of needed action:**<br>***SME targeted collaborative*** objects are needed, involving consumer product manufacturers, nanotechnology experts and end users. |
| VC5-012-short | Cost effective industrial scale technologies for slurries of nanoparticles for interconnections layers (Copper CMP) | ICT | Tools<br>Materials | **Challenges with respect to the state of the art:**<br>**Chemical mechanical polishing (CMP) is a vital step for planarizing multi-level** and it interconnect structures in ultra large-scale integrated circuit applications.<br>The CMP has become the fastest growing semiconductor manufacturing operation in the past decade and is expected to continue its high growth rate with the emergence of next generation interconnect materials such as copper and ultra-low dielectric constant insulators in the coming decade. However, these next generation interconnects, due to their fragility and poor adhesion, are susceptible to CMP-induced defect formation such as microscratches, copper and barrier peeling, low k damage, dishing, and erosion.<br>The state-of-the-art technologies are starting to use copper CMP using nanoparticle based slurries to reduce the defect formation.<br>**Type of needed action:**<br>***Large collaborative research projects including pilot lines*** should continue with these activities. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC5-013-short | Modelling of nanoparticles and microfluidic behaviour (for microfluidic devices, bio-chips etc.) | ICT | Modelling | **Challenges with respect to the state of the art:**<br>The behaviour of fluids at the microscale can differ from macrofluidic behaviour in that factors such as surface tension, energy dissipation, and fluidic resistance start to dominate the system. Microfluidics studies how these behaviours change, and how they can be worked around, or exploited for new uses. At nano scales some interesting and sometimes unintuitive properties appear. In particular, the Reynolds number can become very low. A key consequence of this is that fluids, when side-by-side, do not necessarily mix in the traditional sense; molecular transport between them must often be through diffusion. **Microfluidic structures include micropneumatic systems**, i.e. microsystems for the handling of off-chip fluids (liquid pumps, gas valves, etc.), and **microfluidic structures** for the on-chip handling of nano- and picolitre volumes.<br>**Type of needed action:**<br>***Demo targeted collaborative projects*** will be focused on modelling emerging application areas for biochips like clinical pathology, especially the immediate point-of-care diagnosis of diseases or microfluidics-based devices, capable of continuous sampling and real-time testing of air/water samples for biochemical toxins and other dangerous pathogens. |
| VC5-014-short | Modelling for optimization of thermal and electrical properties | ICT | Modelling | **Challenges with respect to the state of the art:**<br>Increasing interests have been paid to nanofluids because of the intriguing **heat and electric transfer enhancement performances** presented by this kind of promising transfer media. Thermal conductivity enhancements of nanofluids could be influenced by multi-faceted factors including the volume fraction of the dispersed nanoparticles, the tested temperature, the thermal conductivity of the base fluid, the size of the dispersed nanoparticles, the pre-treatment process, and the additives of the fluids.<br>**Type of needed action:**<br>***Collaborative projects*** (small or medium) between high specialized research centres, will focus on some challenges<br>• Stability of the suspension,<br>• High interfacial thermal resistance,<br>• Large increases in the critical heat flux in boiling heat transfer. |

## VC6 –INTEGRATION OF NANO

| Code | Name of action | Reference market | VC Step | Description |
| --- | --- | --- | --- | --- |
| VC6-001-short | Overall materials and product design system architecture Unified methodologies for design of nano-enabled materials and products | Semifinished/ Direct Manufacturing/ 3D structures/ Catalysis and Filtration | Modelling Metrology | **Challenges with respect to the state of the art:** An effective and efficient nanomaterial development must rely on the **appropriate design of a computational architecture** as well. The computational architecture, together with the algorithms for hierarchical computations, can facilitate design automation with a high computational efficiency: a similar result is achieved with the adoption of unified and internationally recognized methodologies. **Type of needed action:** ***Coordination and support action, linked to collaborative project in this VC***, involving policy makers, industrial associations and end user associations are needed. |
| VC6-002-short | Assess and control potential human and environmental exposure during multiple manufacture routes | Semifinished/ Finished Net Shaped/ Direct Manufacturing/ 3D structures | Materials Modelling | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC6-003-short | Characterise and control potential particle release during extrusion and other processes. Understand potential hazards of composite particles as released from the processes | Semifinished/ Finished Net Shaped/ Direct Manufacturing/ 3D structures | Metrology Components | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC6-004-short | Unified methodologies for design of nano-enabled materials and products | Finished Net Shaped | Modelling<br>Metrology | **Challenges with respect to the state of the art:**<br>Nanometrology and standards is a key pre-requisite for reproducibly measuring key operational characteristics of materials, structures, devices, facilitating also their simulation and design. The next challenges are the **development of methods for measuring properties** for which currently no methods exist; and the ensuring of the traceability, or at least the reproducibility, of existing methods<br>**Type of needed action:**<br>***Large collaborative projects*** are needed, helping industry and SMEs in particular, to access and deploy nanotechnology bringing towards an advancement in existing and new products and advancement of standardisation in the nanotechnology field. Link with VC7 actions is foreseen. |
| VC6-005-short | Characterise and control potential release of particles during manufacture and transport of materials. Understand the hazardous nature of these materials | Catalysis and Filtration | Tools<br>Materials<br>Modelling | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |
| VC6-006-short | Adopt safety by design into material selection | Catalysis and Filtration | Metrology | These safety/standardization tasks need to ***embedded in the projects of this VC***. Link with NT actions. |

## VC7 – INFRASTRUCTURE for MULTISCALE MODELLING and TESTING

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC7-001-short | Connect simulation tools and programs to test and demonstrate capabilities and create reliable benchmarks | Complex Adaptive Systems for complete product design | Components | **Challenges with respect to the state of the art:**<br>**Software tools** give the possibility to simulate new devices without physically building them. Once the software computes and shows all the desired characteristics of a simulated device, then engineers are able to build a prototype, minimizing – and ideally eliminating – the risk of failure. Also **benchmarking** software tools allow comparing the performance of different nanocomponents.<br>**Type of needed action:**<br>***Collaborative projects including a wide set of demonstration activities*** and focusing on the development of this kind of tools, involving producers and customers association are needed. |
| VC7-002-short | Define, build, test a framework and data repository, for integrating test data and calculated data for nano-materials and processes. | Complex Adaptive Systems for complete product design | Materials Modelling | **Challenges with respect to the state of the art:**<br>At present stage are already present some examples of **nanoscience repository of molecular data** for functional and complex materials and protocols for synthesis and modelling of nanostructured systems so as to make the results of nanoscience centres more directly suitable for specific applications developed by technology districts as well as for next generation products manufactured by industries and SMEs.<br>**Type of needed action:**<br>***Coordination and support actions as well as collaborative projects*** will permit to fully exploit emerging e-infrastructures in order to achieve high impact and capillarity in making nanoscience outcome promptly available to society. |
| VC7-003-short | Provide a focus point for integration of all test data collected by the other VCs | Complex Adaptive Systems for complete product design | Metrology | **Challenges with respect to the state of the art:**<br>**Test data integration** collects and saves all test data sets taken for testing the application. Various types and size of input data will be taken for testing the applications, in function of different value chains.<br>**Type of needed action:**<br>A methodology for nanostructured systems in order to make the results of nanoscience centres more directly suitable for specific application should be enhanced through ***coordination and supporting actions***. |

| Code | Name of action | Reference market | VC Step | Description |
| --- | --- | --- | --- | --- |
| VC7-002-short | Multiscale and Multiphysics modelling technologies for a range of material systems and for various key problems (length and time-scales, etc): Cost; Thermal stability;<br>• Material processing including material synthesis processes;<br>• Material growth processes;<br>• Material properties;<br>• Material/process interaction. | Complex Adaptive Systems for complete product design | Assembly<br>Final product | **Challenges with respect to the state of the art:**<br>**Multiscale and multiphysics modelling methodologies are used to predict the complete nanotechnology** processes. They are expected to capture the essential physics and guide the design of nanoproducts, without a large number of expensive, precision experiments.<br>They allow researchers to control and tailor structural properties and to design optimal responses for precise advanced applications.<br>**Type of needed action:**<br>***Large collaborative research projects*** are needed: starting from actual technologies like finite Element (FE) Analyses, they will improve the range of action to solve various key problems. |

# Annex B Medium Term Actions

# Annex B Medium Term Actions

## Non- Technological Cross- Cutting Actions

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| NT1-medium | Regulation | Appropriate level of regulation to address EHS issues whilst supporting innovation | Modelling Metrology | **Challenges with respect to the state of the art:** Appropriate safeguards must be in place to ensure safety of human health and the environment. Specifically, the handling of these nanomaterials needs to be addressed to ensure workers' protection. **Regulation of raw materials** can affect their availability and ultimately the production chain. Hence the regulation of materials is crucial to the successful marketability of nanomaterials. **Type of needed actions:** Furthermore, it is important that such regulation of nanomaterials is harmonized throughout the EU to ensure successful transnational cooperation in development of nanomaterials and to promote innovation. |
| NT2-medium | Regulation | Appropriate level of regulation to address EHS issues whilst supporting innovation | Final Product | **Challenges with respect to the state of the art:** Regulation at the product stage is important for both defining compliance requirements for manufacturers and ensuring the safety and confidence of consumers. The r**egulation of products using nanotechnology and/or nanomaterials** needs to be developed uniformly throughout the EU in line with principles of the internal market and free flow of goods from one Member State to another. **Type of needed actions:** Regulation of products should build upon existing product liability regimes and existing safety testing methods so that products using nanotechnology and/or nanomaterials are not unnecessarily overburdened. It is important that stakeholders provide data to the authorities in this process, so that regulators can build a knowledge base from which appropriate regulation may be drawn. In this way, regulation can be based on representative data rather than hypothetical. |

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| NT3-medium | Education | Greater involvement of industry in academic curriculum development and Learning Factories | All phases | **Challenges with respect to the state of the art:**<br>The Learning Factories on nanotechnology are currently poorly present in Europe. The Learning Factories would provide a unique opportunity for industry sponsors to partner with universities and research institutions to help educate the next generation of World Class nanotechnology researchers using state-of-the-art facilities for design, prototyping, fabrication, etc.<br>**Type of needed actions:**<br>To support the development of nanotechnology degree programs that have strong industrial involvement:<br>• the involvement may span from initial consultation at the start of the programs with little to no further direct contact, to high levels of ongoing contact with industries (i.e., donations of funding and equipment, provision of internship and/or post-program job placement opportunities for students).<br>• Strong outside management and knowledgeable board, with people from industry, are critical to compensate for the ‘knowledge gap’ between academia knowledge and industry needs.<br>• a key issue could be to provide nanotechnology students with practical hands - on experience in “learning factories” through industry-sponsored capstone design projects. |
| NT4-medium | Education | Education on Marketing and Communication Skills | All phases | **Challenges with respect to the state of the art:**<br>While there is an amazing amount of research activities across the world, there is only a limited number of viable ideas with commercial potential. Lots of ‘cool technology’, but will they lead to ‘hot products’? Nanotechnology scientists and engineers must **communicate** more effectively with other sectors of society, technical and non-technical alike, beyond the science and engineering communities. They must put their discoveries and their goals into words that make sense to non-experts.<br>Generic skills and entrepreneurship are needed to translate scientific knowledge into nanotechnology processes and products.<br>**Type of needed actions:**<br>Develop a set of strategies to promote an effective and interdisciplinary education and training of R&D personnel involved in nanotechnology together with a strong entrepreneurial mindset. |
| NT5-medium | Communication & Networking | Effective communication to the EU society on the social and economic impact. To foster more dialogue among policy makers about best practices in nano | Final product<br>End of life | **Type of needed actions:**<br>**Societal and costing product life cycle assessment tools** should provide reports on social and economic impacts, considering also the dismantling solutions.<br>Proper templates for disseminate results on nano at different levels of interlocutors will be prepared.<br>Round tables on how to improve actual technologies, create new practices are an optimal solution in the direction of fostering dialogue. |

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| NT6-medium | Tech Transfer & Innovation Financing | Involvement of investors and Investment readiness programmes for SMEs | Final product End of life | ***Challenges with respect to the state of the art:***<br>The European technological platforms, using their wide network of knowledge are in charge of creating **contacts with possible investors**.<br>**Type of needed actions:**<br>***Coordination and Support Actions as well as Tenders*** can be proposed in order to facilitate networking across European Union.<br>Strong motivation and willingness to participate in SME programmes are a primary condition to warrant the creation of consortiums, highly oriented towards the developments of innovative nano-products. |
| NT7-medium | Tech Transfer & Innovation Financing | New business strategies and business models for nano-enabled products | Modelling Metrology | **Challenges with respect to the state of the art:**<br>It is fundamental an analysis of **most exploitable markets** through assessment of purposes, offerings, strategies, infrastructure, organizational structures, trading practices, and operational processes and policies.<br>**Type of needed actions:**<br>It is necessary to focus the strategic technology business plans in accordance with the market, in order to get a successful and specific business model. This task may be achiede by a ***supporting action***. |
| NT8-medium | Tech Transfer & Innovation Financing | ICT and TT commercialization tools | Final product End of life | **Type of needed actions:**<br>Recent Congressional legislation has boosted the use of some unique and proactive technology transfer tools. These include Cooperative Research and Development Agreements (CRADAs) and patent licenses. ICT tools for disseminating knowledge, promoting TT, are already used in EU projects. Their function can be highlighted and implemented in order to make easier the link between different industrial sectors. |
| NT9-medium | Tech Transfer & Innovation Financing | Support infrastructure for TT service (eco-system of labs and skilled persons) | Modelling Metrology Components | **Type of needed actions:**<br>EU stakeholders are in charge of making available financial support to create new laboratories, research centres, university departments focused on nanotechnologies. These centres will focus on highly specialized researches on what is related to nanotechnology, trying to create also a link with industry R&D centres. |

# Technical Actions

## VC1 – LIGHTWEIGHT MULTIFUNCTIONAL MATERIALS and SUSTAINABLE COMPOSITES

| Code | Name of action | Reference Area | VC Step | Description |
|---|---|---|---|---|
| VC1-001-medium | Nanoporous textiles | Textile and sport sectors | Components<br>Assembly<br>Final product | **Challenges with respect to the state of the art:**<br>Actually the research is focused on **fabric enhanced with nano-porous material** that has different properties: deodorization, antibacterial, colourfastness to seawater, sunlight, emission of far infrared. The technology for obtaining these products are various: electrospinning, chemical synthesis, 3D printing/assembling, (Laser) structuring, pyrolysis of polymer/ceramic networks etc.<br>**Type of needed actions:**<br>Having in mind a specific function a ***R4SME projects*** could be a useful way to develop a new nanoporous textile. |
| VC1-002-medium | Composites with added functionality | Textile and sport sectors/ Packaging | Components | **Challenges with respect to the state of the art:**<br>There is also some potential application of textile nanostructure in the medical sectors for the production of bio miming nanostructure to be used as scaffold in tissue engineering.<br>In particular, the main challenge related with the production of sportswear textile that allow the consumer to **stay dry and comfortable during a sports workout**. For this reason the activities on this specific field should be focus in the improvement of thermo-regulation and in the transpirability of the clothes. While certain combinations of fabric construction, chemical finishes, and garment construction can also keep the body warmer or cooler, depending on the environmental conditions, but often it cannot be combined with the comfort. The application of high porous and light material combining vapour transport and Phase change materials could be applied.<br>**Type of needed actions:**<br>***Collaborative research*** activities among textile producers, polymer producers and end-users are needed. |
| VC1-003-medium | Development of methods for functionalization during synthesis to reduce production steps and alignment of nano-objects | Textile and sport sectors/ Packaging/ Transportation/ Construction & Building | Tools<br>Materials | **Challenges with respect to the state of the art:**<br>In textile/sport sectors it is possible to obtain high core strength, low material weight, cost-effective core materials; it is also possible to obtain simultaneously high material impact resistance, virtually zero water absorption, high dimensional thermal material stability, sound and thermal insulation, for **specific and high value realities**.<br>**Type of needed actions:**<br>To develop correct strategies for reducing production steps ***demo targeted collaborative projects*** appear as the best solution. |

| Code | Name of action | Reference Area | VC Step | Description |
|---|---|---|---|---|
| VC1-004-medium | Porous materials for low-k dielectrics | Packaging | Materials Modelling | **Challenges with respect to the state of the art:** Both porous organic and inorganic materials are used for low dielectric value in packaging sector. Several points have to be improved: ***weakness mechanical properties; lower thermal conductivity***. Pores need to be closed cells to prevent crack propagation and moisture absorption. **Type of needed actions:** The research through different schemes ***(e.g. small collaborative projects)*** can be focused on these areas. |
| VC1-005-medium | Multilayer materials | Packaging/ Energy | Metrology Components | **Challenges with respect to the state of the art:** Multi-layer sheet is used for creating high barrier packaging containers commonly used in aseptic, hot fill, and retort packaging applications. Producers can create both rollstock and containers with very strong oxygen and moisture vapour transmission protection for product **sensitive and long-term shelf life applications**, through layered manufacturing and physical processing. **Type of needed actions:** ***Collaborative research and demonstration*** activities among packaging producers, specialized R&D centres and end-users are needed. This task ***may be included in a large FET-type of project*** including actions from short to long term (e.g. VC1-008-short and VC1-008-long) |
| VC1-006-medium | Adaptation of machines and process parameters to maintain functionalities | Packaging/ Construction & Building | Components Assembly | **Challenges with respect to the state of the art:** The process flexibility according the desired functionality that should be inserted on substrate, requires adaptable machines. **Adaptive controls, automatic controllers** are the challenge for this action in the future. **Type of needed actions:** ***SME targeted projects***, involving high specialized companies could be the best funding scheme. |
| VC1-007-medium | Design of multifunctional materials tailored for different needs | Packaging/ Transportation/ Construction & Building | | **Challenges with respect to the state of the art:** The future of engineering materials is to **manufacture multifunction for Performance-Tailored products**. Multifunctional materials are typically a composite or hybrid of several distinct material phases in which each phase performs a different but necessary function such a structure, packaging, transport, logic, and energy storage. **Type of needed actions:** The achievement of two phase multifunctional systems show the promise of true materials integration; however, the combination of three or more functions including logic, sensing, energy storage, structure, and actuation will be required to achieve truly smart material systems, ultimately analogous to biological systems. A ***large collaborative project*** scheme will be needed. |
| VC1-008-medium | Multilayer materials Thin glass | Transportation | Components | **Challenges with respect to the state of the art:** The state of the art of production of multilayer nano-enabled materials regards **different technologies** like extrusion and adhesive lamination, co-extrusion, physical and chemical thin layers deposition techniques, vacuum deposition processes. **Type of needed actions:** Research projects (e.g. ***demo-targeted collaborative projects***) are needed to overcome some bottlenecks like the multilayer thickness which is a critical feature that determines the functionality of the lipid multilayer structures |

| Code | Name of action | Reference Area | VC Step | Description |
|---|---|---|---|---|
| VC1-009-medium | Metal foams based panels Ceramic parts | Transportation | Assembly Final product | **Challenges with respect to the state of the art:** Metallic foams have an enormous future potential for applications where lightweight combined with **high stiffness and acceptable manufacturing costs** are of prime interest. The metallic foams, in particular those made of aluminium, give the possibility to manufacture different products such as foamed panels, sandwiches, complex 3-D-parts, foamed hollow profiles as well as castings with foamed cores. Moreover ceramics may be the enabling technology for many **critical components in engines of the future** because of their unique heat, wear, and corrosion resistance, light weight, and electrical and heat insulation. Ceramic nanoporous membranes are distinguished by high thermal, chemical and mechanical stability. Most interesting selective materials are amorphous metal oxides (Sol-Gel-Synthesis), Zeolites and carbon. **Type of needed actions:** Projects related on modelling of new processes (materials interaction) of thin glass layers fabrication, are the future of the research. This task ***may be included in a large FET-type of project*** including actions from short to long term (e.g. VC1-015-short and VC-011-long) on porous and foam materials. |
| VC1-010-medium | Composites with added functionality | Transportation/ Construction & Building | Materials Modelling | **Challenges with respect to the state of the art:** Textile nanofibres could be efficiently exploit in this market sector by developing multifunctional nanocomposites not only exhibit excellent **mechanical properties, but also display outstanding combination of optical, electrical, thermal, magnetic and other physic-chemical properties**. The key drivers for the use of polymer nanocomposite-enabled parts in the automotive industry are reduction in vehicle's weight, improved engine efficiency (fuel saving), reduction in CO2 emissions and superior performance (greater safety, increased comfort and better driveability). However, there are still many limitations and challenges for nanocomposites production. These include: Consistency and reliability in volume production: It is possible to get consistency and reliability in volume production materials to a great extent. High lead time: Commercializing the end-use products would take a longer time, mainly due to stringent approval and OEMs acceptance. **Type of needed actions:** ***Collaborative projects*** are required in order to allow the different actors involved to overcome these limitations. |
| VC1-011-medium | Monitoring of materials structure, properties and functionalities | Transportation Construction & Building | Metrology | **Challenges with respect to the state of the art:** Having in mind nanotechnology applications in transport sector, an important action is also monitoring the nanoproducts through **specific system for collecting and storing status.** **Type of needed actions:** ***Collaborative supporting actions*** are needed, involving stakeholders in defining correct procedures. |

| Code | Name of action | Reference Area | VC Step | Description |
|---|---|---|---|---|
| VC1-012-medium | Nanoporous materials in assembled products (gas storage, batteries) | Energy | Assembly<br>Final product | **Challenges with respect to the state of the art:**<br>Nanoporous materials are a special class of nanomaterials of which the key property of interest is their porosity at nanoscale. Nanoporous materials-based products are used in critical cleantech applications, such as energy efficiency (such as building insulation), water treatment, energy storage (Battery electrode materials, supercapacitors) and energy generation. That innovative material can enable economically **viable solutions to critical global issues related to energy and the environment**.<br>Different technologies are available for their production: self-assembly, chemical Synthesis, 3D printing/assembling, (Laser) structuring, pyrolysis of polymer/ceramic networks.<br>**Type of needed actions:**<br>***Collaborative projects*** between all actors of the value chain are needed. |
| VC1-013-medium | Design methodologies for foams production and joining technologies | Energy/ ICT | Materials<br>Modelling | **Type of needed actions:**<br>New technologies for multinanolayering lamination processes, metal etching, self assembling and gluing shall be studied through collaborative research projects which involve manufacturers and R&D high specialized centres. |
| VC1-014-medium | Control of nanolayer interfaces and adhesion | Energy/ ICT | Metrology | **Challenges with respect to the state of the art:**<br>Molecular nanoglue for enhancing interface strength and toughness by utilizing self-assembling molecular nanolayers (MNL) and thin films within the interface are yet in an embryonic development phase.<br>When sandwiching the interfaces, the resulting structure is 5 times tougher than a classic sealant. Copper/Silica interface. Such high toughness values had previously only been achieved by using much thicker interface layers, which are less desirable for microelectronics. This characteristic could support **applications in extreme environments** like aerospace engines and power turbines, beyond energy production.<br>**Type of needed actions:**<br>Tender actions can be the best funding scheme to improve adhesion features. |
| VC1-015-medium | Assembled multilayer materials | ICT | Components<br>Assembly | **Challenges with respect to the state of the art:**<br>New phenomena have been discovered in nano multilayers products and are now being optimized for industrial applications, extending the conventional electronics with new functionality. However, most of the current research on multilayer materials and its device applications rely on conventional equilibrium electron transport. The full potential of **nano-structuring, which leads to a broad spectrum of novel non-equilibrium transport phenomena**, is therefore not realized.<br>Physical and chemical thin layers deposition techniques. Vacuum deposition processes. Photopolymerisation, photocrosslinking are some of the technologies used in assembly nano-multi layer materials.<br>**Type of needed actions:**<br>***Collaborative research projects*** will focus on practically unexplored functional principles that can be implemented in nanostructures produced by state-of-the-art lithography and surface manipulation techniques. |

| Code | Name of action | Reference Area | VC Step | Description |
|---|---|---|---|---|
| VC1-016-medium | LCA of the process and integration of wastes in the LCA analysis | Construction & Building | End of life | **Challenges with respect to the state of the art:**<br>Life Cycle Assessment (LCA) is emerging as one of the most functional assessment tools. LCA results help answer numerous **questions** that arise during the **design and construction of a green building**.<br>**Type of needed actions:**<br>The EU can promote ***tenders or coordination and support projects*** in order to define an exactly methodology for building assessment that takes into account also the use of nanomaterials for multiple purposes. |
| VC1-017-medium | Multilayer components | Construction & Building | Metrology Components | **Challenges with respect to the state of the art:**<br>The roof industry has been “built-up” **systems** in which various components where laid down in a series of layers **to achieve soil containment, water retention, and drainage**. In addition panel for both structural and aesthetic uses have been designed with incorporation of nano particles for fire protection, water retentions, etc. Extrusion and adhesive lamination to produce multilayering are the more common technologies.<br>**Type of needed actions:**<br>***Demo targeted collaborative projects*** may be a great occasion to develop new products: the participation of end-user, panel producers, building constructor associations is needed. |

## VC2 – NANO-ENABLED SURFACES FOR MULTI-SECTORIAL APPLICATIONS

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC2-001-medium | Integration of novel nano-enabled surfaces on common rigid engineering materials into existing industrial production and assembly lines | Wet Engineered/ Plasma and Vacuum Engineered | Components Assembly | **Challenges with respect to the state of the art:**<br>The aim for the next years is the development and integration of the enabling technologies of the future, such as **engineering technologies for adaptable machines and industrial processes, ICT, and advanced materials**<br>**Type of needed actions:**<br>The stakeholders will work together to identify the R&D needs of manufacturing industry and in particular SMEs: a large part of the activities in the projects is expected be performed by industrial organisations themselves. The final objective of the ***SME targeted projects*** is the fast integration of advanced technologies and new business strategies for the industrial implementation of greener production approaches. |
| VC2-002-medium | Process upscaling for deposition on rigid organic and metallic sheet materials | Wet Engineered | Tools Materials | **Challenges with respect to the state of the art:**<br>**Nanopatterning, kinetic deposition methods, thin and thick coatings** are actually the state of art of deposition on rigid organic and metallic sheet materials.<br>**Type of needed actions:**<br>***Projects oriented on the benefit of the SMEs (research and demo)*** should be a great occasion for processes upscaling. |
| VC2-003-medium | High speed characterization of nano-enabled thin films on rigid substrates and combinatorial approaches | Wet Engineered | Metrology Components | **Challenges with respect to the state of the art:**<br>Combinatorial library approaches are used for **measuring and optimizing the effect of substrate chemical functionalization** on the structure and performance of polymer thin film materials and rigid devices. Fabricated via novel combinations of self-assembly, microfluidic, soft-lithography, and surface-initiated polymerization, these are instruments for designing advanced polymeric coatings and surface functional layers.<br>**Type of needed actions:**<br>***Collaborative research projects*** will be focused on the tribo-mechanical characterization of ultra thin films, allowing for scratch hardness and scratch adhesion evaluation on a nano level. |
| VC2-004-medium | Process development for deposition on semi-flexible and flexible substrate materials | Wet Engineered | Tools Materials | **Challenges with respect to the state of the art:**<br>**Thermal spray** technologies (air or controlled atmosphere), atomic/molecular deposition technologies (CVD, PVD, sputtering,...), **wet chemistry** (in-situ, sol-gel, polymerisation, inkjet,...), **layer-by-layer** deposition are the actual reliable technologies for deposition on semi-flexible substrate.<br>**Type of needed actions:**<br>The demonstration of the process validity needs to be addressed in close cooperation with designers, manufacturers and end-users. The added value of nanostructured materials has to be demonstrated in priority with a few most successful case studies ***(demonstration projects/ pilot lines)***. That will be a strong advertisement and an impulse towards further implementation of such materials in engineering. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC2-005-medium | Modelling high energetic beam interactions at e-/T conductive or non-conductive surfaces | Plasma and Vacuum Engineered | Modelling Metrology | **Challenges with respect to the state of the art:**<br>In a **high energy beam interaction**, the primary electron beam is accelerated to and focused on a high atomic number target in order to generate X-rays. The huge energy density deposited into the material is such that temperature rises up to 15000°K and that clusters and particles are violently ejected from the surface. In that mechanism, the backward emission speed can reach 5 $km/s^{-1}$ and the debris can gradually accumulate and subsequently contaminate some sensitive parts of the machine.<br>**Type of needed actions:**<br>In order to protect the whole accelerating line from the detrimental effect of back-ejected particles, ***large collaborative research projects*** involving R&D centres should investigate on the technical feasibility of a thin foil implementation upstream the X-ray converter. |
| VC2-006-medium | Industrial upscaling of nano-enabled deposition on rigid and semi-flexible sheet materials | Plasma and Vacuum Engineered | Tools Materials | **Challenges with respect to the state of the art:**<br>**Nanopatterning, kinetic deposition methods, thin and thick coatings** are actually the state of art of deposition on rigid and semiflexible sheet materials. Projects oriented on the benefit of the SMEs should be a great occasion for processes upscaling.<br>**Type of needed actions:**<br>Once that will be achieved it will be necessary to act intensively on the transfer of know how to SME and medium scale industries coupled to the development of appropriate technical tools allowing the up scaling of the processes in view of large scale applications. |
| VC2-007-medium | High speed characterization of complex architectured nano-enabled thin films on flexible substrates and combinatorial approaches | Plasma and Vacuum Engineered | Components | **Challenges with respect to the state of the art:**<br>**Combinatorial library approaches** are used for measuring and optimizing the effect of substrate chemical functionalization on the structure and performance of polymer flexible thin film materials and devices. Fabricated via novel combinations of self-assembly, microfluidic, soft-lithography, and surface-initiated polymerization, these are instruments for designing advanced polymeric coatings and surface functional layers.<br>**Type of needed actions:**<br>***Collaborative research projects*** will be focused on the tribo-mechanical characterization of ultra thin films, allowing for scratch hardness and scratch adhesion evaluation on a nano level. |
| VC2-008-medium | Industrial selective deposition of nano-enabled thin films with tailored functionalities on flexible substrates into novel devices and/or with molecular control of thickness and composition | Plasma and Vacuum Engineered | Assembly Final product | **Challenges with respect to the state of the art:**<br>**Thermal spray technologies** (air or controlled atmosphere), **atomic/molecular deposition technologies, sputtering, layer-by-layer deposition**, nanopatterning, lithography are some of the nano deposition technologies, that enable the creation of thin but complex structures with properties tailored by controlling the molecular makeup and arrangement.<br>***Type of needed actions:***<br>***Collaborative and SME targeted projects, including pilot lines and demonstration activities*** should deepen the knowledge of internal structure of layers and the dynamic interaction between film components. |

## VC3 – STRUCTURED SURFACES

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC3-001-medium | 3D - 3D + time (4-dimensional) modelling of processes (design mould) | Energy/ Medicine/ Transportation/ Constr. & Building | Modelling Metrology | **Challenges with respect to the state of the art:** Layer wise deposition of extruded filaments is a technique for the **fabrication of scaffolds**, originating in the field of Rapid Prototyping. Strands of scaffold material are plotted in a 2D pattern, forming a single layer, upon which the next layer is then built, and so on, until a 3D construct is achieved. This production method allows for good control over scaffold geometry and porosity. **Type of needed actions:** ***Demo targeted collaborative projects*** are needed for improving some technical aspects in modelling 3D processes: process temperature reduction, process control. |
| VC3-002-medium | 2D & 3D - Metrology for process and functional properties analysis | Energy/ ICT/ Textile/ Medicine/ Transportation/ Constr. & Building | Metrology Components | **Challenges with respect to the state of the art:** The performance of nanoenabled products (like solar cells) depends on a number of parameters such as film thickness, substrate texture, accurate contact finger formation and wafer edge quality. Surface texture could be evaluated through automated 2D or 3D **Measurement System** that offer true colour analysis and imaging of complicated surface in less than 1 min for each site. **Type of needed actions:** ***Coordination and support actions***, including also standardization committees can be useful to draw up future 3D surface texture standards and improve technologies. |
| VC3-003-medium | 2D – Integration of technologies with increased throughput and definition (S2S, HE, NIL, Laser, Litho…) | Energy/ ICT/ Textile/ Medicine | Components Assembly | **Challenges with respect to the state of the art:** The technologies integration is the incorporation of technology resources and technology-based practices into the standard manufacturing chain. **Type of needed actions:** ***Research for the benefit of the SMEs*** projects could warrant integration be routine, seamless, and both efficient and effective in supporting school goals and purposes. |
| VC3-004-medium | 2D - Molecular lithography and self-assembling on larger area, reliable at pilot/ production scale | ICT/Medicine | Tools Materials | **Challenges with respect to the state of the art:** Actual challenges are the development of **new polymeric materials with improved performance** in terms of functionality and self assembling properties to be used in lithography (i.e. block copolymers”). **Type of needed actions:** ***Collaborative research actions*** can be the most adapt funding scheme. |

## VC4 – FUNCTIONAL ALLOYS, CERAMICS and INTERMETALLICS

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC4-001-medium | Synthesis of 'hosted' nano particle systems: synthesis strategies for size control in the range of 1nm, including interface recombination | Energy Harvesting & Conversion | Tools<br>Materials<br>Modelling | **Challenges with respect to the state of the art:**<br>**Synthesis strategies** for size control in the range of 1nm comprise interface recombination, modelling of chemical composition, size and optoelectronic properties modelling as a function of growth conditions. Moreover the control of cost for large-scale systems is required. Different technologies are available: Molecular Beam Epitaxy, Metal Organic Chemical Vapour Deposition, wet and dry chemical/physical methods (e.g. sol-gel, evaporation/condensation).<br>**Type of needed actions:**<br>***Collaborative projects*** are needed. |
| VC4-002-medium | Modelling of chemical composition size and optoelectronic properties as a function of growth conditions for hosted nano particle systems | Energy Harvesting & Conversion | Metrology<br>Components | **Challenges with respect to the state of the art:**<br>The **enhanced functionality and tunability of electronic nanomaterials** enables the development of next-generation photovoltaic, optoelectronic, and electronic devices, as well as biomolecular tags. Design and efficient synthesis of such semiconductor nanomaterials require a fundamental understanding of the underlying process-structure/composition-property-function relationships.<br>**Type of needed actions:**<br>Large ***collaborative projects*** are needed to deeply study these models. |
| VC4-003-medium | Synthesis of 'hosted' nano particle/nanowires/ nanotubes/ 2D monolayer systems: Synthesis strategies for size control, including interface recombination | ICT, Functional Packaging | Tools<br>Materials<br>Modelling | **Challenges with respect to the state of the art:**<br>Nanotechnology has recently attracted a vast amount of research attention, and has become a subject of intense scientific interest. Particularly, the inexpensive formation of periodically **ordered structures** (e.g., nanopore, nanotubes and nanowire arrays) with a periodicity lower than 100 nm, for functional packaging is one of the challenges for next activities in research.<br>**Type of needed actions:**<br>Synthesis strategies for size control comprise interface recombination, modelling of chemical composition, size and optoelectronic properties modelling as a function of growth conditions. Moreover the control of cost for large-scale systems is required.<br>Different technologies are available: Molecular Beam Epitaxy, Metal Organic Chemical Vapour Deposition, wet and dry chemical/physical methods (e.g. sol-gel, evaporation/ condensation).<br>***Collaborative projects*** are needed. |
| VC4-004-medium | Modelling of chemical composition size and barrier properties as a function of growth conditions for hosted nano systems | ICT, Functional Packaging | Metrology<br>Components | **Challenges with respect to the state of the art:**<br>The addition of certain **nanoparticles into shaped objects and films** has been shown to render them light, fire-resistant and stronger in terms of mechanical and thermal performance, as well as less permeable to gases. New packaging solutions will focus more on food safety by controlling microbial growth, delaying oxidation, improving tamper visibility, and convenience.<br>**Type of needed actions:**<br>***Large collaborative projects*** are needed between high specialized R&D centres, specialized producers and end user should be founded. |

## VC5 – FUNCTIONAL FLUIDS

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC5-001-medium | Adaptation of existing tools for direct use or integration in devices of novel multi-fluids | Transportation/ Constr. & Building | Components Assembly | **Challenges with respect to the state of the art:**<br>Nanofluids have a great scientific interest because they surpass the fundamental limits of conventional macroscopic theories of suspensions. Furthermore, **nanofluids technology** can provide new opportunities to develop nanotechnology-based coolants for a variety of innovative applications.<br>**Type of needed actions:**<br>The research, through ***collaborative projects*** should focus on tools improvements for each type of nanofluids. |
| VC5-002-medium | Design of multifunctional materials tailored for different needs | Transportation/ Constr. & Building/ Medicine & Pharma | Modelling | **Challenges with respect to the state of the art:**<br>Smart Materials are materials that can respond to environmental stimuli by **exhibiting particular changes** in some of their properties. Depending upon the change in some external condition, a smart material can change its own characteristics (mechanical, electrical, appearance), structure, composition and/ or response. These materials are usually embedded into systems whose inherent properties change favourably in order to meet performance needs.<br>**Type of needed actions:**<br>Barriers specific to multifunctional materials development and use include a lack of multifunction modelling and design tools; ***large collaborative projects*** should answer to the need to develop a relevant and expanded (truly multifunctional at many size scales) metrology base and they should strengthen the potential complexity of the supply chain that will be needed in the production and exploitation of products incorporating this technology. |
| VC5-003-medium | Monitoring of materials structure, properties and functionalities | Transportation/ Constr. & Building/ Medicine & Pharma/ Consumer products/ ICT | Metrology | **Challenges with respect to the state of the art:**<br>**Comprehensive knowledge** over the shape of nanomaterials is a critical factor in designing devices with desired functions. Thematic efforts have been made to find various parameters that directly affect the intrinsic properties, structure and functionalities of nanomaterials<br>**Type of needed actions:**<br>***Collaborative projects*** (probably at small scale) involving R&D centres, laboratories and users are needed in order to define and provide new monitoring solutions. |
| VC5-004-medium | Methods for functionalization during synthesis to reduce production steps of nanofillers | Medicine & Pharma | Tools Materials | **Challenges with respect to the state of the art:**<br>Actually synthesis and functionalization methods are separated in different production steps. One of the main objectives is the **integration of some production steps**, in order to achieve major efficiency, space reduction, cost decrease and eventually better environmental performances.<br>**Type of needed actions:**<br>To develop correct strategies for reducing production ***steps demo targeted collaborative projects*** appear as the best solution, focusing of intelligent tools and reliable materials. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC5-005-medium | In vivo studies: effective testing and monitoring of material behaviour in use | Consumer products | Metrology Components | **Challenges with respect to the state of the art:** Assessing the Safety of Nanomaterials in Cosmetic Products is an important metrology issue. The safety assessment for cosmetic products using nanomaterials should address the physic-chemical characteristics of the nanomaterials, impurities, if present, and the potential product and ingredient exposure levels to help determine what other testing may be needed. The **safety assessment** should include consideration of the toxicity of both the ingredients and their impurities; dosimeter for in vitro and especially in vivo toxicology studies, if needed; and clinical testing, if warranted. The safety assessment should also address the issues of toxicokinetics and toxicodynamics. The overall package of data and information should substantiate the safety of the product under the intended conditions of use. **Type of needed actions:** ***Collaborative projects linked with a and support action*** involving producer associations are needed to continue with these activities and develop standards and SOPs. |
| VC5-006-medium | Reproducible and cost effective lab scale production of safe cosmetics | Consumer products | Components Assembly | **Challenges with respect to the state of the art:** The applications of nanotechnology and nanomaterials can be found in many cosmetic products including moisturisers, hair care products, make up and sunscreen. The production process needs improvement to increase **loading capability and stop expulsion of the contents during storage**. The research for reproducibility and cost effectiveness should take care also of safety assessment procedure for all products containing nanomaterials, which could lead to a ban on a substance if there is a risk to human health. **Type of needed actions:** ***Research for the benefit of the SMEs*** actions will analyze these issues. |

## VC6 –INTEGRATION OF NANO

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC6-001-medium | Reactive/In Situ production In process generation of the nano-features | Semifinished/ Direct Manufacturing | Materials | **Challenges with respect to the state of the art:**<br>The main objective of this action is offering **custom fabricated semi finished components from advanced materials**, including nanofoams and nanopowders.<br>An example is the conception and the realization of the in-situ production of single walled carbon-nanotube (SWCNT) based semi finished products. This technology includes the SWCNT-formation by carbon evaporation (by laser or arc discharge) in an elongated reactor with various reaction zones. The formation takes place in a continuous gas flow. In additional reaction zones a gas phase reaction for SWCNT-elongation is stimulated, followed by steps for gas phase cleaning, plasma functionalization and forming of semi finished products (for example bucky papers).<br>**Type of needed actions:**<br>***Collaborative projects including demonstration activities and pilots*** are needed in order to pursue the objective of safe, integrated and controlled production of multifunctional nanostructured products including their recycling and ensuring competitive production technologies. |
| VC6-002-medium | Nanomaterials extrusion, rapid solidification, electrochemical deposition, tape casting, block co-polymerization | Semifinished | Components Assembly | **Challenges with respect to the state of the art:**<br>All these processes are more or less in a consolidate **industrialization state**: they produce semifinished products that obviously need further processing before being a finished good.<br>**Type of needed actions:**<br>The research should be focused on the performance optimization, elimination of bottlenecks, reliability increase: for this reason ***demo targeted collaborative projects*** are needed. |
| VC6-003-medium | Colloidal chemistry, micells, source nanomaterials Coatings, self assembling, etching, sintering | Semifinished/ Catalysis and Filtration | Tools Materials | **Challenges with respect to the state of the art:**<br>The potential technological applications of nanoparticle coatings necessitate the development of rapid, inexpensive and easily controlled **deposition procedures**.<br>**Type of needed actions:**<br>***Demo targeted collaborative projects*** are needed in order to provided the means to control and tune the coating structure and properties. |
| VC6-004-medium | Large scale, low cost source of nanomaterials {Obtained by Friction, Plastic deformation, Supercool laser, Self-assembly/ phase separation (organic), In situ crystallization} | Semifinished/ Finished Net Shaped/ Catalysis and Filtration | Tools Materials | **Challenges with respect to the state of the art:**<br>Successful adaptation of nanotechnology in the end-products requires an **access to the nanofiller technology and to the raw materials**.<br>**Type of needed actions:**<br>There is the need to develop an efficient, continuous method of large-scale, low-cost synthesis of such materials. To answer to this need the following steps are suggested:<br>1) Integrate the functionalization of the high-quality nanoparticles directly on the continuous mass-production process already in the mining industry,<br>2) ensure controlled dispersion to the matrix material in large scale by cooperation between nanoparticle producer and end-product manufacturer,<br>3) assure sustainable and safe production and use by state-of-the-art life-cycle analysis.<br>All these steps can be improved and deeply analyzed in large collaborative projects. This action may be include in a ***large pilot line type of project***. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC6-005-medium | 3D manufacturing control, Process control, analytical control, Material interfaces, Extrusion | Semifinished/ Catalysis and Filtration | Metrology | **Challenges with respect to the state of the art:**<br>Nanotechnological intermediary and final products are already produced in several branches, such as nanoparticles or nanosurface coatings. Further products are also expected. Here **automation** is increasing and **process control** is becoming increasingly complex and meaningful.<br>The role of controlling procces subsystem in innovative activity of textile enterprises is important.<br>**Type of needed actions:**<br>***Collaborative research projects (small or medium)*** are useful in order to make process control systems as much as possible dynamic and self consistent. |
| VC6-006-medium | Effective funding actions for SMEs and integration of them in EU value chain<br>Support to SMEs in successful IPR management | Semifinished/ Finished Net Shaped | Metrology Components Assembly Final product | **Type of needed actions:**<br>Promote research through different and appropriate funding schemes **(incentives to SMEs, research and demonstration actions for the benefit os SMEs and SME-Ags, CSAs, training courses)**. The projects should be aware of current and past initiatives in education and networking (e.g. NT actions). |
| VC6-007-medium | Clustering and networking among different sectors, opening new market opportunities | Semifinished/ Finished Net Shaped | Assembly Final product End of life | **Challenges with respect to the state of the art:**<br>Cluster initiatives and company networks are important instruments for economic development and innovation policy especially in case of SMEs. They contribute considerably to the competitiveness of regions of all sizes in terms of creation of a regional profile and fostering sustainability and research by supporting especially SMEs.<br>**Type of needed actions:**<br>The two key elements are the development of:<br>• Quality Guidelines for effective cluster management on policy level: (cross-regional co-operation, strategic linkage on all levels, active participation of cluster companies, clear organisational structures, long-term financial support) and on management level: consensus on cluster strategy, services of cluster initiatives e.g. in field of networking, information & communication, opening of international markets.<br>• Common strategic issues for future innovation and cluster policy on policy and administration level (focus on cluster initiatives in EU programmes, cross-border co-operation of clusters, international visibility of EU clusters, sustainable cluster policy, co-operation between R&D and entrepreneurs, give companies a steering role in cluster initiatives) and on cluster and network initiatives level (platform for EU cluster initiatives, closer cooperation universities-R&D-companies, high qualification for cluster companies and trainings for cluster managers, access to global markets).<br>Such tasks may be carried out by ***CSA type of projects***. |
| VC6-008-medium | Blending/mixing generating master batches/'vehicles' for nano functionalization, solution based techniques | Finished Net Shaped | Assembly Final product | **Challenges with respect to the state of the art:**<br>A significant challenge faced in the use of nanoscale building blocks is developing parallel methods for ***interconnecting and patterning assemblies of the individual components***. Several studies demonstrate that nanolithography (the arrangement of nanoscale building blocks) is a viable approach to interconnecting individual devices into extended, closely spaced assemblies.<br>**Type of needed actions:**<br>***Small collaborative projects***, involving partners from entire value chain are needed. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC6-009-medium | Tooling and process for Plasma sintering and net shaped rapid forming | Finished Net Shaped | Tools Materials | **Challenges with respect to the state of the art:**<br>Plasma Sintering is a relatively **new rapid forming** technique to fabricate complex and near net-shaped components with fairly good mechanical properties.<br>**Type of needed actions:**<br>***Demo targeted (small and medium) collaborative projects*** focusing on key processing issues related to final sintered and relation to the resulting mechanical properties, are needed. |
| VC6-010-medium | Assembly of nanoalloys/ ceramics/ composites at large scale for metal based finished products (Rapid consolidation, additive manufacturing) | Direct Manufacturing/ Catalysis and Filtration | Components Assembly | **Challenges with respect to the state of the art:**<br>Production of bulk nanostructured or nanocomposite materials (metallic, ceramic, and polymeric/composite types) was demonstrated a long time ago and the superior property and performance characteristics of these novel materials have been demonstrated under a wide range of application conditions. In particular, ceramic-based nanostructured or composite materials have recently become very popular in **applications related to metal based finished products** (used in military, aerospace, electronics, medical, wind energy (Turbines), oil drilling (Pumps), etc.).<br>**Type of needed actions:**<br>***Demo targeted collaborative projects***, probably focusing on specific sectors are needed. |
| VC6-011-medium | Reactive/In Situ production and Structure Refinement | 3D structures | Materials | **Challenges with respect to the state of the art:**<br>The main objective of this action is offering **custom fabricated 3D product**.<br>An example of technology is the annealing process was utilized. The annealing procedures included: heating the sample to 120°C at a rate of 20°C/sec and maintaining that temperature for 40 minutes; then cooling the sample in the open air to room temperature.<br>**Type of needed actions:**<br>***Research for the benefit of the SMEs*** projects are needed in order to pursue the objective of safe, integrated and controlled production of multifunctional nanostructured products including their recycling and ensuring competitive production technologies. |
| VC6-012-medium | Nanomaterials electrochemical deposition, tape casting, block co-polymerization, self assembly, (chemical/physical/ mechanical deposition) Printing | 3D structures/ Catalysis and Filtration | Components Assembly | **Challenges with respect to the state of the art:**<br>Various materials, including semiconducting, magnetic, noble metallic, and insulating materials, can be used to form three-dimensional (3D), complex nanostructures with controlled composition and physical properties.<br>Different technologies are present for **coating, deposition, printing** (like Atomic Layer Deposition) onto 3D device architectures involving nanowire/tube arrays.<br>**Type of needed actions:**<br>***Demo targeted collaborative*** projects should provide a solution for the fabrication of 3D devices having complex, high-aspect-ratio surfaces by coating active and/or passive materials such as semiconducting, insulating, and metallic layers. |
| VC6-013-medium | Self-assembly/ phase separation (organic), In situ crystallization | 3D structures | Tools Materials | **Challenges with respect to the state of the art:**<br>It is well-know that the self-assembling techniques, in situ crystallization are among the promising approaches in “bottom-up” strategy in nanoscience and nanotechnology.<br>These seek to arrange **smaller components into more complex assemblies**, against Top-down approaches that seek to create smaller devices by using larger ones to direct their assembly.<br>**Type of needed actions:**<br>All these technologies can be improved and deeply analyzed in ***large collaborative projects***. |

## VC7 – INFRASTRUCTURE for MULTISCALE MODELLING and TESTING

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC7-001-medium | Second framework implementation to support the second generation of nanotechnology (from passive to active nanostructures to nanosystems) and model materials alongside test data. | Complex Adaptive Systems for complete product design | Materials Modelling Metrology | **Challenges with respect to the state of the art:** It has been suggested that an important transition in the long-run trajectory of nanotechnology development is a shift from passive to **active nanostructures** and then to nanosystems. Such a shift could present different or increased societal impacts and require new approaches for risk assessment. An active nanostructure "changes or evolves its state during its operation," according to the National Science Foundation's (2006) Active Nanostructures and Nanosystems grant solicitation. Active nanostructure examples include nanoelectromechanical systems (NEMS), nanomachines, self-healing materials, targeted drugs and chemicals, energy storage devices, and sensors. The modelling framework to support the design and testing of such passive and active structures should be developed. **Type of needed actions:** ***Collaborative projects as well as one or more Research Infrastructures*** projects are needed. |
| | FOCUS on Safety: Implementation of a Centre of Excellence to help SMEs understand the issues, quantify and certify the materials, products and processes (in characterisation, hazard and exposure assessment). Includes services for SMEs, use of standard protocols, data repository, use of reference materials. Intended to be a service centre, not a research centre. | Complex Adaptive Systems for complete product design | Modelling Metrology Components Assembly | **Challenges with respect to the state of the art:** There is strong need for an **independent centre of excellent focused on nanosafety issues**, including services to SMEs. This centre should receive public but also investment and support from stakeholders and other European and national initiatives **Type of needed actions:** ***Tenders*** may be a good possibility to fund the initial development of such centre. |

# Annex C Long Term Action

# Annex C Long Term Action

## Non- Technological Cross- Cutting Actions

| Code | Reference Area | Name of action | VC Step | Description |
|---|---|---|---|---|
| NT1-long | Communication & Networking | Extra EU trans-national cooperation & Networking | All | **Challenges with respect to the state of the art:**<br>The EU stakeholder (researchers, universities, industries, policy makers) should use their international contacts, for creating **links with foreign institutions, entrepreneurs, laboratories**.<br>The actions could be focused on specific geographical areas, in function of expected markets sizes and customers interests.<br>**Type of needed action:**<br>***CSAs*** to bring together academia, industry and relative organizations of all world countries in order i) to define skills needs for nanotechnology related positions (scientist and technicians), ii) Examine the success of nanotechnology programs graduates in the labour market and iii) help policymakers to identify program elements that are important to foster the development of particular types of program models in the future.<br>The creation and use of regional and cross-sectorial alliances and partnerships, among government, industry, the academic community and the research and development community, should be strongly emphasized as a means of addressing many, if not all, of the key policy issues and challenges related to skills development in the 21st Century. |

# Technical Actions

## VC1 – LIGHTWEIGHT MULTIFUNCTIONAL MATERIALS and SUSTAINABLE COMPOSITES

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC1-001-long | Nanoporous textiles | Textile and sport sectors | Components<br>Assembly<br>Final product | **Challenges with respect to the state of the art:**<br>Actually the research is focused on **fabric enhanced with nano-porous material** that has different properties: deodorization, antibacterial, colourfastness to seawater, sunlight, emission of far infrared. The technology for obtaining these products are various: electrospinning, chemical synthesis, 3D printing/ assembling, (Laser) structuring, Pyrolysis of polymer/ceramic networks.<br>**Type of needed actions:**<br>Having in mind a specific function a ***R4SME project*** could be a useful way to develop a new nanoporous textile. |
| VC1-002-long | Adaptation/ modification of novel technologies for production on industrial scale smart polymer; implementation of these materials into different devices | Textile and sport sectors/ Transportation | Components<br>Assembly | **Challenges with respect to the state of the art:**<br>Actually **nanoenabled smart polymers** are used for the production of hydrogels, biodegradable packaging, and to a great extent in biomedical engineering.<br>**Type of needed actions:**<br>The ***collaborative research*** should be focused on new chemical and biological processes through tenders action or collaborative projects.<br>There are feasible applications that appear to be coming in the near future: for instance environmental biotechnology, smart irrigation. |
| VC1-003-long | Understanding of relationships morphology/ functionality/triggers of multifunctional polymers | Textile and sport sectors/ Transportation | Modelling<br>Metrology | **Challenges with respect to the state of the art:**<br>The actual strengths in this field are focused on the **synthesis and behaviour assessment of materials** that can respond in situ to a variety of stimuli (ionic strength, pH, temperature, and shear stress): for instance in Enhanced Oil Recovery (EOR) processes. Through the utilization of these advanced multifunctional polymers, the ability to recover more of the original oil in place and a larger portion of that by-passed or deemed "unrecoverable" by conventional chemical flooding should be possible.<br>**Type of needed actions:**<br>Projects promoted S***ME-targeted collaborative projects*** are needed. |
| VC1-004-long | Low cost and large scale functionalized composites | Transportation/ Construction & Building | Assembly<br>Final product | **Challenges with respect to the state of the art:**<br>The use of advanced composite materials in commercial transport primary and secondary structures has continued to increase with the introduction of each new product.<br>One of the primary challenges facing the transportation industry in the next decade is to fully obtain the **performance benefits of composite** materials while dramatically lowering production and operating cost with a minimal impact on the environment.<br>**Type of needed actions:**<br>***Large scale collaborative projects*** among producers, end-users and R&D centres are needed focusing both on new processes Mixing, blending, sintering, in-situ synthesis) that new materials and functionalization. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC1-005-long | Multilayer materials Thin glass | Transportation/ ICT | Components | **Challenges with respect to the state of the art:** The state of the art of production of multilayer nano-enabled materials regards different technologies like extrusion and adhesive lamination, co-extrusion, physical and chemical thin layers deposition techniques, vacuum deposition processes. **Type of needed actions:** Research projects ***(demo-targeted collaborative projects)*** are needed to overcome some bottlenecks like the multilayer thickness which is a critical feature that determines the functionality of the lipid multilayer structures |
| VC1-006-long | Advanced smart multifunctional foams | Transportation | Assembly | **Challenges with respect to the state of the art:** Nano-enabled foams and honeycombs exhibit, apart from this unusual deformation, **enhanced structural integrity, sound absorption and dielectric loss** compared to analogous material with more classical mechanical behaviour. **Type of needed actions:** ***Collaborative projects.*** |
| VC1-007-long | Characterization and monitoring of materials structure, properties and functionalities | Transportation/ Construction & Building | Metrology Components | **Challenges with respect to the state of the art:** Future composite technology research and Development efforts must focus on new low cost material product forms and automated processes that will markedly increase production efficiencies. **Type of needed actions:** All the production parameters will be deeply analyzed through ***collaborative projects***. |
| VC1-008-long | Integrated multilayer materials | Energy/ICT | Assembly Final product | **Challenges with respect to the state of the art:** Multi-layer sheet is used for creating **high barrier packaging containers** commonly used in aseptic, hot fill, and retort packaging applications. Producers can create both rollstock and containers with very strong oxygen and moisture vapour transmission protection for product sensitive and long-term shelf life applications, through layered manufacturing and physical processing. **Type of needed actions:** The integration of multilayer materials through self-assembly or industrial processes is an important key research area, exploitable in FET-type of projects, which go from short to long term actions on multilayer materials (e.g. VC1-008-short and VC1-005-medium). |
| VC1-009-long | Design methodologies for foams production | Energy/ ICT | Material Modelling | **Challenges with respect to the state of the art:** Actually the wind energy sector is trying to produce high-performance PET foams with very high densities. PET foams are both temperature- and chemical-resistant. As well as being used in the wind energy sector, **high quality PET** foam boards are employed in lightweight composite materials that are particularly well-suited for applications in the automotive and aeronautics industries, as well as in shipbuilding. **Type of needed actions:** The ***collaborative research*** should be focused in new foaming technologies, that give to possibility to easily insert nanoparticles: highly specialized foam. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC1-010-long | Materials modelling, thermal simulation and process design | Energy/ ICT/ Construction & Building | Materials Modelling | **Challenges with respect to the state of the art:**<br>Most of today's electric products are powered by lithium-ion (Li-Ion) batteries. A battery with twice the energy storage of today's state- of-the-art Li-Ion battery is a main target for electronics. Nanotechnologies (such as nanoparticles, nanofibres etc.) a way to **improve the energy density of a type of battery** known as lithium-air (or lithium-oxygen) batteries, producing a device that could potentially pack several times more energy per pound than the lithium-ion batteries that now dominate the market for rechargeable devices in everything from cellphones to cars.<br>**Type of needed actions:**<br>***Collaborative research projects*** are required since several parameters and aspects must be set up in order to optimise lightweight and high density batteries' components, including conductive materials (i.e. polymers). |
| VC1-011-long | Nanoporous materials in assembled products (gas storage, batteries) | Energy | Assembly Final product | **Challenges with respect to the state of the art:**<br>Nanoporous materials are a special class of nanomaterials of which the key property of interest is their porosity at nanoscale. Nanoporous materials-based products are used in critical cleantech applications, such as energy efficiency (such as building insulation), water treatment, energy storage (Battery electrode materials, supercapacitors) and energy generation. That innovative material can enable economically viable solutions to critical global issues related to **energy and the environment**.<br>Different technologies are available for their production: self-assembly, chemical Synthesis, 3D printing/assembling, (Laser) structuring, pyrolysis of polymer/ceramic networks.<br>**Type of needed actions:**<br>The demonstration related to this topic may be included in ***FET-type projects*** going from short to long term actions on foam and porous materials (e.g. VC-1-015-short and VC-009-medium). |
| VC1-012-long | Control of nanolayer interfaces and adhesion | Energy | Metrology | **Challenges with respect to the state of the art:**<br>Molecular nanoglue for enhancing interface strength and toughness by utilizing **self-assembling molecular nanolayers (MNL) and thin films** within the interface are yet in an embryonic development phase.<br>When sandwiching the interfaces, the resulting structure is 5 times tougher than a classic sealant. Copper/Silica interface. Such high toughness values had previously only been achieved by using much thicker interface layers, which are less desirable for microelectronics. This characteristic could support applications in extreme environments like aerospace engines and power turbines, beyond energy production.<br>**Type of needed actions:**<br>***Collaborative projects*** can be the best funding scheme to improve adhesion features. |
| VC1-013-long | Advanced smart multifunctional foams and multilayer components | Construction & Building | Final product | **Challenges with respect to the state of the art:**<br>Nanoporous membranes are characterized by pores with diameters in the range of nanometers and sub nanometers witch are able **to separate liquid or gaseous mixtures**. The separation of the fluids bases on the different size of the components (mole sieving), different adsorption (adsorption selectivity), wetting or steric hindrance.<br>**Type of needed actions:**<br>***Collaborative projects*** aimed to research new foaming technologies or new layering solutions are useful. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC1-014-long | Adaptation/ modification of novel technologies for production on industrial scale smart polymer and concrete | Construction & Building | Components Assembly | **Challenges with respect to the state of the art:**<br>In building sector the request to improve the performances of the materials used are very important. The use of nanomaterials (higher surface area) has advantages in terms of **filling the cement matrix, densifying the structure, resulting in higher strength and faster chemical reactions** (e.g. hydration reactions). The possibility to produce such materials (such as carbon fibres from waste materials) is an important issue.<br>**Type of needed actions:**<br>***Collaborative projects*** should be required in order to optimise the production of this kind of materials and to realise an exploitable products. |

## VC2 – NANO-ENABLED SURFACES FOR MULTI-SECTORIAL APPLICATIONS

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC2-001-long | Implementation of novel technologies for production of nano-enabled surfaces with dedicated functionalities on flexible substrates into novel devices | Wet Engineered | Components Assembly | **Challenges with respect to the state of the art:** Many wet chemical methods such co-precipitation, sol-gel, high-energy, ball milling, micro-emulsion, nitrate glycine combustion and hydrothermal have been employed to synthesize **nanocrystalline powders and functionalized substrate**. **Type of needed actions:** ***Demo-target collaborative projects*** may demonstrate the success of such nanostructured surface modified materials or surfaces in for relevant multi-sectorial applications, in close cooperation with designers, manufacturers and end-users |
| VC2-002-long | Unravelling relationships processing / morphology / functionality of nano-enabled thin films with complex architectures | Wet Engineered | Modelling Metrology | **Challenges with respect to the state of the art:** The nanometre-scale architectures in thin films of self-assembling block copolymers have inspired a variety of new applications. Actually the challenge is trying to **simplify these architectures**, maintaining films properties and performances. **Type of needed actions:** ***Collaborative projects*** between technology providers are needed. |
| VC2-003-long | Development of complex architectured nano-enabled thin films by high energetic beams on flexible substrates | Plasma and Vacuum Engineered | Tools Materials | **Challenges with respect to the state of the art:** Various **surface coating tools**, vacuum, physical, chemical etc. also printing e.g. molecular imprint polymer technology are enabled by high-energy electron beam irradiation. **Type of needed actions:** ***Demo-target collaborative projects*** may demonstrate the success of such nanostructured surface modified materials or surfaces in for relevant multi-sectorial applications, in close cooperation with designers, manufacturers and end-users |
| VC2-004-long | Mapping novel functionalities of nano-enabled thin films with complex architectures | Plasma and Vacuum Engineered | Modelling Metrology | **Challenges with respect to the state of the art:** The nanometer-scale architectures in thin films of self-assembling block copolymers have inspired a variety of new applications. Actually the challenge is to exactly understand the **novel functionalities** enabled by plasma and vacuum technologies. ***Type of needed actions:*** ***Tenders or collaborative projects*** between technology providers are needed. |
| VC2-005-long | Optimization of design and processing of nano-enabled surfaces on flexible substrates | Plasma and Vacuum Engineered | Metrology Components | **Challenges with respect to the state of the art:** Various **surface coating tools for flexible substrates** are actually present: vacuum, physical, chemical etc. also printing e.g. molecular imprint polymer technology. **Type of needed actions:** R&D centres, industries using the technologies should be involved in ***collaborative projects*** to optimize and renovate these processes. |

## VC3 – STRUCTURED SURFACES

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC3-001-long | 3D – Integration of structured films (plastic, metals) into 3D parts and in-line process development (thermoforming, IML, lamination… | Energy | Components Assembly Final product | **Challenges with respect to the state of the art:**<br>The research is focused on the development of novel technologies or processes to be able to combine them in order to demonstrate the potential of **engineering surfaces into hierarchical structures** demonstrating super-hydrophobicity, anti-fouling, drag reduction, etc...<br>**Type of needed actions:**<br>***Collaborative research actions***, probably small or medium, are needed. |
| VC3-002-long | 3D – Optimization of technologies on 3D large area and pilot scale (molecular nanoimprint, HE, Litho, self assembling | ICT/ Medicine/ Transportation/ Constr. & Building | Components Assembly | **Challenges with respect to the state of the art:**<br>Widespread approaches to fabricate surfaces with robust micro- and nanostructured topographies have been stimulated by opportunities to enhance **interface performance by combining physical and chemical effects**. In particular, arrays of asymmetric surface features, such as arrays of grooves, inclined pillars, and helical protrusions, have been shown to impart unique anisotropy in properties including wetting, adhesion, thermal and/ or electrical conductivity, optical activity, and capability to direct cell growth.<br>**Type of needed actions:**<br>***Large collaborative research projects*** should exploit opportunities for new fabrication methods that combine lithography with principles of self-assembly for fabrication of arbitrary 3D surface textures over large areas. |
| VC3-003-long | 3D – Integration of structured films (passive and active fabrics) into 3D parts and in-line process development (polymer composites, thermoforming, IML, lamination… | Textile | Components Assembly | **Challenges with respect to the state of the art:**<br>Technical textiles are the high performance f**abrics specially manufactured for various industrial specialized individual applications**. These products are primarily preferred for their functional attributes. Besides a new category of smart and intelligent textiles is also being developed. 3D integrated systems show continue reduction in structure areas and enable optimized partitioning, both which decrease the fabrication cost of the system.<br>**Type of needed actions:**<br>***RTD Collaborative project*** are required since a new low cost fabrication approach for vertical system integration is required. |
| VC3-004-long | 3D – Integration of structured films (plastic) into 3D parts and in-line process development | Medicine | Components Assembly | **Challenges with respect to the state of the art:**<br>Micro- and nanostructures significantly influence the physical and chemical properties of surfaces. Plastic structures can be used to functionalize surfaces and adjust the surface properties to the specific requirements of a certain application. A typical surface effect based on topological patterning is the self-cleaning surface, similar to the well-known lotus effect based on micro- and nano roughness.<br>Many approaches have been proposed for the fabrication of such structures to **imitate the effects of nature and use them in industrial applications**.<br>For economical use of these structure effects, fabrication processes are needed that meet the standard set by industry: the production of robust structures with a high lifetime in an easily reproducible and cost efficient way. Typical replication processes to fulfil these requirements are Injection Moulding or Imprint processes. A remaining challenge is the integration of functional structures into microdevices to achieve in-line patterning in 3D.<br>**Type of needed actions:**<br>***Large collaborative projects*** involving process developers, R&D and users are needed. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC3-005-long | 3D - modelling of surfaces functionalities | Transportation/ Constr. & Building | Modelling | **Challenges with respect to the state of the art:**<br>Solid/surface functionalities 3D modeller primary use is for **modelling**, but it also can provide photo **realistic rendering and object-centric animation support**.<br>They are used in dynamic structure from where it is possible to work with either solid, surface, wireframe. These modelling commands combined with advanced surface editing make it easy to heal imported geometry or construct the most complex 3D data.<br>**Type of needed actions:**<br>***Tenders or Research for the benefit projects***, involving high specialized SMEs are needed. Coordination with VC7 actions is needed. |
| VC3-006-long | 3D – Integration of structured films (plastic, metals) into 3D parts and in-line process development thermoforming, IML, lamination… | Transportation/ Constr. & Building | Components Assembly | **Challenges with respect to the state of the art:**<br>Micro- and nanostructures significantly influence the **physical and chemical properties of surfaces**. Plastic structures can be used to functionalize surfaces and adjust the surface properties to the specific requirements of a certain application.<br>There are also technologies, like metal assisted chemical etching that consists in anisotropic wet etching method, capable of producing high aspect ratio semiconductor nanostructures from patterned metal film.<br>For economical use of these structure effects, fabrication processes are needed that meet the standard set by industry: the production of robust structures with a high lifetime in an easily reproducible and cost efficient way.<br>A remaining challenge is the integration of functional structures into microdevices to achieve in-line process development (thermoforming, lamination, etc.).<br>**Type of needed actions:**<br>***Large collaborative project***s involving process developers, R&D and users are needed. |
| VC3-007-long | Direct texturing of plastic and metal parts with high throughput laser, NIL, etching) | Transportation/ Constr. & Building | Tools Materials | **Challenges with respect to the state of the art:**<br>Up to now, the technologies have been developed to a point where **demonstration of their use in specific applications** is needed to convince end-users in their applicability towards high throughput, large areas, etc..<br>**Type of needed actions:**<br>Collaborative research actions (probably Large or SME oriented if several applications should be addressed)<br>The action should cover:<br>- upscaling of the technology<br>- standardization and metrology issues<br>- prototypes fabrication |

## VC4 – FUNCTIONAL ALLOYS, CERAMICS and INTERMETALLICS

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC4-001-long | Scaling up of existing technologies typically above 100 kg/day, design of high volume reactors<br>Improvements in colloidal chemistry: uniformity | Energy Harvesting & Conversion | Metrology<br>Components<br>Assembly | **Challenges with respect to the state of the art:**<br>Many university departments, spin-offs and private companies have developed processes for the manufacture of nanomaterials but the large part of them may only be producing small quantities for research and development (R&D) purposes. However, some have the potential t**o scale up** to produce large quantities. The nanotechnology industry in the EU has strong R&D backup from universities and related institutions.<br>**Type of needed actions:**<br>***Collaborative projects*** are required. This action may be also the starting point for a ***FET-type of project***. |
| VC4-002-long | Modelling of the growth process and electronic and optical properties at material level. Requiring:<br>Improvements in colloidal chemistry, merging of classical semiconductor technologies and wet chemical processing<br>Precise analytics on the nanoscale | Energy Harvesting & Conversion | Tools<br>Materials<br>Modelling | **Challenges with respect to the state of the art:**<br>The **growth model and electronic and optical structure** of nano molecules are currently studied by different tools (for instance XPS and UPS as a function of coverage and annealing temperature).<br>**Type of needed actions:**<br>A set of modular modelling tools applicable to a range of material systems, like multiphysics modelling tools, molecular dynamics and multiscale modelling tools are already in market. Large collaborative ICT projects are needed for developing ICT infrastructures that integrate models and experimental data. This action (possibly ***a collaborative project***) should be made in collaboration/coordination with VC7 actions. |
| VC4-003-long | Integration of nano particles and aggregates into materials | Energy Harvesting & Conversion | Assembly<br>Final product | **Challenges with respect to the state of the art:**<br>The next generation of opto/electronics devices, sensors, micro and nanosystems is going towards a **higher level of miniaturization and lower power consumption** for their integration in new emerging systems such as wireless systems. New strategies are required in the developments of these components for their deployment.<br>The future challenges are the integration in combining different nanomaterials together across length scales and into nanosystems to achieve novel properties and performance.<br>**Type of needed actions:**<br>***Collaborative projects*** involving high specialized R&D centres for the definition of a common strategy for materials in energy-related applications are needed.<br>Two important tackling aspects are the integration of nanoparticles in photovoltaic devices and in energy storage devices. |
| VC4-004-long | Integration of nano fillers and aggregates into materials | ICT, Functional Packaging | Assembly<br>Final product | **Challenges with respect to the state of the art:**<br>Nanotechnologies combined with printed electronics in its large definition have been identified as key enabling technologies for the **deployment of ICT solution and functional packaging**. The developments of these technologies hold the potential to revolutionize the smart systems of tomorrow. Successful developments could lead to a wide range of novel devices and technologies useful and essential for the next generation of ultra-low power sensors and microsystems, highly sensitive sensors, wearable/flexible/transparent/stretchable/ devices, smart packaging, etc.<br>**Type of needed actions:**<br>***Demo targeted collaborative projects*** are a great chance to stimulate and increase the activities on these topics, involving university groups and non-corporate research centres, industries and end users. |

## VC5 – FUNCTIONAL FLUIDS

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC5-001-long | Modelling of nanoparticles behaviour in active systems through re-engineering of actual systems | Transportation/ Medicine & Pharma | Modelling | **Challenges with respect to the state of the art:**<br>Actually there are different experimental methods for the measurements of the transport of engineered nanoparticles through porous media in the absence and presence of a **non-aqueous phase liquid (NAPL)**.<br>For instance the transport, retention and accumulation of ferrite nanoparticles and quantum dots in the presence of NAPL (surrogate oil) are measured experimentally in one-dimensional (1-D) columns and two-dimensional (2D) cells.<br>**Type of needed actions:**<br>***Tenders*** are needed to implement these experimental methods and ***collaborative projects*** are useful for re-engineering of actual systems. |
| VC5-002-long | Monitoring of material behaviour in use | Transportation/ Medicine & Pharma | Metrology | **Challenges with respect to the state of the art:**<br>The increasing use of nanomaterials in almost all sectors of society (e.g., health or energy to agriculture and transport) has generated a need for **innovative detection methods for nanomaterials**, to enable their continued development, environmental and toxicological monitoring, and risk assessment. There are both real time than remote techniques for nanomaterial behaviour in use.<br>**Type of needed actions:**<br>***SME targeted collaborative projects*** are needed to keep up to date risk assessment methods as the use of nanomaterials expands, especially as they find their way into consumer products. |
| VC5-003-long | Adaptation of devices integration smart fluids | Transportation/ Constr. & Building/ Medicine & Pharma | Components Assembly | **Challenges with respect to the state of the art:**<br>**Smart fluids** have attracted a **resurgence of interest**; they are finding use as dampers for vehicle vibration control, rotary brakes for aerobic exercise equipment, special-purpose devices for medical rehabilitation, and erasable Braille displays for the blind, as well as for seismic damping and virtual surgery.<br>**Type of needed actions:**<br>***Research for the benefit of the SMEs projects*** are needed for proposing new solutions for devices adaptation. |
| VC5-004-long | Development of technology able to produce in reproducible way complex nanomaterials | Tools Materials/ Constr. & Building/ Medicine & Pharma | | **Challenges with respect to the state of the art:**<br>Actually are already present on the market versatile instruments capable of **patterning a variety of materials with nanoscale accuracy** and precision. They are able to synthesize geometrically and structurally complex nano structures. Graded and composite nanoscale materials will be fabricated to function as model systems for materials in order to have more sustainable materials development.<br>***Type of needed actions:***<br>***Large collaborative projects*** are needed to extend the use of existing methods and develop new methods and tools to detect, monitor and track nanomaterials in complex media (egg environmental and biological systems). Alternatively, a ***FET-type of project*** may be started on this topic. |

## VC6 –INTEGRATION OF NANO

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC6-001-long | Completed framework for concurrent design of products and nano-enabled materials working for all material classes, design areas and applications | Semifinished/ Finished Net Shaped/ Direct Manufacturing | Modelling Metrology | **Challenges with respect to the state of the art:**<br>Concurrent design of materials and products is achieved by linking materials models at multiple length and time scales to address problems relevant to specific products and applications. Significant achievements have been demonstrated in **computational materials design and its broadening application in concurrent engineering**. Best practices are already assessed and opportunities for improvement identified, with implications for modelling and simulation in science and engineering.<br>Concurrent design of hierarchical materials and structures is facilitated by the confluence of engineering science and mechanics, materials science/physics, and systems engineering.<br>**Type of needed actions:**<br>***Collaborative actions (and one supporting action)*** are recommended in order to establish a national roadmap addressing (i) databases for enabling materials design, (ii) developing principles of systems design and the prospects for hierarchical materials systems, and (iii) identifying opportunities and deficiencies in science-based modelling, simulation and characterization "tools" to support concurrent design of materials and products. |
| VC6-002-long | Precision large scale nano/ micromanufcaturing of 3D structures | Finished Net Shaped/ Direct Manufacturing/ 3D structures/ Catalysis and Filtration | Components | **Challenges with respect to the state of the art:**<br>The development of precision and large scale manufacturing processes by encompassing a wider range of innovative materials and geometric shapes, satisfying functional and technical requirements, allowing the **emerging of new microproducts** in many technological fields is a key aspect of 3D structures.<br>Technologies like nanoimprint, printing, laser, plasma, self assembly combined with nanoimprinting will be further developed and optimized through<br>**Type of needed actions:**<br>***Demo targeted collaborative projects***, involving machine producers and research centres are needed. |
| VC6-003-long | Net shaping of 3D Nanoproducts large scale | Direct Manufacturing | Assembly | **Challenges with respect to the state of the art:**<br>More and more emerging new micro- and nano-products such as microfluidics, nanofluidics, plasmonic lenses, nanogratings etc, are designed to incorporate complex 3D shapes or structured surfaces.<br>Although some **process optimization approach** has been developed for machining micro-products, costly "trial-and-error" approach is still commonly used to select tool path and manufacturing parameters for machining nanoproducts.<br>**Type of needed actions:**<br>***Collaborative projects*** should focus on: reproducibility, control of the size, shape, homogeneity and robustness of the manufactured structures as key parameters for industrial use of the processes. |

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC6-004-long | Materials/shape control in the micron range | Direct Manufacturing/ Catalysis and Filtration | Metrology Components | **Challenges with respect to the state of the art:** Materials and shape control are very important especially in nanostructured materials where the **precision and reliability** is a strong issue. **Type of needed actions:** Models and concepts should be improved by ***collaborative projects*** (small probably). |
| VC6-005-long | Design of material architectures for unbounded properties | Direct Manufacturing/ 3D structures/ Catalysis and Filtration | Modelling | **Challenges with respect to the state of the art:** Nanomaterials can be processed in many different ways. They can be **powders** that are mixed with liquids (e.g. creams) to confer certain properties on the liquids in question (unbound nanomaterials). **Type of needed actions:** ***Research for the benefit of the SME*** projects can design solution for study and analyze material architectures. |

## VC7 – INFRASTRUCTURE for MULTISCALE MODELLING and TESTING

| Code | Name of action | Reference market | VC Step | Description |
|---|---|---|---|---|
| VC7-001-long | Complete integration of the set of available tools, according to the state of the art of scientific development in computational materials science | Complex Adaptive Systems for complete product design | Assembly<br>Final product<br>End of Life | **Challenges with respect to the state of the art:**<br>**Computational materials science and engineering** play important roles in the research and development of nanoproducts. This is owing to the advances in high-performance computers, the development of robust theories and schemes to reproduce energies, structures and properties of many products such as the density-functional theory (DFT).<br>In recent days, there are several new directions in the research and development in this field. The first is to attain the higher accuracy in the energy and atomic and electronic structure by overcoming the faults in the present DFT; the second is to extend the applicability of the present DFT scheme so as to deal with various properties or phenomena such as quantum conductivity, redox reactions, atomic-scale dielectric permittivity, and free energies; the third is to deal with practical huge systems with enough quantitative accuracy such as order-N, hybrid and multi-scale schemes. These three directions of research activities are essential to promote the computational materials science and engineering as an essential tool in nanoscience and nano-technology.<br>**Type of needed actions:**<br>***A large collaborative project (or a wide demonstration-type of project)*** may be needed. |

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SEVENTH FRAMEWORK PROGRAMME

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