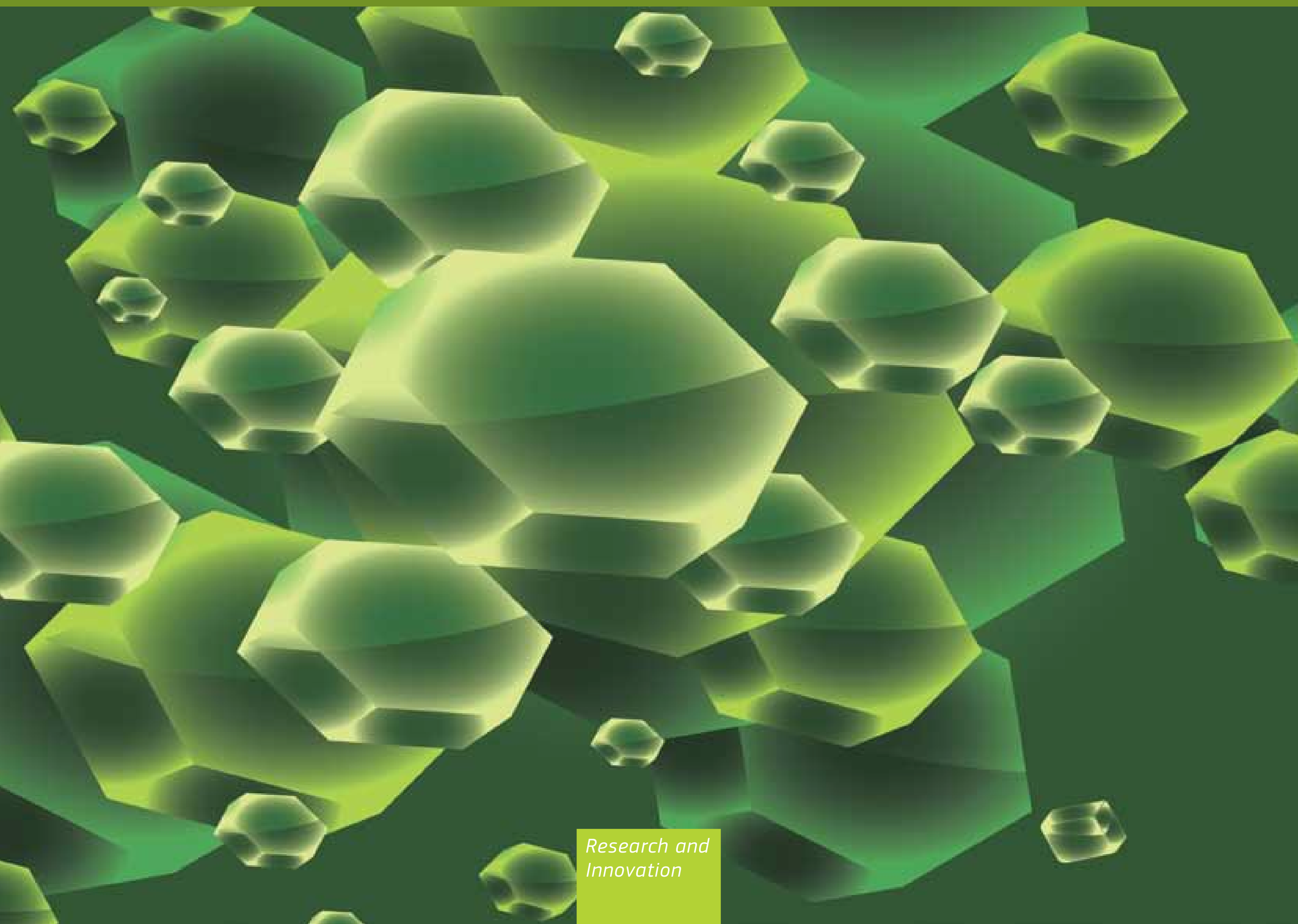
European Commission

Technology and market perspective for future Value Added Materials

Final Report from Oxford Research AS



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EUROPEAN COMMISSION

Technology and market perspective for future Value Added Materials

Final Report
from Oxford Research AS

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Chapter 1. Executive summary / Conclusions

A range of new materials with advanced properties are created through the process of technological development and knowledge intensive production. These are known as Value Added Materials (VAMs). New materials appear all the time in the natural course of industrial development; however advanced materials are tailored to fulfil specific functions and/or have superior structural properties.

We distinguish four conditions that define Value Added Materials:

- a knowledge-intensive and complex production process,
- new, superior, tailor-made properties for structural or functional applications,
- potential to contribute to competitive advantage on the market,
- potential to address Europe's Grand Challenges. [1]

> Value Added Materials are a group of advanced materials that have strategic importance for economic growth, industrial competitiveness or for addressing the Grand Challenges of our times.

Value Added Materials are present across all groups of commonly engineering materials. Within the scope of material science, they may be classified broadly into the following three main (traditional) and two (relatively new) additional classes:[2]

1. metals and alloys (ferrous and non-ferrous),
2. ceramics,
3. polymers,
4. semiconductors,[3]
5. composites.

Aim of the study

This study delineates a precise overview of VAMS through multiple perspectives of their various market sectors.

This major study seeks to achieve the following objectives:

1. definition and classification of VAMs;
2. analysis: VAMs by sector;
3. detailed current market analysis by sector and technology application;
4. prediction of VAMs' market development by sector;
5. current and potential future technological market drivers;

---

[1] The Grand Challenges, a term first used in the Lund Declaration, have been defined differently in various settings and have evolved over time. In the recent formulation of Grand Challenges used for planning Horizon 2020 within the European Commission, DG Research lists the following:

- health, demographic change and wellbeing;
- food security and bio-based economy;
- secure, clean and efficient energy;
- smart, green and integrated transport;
- supply of raw materials;
- resource efficiency and climate protection;
- inclusive, innovative and secure societies.

[2] Vinay Swastik, 'Classification of Materials', ,*Metallurgist Encyclopedia.*

[3] Items 4 and 5 of this list follow the classification of materials by Ash Tan. : http://EzineArticles.com/2894736

6. analysis of potential economic and technological issues in the frame of society's Grand Challenges.

Market size for Value Added Materials

As confirmed by this and other studies the market for VAMs has the potential to grow more than 10 times over next 40 years.

Our market size prognosis, based on secondary and primary data sources, shows the following growths:

Table 1: VAMs market share by sector

	2008	2015	2020	2030	2050
Energy	7,1	14,3	18,9	37,0	175,7
Transport	9,6	13,1	15,8	24,3	52,6
Environment	24,6	38,2	48,0	86,8	352,2
Health	27,0	32,1	37,4	55,0	115,2
ICT	29,6	38,8	46,6	70,7	152,2
Others / Cross-cutting	3,6	13,5	19,3	42,2	250,8
Total projected value of identified VAMs markets	**101,7**	**150,0**	**186,1**	**316,0**	**1098,6**

Source: Oxford Research AS. Unit: billion euro.

Market size for Value Added Materials is foreseen to grow much faster than the average growth of analysed industrial sectors. Their market share is expected to grow disproportionately high in the nearest future. In average, it is to reach 17per cent compound annual market growth (CAGR[4]) in all analysed sectors.

Our analysis demonstrates that advanced materials already influence industrial and economic competitiveness. They will play an increasingly prominent role in determining competitiveness in the future, as these applications will influence a large part of markets, constituting between 6 and 8 per cent of total market value.

Today's VAM research and applications promise to deliver many solutions to the difficulties catalogued by the Grand Challenges. Materials applications across all possible sectors of industry will play enormous roles in the future. Currently available technologies, as well as those not yet identified or still in the lab phase, indicate that many of the problems of today may be solved. They 'just' need to be introduced to the market.

We suggest that the European Commission communicate more with the investment markets (venture capital and other private investors) in order to assure better innovation orientation of the research. This shall also reduce the critical time-to-market indicators for Value Added Materials.

[4] Compound Annual Growth Rate: The year-over-year growth rate of an investment over a specified period of time. CAGR is not an accounting term, but remains widely used, particularly in growth industries or to compare the growth rates of two investments because CAGR dampens the effect of volatility of periodic returns that can render arithmetic means irrelevant. The CAGR is calculated by taking the n^{th} root of the total percentage growth rate, where n is the number of years in the period being considered. Source: http://www.investopedia.com/terms and http://en.wikipedia.org/

Market specific conclusions

- Patent protection is a very important factor for VAMs. Only well protected material innovation assures the competitive advantage on the market in the long run.
- Scalability is a problem for VAMs. Knowledge intensivity makes them hard to scale into existing industrial applications. That is also one of the reasons for such a long time-to-market lag for many sophisticated materials (claimed to be around 20 years).
- In order to improve time to market and obtain a higher impact of technologies on a shorter time scale, the European Commission may consider discussing research efforts with financial investment actors-investors on venture capital (VC) and private equity (PE) markets.
- Some large industries are considered to be already well covered (information and communication technology [ICT], automotive, pharmaceutical). Therefore research investment in these sectors is claimed to be less profitable.
- The market must be ready for any given VAM and there must be a potential to use the new appearing material. The demand for a new material is largely dependent on its value. If the price is too high, producers will simply not buy it. This involves an important dimension of scalability, but also complexity of production.
- Return on Investment (RoI) for various types of materials differs. It must be considered individually. Each deal made by a VC or PE investor is expected to give a reasonable RoI, but even so for majority this is not the case. In several interviews, our informants said that only four out of ten deals return money, and in reality a mere one to two bring multiple RoI.
- In general terms the expected RoI differs between industries, also because of sectoral specific conditions. For example, investments in information and communication technologies have a short investment period, while those in energy or environment a very long one. The health sector has its own specific conditions due to additional safety regulations.

Investment willingness

- Venture capital and private equity investors claim that the Grand Challenges started to influence their investment decisions in the past years and will even influence them more in the future.
- Energy, environment and health were estimated to be the most promising sectors to invest in, due to the potential big markets for sales in the future and still unsolved problems for all humanity.
- These three sectors — energy, environment and health — cover over 80 per cent of investors' 'willingness' to allocate their resources.

Key industrial sectors where VAMs will play an important role

- Energy: important issues are generation, distribution and storage, efficiency, and ways to integrate VAMs into existing structures.
- Environment: a cross-cutting sector across the other industry sectors, interconnected with the energy sector.
- Health: medical devices, biomaterials, tissue engineering and nanostruc-

tures— all are big markets, dealing with the concerns of an ageing society.

- Transport sector: lightweight materials will be especially critical.
- Information and communication technologies sector: traditionally ICT has high growth rates in many areas, especially in superconductivity and data transfer technologies, as well as displays.

Most promising market growths

Several applications of Value Added Materials have the potential for extreme growth in the future.

Within the **energy sector,** average growth rate for identified Value Added Materials' applications will reach 19 per cent.

Most important growths will be associated with:

- stationary fuel cells, with growth rate of 55per cent towards 2017;
- supercapacitors for the energy sector, with growth rate of 49per cent towards 2015;
- biogas plant equipment, with a CAGR of 30 per cent between 2010 and 2014;
- nanoscale materials used in energy, catalytic and structural applications, with growth rate of 29 per cent currently;
- inks and catalysts, with growth rate of 28per cent towards 2015.

For the **transport sector** the identified applications of Value Added Materials will reach the average growth rate of 15 per cent, with especially high growths within:

- supercapacitors for the transportation sector, with growth rate of 35 per cent before 2015;
- market for electric vehicles with, growth rate of 20 per cent.

Within the **environment sector,** identified Value Added Materials applications will reach growth rates on the level of 17 per cent, with higher growths in:

- carbon capture technologies, with 63 per cent growth rate;
- nanotechnology for environmental applications, with 61 per cent growth rate up to 2014;
- wastewater treatment delivery equipment, instrumentation, process equipment and treatment chemicals, with growth rate of 28per cent currently;
- nanofiltration membranes for water treatment, with current growth rate of 27per cent.

Health sector materials are characterised by lower perspective growths (average for selected materials' applications on the level of 11 per cent) when compared to other sectors. Some high growing fields within health related materials are:

- RNAi[5] drug delivery market, with growth rate of 28 per cent towards 2015;
- quantum dots for the biomedical sector and microspheres used in medical technology, both with growth rates around 25per cent before 2015.

The **Information and Communication Technologies (ICT) sector** is still characterised by enormous potential for some materials applications since the challenges we face with the growing demand for information require new technologies. The average growth rate for identified materials' applications will be on the level of 25

[5] RNA interference (RNAi) is a highly evolutionarily conserved mechanism of gene regulation. See http://www.rnaiweb.com

per cent! Still this sector was considered by PE and VC investment specialist as largely overinvested, with a high ratio of large companies present as research actors.

Some key technologies where the highest growths will be encountered:

- compound semiconductors for solar cells, with growth rate of 85per cent currently;
- organic materials for transparent electronic components, with growth rate of 57 per cent towards 2015;
- superconducting electrical equipment with growth rate of 108per cent before 2015;
- nanorobots and NEMs (nanoelectromechanical systems), and related equipment and materials, with growth rate of 174 per cent up to 2015.

As one can see, the market potential and foresighted growth of VAMs is sometimes enormous. All data gathered within this study and presented in the following pages demonstrate tremendous prospects for further development of a large range of applications.

The future for Value Added Materials looks bright. Yet many challenges exist and many barriers must be overcome in order for all existing and new coming technologies to really influence our lives and respond to the Grand Challenges of our time.

Methodology

This study is based on primary information gathered from interviews with two groups of stakeholders: materials experts and investors/investment advisors who deal with venture capital (VC) and private equity (PE) investments. Our group then prepared a detailed analysis of available secondary sources. When all relevant primary and secondary data were available, the team elaborated the market analysis and prediction.

Chapter 2. Introduction to the study

2.1 Materials technology and advancements in engineering

The use and processing of materials has been one of the main driving forces of development and prosperity since the early days of civilization. For centuries materials developed mainly in the fields of ceramics, metallurgy and glass .[6] More recently an increasingly wide and complex range of different advanced materials, production processes, and integrated functional systems has emerged.

Materials science and engineering drastically intensified in the 1960s, when applications of materials became increasingly based on scientific principles rather than the empiricism that prevailed prior to World War II.[7] Materials science and engineering today can be described as 'the study of substances from which something else is made or can be made; [and] the synthesis, properties, and applications of these substances.'[8] This definition covers both natural, traditional materials as well as synthetic, designed materials.

Since the 1970s there has been an unprecedented expansion in the number of advanced materials, novel production processes, and devices that have entered many aspects of human life.[9] These advanced materials, which form a basis of the modern high technology,[10] include:

- steels and other metallic alloys
- super-alloys
- polymers
- carbon materials
- optical, electronic and magnetic materials
- superconductors
- technical ceramics
- composites
- biomaterials.

Many of these have been successfully adapted by the markets and are now utilized in a range of industries and the urban living environment. Examples are encountered daily in the areas of health, communication, consumer goods and transportation.[11] According to the Max Planck Institute of Materials Research, 'Materials science plays a key role as one of the main pillars of economic progress and social well-being in Europe and, indeed, the world as a whole.'[12]

The Technical Revolution (also called the Second Industrial Revolution) in the late 19th and 20th centuries is a good illustration of severely disruptive developments in

6 http://www.materialmoments.org/top100.html
7 http://www.accessscience.com
8 http://www.mpg.de/pdf/europeanWhiteBook/wb_materials_010_015.pdf
9: http://www.britannica.com
10 http://www.mpg.de/pdf/europeanWhiteBook/wb_materials_010_015.pdf
11 http://www.mpg.de/pdf/europeanWhiteBook/wb_materials_011.pdf
12 http://www.mpg.de/pdf/europeanWhiteBook/wb_materials_016_017.pdf

manufacturing technologies. Advancements in chemical, electrical, petroleum and steel industries subsequently led to improvements in their respective application areas. As an example, the invention of the Bessemer converter enabled inexpensive mass production of steel, which motivated the rapid construction of railroad systems, skyscrapers and large ships.[13]

2.2 Study context and approach

This study on 'Technology and market perspective for future Value Added Materials' was commissioned by Directorate General for Research & Innovation, Materials Research.

This assessment aims to understand the market of Value Added Materials through its social, economic, legal, political, economic and ecological effects. Our investigation presents decision-oriented options and points out various technical and economic scenarios when novel materials are developed and used.

This study focuses on the following market segments:

- energy
- environment
- health
- information and communications technology (ICT)
- transportation
- others (chemistry and catalysts, construction, etc.).

At the request of the European Commission, study authors invited experts to give their opinions about these developing VAM markets. Materials experts as well as financial advisors and investors who are directly engaged in related investments contributed to this inquiry.

The result is a unique set of information about the intended decisions of private investment actors who deal with advanced technologies.

Our technology and market assessment highlights areas where two different types of specialists (materials experts and investment advisors) generally agree on the development of Value Added Materials and their applications. A large set of secondary data,[14] especially regarding markets' size, supports the ideas presented by these primary sources.

Finally, this study lists commonly agreed-on facts for policy makers and elucidates issues to be solved through the political process.

Future research policies should not aim exclusively at technical efficiency and economic rationality. The social and economic consequences of introducing specific technologies and novel materials need to be considered as well. Geopolitical considerations linked to the supply of strategic raw materials are also addressed.

[13] http://www.britannica.com/EBchecked/topic/195896/history-of-Europe/58404/The-Industrial-Revolution#ref643971

[14] Data from other sources relevant for the study included market size information from other institutes, relevant reports and forecasts.

Chapter 3. Definition and classification

3.1 A general reflection on 'value'

Common sense tells us that 'value added' — be it in reference to a material, a process, a factor, a phenomenon, or an element — is something that improves something else. A material with particular properties can be deployed to enhance the functionality of a product, which gives it a higher degree of functionality and quality.

'Value' is subjective, reflecting the context in which it is used. The 'value' of the material will have different meanings depending on the stakeholders (companies/producers of VAMs, companies/users of VAMs, investors, researchers, consumers), but also it will vary in different economic regions: Europe, Asia, Americas.

For an industrial company the value of a highly performing product lies in its capacity to increase the company's competitive advantage in the market. For a venture capitalist who has invested in such a company, the value of the highly performing product lies in the return on investment (RoI) generated. The value of a highly performing product can lie in its potential to contribute to efficient energy savings. But it is also possible that the 'value' for this same product could have a negative effect on the environment or human health.

It is thus highly important to clarify what is meant by 'value'. In this respect, the definition of 'Value Added Materials' is a challenge, because the word 'value' has different meanings.

3.2 Value Added Materials versus commodity materials

It is important to make a clear distinction between *commodities* and *Value Added Materials* in order to lay down a rational basis for this study. A commodity is a good for which there is demand, but that is traded without any specific qualitative segregation across a market segment. A commodity is fully or partially *interchangeable*; that is, the market treats the good as equivalent regardless of source or means of production. A raw material is a commodity: a basic substance in its natural, modified, or semi-processed state, used as an input to a production process for subsequent modification or transformation into a finished good.[15] Soft commodities are primarily goods that are grown, such as coffee and soy beans, while hard commodities are mainly extracted through mining or similar exploitation and subject to a certain degree of processing, such as extraction of iron from its ore.

Therefore, commodity material suppliers compete basically on the basis of costs: their success depends on their internal cost position and not on the basis of material performance. Petroleum and copper are examples of well-known commodities. The price of petroleum is universal, and it varies on a daily basis due to global supply and demand. Thus, one of the characteristics of a commodity good is that its price is established as a function of its entire market. Commodities — raw or primary products — are exchanged on so-called commodity markets. These goods are traded

[15] http://www.investorwords.com

on regulated exchanges, in which they are bought and sold in different types of standardised contracts.

Value Added Materials, on the other hand, are normally produced by a complex, interlinked industry. In the most stringent interpretation, Value Added Materials are products whose worth is based on their performance or functionality, rather than their composition. They can be single entities or formulations/combinations of several materials whose composition sharply influences the performance and processing of the end product. Products and services in the materials industry require intensive knowledge and powerful innovation.

The *commoditisation* of a good occurs when a goods market loses segregation relative to its supply base. This means that goods that previously had high margins for market actors become commodities, such as generic pharmaceuticals and silicon chips. It is therefore possible that certain Value Added Materials may become commodities due to technological developments.

3.3 VAM properties based on literature review

The following discussion is based on a comprehensive survey of a wide range of publications on materials science and technologies, numerous articles and a number of webpages, including ASM International (The Materials Information Society) sources and other materials-specialised institutions.

The first observation is that different names related to VAMs emerge in the literature. This indicates that while these terms are interconnected, there is no standard definition to date.

Different but interrelated terms:

- value-added materials
- added value materials
- advanced materials
- new/novel materials

The most-used terms in the literature are 'advanced materials' and 'new materials'. The term 'Value Added Materials' appears very seldom. We even find the inversed use 'added value materials'. The term 'Value Added Materials' appears predominantly in the EU documentation, in its work with FPs calls for proposals, work programmes and policy documents.

A search through Google, Google-scholar, EBSCO databases and electronic books has brought no significant results on other sources where VAMs specifically are defined or discussed. We concluded that scientists and the industry don't have single definition of what VAMs are, so we turned to policy documents and other documents from the European Commission. The first observation is that VAMs are a kind of advanced materials with specific properties, that have both functional and structural applications, and that they are new. The question that we asked ourselves at this stage was what differentiates VAMs from the rest of the advanced materials, from the rest of the functional materials, and from the rest of the new materials. We looked for answers in material science and nanotechnology books and articles to find any defining elements that would help us to differentiate between them.

Adopting an open approach, the search was undertaken for the properties of the three 'kinds' of materials: VAMs, advanced materials, and new materials. A range of elements was found, describing the three in terms of properties, applications, production process, market characteristics, different effects, and their potential. These elements were analyzed and weighed. Several of them were chosen for further elaboration based on their relevance for the definition of VAMs and on context of the assignment.

The literature shows that through the current technological development and knowledge intensive production processes, a range of new materials with advanced properties are created. *New materials* appear all the time in the natural course of industrial development. Out of these a special group is tailored to fulfil specific functions and/or have superior structural properties; these are the *advanced materials.*

Schulte described one special group of advanced materials 'at the nanoscale …it seems that in terms of engineering there is a good chance that all the good things found close to the top (micro) and the bottom of the scale (atom, molecule) can be combined to produce something entirely superior or new.'[16]

Similarly, most advanced materials are called a 'new generation' of materials[17] that display physical attributes substantially different from the generics[18] and provide superior performance capacities.

If we assume that VAMs are included in the term 'advanced materials', it can be deduced that VAMs share to a certain degree, if not entirely, properties that characterize advanced materials.

Advanced materials are described in the literature through the following properties and processes:

- properties that are superior to those exhibited by commodity materials, that is, more durable and resistant materials, such as advanced steels;
- materials and systems made out of these materials can be designed to exhibit novel and significantly improved physical, chemical and biological properties, phenomena and processes;
- higher energy absorption capacity;
- tailored, significantly enhanced properties and predictable performance;
- new functionalities and improved performance, with higher knowledge content in the production process.

More specifically, we find the following descriptions that define the new and advanced materials, which we believe include the VAMs.

---

16 Schulte, J., (ed.) 2005. p. 98.

17 For example in: EU Commission 2011. Fisher, et al. 2008., Weng, Y., et al. 2011. Pinciotta, F., 2011. Waqar A., and M. J. Jackson,. 2009.

18 In Weng, Y., et al. 2011. Krueger, A., Kelsall, R., et al. 2005.

Schulte describes advanced materials created through nano-engineering:.[19]

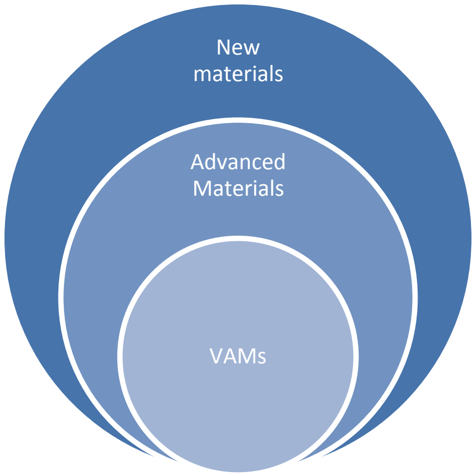
> *'Many of these new materials are assembled out of existing building blocks, but are put together in novel ways, with properties that are often designed in, deliberately and consciously created to have specific, desired physical and chemical properties. The ability to measure, control and modify matter at the nanoscale, i.e. at the atomic and molecular level, results in materials with new structural and functional properties that have the potential to revolutionize existing markets or create whole new markets.'*

Another description of advanced materials is in Rensselaer.[20]

> *'Advanced materials refer to all new materials and modifications to existing materials to obtain superior performance in one or more characteristics that are critical for the application under consideration.'*
>
> *'Advanced materials are materials that are early in their product and/or technology lifecycle, that have significant room for growth in terms of the improvement of the performance characteristics (technology lifecycle) and their sales volume (product lifecycle.).*

By this point, the conclusion must be made that the VAMs are a kind of advanced materials, but still there is a need to find the fundamental features that differentiate them from other materials categories. Schematically we understand the VAMs as a part of the advanced materials and new materials (see figure 1).

Figure 1: VAMs as a part of advanced and new materials



Our search for the fundamental features that differentiate VAMs from the rest of the advanced materials brought us back to the European Commission's own documents. Especially, the content of the work programmes reflects the Commission's position and understanding of VAMs based on consultations with NMP Expert Advisory Group and the European Technology Platforms, as well as inputs from other FP7 themes, EURATOM[21] and RFCS[22]. An important observation is that the Commission acknowledges the potential of advanced materials to contribute to fulfilling two strategic objectives of the European Union. These are: **European industrial and economic competitiveness** and meeting the **Grand Challenges**.

[19] Schulte, J., (ed.) 2005. p. 111.

[20] Rensselaer. 2004. *Advanced Materials Sector Report*, p. 1.

[21] European Atomic Energy Community.
[22] Research Fund for Coal and Steel.

Some examples where the potential and the role of VAMs are described in European Commission documents follow below:

‘Materials will also support the development of solutions in materials sciences and engineering (including “horizontal technologies”) in order to overcome scientific, technological and related bottlenecks enabling new technologies that can give European industry a strong competitive advantage *in the years to come.’*[23]

‘European competitiveness *will be directly related to the ability in maintaining advanced technology in experimental facilities and continuously developing new analytical tools.’*[24]

‘*Added value materials with higher knowledge content, new functionalities and improved performance are critical for industrial competitiveness and sustainable development; the materials themselves represent a key step in increasing the value of products and their performance, including design and control of their processing, properties and performance.*’[25]

The term ‘Value Added Material’ can also be linked to Sanford Moskowitz’s discussion of the *Advanced Materials Revolution*.[26] He argues that the new generation of advanced materials increasingly plays a prominent role in determining industrial and economic competitiveness, far more than their counterparts did in the past. The two former materials revolutions — the first based on coal-tar (in Germany) and mass production of metals and alloys (in the US) between 1870-1930 and the second petrochemical-based in the US between 1930-1960 — did not primarily rely on materials as such but rather on engineering design. Since 1980 a new generation of advanced materials has emerged, and these, contrary to novel materials in the past, will actually set the pace of innovation itself. Industrial competiveness now wholly depends on the continued development and growth of the so-called ‘science’ or knowledge-based industries, that include biotechnology, pharmaceuticals, and micro- and nano-electronics. As an example, the silicon chip is expected to reach its technological limit in its ability to miniaturise. After this point is reached, new electronic materials must be tailored to provide the basis for further developments in miniaturisation.

Current and future materials with new properties thus help remove innovation bottlenecks in the development and competitiveness of industrial sectors. As a result of this, ‘added value’ translates into the inherent capacity of a material to overcome barriers in the development of new products in the science/knowledge-based economy.

In terms of VAMs’ role in addressing the Grand Challenges, we find the following in the work programmes:

‘*Research will focus on materials science and engineering defined in order to contribute to Europe's Grand Challenges, in line with the ‘Lund Declaration’, which states that "Meeting the Grand Challenges also requires (…) taking a global lead in the development of enabling technologies such as (…) materials."’*[27]

‘*Key Enabling Technologies (KETs) such as advanced materials are of exceptional importance. Mastering such technologies lays stable foundation for well-paid jobs in the EU and allows for sustainable, societal-agreed growth.’*[28]

‘The key objective is to radically improve materials by increasing knowledge in materials sci-

[23] Work Programme 2012, Cooperation, Theme 4, *Nanosciences, Nanotechnologies, Materials and New Production Technologies.*
[24] Ibidem.
[25] Ibidem.
[26] Moskowitz, S.L. 2009: *The Coming of the Advanced Materials Revolution.*

[27] Work Programme 2012, Cooperation, Theme 4, *Nanosciences, Nanotechnologies, Materials and New Production Technologies.*
[28] Ibidem.

ence, in particular at the nanoscale, as well as to make progress in the field of environmentally friendly materials able to substitute currently harmful applications, and in the field of clean, flexible and efficient materials processing.'[29]

3.4 Definition of VAMs based on interviews

In general most of the experts and the investors we interviewed agree with the four criteria defining VAMs proposed in Chapter 3.5 .

Some interviewees understand VAMs in terms of their breakthrough nature or the technologies using them. 'Breakthrough' is understood as intelligent solutions for difficult problems that will have a big impact in society or a revolutionary effect with respect to current practices.

There is also confusion with regards to the term 'Value Added Materials'. The examples below illustrate this.

VAMs understanding too narrow?

Our experts observed that the material is usually not considered 'valuable' in itself, but through the combined value of the devices, structures and systems of technologies and production processing. In this sense, the material is just an element, a part of a structure. It is the value of the structure that the interviewees talk about and not the value of a specific material.

VAMs understanding too wide?

There were quite a few informants who perceive VAMs from the perspective of the production chain process. Here value is understood in terms of processing any matter that has been arranged for human purpose. In this meaning as soon as the matter becomes a material it has a certain value and with every step in any production process, value is added to the material. From this perspective any materials that are used by humanity today have a value in themselves.

Examples from our interviews:

'Copper is a commodity. As soon as you try to modify it or combine it, I would call it a VAM. Plumbing tube that has an improvement coating on starts to be a value added material.'

'You create some value in respect to a basic commodity. Doing something, you add value.'

'You take a material and you shape and form it so that you have a more complex structure, or function in the end. The production process in itself is adding value to the material. In every single step in the production chain, you have added value, sometimes by work, sometimes by materials or technology.'

Take integration into account

An interesting approach emerged from a number of interviews:

'You cannot separate materials from technology or manufacturing process. Materials are the first step of processing. We are dealing with complex, integrated systems that materials are a part of. The next generation of devices will have it all in one. ...The key word is integration and VAMs should facilitate this integration. Materials are becoming a part of the structure; they serve integration... Integration is adding new functionalities and combing functionalities in the sense that we now have the result of having a system, structure, device that can offer more than one functionality.'

"Materials are not the end but a beginning of the feeding chain of the industrial system."'

[29] Ibidem.

3.5 VAM definition

Policy definition

A special group of advanced materials has a significant potential to address the Grand Challenges and contribute to industrial and economic competitive advantage on the market. In this respect the 'added value' of these advanced materials is for the whole society and not merely for a specific company or industry. The 'added value' of the material is, in addition, of a strategic and long-term nature, targeting the whole society. In other words, a group of advanced materials that have a *strategic importance for society and technology* shall be considered VAMs.

We distinguish four conditions that define VAMs:

1. Knowledge-intensiveness and complex production process.
2. New, superior, tailor-made properties for structural or functional applications.
3. Potential to contribute to competitive advantage on the market.
4. Potential to address the Grand Challenges.

Thus the definition of VAMs can be formulated like this:

'VAMs are a group of advanced materials that have strategic importance for economic growth, industrial competitiveness and address the Grand Challenges of our times.'

3.6 What shall be not considered Value Added Material

To address the question 'What is not a VAM', we return to the main definition factors. The first differentiating point for VAMs is the 'knowledge intensivity' in the process of material production. Note that a 'knowledge-intensive process' is not precisely defined and therefore leaves the field open for further discussion. However, the high level of knowledge required leads to the assumption that the manufacture of novel VAMs is associated with the creation and protection of intellectual property. This means that the knowledge necessary for their creation is not commonly accessible in the market.

In this way widely known examples of thermoplastics as polyethylene, polypropylene, polystyrene and polyvinyl chloride shall not be considered VAMs. Their production methods are well-known and the production process is not knowledge intensive. It is also no longer characterised by intellectual property protection. Thermoplastics have become bulk materials.

On the other hand if we take simple plastic and enhance its structure with nanoparticles in a complex process probably not available to most manufacturers in order to obtain novel or enhanced properties, this process would result in a creation of VAM.

The same logic may apply to such commonly used materials as glass for windows, cement for construction or aluminium for car industry. In general these are bulk materials used and produced in multiple applications. The production of these does not give any market advantage based on 'unique' material properties. The producers only compete with the price of the produced outcome. In most cases these common materials are produced in processes that can no longer be viewed as knowledge intensive. Simplifications in the manufacturing process and the possession of its knowledge does not provide a competitive advantage on the market. Expiration of patent protection after 20 years, means that any competitor is free to manufacture the material.

On the other hand laboratories of large and small companies work intensively to enhance properties of such bulk materials in order to create VAMs that address many challenging applications. These materials — having extraordinary, enhanced or new properties and able to respond to market needs, thus creating market advantage for the producer — meet the definition of VAM.

3.7 Classification

Common engineering materials within the scope of Material Science may be classified broadly into the following three main (traditional) and two (relatively new) additional classes: [30]

1. metals and alloys (ferrous and non-ferrous),
2. ceramics,
3. polymers,
4. semiconductors,[31]
5. composites.

These classes can be further broken into various sub-groups, each with different applications. Every object we come across belongs to one or combinations of these classes.[32]

[30] Vinay Swastik, 'Classification of Materials', *Metallurgist Encyclopedia*.
[31] Items 4 and 5 of this list follow the classification of materials by Ash Tan; http://EzineArticles.com/2894736
[32] Ibidem.

Table 2: Classification of common engineering materials

Group	Important characteristics	Common examples of engineering use[33]
Metals and Alloys	Hardness, resistance to corrosion, thermal and electrical conductivity, malleability, stiffness and property of magnetism.	Iron and steels, aluminium, copper, zinc, magnesium, brass, bronze, invar, super alloys, super-conductors, etc.
Ceramics	Thermal resistance, brittleness, opaqueness to light, electrical insulation, high-temperature strength, abrasiveness, resistance to corrosion.	Silica, glass, cement, concrete, refractories, silicon carbide, boron nitride abrasives, ferrites, insulators, garnets, etc.
Organic Polymers	Soft, light in weight, dimensionally unstable, poor conductors of heat and electricity, ductile, combustible, low-thermal resistance.	Plastics – poly vinyl chloride, poly tetra fluoroethylene, polycarbonates.
		Natural and synthetic fibers – nylon, terylene, leather, etc.
		Other uses – explosives, refrigerants, insulators, lubricants, detergents, fuels, vitamins, medicines, adhesives, etc.
Source: *Metallurgist Encyclopaedia*.		

New additional classes for VAMs

Semiconductor materials are nominally small band gap insulators. The defining property of a semiconductor material is that it can be doped with impurities that alter its electronic properties in a controllable way. The most commonly used semiconductor materials are crystalline inorganic solids. Semiconductors can be classified into many groups following periodic table groups of their constituent atoms [34] as well as by different approaches following their general properties: e.g. elemental semiconductors, compound semiconductors, layered semiconductors, magnetic semiconductors, organic semiconductors, charge-transfer complexes and others.

Composite materials constitute the category where most VAMs will be identified. Composites are materials composed of two or more distinct phases (matrix phase and dispersed phase) and having bulk properties significantly different from those of any of the constituents. A composite therefore is a combination of two or more chemically distinct materials whose physical characteristics are superior to its constituents acting independently. The classification of composite materials (based on matrix material) follows this basic split:[35]

- *Metal Matrix Composites (MMC)* Metal matrix composites are composed of a metallic matrix (aluminium, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase.
- *Ceramic Matrix Composites (CMC)* Ceramic matrix composites are com-

[33] Please note that these are not necessarily examples of VAMs, but definitely there are VAMs existing within these groups in the form of different composite materials.

[34] See Fluck, E. 'New notations in the periodic table'. *Pure & App. Chem*. 1988, 60, 431-436; and Leigh, G. J. 'Nomenclature of Inorganic Chemistry: Recommendations.' Blackwell Science, 1990.

[35] Dr. Dmitri Kopeliovich, 'Classification of composites'. http://www.substech.com/

posed of a ceramic matrix and embedded fibres of other ceramic material (dispersed phase).

- *Polymer Matrix Composites (PMC)* Polymer matrix composites are composed of a matrix from thermoset (unsaturated polyester [UP], epoxy [EP]) or thermoplastic, (polycarbonate [PC], polyvinylchloride [PVC], nylon, polysterene) and embedded glass, carbon, steel or kevlar fibres (dispersed phase).

Another classification of composite materials based on reinforcing material structure divides them into:

1. *Particulate Composites-*
   These consist of a matrix reinforced by a dispersed phase in the form of particles:
   - composites with random orientation of particles, or
   - composites with preferred orientation of particles. Dispersed phase of these materials consists of two-dimensional flat platelets (flakes), laid parallel to each other.
2. *Fibrous Composites*
   - Short-fibre reinforced composites consist of a matrix reinforced by a dispersed phase in the form of discontinuous fibres (length < 100* diameter).
   - Long-fibre reinforced composites consist of a matrix reinforced by a dispersed phase in form of continuous fibres.
3. *Laminate Composites*
   - When a fibre-reinforced composite consists of several layers with different fibre orientations, it is called a multilayer (angle-ply) composite.

Sanford L. Moskowitz[36] elaborates on *advanced-material families* based on properties, production methods and applications, as well as the classical materials split presented above. Moskowitz divides them into:

- bioengineered materials,
- advanced metals: advanced stainless steel and 'superalloys',
- advanced ceramics and superconductors,
- nanoceramics,
- piezoelectric ceramics,
- synthetic engineering (nonconducting) polymers,
- organic electronic materials (conducting polymers),
- organic polymer electronics (OPEs) and display technology,
- OPEs and the integrated circuit,
- advanced (nonthin) coatings,
- thermal barrier coatings,
- conductive coatings,
- anticorrosion metallic coatings,
- multifunctional ('smart') coatings,
- nanopowders and nanocomposites,
- nanocarbon materials,
- metal fullerenes,
- nanotubes,
- nanofibres,
- thin films,
- advanced composites.

The same study also suggests a simpler approach to classification, grouping new materials as follows:

- bioengineered materials,
- advanced ('super') alloys,
- advanced ceramics,
- engineering polymers,

[36] Sanford L. Moskowitz. *Advanced Materials Revolution Technology and Economic Growth in the Age of Globalization;* John Wiley & Sons, Inc.,2009.

- organic polymer electronics (OPEs),
- advanced electronic materials (other),
- advanced coatings,
- nanopowders,
- nanocarbon materials,
- nanofibers,
- thin films,
- advanced composites.

Production process dimension — the 'nano' level

VAMs classification can be also approached by the dimension on which the material is produced.

In short the main split here will be the macro, micro and nano levels. Most of the commonly used composites are obtained at macro and micro levels. The lower the scale, the more knowledge-intensive the process for material creation is; therefore more VAMs can be found on the micro and nano scale. Today OECD's database of nanomaterials[37] contains a record of more than 300 different materials produced at the nano level, divided into following categories:

- nano carbon (e.g. multi-walled carbon nanotubes-SWCNTs),
- polymers specifically synthesized to exploit nano-properties (e.g. specifically synthesized polystyrene),
- dendrimers (e.g. polyamidoamine-PAMAM),
- components of quantum Dd (e.g. barium titanate CAS 12047-27-7, or silicon germanium),
- inorganic nanomaterials (e.g. aluminium borate CAS 6179-70-7, indum oxide CAS 1312 43-2, silicon dioxide CAS 60676-86-0),
- polymers and other organics,
- dendrimeres,
- nanorodes,
- nanoplates,
- nano clay (e.g. kaolinite).

[37] OECD Database on Research into the Safety of Manufactured Nanomaterials. http://webnet.oecd.org/NanoMaterials/Pagelet/Front/Default.aspx

Chapter 4. Qualitative technology assessment and perspective in the social and economic context

Investors interviewed for this study revealed a representative opinion focused on research-demanding businesses. A number of investment experts indicated that research in advanced technologies has become more socially responsible, and eager to address the major problems of our times.

Quantitative information gathered during these interviews indicates that future investments will be largely directed towards the three most important sectors in this context: energy, environment and health.

In this chapter we give an overview of the Grand Challenges and point out possible VAM implementations that may solve them. These application areas are the result of secondary data analysis, based on the available strategies, roadmaps and foresights for industrial technologies as identified in our research mission. Annex 1 provides a full list of market sizes gathered from the secondary sources analysed.

4.1 Grand Challenges

The Grand Challenges reflect Europe's issues, current and future trends and the policies being developed in response. .

This important discussion joins the future of the Community with Community spending, since Value Added Materials development may influence our future ability to answer the Grand Challenges. The Lund Declaration[38] identifies a set of themes in urgent need of solution. The Declaration emphasises the necessity for the European research community to respond. Following this declaration, the European Commission (EC) Research and Innovation DG published a report on 'The Role of Community Research Policy in the Knowledge-Based Economy',[39] prepared by the European Research Area Expert Group (ERA-EG). It has identified ways to maximise the efficiency of Community research policy in the post-2010 period. Among its most important recommendations is a call for concentrated research efforts to solve the major problems it terms 'Grand Societal Challenges'.

Later on, the European Commission (EC) Research and Innovation DG published 'Strengthening the role of European Technology Platforms in addressing Europe's Grand Societal Challenges'.[40] This report summarises the work of an expert group

[38] Lund Declaration, 'Europe Must Focus on the Grand Challenges of Our Time', Swedish EU Presidency, 8 July 2009, Lund, Sweden. http://www.se2009.eu/polopoly_fs/1.8460!menu/standard/file/lund_declaration_final_version_9_july.pdf

[39] Report of the European Research Area Expert Group on 'The Role of Community Research Policy in the Knowledge-Based Economy', [Online] http://ec.europa.eu/research/era/index_en.html

[40] Report of the European Technology Platforms Expert Group. 'Strengthening the role of European Technology Platforms in addressing Europe's Grand Societal Challenges'. http://www.ectp.org/groupes2/params/ectp/download_files/27D1047v1_ETP_ExpertGroup_Report.pdf

on European Technology Platforms, convened by DG Research in early 2009. The expert group examined how the current 36 European Technology Platforms (ETPs) should evolve in the near future. This report proposes that all ETPs be encouraged to work in flexible clusters focused on addressing the key problems facing Europe. These clusters should involve all relevant stakeholders, work across all aspects of the knowledge triangle (innovation, research, education), and be responsible for implementing potential solutions.

Each of the Grand Challenges raises significant issues for the future, while potential solutions may be linked to Value Added Materials.

When planning future research activities, the European Commission formulated the following Grand Challenges:

- health, demographic change and wellbeing;.
- food security and the bio-based economy;
- secure, clean and efficient energy;
- smart, green and integrated transport;
- supply of raw materials;
- resource efficiency and climate action;
- inclusive, innovative and secure societies.

Sections below discuss these challenges, then present an overview of how VAMs might address them within a wider social and economic context.

4.1.1 Health, demographic change and wellbeing

Europe is bracing for the social and economic impacts of a retiring 'baby boom' generation. But the aging of the population is not a temporary European trend — it is a long-term and global development, one that will be felt for generations to come. Paradoxically, perhaps, the new technologies to some extent add to longevity, as medicine, sanitation, and agricultural production have improved. Life expectancy around the world has risen and continues to rise. This, combined with falling birth rates, is causing what experts call the 'demographic transition'—the gradual change from high to low levels of fertility and mortality.

One of the most important implications of this transition is that the elderly constitute a much greater share of the total population than before. Europe has seen both mortality and fertility fall since the 19th century. Since the 1960s, however, fertility has declined even more dramatically. Europe now has so many elderly people and so few newborns, that mortality rates have started to climb again, now reaching levels similar to some developing countries.

Today, 19 of the world's 20 'oldest' countries — those with the largest percentage of elderly people (age 65 or older) — are in Europe. In Italy, the world's oldest country by these standards, over 19 per cent of the population is elderly. This figure is expected to reach 28 per cent by 2030.

Aging populations will create a number of challenges for current and future governments. One is how to sustain public pension/social security systems as a larger proportion of people reach retirement and enjoy a longer life. New technological solutions including Value Added Materials may be used to cope with some problems related to old age and frailty, and most of all to health related challenges.

Public health and pandemics

The main consideration in public health issues is to provide medical care to everyone while minimising discrimination.

The terms of reference for this contract exclude pharmaceuticals as such from the potential list of Value Added Materials in the strict sense. Still drug research is important to public health and official responses to pandemics.

In this context other materials' applications with a high potential to address this challenge are listed in analysed secondary sources.

- Materials with new functionalities and improved properties and comfort: resistance against an aggressive environment, hygienic and easy to clean, moisture control, thermal, electromagnetic and acoustic isolation, heat storage and climatic functionality. These qualities create a 'warm feeling' and aesthetic appearance.
- Active, multi-functional materials that improve the indoor climate and energy consumption of buildings by means of nano, sensor and information technology.
- Development of new materials based on bio-technologies, for example embedded bioelectronics, active surface properties, or natural process technologies.
- Smart garments that can adapt their insulation function according to temperature changes (through integrated sensors and actuators), detect vital signals of the wearer's body and react to them, change colour or emit light upon defined stimuli (through integrated sensors and actuators), detect and signal significant changes in the wearer's environment (absence of oxygen, presence of toxic gases or chemicals, radiation, strong electromagnetic fields etc.), generate or accumulate electric energy to power medical and other electronic devices.
- Materials speeding up recovery after medical treatment: innovative wound dressings; light, breathable orthoses/protheses.
- Materials improving everyday life for the elderly: adaptive compressing stockings, functional diapers, customised clothing for easy use and functionalities adapted to special needs.
- Textile-compatible energy storage systems like electrochemical batteries and supercapacitor materials.
- Flexible or fibre-based photovoltaic cells and piezo-electric materials.
- Electroconductive materials and polymer optical fibres for communication. Materials for wireless textile communication systems.
- Nanobio-devices for diagnostics, 'cells-on-chips' for sensing elements.
- Targeting agents or contrast agents, swallowable imaging, diagnostic and therapeutic 'pills'.
- Materials for wireless implants and autarkic sensors (smart power management).
- Active delivery systems, releasing drugs, vitamins or nutrients into the body when certain conditions occur.
- Materials for integrated microprocessors capable of data analysis, enabling early detection and diagnosis of illnesses or diseases.
- Smart clothes fitted with nanosensors to record parameters such as blood pressure, pulse and body temperature.
- Photosensors for fluorescence (vision systems).
- Carbon nanotube ink batteries, micro batteries, supercapacitors, and micro

fuel cells built with 3D nanostructures and nano materials.

- Wide bandgap semiconductor material for energy conversion systems.
- Advanced materials for interconnections and bonding techniques, thick layer deposition processes and encapsulation techniques.
- Materials for LED phototherapy unit producing blue light and minimizing exposure to harmful ultraviolet radiation.

4.1.2 Food security and the bio-based economy

Malnutrition affects 2 billion people in the world today. With the predicted growth in population, by 2025 this number likely will increase vastly (especially in Africa and South Asia), as food demand in emerging countries increases. Moreover, supply is likely to be reduced and food prices may prove prohibitive for the poorest groups because of the reduction of agricultural land, irrigation problems and the general effects of climate change. Value Added Materials in the chemical sector that support agriculture production may be an important factor in future solutions.

In general the VAMs may not directly influence the food production sector apart from such applications as:

- advanced chemicals and biochemicals supporting agricultural production;
- new packaging materials for food.

Water

The need for water will increase sharply with the increases in world population and the rise in the standard of living and expectations in emerging countries. Strong tensions may emerge, as the quantities available are likely to decrease due to climate change.

Desalination plants may proliferate around the Mediterranean, in Asia, Australia and California. Early plants first located in the Middle East today produce half of the world's desalinated water. Such first-generation desalination technologies use a great deal of combustion energy. Thus current methods of desalinisation will contribute to increased CO_2 emissions and exacerbate problems in the natural hydrologic cycle.

Water suppliers are already using new technologies based on Value Added Materials, and VAMs' influence can be expected to grow in the future. Applications for water supply systems include:

- materials for advanced technologies to permit the re-use of waste water;
- materials for treatment systems for rainwater harvesting;
- materials that remove microbial pollution (including viruses) and emerging contaminants;
- materials for seawater desalination by innovative solar-powered membrane distillation systems;
- integrated long-term materials and components, based on innovative, cost-efficient technologies, for new and existing infrastructures;
- materials for manufacturing nanoporous membranes (filtration, packaging, electrolytic devices, large surface electrodes);
- materials that reduce energy and chemical use in water and wastewater treatment systems.

4.1.3 Secure, clean and efficient energy

There is an increasing tension between rapidly growing demand and restricted supplies of petroleum-based resources (oil, gas). Their polluting nature is a complicating factor, which holds true for a resource that is still abundant: coal. These tensions have caused an almost constant rise in energy prices. Increased use of renewable energy, as well as progress in the reduction of energy consumption, may help to contain price rises. But opinion is divided over the scope of possible change, and how and when this might happen. Value Added Materials may have a strong role here, responding to the need of technologies to create effective alternate energy sources.

Despite our technological sophistication, in 2025 the world's energy demand will have increased by 50 per cent (relative to 2005) and will reach the equivalent of 15 billion tons oil equivalent. Oil production will have peaked, and some experts believe coal will become the prime energy source between now and 2050. Possibly, oil will still largely be in the lead in 2025.[41] The security of energy supplies increasingly will be called into question in Europe. If policy does not change the EU of the future will be more dependent on external sources than in 2005. In 2030, the Union will import almost 70 per cent of the energy it needs.

Value Added Materials have the potential to modify some of those figures with low energy or green energy solutions. VAM alternatives can redesign today's energy-consuming devices in both homes and industry.

The list of possible applications in the energy sector may be tracked from currently available roadmaps and industry strategies.

1. Energy production

- Generate electricity, heat and clean fuels (hydrogen, bio-fuels, etc.) using advanced materials. Examples are high-temperature materials, coatings and functional materials for zero-emission fossil fuel; nuclear, biomass and waste-fired power plants; fuel cells.
- Materials for renewable energy systems: solar (photovoltaic and thermal), wave/tidal and wind. Technologies include improved solar panels, materials and production technologies for concentrator solar cells with very high efficiencies.
- New materials to substitute petroleum-based chemical with bio-based ones: 'Green' specialty chemicals.
- Advanced biofuels: cellulosic ethanol, advanced biodiesel, other biomass/sugar-based biofuels, biosynthetic gas.
- Propulsion technologies: materials required for reductions in the number, cost, size and weight of the electrical equipment; alternators, transformers, frequency converters, generators and electric motors.
- Nanotechnologies: new catalysts to increase the conversion efficiencies of fuel cells and biodiesel, and to synthesize biodegradable lubricants.
- Bioisoprene applications: rubber, adhesives, specialty elastomers, biochemical and bio-based hydrocarbon fuel for transportation.
- Materials with specific requirements for power plants with corrosion resistance (aqueous and high tempera-

[41] International Energy Agency foresight.

ture), light weight technologies (composites, plastics) and environmental coatings.

- Improved materials for nuclear energy sector used for plasma surrounding components.
- Innovative fuels for nuclear energy sector (including minor actinide-bearing) and core performance.
- New high temperature resistant materials for nuclear reactors, energy micro-generation units for MST energy scavenging and conversion materials for energy waste.
- Catalyst with higher longevity and robustness.
- Catalysts to exhibit oil stability over time; upgrading to fungible biofuel.
- Materials allowing for exploration and extraction in a harsh environment (especially those that address corrosion).

2. Energy transmission

- Materials for high-power electronic systems.
- New materials with conducting and superconducting properties for transmission of large electrical currents over long distances without energy losses.
- Materials for electricity, gas and hydrogen distribution; pipelines for captured CO_2 (such as new ceramic materials).
- Advanced materials for overhead transmission: high-temperature conductors suitable for use on both transmission and distribution circuits to increase their thermal ratings, improved insulation systems.
- Advanced materials for underground/submarine transmission: high temperature conductors and insulation systems for cable transmission, high temperature superconducting cables and Gas Insulated Lines.
- Functional coatings with advanced thermal control: high capacity heat pipes (500 w/m), phased loop (10 to 1000 kw.m).

3. Energy storage

- Advanced materials for large- and small-scale energy storage.

4. Energy use and efficiency

- Materials for sensors, actuators, and control and communication systems to efficiently manage all the devices within buildings.
- Materials for outdoor smart lighting.
- Materials for energy conservation and efficiency in construction, such as advanced glass, insulating materials, ceramics, coatings, etc.
- Nanostructured antireflection coatings, photonic crystal, plasmonic guiding and other nanoscale coupling structures to reduce reflection losses and improve light capture.
- Radically-advanced construction concepts such as integrated and intelligent agent systems, programmable nano-materials and nano- constructors, bio-mimetic materials, structures and facility systems.
- Active phase-changing materials that control the climate within the house.
- New nanoporous insulating materials that enhance insulation.
- Radiant barriers in ceilings and walls to reduce heat loss by over 50 per cent by reflecting or absorbing infrared radiation.

- Durable materials with prolonged and predictable service life under aggressive conditions, featuring self-assessment and non-intrusive in-situ inspection techniques.
- Compound semiconductors ingots and wafers for Solid State Lighting.
- Efficient lighting in the form of light emitting diodes: LEDs, OLEDs. Materials for LED device performance.
- Materials for electrochromic 'smart' windows (OLAE, chips), advanced materials (nanostructured silver chloride or halide, photochromic production).
- Materials for high quality, low cost optical transceiver modules.
- Materials replacing silicon with higher speed properties.

4.1.4 Smart, green and integrated transport

'Transport is rightly considered (...) as a key societal challenge. It should be also kept in mind that transport is a key condition for competitiveness.'[42]

Value Added Materials will play a central role in one of the key grand challenges: green transport.

Innovative solutions for transport address materials and manufacturing processes for lower fuel consumption and development of alternative fuel sources. Materials science is engaged in developing new construction materials for roads and rail roads, as well as materials for transport security. Such processes will be critical to strengthen the global competitiveness of the European transport industry.

It must be noted that advanced materials are used now in the transport industry to a very large extent. This may be seen in the advanced cars produced today.

Advanced cars begin with a chassis of complex aluminium composite. In many cases they are covered with nano enhanced, self-healing coatings, with anti-reflex windows produced of advanced glass. The interiors are filled-in with advanced electronics and sensors. Finally, energy supply in combustion vehicles uses a number of composites based on polymers and ceramic materials. The future holds more environmentally-friendly solutions, with advanced materials used for efficient energy storage as well as materials for alternative energy production (hydrogen fuel cells, photovoltaics, and so on).

The 'green' aspect of transport is very much aligned with two other Grand Challenges described here– 'resource efficiency and climate action' and 'secure, clean and efficient energy'. Further examples of applications of Value Added Materials for transport will be developed in other sections.

4.1.5 Supply of raw materials

Raw materials are not a key subject of this study. VAMs in this context shall be seen rather as alternatives for raw materials. In fact, current problems with raw materials availability have put VAMs into the forefront of political discussion.

The European Commission claims that 14 critical raw materials used for high tech products such as mobile phones, laptop computers and clean technologies are in danger of shortage. Increased recycling of products containing these materials will be

[42] Informal discussion with stakeholders on the transport component of the next common strategic framework for research and innovation, Brussels, 16 June 2011.
http://ec.europa.eu/research/horizon2020/pdf/workshops/smart_green_integrated_transport/summary_report_workshop_on_16_june_2011.pdf#view=fit&pagemode=none

needed in the future. The list includes cobalt, gallium, indium and magnesium. They are increasingly used for 'emerging technologies' but are mined in only a few countries such as China, Russia and Mongolia. These countries could either manipulate the supply of these critical materials or take environmental action that may jeopardise EU imports.

After recent problems with materials availability from China, EU is working to secure supplies of these minerals from outside the EU, such as from Latin America, Africa and Russia. The EU also started stockpiling— to better profit from the material that we have here.[43]

Demand from emerging technologies (including demand for rare earths) is expected to increase significantly by 2030, according to EU estimates.[44]

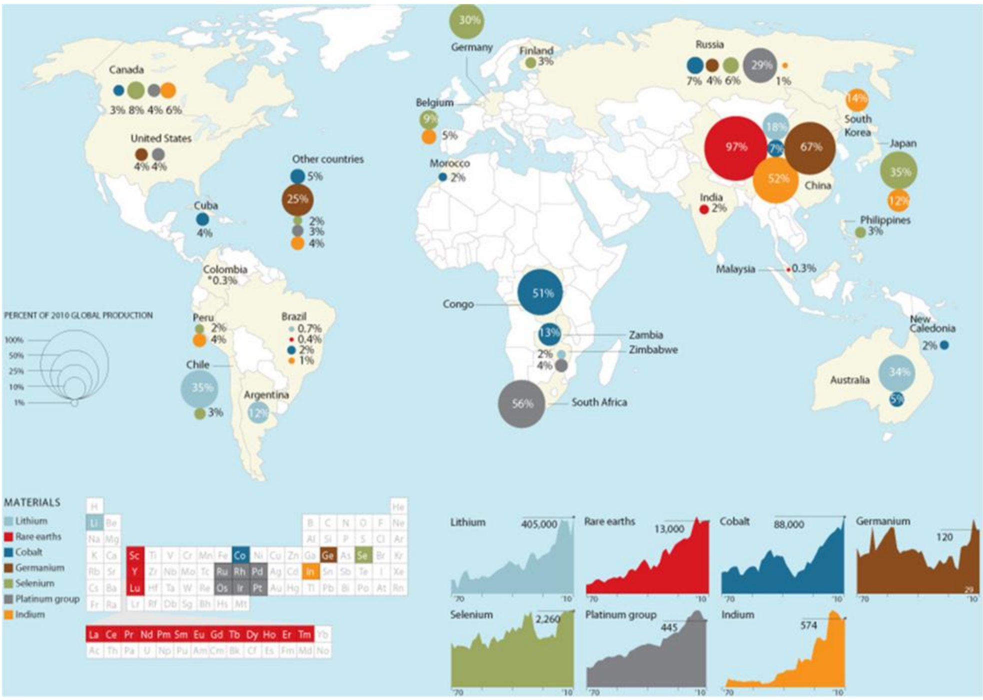
Materials experts whom we interviewed described this situation as influencing the possibilities for large development of materials' technologies. Our informants noted the difficulties of replacing critical raw materials which sets the stage for development of VAMs' market, especially in the field of catalysts and materials for energy storage. They also said that without a technological breakthrough it will not be possible to fully reduce the market need for critical raw materials.

The experts identified another approach: increased recycling of raw materials to reduce demand side of the market. Therefore one response to the raw materials challenge is more research on how to recycle technically-challenging products and improve collection. Here again Value Added Materials might be of use in the design of such advanced recycling systems.

[43] Andrea Maresi, press officer for EU Industry Commissioner Antonio Tajani.

[44] Report of the Ad hoc group on defining critical raw materials, June 2010, Brussels. http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/report-b_en.pdf , http://europa.eu/rapid/pressReleasesAction.do?reference=IP/10/752&format=HT and http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/10/263&format=HTML&aged=0&language=EN&guiLanguage=en

Figure 2: Production concentration of critical raw mineral materials



Sources: U.S. Geological Survey; Johnson Matthey; British Geological Survey. Information graphic by Tommy McCall and Mike Orcutt, 'Technology Review' by MIT.
Some percentages do not add up to 100 due to rounding. 2010 global production figures are estimates. U.S. production figures for selenium and indium are withheld. The historical production of lithium refers to lithium ore.

VAMs have the potential to substitute for raw materials. Still, interviewed experts see such applications as challenges for future research.

According to the secondary sources of this study, the research and industry deployments in nearest future will focus on:

- improved physical methods for minerals concentration (enrichment of non-ferrous ores, froth flotation);
- new technologies for production of precious metals;
- development of chloride metallurgy;
- processing systems for re-use and recycling;
- innovative use of alternative energy sources for processing raw materials and metals recovery.

4.1.6 Resource efficiency and climate action

Global warming is no doubt one of the most serious problems facing humanity today. Two separate dimensions of global warming correspond to different kinds of advanced technologies under discussion. First is the prevention of the global warming itself (reduction of emissions, clean production, less pollution in general). Second is the technological efforts to mitigate the consequences of global warming (natural disasters such as flooding, forest fires, hurricanes, desertification).

Global warming is also connected with other Grand Challenges, as it will have an impact on the long-term health and economic well-being of current and future generations.

In order to prevent a downward spiral, the current strategy underlines the need to reduce emissions of heat-trapping gases by using the technology, know-how, and practical solutions already at our disposal. Secondly the strategy purses promising new technologies, including Value Added Materials, that will enable us to produce highly efficient products with less pollution, thanks to knowledge-intensive production processes.

> Interviews again revealed the important relationship between the research of Value Added Materials and their market implementation.
>
> Although by definition VAMs are knowledge intensive, their market implementation is dependent on relatively simple (short and inexpensive) production processes. Only the VAMs that are able to be used in mass production with high cost efficiency have the potential of addressing environmental challenges. This is due to the direct linkage between complexity, cost and pollution impact of the production processes. The more complicated the production process, the more energy it takes; therefore the VAM becomes more expensive and finally more polluting.

The European Commission followed this strategy to tackle global warming since the introduction of climate-related initiatives in 1991, when it issued the first Community strategy to limit carbon dioxide (CO_2) emissions and improve energy efficiency. Several important directives were introduced at that time, including those to promote electricity from renewable energy, voluntary commitments by car makers to reduce CO_2 emissions by 25 per cent and proposals on the taxation of energy products. All those fields benefit from implementation of Value Added Materials.

Examples include filters, protection and isolation films, new combustion sources, energy storage and electricity grids.

However, it is clear that action by both Member States and the European Community need to be reinforced, if the EU is to succeed in cutting its greenhouse gas emissions to 8per cent below 1990 levels by 2008-2012, as required by the Kyoto Protocol. On the political level this was supported by the EU Council of Environment Ministers, who acknowledged the importance of taking further steps at Community level by asking the Commission to put forward a list of priority actions and policy measures. The Commission responded in June 2000 by launching the European Climate Change Programme (ECCP). The political dimension and commitment later on was strengthened through the engagement of the European Commission in the development of technologies, particularly in the context of the framework programmes (FPs). Industrial technologies play a crucial role in the Commission's portfolio of tools, and are strongly represented in European FPs, especially with the NMP priority in FP6 and FP7.

The second European Climate Change Programme (ECCP II), which was launched in October 2005, is still influencing the shape of the strategic dimensions of research conducted in FP7.

In spite of all political actions, the most important source of CO_2 emissions worldwide is caused by the transportation of goods and people. Fossil fuel combustion generates more than 90 per cent of the world's CO_2 emissions.

Several materials applications are able to address this fossil fuel combustion challenge:

- high strength, low weight materials to reduce weight and friction, and therefore fuel consumption and CO_2 emissions (advanced composites, alloys and sandwich structures, near net shape materials);
- materials reducing maintenance (low thermal expansion polymer matrix nanocomposites, super hard nanocrystalline metals, alloys and intermetallics);
- multimaterials (hybrid) systems: metals-plastic, ceramics-metals, composites, Al-Steel, metal-rubber, plastic-TPEs, plastic-metal-TPEs for automotive applications;
- functionally graded materials and self-lubricant coatings for critical working environments (engines, sensors, mechanical components, bifuel and trifuel engines, energy or fuel storage);
- high temperature materials (thermal barrier coatings, nanocoatings, ceramic thin film coatings) for engine components, turbines resistant to corrosion, wear, creep, temperatures;
- catalytic and photo-catalytic materials and nanostructured coatings for different applications (new combustion systems, alternative fuels, micro-combustion, environmental treatment);
- materials for embedded sensors, to improve data acquisition, on-line monitoring and new designs;
- environmentally friendly coatings for transport components (free of Cd, Cr, and Pb);
- biodegradable and renewable materials (lubricants, fuels, plastics) to reduce the CO2 emissions;
- advanced road surface and bridge materials;

- materials for electronic paper as an alternative to conventional books, newspapers and magazines.

After fossil fuel combustion the next two areas with high CO_2 emission impact are iron, steel and cement production.

As indicated in the interviews future research on VAMs shall include new/improved methods of steel and cement production in order to minimise their environmental impact. . Some expert opinions indicate the need for new research to change the chemical processes behind production of cement.

4.1.7 Inclusive, innovative and secure societies

This grand challenge is in fact composed of three separate issues. Openness of societies is hardly connectable with discussion on advance materials; nevertheless in a larger context security is fundamental for society's ability to be open. An innovative society, meanwhile, is the overwhelming factor motivating this study. Therefore in this section we will only address the security issues that can be directly answered with material science.

Current developments in the Arab countries in Northern Africa, mass migrations influencing southern European countries and growing terrorist risks put security in forefront for industrial technologies and novel materials research. The European security strategy, 'A Secure Europe in a Better World', endorsed by the European Council in December 2003, outlines the global challenges and key threats in this area.

The Commission Communication from 2003 on 'The European Defence and industrial and market issues – Towards an EU Defence Equipment Policy' emphasises the need for effective cooperation between national research programmes in the field of global security. The idea is to concentrate on a few carefully selected subjects of advanced technology accompanied by specific measures.

Security is an evolving issue that presents many challenges to the EU. It impacts a wide range of existing and emerging EU policies (include competitiveness, transport, environment, energy, health, consumer protection, finances, trade, space and telecommunications). It is a critical consideration of the Common Foreign and Security Policy (CFSP) and the European Security and Defence Policy (ESDP). The research policy plays a crosscutting role to target threats and reduce citizens' concerns, helping to protect against terrorist threats.

The Union needs to use a range of instruments to deal with such current hazards as terrorism, proliferation of weapons of mass destruction, failed states, regional conflicts and organised crime. Industrial technologies can give the necessary assistance, offering scientific innovations in the area of detection, monitoring and early warning systems and technologies. Value Added Materials are often used for production of final products used in the area of security.

Technology itself cannot guarantee security, but security without the support of technology is impossible. It provides information about dangers, helps to build effective protection against them and, if necessary, enables designated agencies to neutralize them. In other words: technology is a key 'force enabler' for a more secure Europe. Space technologies are a perfect illustration of this: A decision as to whether global positioning or earth observation systems, for example, are to be used for defence and security purposes is primarily political in character, not technological. In any case, any developed system will very likely use Value Added Materials for many of its applications.

- Secondary sources for our security discussion contain mostly materials applications within the fields of optics, electronics, data transfer and advanced armours and body protection systems. VAMs possess trans-sectoral applicability in surveillance, military personal communication systems and personal security. New materials for electronics: materials for superconductors, polymeric conductors and semiconductors, dielectrics, capacitors, photo resists, laser materials, luminescent materials for displays, as well as new adhesives, solders and packaging materials.
- New materials in the field of optical data transfer: non-linear optics materials, responsive optical materials for molecular switches, refractive materials and fibre optics materials for optical cables.
- Metamaterials for photonics (synthetic materials, mostly nanostructured): Photonic crystals, quantum dots (including composite colloidal nanoparticles in a glass or polymer matrix or semiconductor media) and materials exhibiting negative permittivity or permeability or both.
- Group IV photonics: this includes silicon (Si) and its combination with germanium (Ge) and tin (Sn) for applications such as modulators and light sources with higher optical functionality and performance.
- Carbon nanotubes and graphene, which offer new vistas in photonics with their high absorption and mobility, complementing their use in non-photonic fields such as catalysis.
- Material engineering in oxides and chalcogenides: while these materials have been known for a long time, nanotechnology offers new possibilities to utilise phenomena such as phase changes to significantly alter optical characteristics in a way not achieved with other materials.
- Materials for ultraviolet and mid-infrared devices and fibres, including acousto-optic materials and Faraday rotators for optical isolators.
- Organic phosphor materials for solid-state lighting, to achieve higher light conversion efficiencies than inorganic materials at significantly lower cost.
- Nanoparticle integration in dielectric coating matrices for the development of improved optical switches, laser concepts and sensors.
- Advanced polymer coatings which exhibit superior functional properties for photonic devices at low cost. It is possible to modify the physical, mechanical and chemical characteristics of polymers in order to increase the functionality of optical devices. One example is including nanoparticles in the polymer matrix. Polymers also provide the key to flexible optical devices whilst the combination of polymers with semiconductor materials will give rise to novel components such as those based on optofluidics.
- Graphene and carbon-based materials have highly desirable electronic properties such as ultrahigh mobility, possibility of innovative approaches to bandgap engineering, and ballistic transport at room temperature. Also they have excellent thermoelectric

properties, mechanical strength and electromechanical properties.

- Manufacturing of low-power non-volatile 4M-bit carbon-based memories with equivalent switching performance as SRAMs.
- Carbon-based memories with ultra-low power consumption and non-volatility that serves as universal memory.
- Materials for 'harsh environment skin'— close-to-body protective materials for harsh environments.
- Materials for radiation-hardened chips, sensors and radars, PV modules.
- Lightweight structures for satellites and observations systems.
- Materials for structures giving stiffness/low mass/thermal properties, electrical-combined properties, moisture insensitive (non-hydroscopic) properties.
- Materials for high-speed data processing.

4.2 Business challenges

Experts interviewed for this study clearly set forth several business-related issues. Seen in the context of existing economic limitations on the markets for VAMs, these concerns illuminate ways to address the Grand Challenges with greater strength.

Patent protection

Our definition of Value Added Materials in chapter 3 lists two important factors to consider while discussing the new and advanced materials on the market today. These are *knowledge intensivity* in production process and *competitive advantage* on the market. These two factors, taken together and in context, lead us to the conclusion that VAMs knowledge intensive production processes must be patent protected in order to assure competitive advantage on the market. Simultaneously this is one way of preventing VAMs from becoming a commodity over time. Only materials that are protected by intellectual property regulations for 20 years will be able to maintain the competitive advantage on the market. Limiting the competition through patents provides the necessary incentive to research and development, and rewards inventiveness.

Time to market

Time to market indicates the length of time it takes from a product's conception until it is available for sale. This term is crucial for Value Added Materials, as well as for all other industry products and services. All interviewed experts saw the time to market as far too long for VAMs. Examples given by car producers and aircrafts producers confirm that the average time to market in these industries is around 20 years. This in reality is how long it takes before a new material gets from lab to demonstration, through tests and certifications, and finally to production. In fact today's cars and planes are built with materials invented in the early '80s.

European research programmes must consider this particular factor in their planning. Investors we interviewed clearly stated that it might be more reasonable for future research programmes to demonstrate a more business-based approach by investing in ideas where the market implementation is closer and the product life cycle may start sooner. Venture capital market advisors and business angels' networks have to gain profits from the business ideas they support. The obvious conclusion is to learn from them when selecting research to be financed.

Another very strong opinion from the interviews is that we 'just' have to implement all technologies available today in order to deal with the societal challenges. In other words, the technological sophistication exists now. It is the means that is lagging. From the perspective of 2020, there is no time for new research.

Small and Medium Enterprises (SMEs) need to be supported

SMEs are considered the primary innovation actors in developing the VAMs and their applications. But SMEs still encounter problems when striving to finance their projects, reach the market and make their products known to customers, while building solid networks that would help them promote their VAMs. The role of private equity and venture capital is highlighted in this context.

Too high production costs

For a VAM to be considered interesting, it should be 30 per cent cheaper or perform 30 per cent better. This is the rule of thumb when replacing an old material with a new one in the open market. The exception is fulfilling a regulation that bans the old materials for reasons of health risks, CO_2 emissions and so on. The next several sections examine why.

The scale-up problem

The up-scaling step – taking a technical solution from the research laboratory to industry production — is very difficult to make. There must be a sufficient market for the product and a scalable production technology behind the idea. This is the 'valley of death' problem: a lot of very valuable materials are created in labs but the step into industrial application has not been achieved. Manufacturers cannot produce them at industrial scale at an economically reasonable price, and thus a chicken-and-egg dilemma appears. To create a market for a material, it must be produced in large quantity in order to be profitable, but new markets have an inherent risk of too-small demand.

Economies of scale and scope

Economies of scale[45] occur when increasing production volumes permit significant lowering of average cost. Because of the small volumes in typical production runs, scale economies are rarely exhibited and are not a feature of new and advanced materials supply. Once volumes become large and scale economies occur, the material is, by definition, neither new nor advanced.

Economies of scope are likely to be more important for some new materials than economies of scale. Economies of scope are characterised by cost reductions achieved through the jointness of some costs in producing differentiated products (that is, the integration of manufacturing options so that the same processes produce different goods). The associated increase in product variety enables producers to be flexible in fulfilling customer needs. There are significant economies of scope where new and advanced materials (such as engineering ceramics) are tailor-made. However, economies of scope can be difficult to achieve. The use of more specialized materials, unique design, and the level of skills required are all expensive to duplicate, and can discourage entry into niche markets.

Businesses working with VAMs are generally associated with high risk and large capital intensivity

[45] Australian Industry Commission, *New and advanced materials report no. 42*, 1995.

The investors emphasised that work with VAMs is a high-risk type of businesses. Capital intensiveness, commercialization risks, technology risks — all these factors influence capital funds' willingness to allocate resources.

Quotations garnered from our interviews reflect these factors:

'There [are] a lot of interesting things in materials science — the point is nevertheless to identify the commercial need for it. It's not that easy to see it often. It could be a really light and durable material, but you need 1 billion dollars to commercialize it — the magnitude of money is very large here — on billion scales — the risk is tremendous and the time perspective is large. The material may be cool, but the amount of investments needed and the risks involved outweigh its potential to pay off.'

'You need to consider different commercial needs that you believe in, that are not only technically do-able, but also manufactured in such a way that it brings a high yield, with not-so-high production costs and not-so-high risks.'

'People come with new materials and technologies all the time, but these produce small changes in very complicated systems and require [a] huge amount of money. It takes a long time, depending on what they do. Even if in the lab the results are good it may not be the same when tested in the industry. Many don't understand how much time and money it takes to bring a new technology to the market. It is common that people put a lot of money in R&D of a material and then they search for its applications: i.e. start from the technical side and try to match with some commercial needs. These applications can pay for all [the] money you need to invest, but one needs to start from the commercial side.'

Reasons for not investing

Our informants revealed several reasons for not investing in new developing businesses in the area of materials industry. The investors' views can be summarised as follows:

- too capital intensive (example: hydrogen storage);
- political complexity (example: hydropower, nuclear power);
- limited market (example: wave energy);
- market not ready (example: energy storage);
- technological challenges (example: superconductivity facing complex technical problems, fuel cells, batteries — lot of R&D resources were invested with little success, hydropower — no mature technology);
- lack of trust in market potential;
- not profitable business (example: transports, environmental related businesses, unless policy regulates the market);
- investor doesn't know much about the specific market (example: prostheses or biomaterials);
- risky business (example: health effects of nanotechnologies);
- overinvested sector (example: ICT).

Many interviewed investors, especially those who invest in clean tech and med tech, are materials or technology experts themselves or have other technical backgrounds. They are updated with the research and developments in their field—they have a clear view on where the breakthroughs are happening and the potential of development in the field.

The decision of how to invest partly reflects the companies' current investment portfolio and partly the respondent's assessment on the future of a potential investment. **Key factors affecting investment decisions in VAM-related businesses**

- if the business provides a unique position on the market;
- if the business is innovative;
- if the business responds to a market need;
- if the invention is or can be patented, or protected by other legal measures;
- if the business has good managers and driving leaders;
- applicability and scalability of the material;
- solid intellectual property structure;
- readiness of the market.

Excerpts from our interviews add context to the above factors. '*You try to find whether the technology has a unique precision when it comes in the market, what sort of influence it will have on the market. Innovativeness is clearly important, but also it has to have a market potential — that there is a market need for it*.'

'As for all VC it is important that you can protect that by a patent, you need to have a good IP position with regards to the competitors.'

'[I]t is important to have the people behind the company, who can drive this process and manage the development.'

'You pick areas where you think that the company will achieve a unique position in the market.'

'It may be a very noble technology, but the market is not ready for that. The market needs to react and show that they are willing to pay for it.'

The exit time for these businesses (mostly VC) varies from 3 to 5 (mostly) up to 10 to 12 years depending on industries, technology types and applications, with the energy and environment tending to have even longer time frames (10 to 20 years) and ICT and health having shorter time frames (2 to 10 years).

Chapter 5. Qualitative and quantitative Value Added Materials market analysis by sector

At the request of European Commission, the approach of this study was to investigate venture capital investors, business angels and investment banks advisors in order to get a picture of their possible investments strategies and most promising investment areas for the future.

5.1 General investment split

Interviewed market investors expressed the opinion that most of the early stage and seed capital investments in advanced materials are not dedicated to a pre-selected particular sector. Investment in research on new materials brings uncertainty but also possible diversity of future applications. Investors at this stage make decisions based on the available flow of investment opportunities and general strategy of the fund. Because of these two factors, their investments are largely predefined.

For the purpose of this study they were asked to conduct a very open exercise: Freely allocate a hypothetical fund into a number of sectors, indicating potential future market growth, based on their best guesses and overview of current situation.

The interviews revealed that investment specialists were able to discuss potential split of investments in the future on a sector level. It was nevertheless difficult for them to provide more precise divisions regarding detailed, expected future allocations per sub sector or application area.

They also estimated the investment timescale for private equity. The general approach is defined here by the so-called 'closing period' of the venture capital funds.

Following the general theory of the private equity business, most venture capital funds have a fixed life of 10 years,[46] with the possibility of a few years of extensions to allow for private companies still seeking liquidity. The investing cycle for most funds is generally three to five years, after which the focus is managing and making follow-on investments in an existing portfolio. This model was pioneered by successful funds in Silicon Valley through the 1980s to invest in technological trends broadly but only during their period of ascendance, and to cut exposure to management and marketing risks of any individual firm or its product.

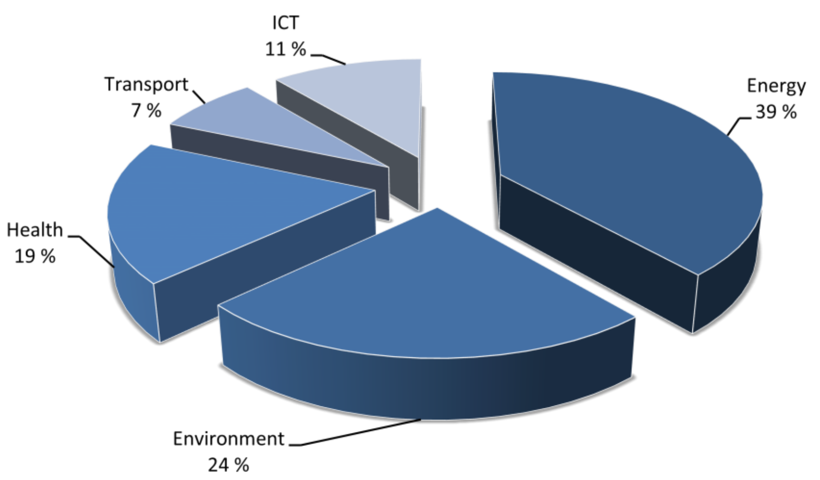
Investors interviewed in this study expressed a clear division in this regard between the selected sectors. While ICT investments are considered 'faster', energy, health and environment sectors are considered to be long-run investments. Therefore in one venture capital cycle, we might expect 3 to 4 investing cycles in ICT related deals, and only 1 or 2 cycles in other sectors where investment requires more than 5 years and sometimes even 10 to 12 years engagement.

When it comes to expected Return on Investment (RoI) it seems that most of the investors are influenced not by the sector but the business idea or technology behind the potential investment deal. In other

[46] http://en.wikipedia.org/wiki/Venture_capital

words, the sector and subsector may not seem to be very lucrative in general terms, but the business may still have the potential to generate very high RoI. In most of the interviews the average expected RoI from a single deal was estimated to be in the range of between 20 to 30 per cent, but as stated before some businesses have a shorter investment time frame than the entire fund duration. In general, the longer the engagement, the higher RoI expected. The RoI expected from VAM-related business varies depending on the type and stage of the company, the industry sector and the time frame. One must remember that it is impossible to define precisely investors' expectations with regard to RoI. Expectations are different each time. Expectations are also high, since each investor wants to multiply his/her investment. One must also remember that out of a number of different deals in one venture capital fund portfolio, some investments will never lead to successful commercialization, and only a limited number of companies financed bring multiple, sometimes astronomical RoI.

Figure 3: Investment willingness for VAMs by sector



Source: Oxford Research AS. Percentage calculated from averages based on values of portfolio allocation (n=12).

The willingness of the interviewed investors to allocate their funds into investments connected with development and market implementation of Value Added Materials is demonstrated in Figure 3. Interviewees clearly believe that the most promising investment sectors of the future are energy and environment, which make up more than 60 per cent of the available hypothetical portfolio. ICT and automotive were not highly ranked by private investment advisors. They reasoned that large enterprises' own research investments made their involvement unnecessary and that these industries were largely addressed by private capital in past decades (especially ICT industry).

Note that ICT is not fully reflected in this study. This particular sector is mostly composed of services and software, so that materials do not influence the market size directly. Our respondents were only asked to give their opinion about investing in projects related to materials. Therefore the ICT sector is underestimated in our hypothetical allocations exercise, although some investors define semi-conductors, micro- and nano-electronics and the like as 'ICT hardware'.

The specificity of the investments is also important for this study. Interviewees claimed that this type of investment in highly risky ideas is mostly addressed by private investors — venture capital funds and private equity business. Banks do not tend to operate within this kind of highly demanding and risky market. Stock market investors will also be far from this kind of investments since by definition such actors may invest only in companies already established on the stock market with a proper public securities structure. Investors interviewed also indicated another important player for the development of research: large industry actors with their own research facilities, agendas and budgets.

A different set of interviews conducted simultaneously with materials experts representing research centres of such larger companies was not included in the results above, since this group was purely oriented in research within their industry (such as automotive, construction materials, etc.) and did not have an overview of the investment market trends.

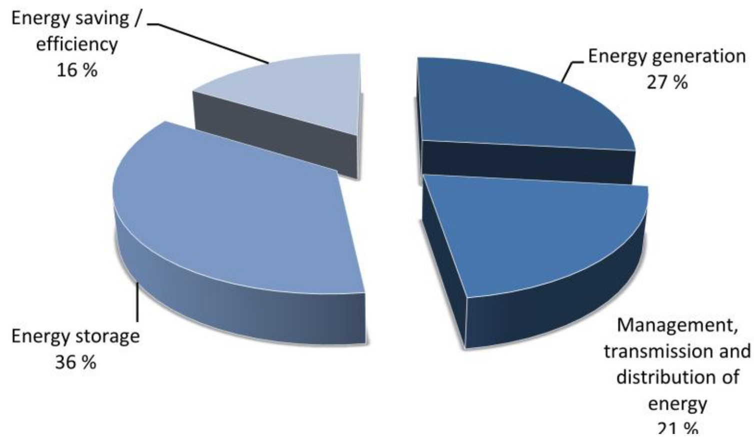
5.2 Overview of sectoral investment willingness

The following charts present results of the investigation of investors' willingness to allocate resources within each of the sectors within the scope of this study.

Their willingness is understood in this context in terms of portfolio allocation. Each of respondents could allocate a hypothetical portfolio of investment fund into different (predefined) sectors. The percentages demonstrated below show therefore the size of potential financial allocations into research-oriented 'deals' of venture capital and private equity investors.

Please note that the less 'popular' the sector was, the lower the number of valid opinions regarding detailed investment directions. Investors could not give more detailed split, as their decisions are based on availability of good business ideas, and not reflecting any particular subsector categories.

Figure 4: Investment willingness for VAMs in the energy sector

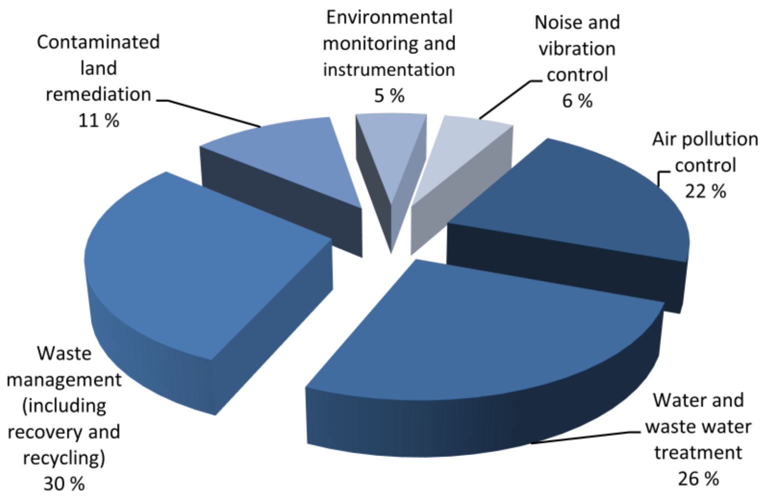


Source: Oxford Research AS. Percentage calculated from averages based on values of portfolio allocation (n=10).

Within the energy sector — which promises the most growth potential in the future — our study indicated the biggest potential in the energy storage field, which garnered one-third of the possible investments. This indicates that batteries and energy storage in large grids are critical issues for future development of many areas of the economy.

Following this were the investments in materials for energy generation and transmission. Finally, energy savings had reasonable share of the potential future market and thus was ranked fourth in this sector.

Figure 5: Investment willingness for VAMs in environment sector

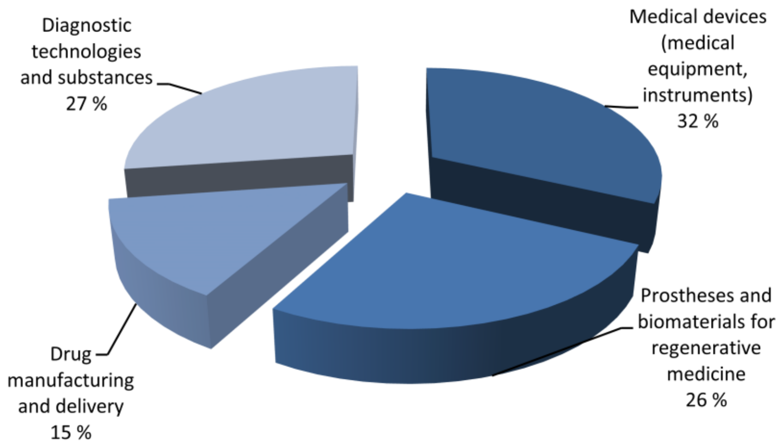


Source: Oxford Research AS. Percentage calculated from averages based on values of portfolio allocation (n=5).

The willingness to invest in the environmental sector was focused on water technologies. All areas — from water treatment, desalination to waste water technologies — took up to 48 per cent of the potential investments.

Another prospective area was solid waste management and related technologies (also related to technologies focusing on energy production from solid waste). These subsectors take more than three-quarters of total environmental sector allocations.

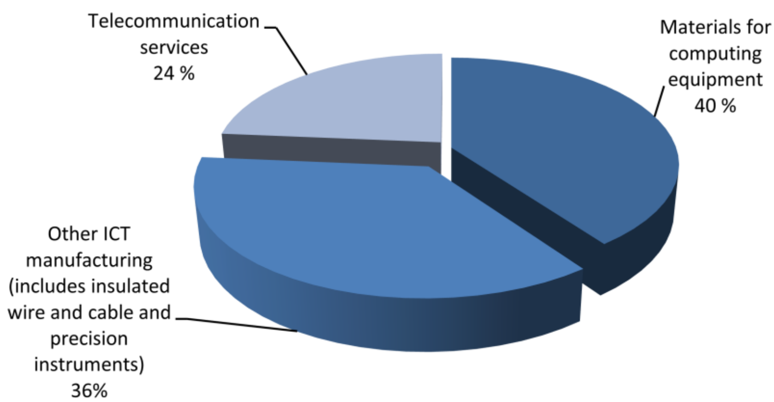
Figure 6: Investment willingness for VAMs in health sector



Source: Oxford Research AS. Percentage calculated from averages based on values of portfolio allocation (n=5).

The health sector is largely dominated by large drug manufacturers with their research-oriented agendas and own laboratories. Still the health sector is very interesting for VC and PE (Venture Capital and Private Equity) in terms of producing medical equipment, new technologies for diagnosis and their related substances. Delivery of prostheses and biomaterials for regenerative medicine is considered a huge market for intensive development in the future. These are seen as highly profitable niche markets where a high innovativeness and knowledge intensivity play crucial roles.

Figure 7: Investment willingness for VAMs in ICT sector



Source: Oxford Research AS. Percentage calculated from averages based on values of portfolio allocation (n=3).

The willingness to invest in transport accounted for 7 per cent of investors' allocations demonstrated at Figure 3 was not depicted in form of graph since there was no division in their answers.

The main reason for this is that the transport sector is normally divided by the mean of transportation including such categories as water, road, rail, air and space. A second approach to possible sector division is two-fold: passenger transport and goods transport. In all cases the use of materials is not determined so much according to this possible market segment division, but rather by the material usability. For example, the ultra-light and highly durable materials for transport will be used in many transport subsectors as they will lower the fuel consumption of the vehicle. Also energy storage and highly efficient fuel cells have the potential to be used in all transport environments. For these reasons investors were not able to give any information on the division of their possible investments in this sector, following the possible subsector divisions.

Investors consider that the applications developed in other sectors will be applied in the transport sector as a matter of course, and therefore they are not interested in directly investing. However weight reduction and the role of lightweight materials is perceived as crucial for this sector.

5.3 Findings from interviews

Interviewees give different estimates of future market shares of VAMs and different assessments in terms of percentages. Still, patterns clearly show confidence in future potential market growths. The difficulty of assessment of market size is caused by the nature of VAMs, which cannot be separated from the production process and integration. VAMs are used in combination with other materials, technologies and structures. Materials are just the beginning of the feeding chain of the industrial system. It is difficult to 'put a finger' on a specific VAM or group of VAMs. Segmenting VAMs is also difficult because of overlap across sectors. These overlaps will always influence the market segmentation and the value-chain structure.

On the other hand all the respondents express confidence that the share of materials will increase the future, although they say it is difficult to give numbers due to complexity of the nature of the VAMs and their context. Typical expressions used with respect to VAMs markets are 'the markets will increase dramatically' and 'we see significant increase in the coming years.'

The development of VAMs markets depend on a range of factors

- The development of materials markets also depends on the political environment: regulations, policies to support renewable sources of energy as well as numerous other factors. For example, nuclear energy, along with the range of VAMs specifically associated with it, is subject to political uncertainty. Regulations of CO_2 emissions and other environmental requirements also influence the markets.
- Emerging markets for the VAMs will depend on the concomitant development of technologies and manufacturing systems that use these different materials.
- The markets for the VAMs will depend on solutions integrating VAMs in different structures and devices. As stated earlier, it is not possible to separate the materials from the production and integration processes. VAMs value depends on streamlined integration solutions, and their position in the value chain.
- Price of VAMs application will matter. The markets for VAMs will depend on the ability of the VAM to be produced with low costs. Price is important when it comes to the competitiveness of a material. If there is a cheaper, non-VAM material available, industry will choose it. Customers will not buy VAMs at any price just because of their functionality or potential for reducing CO_2 emissions or environmental pollution. This is especially true if the price of the specific VAM is much higher. However, the success of the organic food and green building markets, with 'natural' higher-cost products, show that consumers will pay a reasonable higher price for a perceived improvement in quality that is in line with their personal values.
- Producers will consider the total price for these materials and final costs of the entire application/device/structure for industrial production. If development of technology implies multimillion investments, these costs will play a role.
- VAMs need to be produced and used under the conditions of energy saving/energy effective production processes and with minimal CO_2 emissions in order to develop and sustain their markets.

Market growth areas for materials indicated by interviewees:

- catalysts;
- clean tech;
- novel pharmaceuticals;

- tissue repair;
- diagnostic technologies;
- advanced sensors and monitoring systems (in all industries);
- coatings (currently large market, with large market potential in the future);
- intelligent packaging;
- batteries (if a breakthrough happens);
- advanced composites;
- lightweight materials (currently very limited scale, but it will increase in the future);
- fuel cells (currently limited market, but bound to increase in the future, especially with government subsidies);
- bio-based materials;
- nano structures and thin films;
- superconductivity (if a breakthrough that could substitute copper wires occurs);
- LEDs.

Key industrial sectors where VAMs will play an important role, according to the interviewees

- Energy (generation, distribution, storage and efficiency — all the subcategories): Huge market opportunities, but also important area with regard to focus on the Grand Challenges.
- Environment: interconnected with the energy sector. A cross-cutting sector across the other industry sectors.
- Health: medical devices, biomaterials. Tissue engineering, nanostructures considered as big markets, also dealing with challenges of the ageing society.
- Transport sector: lightweight materials.
- Industrial tools, machines, equipment and devices that are used to manufacture VAMs and further integrate them into systems.

'Old' markets and structural materials

The metals that are widely used today in construction, transport, and other sectors — steel, aluminium, copper — already have well-established markets. Entire industries build on them and are developing metallic alloys and hybrid solutions. VAMs cannot replace these materials entirely, at least not until 2030 or even 2050. Instead VAM technologies and production processes can enhance the existing materials by providing them with superior properties, multifunctionality, and making their production more energy efficient.

'There is a danger in focusing lot of effort and resources on certain types of materials and not even know what their markets will be and at the same time ignore the basic materials that still are fundamentally used in many industrial sectors.'

5.4 Emerging technologies within materials

A good complement to the picture given by our expert investors is the yearly MIT 'Technology Review' assessment of emerging technologies. MIT investigates the most promising technologies and materials-related research of the last decade, looking for those that have a potential to produce the greatest impact on our societies. An overview is presented in Table 2.

Table 3: An overview of top emerging technologies within materials and the research centres working on these in the last decade.

Year	System / Technology	Description	Material	Sector	Centre of Excellence
2011	Smart Transform-ers	Controlling the flow of electricity to stabilize the grid	Semiconductors based on compounds of silicon and carbon or gallium and nitrogen	Energy	North Carolina State University; *Others working on smart trans-formers:* Amantys, Cambridge, U.K.; Cree, Durham, North Caroli-na; Electric Power Research Institute, Palo Alto, California
	Cancer Genomics	The use of sequencing to study the genomes of diseased cells		Health and Biotechnology	Washington University, St. Louis, Missouri; *Others working on cancer genomics:* BC Cancer Agency, Vancouver; Broad Institute, Cambridge, Massachusetts; Wellcome Trust Sanger Institute, Hixton, U.K.
	Solid-State Batteries	Smaller and lighter lithium batteries will make electric vehicles more competitive, as liquid electrolyte is replaced with a thin layer of material that's not flammable	Not revealed	Transport, Energy	Sakti3, Ann Arbor, Michigan; *Others working on solid-state batter-ies:* Planar Energy, Orlando, Florida; Seeo, Berkeley, California; Toyota, Toyota City, Japan
	Separating Chromo-somes	A matchbox-size device uses tiny valves, chan-nels, and chambers to separate the 23 pairs of chromosomes in the human genome so they can be analysed individually		Health and Biotechnology	Stanford University; *Others working on separating chromosomes:* Complete Genomics, Mountain View, California; Scripps Re-search Institute, San Diego, California; University of Washington
2010	Engineered Stem Cells	Transforming adult cells into stem cells called iPS cells		Health and Biotechnology	Cellular Dynamics, Madison, Wisconsin *Others working on engi-neered stem cells*: Fate Therapeutics, San Diego, CA; iPierian, South San Francisco, CA.; Children's Hospital Boston, Boston, MA; Kyoto University, Kyoto, Japan
	Light-Trapping Photovolta-ics	Depositing nanoparticles made of silver on thin-film photovoltaic cells increase the cells' efficien-cy, which could make solar power more competi-tive	Thin-film photovoltaic cells	Energy	Australian National University,Canberra; *Others working on light-trapping photovoltaics:* Caltech, Pasadena, CA; University of New South Wales, Australia; FOM-Institute for Atomic and Molecular Physics, Amsterdam
	Green Concrete	Reduce emissions in cement production by replacing limestone (a carbon rich mineral) with magnesium compounds	Magnesium com-pounds	Environment	Novacem, London; *Others working on green concrete:* MIT;. Geopolymer Institute, Los Gatos, CA; Saint-Quentin, France
	Implantable Electronics	Implantable optical and medical devices with silk as the basis for the devices makes them biode-gradable	Films of silk fibroin	Health and Biotechnology	Tufts University, Medford/Somerville, MA; *Others working on implantable electronics:* University of Illinois Urbana-Champaign; Stanford University, CA

2009	$100 Genome	Sequence a human genome for just $100 using a nanofluidic chip		Health and Biotechnology	BioNanomatrix, San Diego, California
	Racetrack Memory	Using nanowires to create an ultradense memory chip	Magnetic nanowires	ICT	IBM,Palo Alto, California
	Nanopiezo-electronics	Piezoelectric nanowires could power implantable medical devices and serve as tiny sensors	Crystalline materials	Health and Biotechnology	Georgia Tech, Atlanta
2008	Graphene Transistors	Transistors based on graphene, a carbon material one atom thick, could have extraordinary electronic properties	Graphene	ICT	Georgia Tech, Atlanta
	NanoRadio	A nanoscale radio in which the key circuitry consists of a single carbon nanotube	Graphene	ICT	University of California, Berkeley
	Atomic Magnetom-eters	Sensors called atomic magnetometers, the size of grain of rice, might someday be incorporated into everything from portable MRI machines to faster and cheaper detectors for unexploded bombs	High-temperature superconducting mate-rials	Health and Biotechnology, Security	U.S. National Institute of Standards and Technology, Gaithersburg, Maryland
2007	Nanocharg-ing Solar	Quantum-dots can hopefully enable the production of more efficient and less expensive solar cells, finally making solar power competitive with other sources of electricity	Semiconductors	Energy, Environment	National Renewable Energy Laboratory, Golden, Colorado
	Invisible Revolution	Structures of metamaterials that can manipulate electro-magnetic radiation, including light, in ways not readily observed in nature	Artificially structured metamaterials	ICT, Energy	Duke University, Durham, North Carolina
	Nanoheal-ing	Tiny fibres will save lives by stopping bleeding and aiding recovery from brain injury	Novel material made of nanoscale protein fragments (peptine)	Health and Biotechnology	MIT, Cambridge, Massachusetts
2006	Stretchable Silicon	Reinventing the way we use electronics by using stretchable silicon	Inorganic semiconduc-tors, single-crystal silicon	Health and Biotechnology	University of Illinois; *Others working on stretchable silicon:* University of Cambridge, England; University of Tokyo; Princeton University, New Jersey
2005	Silicon Photonics	Making the material of computer chips emit light could speed data flow	Silicon photonics	ICT	University of California; *Others working on silicon photonics:* Intel's Photonics Technology Lab; University of Rochester, NewYork
	Quantum Wires	Wires spun from carbon nanotubes could carry electricity farther and more efficiently	Carbon nanotubes	Energy	Rice University, Houston, Texas
2004	Nanowires	Use of nanowires in electronics		ICT	University of California, Berkeley; Harvard University, Cambridge,

					MA
2003	Injectable Tissue Engineering	Inject joints with specially designed mixtures of polymers, cells, and growth stimulators that solidify and form healthy tissue	Polymers	Health and Biotechnology	Johns Hopkins University, Baltimore; *Others working on injectable tissue engineering:* Harvard Medical School, cartilage; Genzyme, cartilage; Rice U., bone and cardiovascular tissue; U. Michigan, bone and cartilage
	Nano Solar Cells	Use nanotechnology to produce a photovoltaic material that can be spread like plastic wrap or paint, it offers the promise of cheap production costs that can make solar power competitive	Nanorod polymer composite	Energy, Environment	University of California, Berkeley; *Others working on nano solar cells:* U. Cambridge; Swiss Federal Institute of Technology, nano-crystalline dye-sensitized solar cells; U. California Santa Barbara; Johannes Kepler University, Linz, Austria
2001	Flexible Transistors	Flexible and cost-effective electronics for ubiqui-tous computing	Polymer semiconduc-tors	ICT	IBM; *Others working on flexible transistors:* Lucent Technologies' Bell Labs; University of Cambridge, England; Pennsylvania State University; MIT
	Micropho-tonics	Photonic crystals are on the cutting edge of microphotonics: technologies for directing light on a microscopic scale that will make a major impact on telecommunications	Photonic crystal	ICT	MIT; *Others working on microphotonics:* University of California, Los Angeles; Kyoto University, Japan; Caltech, Pasadena, CA; Nanovation Technologies, Miami, FL; Clarendon Photonics, Boston, MA

Source: The overview is based on 'Technology Review' (MIT), a yearly assessment of the emerging technologies that have a potential to produce the greatest impact. www.technologyreview.com Note: Year 2002 is missing from the list— no material-related applications listed. Massachusetts Institute of Technology, Cambridge, Massachusetts.

Chapter 6. Quantitative Value Added Materials market overview

Desk research results regarding identified markets for VAMs and their possible applications are presented in the table in Annex 1. Charts below present an overview of results, and are designed to demonstrate the most promising areas and industries. Current foresights available on the market do not bring much information with regard to the long future. Far-reaching market foresights only extend to 2020.

A case study showing the uncertainty surrounding market foresights — how shifts in materials apply to production — is set out below, presenting the development of the smart phones market in recent years. Prior to this massive boom no market forecast managed to predict such a forceful development. This shows the inherent difficulty in such forecasting: it is impossible to take into account the specific and unknown factors that will develop in the future. Therefore forecasts can only be a tool in the work towards defining future markets.

This project was not designed in such a way to produce longer term foresights in full detail. Nevertheless it is believed that summary of foresights presented below may be used as a valid policy-making tool in the future, with a longer time perspective towards 2030 and even 2050.

The projection of precise VAMs market share in the sector on the basis of statistical methods based on primary data from producers or secondary data will not be very credible. The model would have too many uncertainties. The factors to be taken into consideration with such analysis are: general market trends (e.g. growing energy consumption, demand growth, ageing societies), product life cycle (most of VAMs have started their life cycle per definition), precise information about materials share in final product value (interviewed experts had different views here), and finally an unambiguous decision whether the material is to be regarded as VAM or not (if so, to be included in the calculation and projection). Such a model shall be then multiplied for all possible new materials identified on the market. One can see the complexity for measuring market size with such bottom up approach.

The model described above is of course theoretically possible, but — as shown with the smartphones case — largely inaccurate and misleading even with very much developed and known markets, and even with three years' perspective. Therefore the general approach for this analysis is to identify existing market estimates and look for patterns within the data. The collected secondary data are presented in Annex 1, while below we present results of clustering of identified market estimates for each of the sectors.

It is clear that existing market estimates have in almost all cases two dimensions: one measurement of the market in the recent past and one in the near future. This finding suggested ways to cluster the findings in order to present a consistent overview of future market growths and sizes.

When analysing these data one must take into consideration the general rule of foresight science, which says that one shall not make projections for a future that is longer in time perspective than the existing historical data. The secondary market information gathered for VAMs gives market sizes only several years back and projects up to around 2016 to 2020. This is the maximum time frame for prognosis currently available. All other statistical 'tricks' are of course possible, but would not be reliable.

Smartphones; A case of sudden market change and diverse foresights

Smartphones are defined as high-end mobile phones that combine the functions of a personal digital assistant and a mobile phone. Today they also typically serve as portable media players and camera phones with touchscreens, web browsers, GPS navigation, Wi-Fi and mobile broadband access.

Market size

The smartphones' share of the mobile phone market has shown an impressing growth over the last few years. As Gartner[1] has showed, smartphone sales in the US doubled from the third quarter in 2009 to the third quarter in 2010. The global smartphone shipments grew by 74 per cent in the same time period. The total global mobile device sale to end users in 2010 totaled 1,6 billion units, an increase of close to 32 per cent from 2009. This means that the smartphone market is growing at double the rate compared to the overall mobile phone market. This is evident in Gartner's report on market shares for smartphones; smartphones accounted for 19 per cent of the total mobile communications device sales in 2010, up from 11 per cent in the fourth quarter of 2007, and 12 per cent in 2008.

Materials for smartphones

Smartphones are interesting in the context of this VAMs discussion because of the highly specialized materials used for production, especially such components as screen, battery and processor. An interesting fact is that producers are going away from plastic applications. An example here is the iPhone. In the previous generations of iPhones, plastic, glass and aluminum were major elements, however, in the latest editions, plastic is no longer a leading case component.

The growth in the smartphone market means an increase in demand for electronic chemicals and polymers as well as other advanced materials. A key problem is that several of the materials needed in the smartphones are either extremely rare, like indium, a key component in the production of touchscreens, or are almost exclusively mined in China. This means that there are uncertainties related to the supply of such materials, as well as their price in the future. These uncertainties increase the need to find new materials that can replace rare earth materials.

Indium is one example where speculations have been made that its reserves will be exhausted by 2020. This means that within the next decade there is an acute need to find a replacement for this material. According to Gartner's analyst Dean Freeman, the most likely replacement for ITO will be carbon nanotubes, or CNTs. Carbon nanotubes (also known as buckytubes) are allotropes of carbon. These cylindrical carbon molecules have novel properties which make them potentially useful in many applications in electronics, optics, and other fields of materials science, as well as potential uses in architectural fields. But that technology isn't quite ready yet.

Projections

The second factor that increases the demand for materials needed in smartphones is the expected growth in the market. As shown above, the market has already demonstrated high growth levels, and that growth is expected to continue in the future. As there are high levels of uncertainty linked to growth projections, there exist many different estimates on future market size. Gartner has predicted that in 2011 US consumers are more likely to purchase a smartphone than any other consumer device. Berg Insight anticipates that shipments of smartphones will hit 1.2 billion units in 2015, at which time they have estimated that there will be approximately 2.8 billion smartphone users worldwide. In-stat, on the other hand, has a less optimistic estimate for the smartphone market growth, arguing that 850 million smartphones will be shipped by 2015.

Sources for the case study [47]

[47] Sources:
http://www.mobilephonedevelopment.com/archives/1149
http://www.bgr.com/2011/03/10/berg-smartphone-shipments-grew-74-in-2010/
http://www.gartner.com/it/page.jsp?id=1543014
http://www.icis.com/Articles/2011/03/07/9439919/smartphones-and-tablets-fuel-huge-growth-for-electronic.html
http://www.icis.com/Articles/2011/03/07/9439919/smartphones-and-tablets-fuel-huge-growth-for-electronic.html
http://www.azonano.com/news.aspx?newsID=20360
http://www.gartner.com/it/page.jsp?id=1550814
http://www.bgr.com/2011/03/10/berg-smartphone-shipments-grew-74-in-2010/
http://gadgets.tmcnet.com/topics/gadgets/articles/137893-in-stat-expects-850-million-smartphones-shipped-2015.htm

6.1 VAMs market size and development

Not many studies so far tried responding to the general question of market size for advanced materials.

Table 4: Total market sizes for advanced and new materials

	1980	1990	2000	2008	2010	2015	2020	2030
Market for new materials according to Moskowitz study (billion USD)	2	17,5	51,7		102,7		177	316,7
Market for advanced materials according to Expert Group on KETs (billion euro)				100		150		
Source: combined sources.								

Since the Value Added Materials are particularly new in terms of concept, secondary data of current market sizes are taken from two sources: the study by Sanford Moskowitz[48] and the Final Report from High level Expert Group on Key Enabling Technologies[49]. These two studies present comparable estimates of total market sizes. This information, together with trends identified from the interviews, draws a picture of potential market development for VAMS in the future. The data series used for the construction of the model feed are from trends drafted in the above mentioned studies. The size of markets for VAMs after the 2030 was designed on the basis of two different conditions identified in the interviews with materials experts and investors.

- Linear growth of materials applications in the industries with already long-lasting research in the area (automotive, ICT and health). These were indicated in the interviews as sectors with large investment density in the last decades.
- Non-linear growth trend of VAM markets in energy and environment sectors, as well as the emergence of new materials used in multiple applications (cross sectoral).

This approach enabled us to calculate the share of VAMs in all products and markets where they are currently used. We compared the data presented in table 3 (above) with identified market shares in all sectors (presented in Annex 1). It also enabled calculations of proportional market allocations of Value Added Materials per sector and trend prognosis in the future.

The result of this analysis confirms the large potential for development of market applications of Value Added Materials. The market has the potential to grow more than 10 times over the next 40 years. This potential was underlined by all experts interviewed. Therefore the results of this analysis gives a reliable picture of how the markets for VAMs might develop in the future.

[48] Moskowitz, Sanford L. *Advanced Materials Revolution Technology and Economic Growth in the Age of Globalization.* Wiley & Sons, Inc. 2009.

[49] High Level Group on Key Enabling Technologies. 'Report by the working group on advanced materials technologies'. European Commission, June 2011.

Table 5: Size of identified markets where VAMs are applied[50]

	2008	2015	2020	2030	2050
Energy	83	230	335	640	2336
Transport	112	210	280	420	700
Environment [51]	286	615	850	1501	4683
Health	314	517	662	952	1532
ICT	344	624	824	1224	2024
Others / Cross-cutting[52]	42	217	342	731	3335
Total markets value	**1181**	**2413**	**3293**	**5468**	**14610**
VAMs share in sector applications (%)	8,6	6,2	5,7	5,8	7,5
Source: Oxford Research AS. Unit: billion euro.					

Table 6: VAMs market share by sector

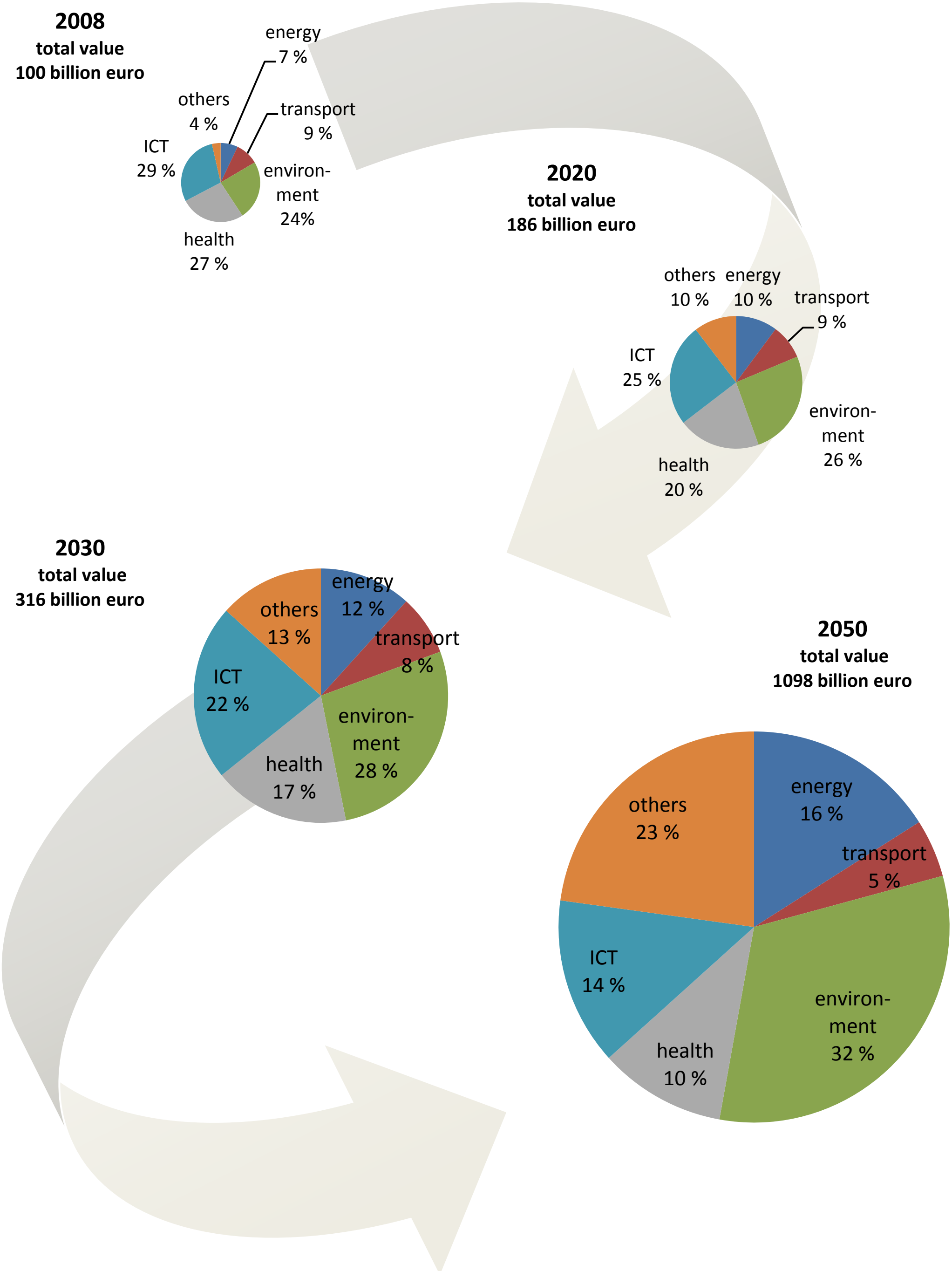
	2008	2015	2020	2030	2050
Energy	7,1	14,3	18,9	37,0	175,7
Transport	9,6	13,1	15,8	24,3	52,6
Environment	24,6	38,2	48,0	86,8	352,2
Health	27,0	32,1	37,4	55,0	115,2
ICT	29,6	38,8	46,6	70,7	152,2
Others / Cross-cutting	3,6	13,5	19,3	42,2	250,8
Total projected value of identified VAMs markets	**101,7**	**150,0**	**186,1**	**316,0**	**1098,6**
Source: Oxford Research AS. Unit: billion euro.					

The change in VAMs' sector presence resulting from the presented model is depicted in Figure 8.Note that the potential for VAMs' market growth is much higher than average European GDP growth estimates.

[50] Table 4 is showing only aggregated value of markets relevant for materials applications and not the value of entire sectors. See details in Annex 1.
[51] The environment sector size is largely influenced by 'energy efficient technologies for environment protection' being currently around 40 % of the total value of the sector, and therefore its size shall be very much considered together with the energy sector.
[52] The category 'Others / Cross-cutting' is used to group all those materials that either:

- cannot be easily allocated to one of the industries analysed in this study;
- have properties that enable them to be used in multiple industries;
- cannot be allocated to any of the sectors at current stage because their market implementation is a subject for current research;
- are used in industries other than those considered in this study (e.g. food, construction, chemical etc.).

Figure 8: Changes in VAMs' sector presence and market growth

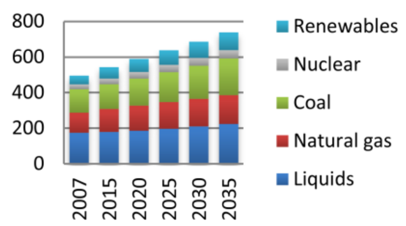


More detailed information regarding the situation in each of the sectors covered by this study is presented in the sections below.

6.2 Energy sector

The existing conservative market estimates[53] from the United States Energy Information Administration reveal that the energy sector in terms of consumption (measured in quadrillions BTU[54]) will develop steadily through the years. USEIA's market estimates also note that the consumption structure is not expected to change radically, based on the scenario of business-as-usual and no radical breakthroughs. Following this scenario 'black energy' produced from oil and coal will remain the main sources of energy for modern humanity. On the global scale the role of renewable energy is predicted to have negligible influence the overall market structure.

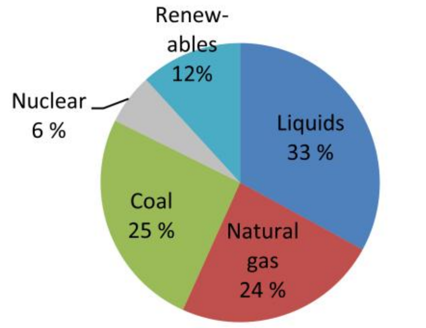
Figure 9: Global energy sector growth and structure 2007-2035



Source: United States Energy Information Administration, Design: Oxford Research AS. Unit: quadrillions BTU.

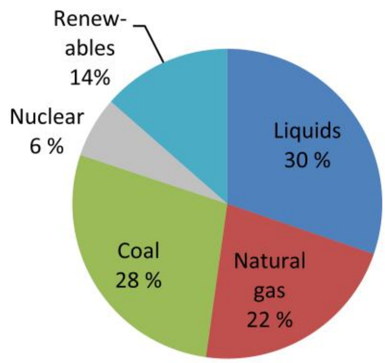
The structure of the energy sector is predicted to remain almost unchanged in terms of consumption and sources structure.

Figure 10: Energy sector structure 2015



Source: United States Energy Information Administration. Design: Oxford Research AS. Unit: quadrillions BTU.

Figure 11: Energy sector structure 2035



Source: United States Energy Information Administration. Design: Oxford Research AS. Unit:- quadrillions BTU.

A contradictory picture appears when simultaneously considering the USEIA data, the European initiatives meant to address future energy challenges, and the infor-

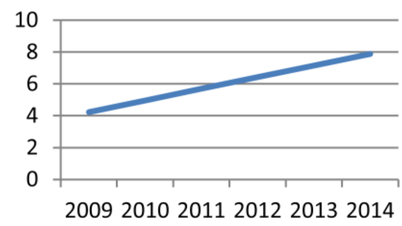
53 Global energy sector estimates are in most cases presented in quadrillions BTU (British Thermal Unit). Different energy sources have different prices, sometimes radically changing over time, and different unit effectiveness. It is common practice to provide market estimates in comparable energy units.

54 Different types of energy are measured by different physical units (barrels or gallons for petroleum, cubic feet for natural gas, tons for coal, kilowatthours for electricity). To compare different fuels, one needs to convert the measurements to the same units. BTU a measure of heat energy, is the most commonly used unit for comparing fuels and therefore covers most of the market.

mation gathered within this study. Reinventing our energy system on a low-carbon model is one of the critical challenges of the 21st Century. Today in the EU, our primary energy supply is 80 per cent dependent on fossil fuels. But the European Commission Strategic Energy Plan, the market estimates expressed by our interviewed experts and investors, and the data from analysed secondary sources all indicate that a share of renewable energy sources in the years to come will rapidly influence the global market structure, especially in developed countries. The perspective that renewables will have more influence than credited by the USEIA is in a way confirmed with available data from MarketResearch.com — a company specializing in long term industry foresights, where the market size is provided not in terms of consumption, but total value. In 2009 the global energy market was estimated to be on the level of 4,235 trillion euros.[55] In 2014 the market size is to reach almost twice that number with 7,875 trillion euros. Detailed market estimates for renewable energies presented in Annex 1 also indicate much faster growth rates of renewables.

With linear data imputation the overall energy market growth is shown in Figure 12 (below). Continuation of current trends will lead to a market of over 20 trillion euros in 2030. Is this possible? None of the interviewed experts was willing to confirm or deny; the perspective is simply too long and the uncertainties too many.

Figure 12: Energy sector size 2015



Source: MarketResearch.com data for 2009 and 2014. Design and trend: Oxford Research AS. Unit: trillion euro.

The average CAGR[56] for all identified energy sector applications of VAMs from 2009 to 2015 is 19 per cent. Highest growths are foresighted within the following categories:

- stationary fuel cells: CAGR 55% between 2010-2016;
- supercapacitors for energy industry: CAGR 49 % between 2010-2015;
- biogas plant equipment: CAGR 30 % between 2010-2014;
- nanoscale materials used in energy, catalytic and structural applications with growth rate of 29 % currently;
- inks and catalysts with growth rate of 28% towards 2015.

The figures above confirm the thesis formulated by experts during conducted interviews. The biggest market size and market growth in nominal terms is foreseen in the area of energy storage and energy production, with a considerable share in photovoltaics and materials for large energy systems and storage.

[55] 6,05 trillion USD, exchange rate used 1 USD=0,7 EUR; being 120 days average, from http://www.x-rates.com/ for Sept 26, 2011.

[56] CAGR is the year-over-year growth rate of an investment over a specified period of time. CAGR is not an accounting term, but is widely used in growth industries or to compare the growth rates of two investments. CAGR dampens the effect of volatility of periodic returns that can render arithmetic means irrelevant.

Since the energy sector is currently largely defined by consumption of oil, coal and gas (not VAMs), the expected share of potential VAM markets in this sector is very limited (compared to entire sector size). The summarized market estimates for VAMs applications are only a minor part of the entire market dominated by commodities.

Table 7: Share of VAM-related technologies in energy markets

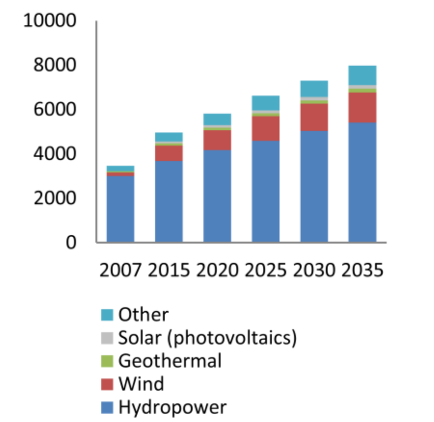
total energy market size 2009	clustered size and CAGR of identified VAM-related markets 2007-2010	clustered size and CAGR of identified VAM-related markets 2012-2016	total energy market size 2014
4,235	0,125	0,203	7,875
100%	2,95%	2,58%	100%

Source: Oxford Research AS on basis of secondary data. Unit: trillion euro.

Increased presence of VAM-based technologies in this market will definitely require a long time perspective combined with large scientific and technological breakthroughs and complex policy efforts. Alternative energy sources will eventually influence the market to a greater extent. The current state of technology deployment indicates a large market potential, considering such prospective technologies as electric vehicles, with its promise of changing the structure of fuels consumption in developed countries. As already discussed, the forecasts of United States Energy Information Administration are very conservative in this regard.

When considering the current structure of alternative renewable energy sources, it's obvious that breakthrough technologies still have not managed to reach their full potential in the market. Currently most of the renewable energy is created by hydropower generation, a category which is much bigger than all the other renewables together. Nevertheless experts interviewed predict much faster growth of solar and other technologies, with great potential to change the markets of the future.

Figure 13: Global renewables growth and structure

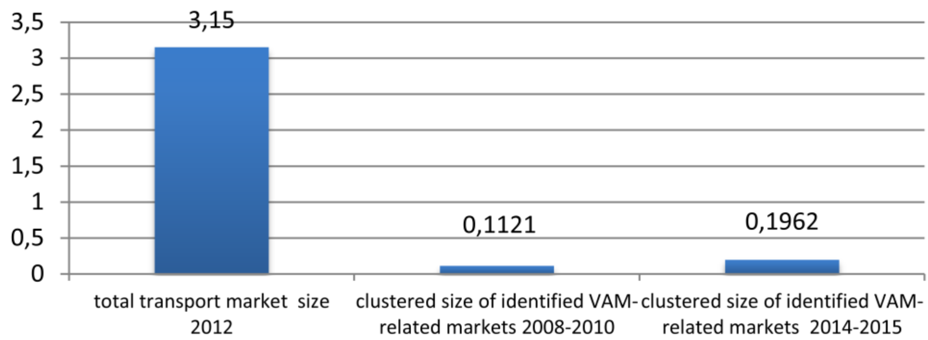


Source: United States Energy Information Administration. Design: Oxford Research AS. Unit: (kWh).

6.3 Transport sector

The global transport sector is estimated to reach 3,12 trillion euros in 2012. This particular sector is mostly composed of services. Transport of goods and persons are leading pillars for all economies and also importantly influence global environmental challenges.

Figure 14: Share of VAM-related technologies in transport markets



Source: Oxford Research AS on basis of secondary data. Unit: trillion euro.

The use of advanced materials in this part of industry is mostly oriented to production of transport means (cars, airplanes, ships, space ships and so on) as well as roads and railways. Another large application area for Value Added Materials is transport efficiency (electronic systems) as well as transport security. Finally there is always a place for materials that will substitute or create an alternative to oil, coal and gas— the market for these materials is depicted in the section (above) about the energy sector.

The two most likely areas in transportation for Value Added Materials are electric vehicles (EV) and ultra-light and highly durable materials. Please note that electronic applications of materials (used in transport and other industries) are discussed later on within the ICT sector.

The secondary data regarding market sizes reveals that the Value Added Materials have still have a high potential within the market, especially in the context of energy efficiency and green transport. The share of identified VAM markets in the global scene will change from 3,5 per cent to 6,2 per cent compared to sector market size in 2012.

The average CAGR calculated from identified materials applications within transport sector is on the level of 15 per cent. For the detailed market growths again the biggest expected CAGR is allocated to supercapacitors for the transportation sector, with CAGR equals 35 per cent and later on to the market for electric vehicles with CAGR equals 20 per cent.

The comparison of market sizes and growth is presented through the figures in Annex 1.

The biggest share of all identified markets for transport applications of VAMs is still the area of lightweight materials. This is the place where materials may still be introduced to the market. This field is also very much concerned by the time-to-market issue. Interviews with experts indicated that the transportation sector is now starting to use materials invented some 15 to 20 years ago. Obviously there is space for improvement regarding time-to-market indicators. This is also an area where innovative new materials might be of particular interest to the industry.

The European Green Car Initiative[57] indicates several challenges in the area of green transport development. One of the most important is energy storage systems, which still require intensive research. Energy storage is suggested as a crosscutting research direction for all current Framework Programme Priorities. This trend is confirmed by our interviews with materials experts and investment specialists.

The problems associated with energy storage will hamper development of electric vehicle (EV) market for the coming years. Still the analysed roadmap indicates that by 2020 it is possible that Europe will start mass production of 5 million EV/PHEV (plug-in hybrid electric) vehicles.

Trends related to energy storage (including batteries for EV) are therefore reflected in our foresight for market growth within the energy sector (above).

57 European Green Cars Initiative PPP
Multi-annual roadmap and long-term strategy; November 2010, www.green-cars-initiative.eu

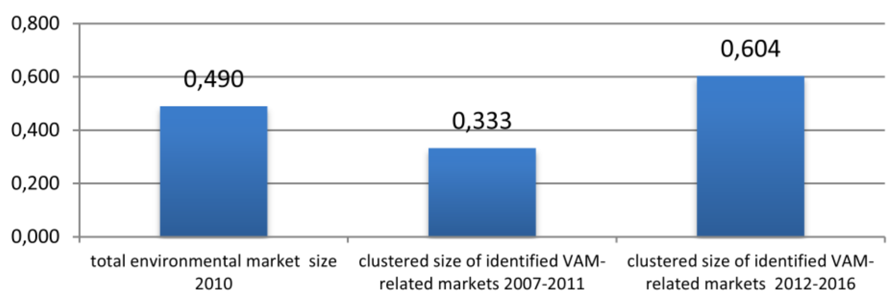
6.4 Environment sector

The environmental industry includes all revenue-generating activities associated with:

- air pollution control;
- water and waste water treatment;
- waste management (including recovery and recycling);
- contaminated land remediation;
- environmental monitoring and instrumentation;
- noise and vibration control;
- marine pollution control;
- clean industrial processes.

Within these fields there is a place for Value Added Materials to play a crucial role in addressing the eco-challenges of our times.

Figure 15: Share of VAM-related technologies in environmental markets



Source: Oxford Research AS on basis of secondary data. Unit: billion euros.

The global environmental market size following some less optimistic scenarios is not growing as fast as would be expected — the past estimates indicate only 2 per cent growth from 461,3 billion euro to 490 billion in 2010.[58]

A more detailed look at existing market estimates from other sources indicates that these numbers are somehow too narrow and pessimistic. Analysed estimates regarding sub-sectors where a number of applications are to appear for VAMs are much more optimistic — the average sector growth calculated on the basis of gathered data is at the level of 17 per cent CAGR. The market for water and water treatment was estimated to have reached 300 billion euro in 2010.[59]

An overview of all other markets for VAMs identified within this sector indicates that only selected markets in total will be higher than the initial current estimate for the entire sector already around year 2016 (see Annex 1 for details).

[58] Office of Energy and Environmental, International Trade Administration, U.S. Department of Commerce.
[59] According to the 'European Technology Platform for Water, 2010 Strategic Research Agenda'.

The most promising technology on the market within this sector is definitely carbon capture technologies, where the expected CAGR will be on the level of 63 per cent between 2010 and 2012. The total market size for this kind of technology is to rise from 62 to over 165 billion in just two years. Another very prospective market for Value Added Materials is 'nanotechnologies for environmental applications', where the CAGR will reach 61 per cent. This relatively small market will grow from 1,4 billion in 2009 to 15,26 billion in 2014.

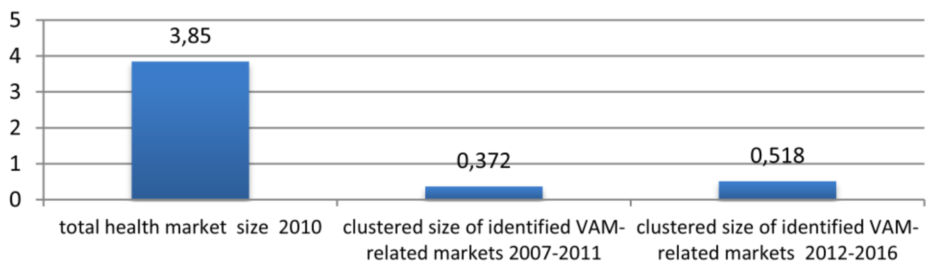
The biggest share in the group of identified technologies is the energy efficient technologies, expected to reach 218 billion euro with CAGR of 9 per cent (much below average for the sector). Second biggest part of the market will be allocated to the intensively growing industry related to carbon capture technologies, mentioned above.

6.5 Health sector

The global health sector is to reach almost 4 trillion euro this year. The foresights made by Plunkett Research Ltd[60]., indicated the market was at the level of 3.85 trillion in 2010. The sector growth between 2006 and 2010 was at the level of 5 per cent CAGR.

Of course the biggest share in this sector is dedicated to services. In the context of this study, the most important market for advanced Value Added Materials is located within drug manufacturing. This part of the market reached 360 billion Euros in 2010 globally.[61]

Figure 16: Share of VAM-related technologies in health markets



Source: Oxford Research AS on basis of secondary data. Unit: trillion euro.

The non-drug VAMs' share in the market will grow within the years to come with average CAGR of 11 per cent.

The data available from the document 'Roadmaps in nanomedicine: Towards 2020'[62] indicate even much more intensive growth of the sector, with average growth of 30 per cent CAGR between 2015 and 2025 (see details in Annex 1).

In order to make this study comparative between sectors, this analysis of non-drug VAMs takes into consideration market estimates published by BCC Research[63].

The identified application areas where VAMs will play important role constitutes a growing part of the health sector in the future.

The drug market is a separate subject, due to specifications of the European Commission research programmes; so it will not be considered in further analysis.

Other existing markets for Value Added Materials are nevertheless very much influential.

The fastest growing market is definitely connected with RNAi[64] drug delivery technologies, projected to grow from 4,9 billion euro in 2010 to the level of 16,87 billion euro in 2015. The CAGR in this period will be on the level of 28 per cent. The biggest share of the market within selected technologies will be allocated to biotechnologies used in medical applications. Biotech

[60] Plunkett's Health Care Industry Almanac, 2011 edition
[61] Plunkett Research®, Ltd.201, http://plunkettresearch.com/health%20care%20medical%20market%20research/industry%20and%20business%20data

[62] 'Roadmaps in nanomedicine: Towards 2020', Joint European Commission & ETP Nanomedicine Expert Report, 2009.
[63] http://www.bccresearch.com
[64] RNA interference (RNAi) is a highly evolutionarily conserved mechanism of gene regulation. See http://www.rnaiweb.com

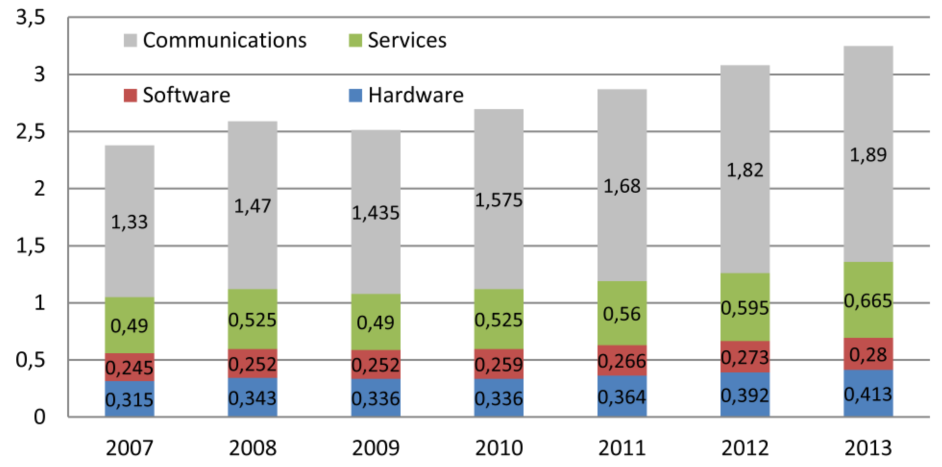
will have a 15 per cent growth rate, starting from 77 billion in 2010 to 156 billion euro in 2015. All market sizes are presented in detail in Annex 1.

6.6 Information and Communication Technologies (ICT) sector

The ICT sector is expected to grow an average CAGR of 5 per cent between 2007 and 2013.

Details regarding sector split are presented with Figure 17, below.

Figure 17: ICT sector split and growth



Source: Digital Planet 2010. Design: Oxford Research AS. Unit: trillion euro.

The share of identified VAM-related markets in the entire sector is expected to grow substantially in the years to come. This comparative data are based on two sources (Digital Planet for total market estimates and BCC Research for selected markets summary). Therefore foresights with data from BCC Research have in this case higher growth ratio than Digital Planet's estimates for the entire market, resulting in numbers that first seem to show a growth of market share for materials markets from 14,9per cent to 40,8 per cent.

The ICT sector suffered a downturn in 2009 directly connected with the global financial crisis. Since that time sector growth has stabilized with the highest expected growth in communications (CAGR 6 per cent) and hardware and services (with expected 5 per cent CAGR). The potential markets for materials are mostly in hardware, and to a much smaller extent in communications infrastructure.

This situation will not happen in reality, as the market in general is mostly composed of services and software. But such indicators may legitimately lead to the conclusion that materials market share will grow extremely well in the years to come.

Information regarding the share of detailed materials markets in the ICT sector is presented in Annex 1.

Table 8: Share of VAM-related technologies in ICT markets

average ICT market size 2007-2010	clustered size and CAGR of identified VAM-related markets 2007-2010	clustered size and CAGR of identified VAM-related markets 2012-2016	average ICT market size 2011-2013
2569	384,5	1247,3	3056,6
100%	14,9%	40,8%[65]	100%
Source: Oxford Research AS on basis of secondary data. Unit : billion euro.			

6.7 Other market estimates

Since many of new and advanced materials are cross-cutting above listed sectors, Figure 7 in Annex 1 presents information regarding their markets without sector allocation.

[65] Without superconducting electrical equipment market, the total share of VAM markets will be around 325 bln euro and 20,44% of the entire ICT market.

Chapter 7. Potential future technological challenges

Relevant industry roadmaps, foresights and strategic papers reveal a number of current technological challenges and issues in the development of future materials.

This chapter presents an overview of the identified challenges to bringing VAMs into common use. This discussion again follows the delineation of Grand Challenges used by the European Commission for planning future research programmes.

Several materials experts within this project voiced an important and widespread opinion: In order to tackle the biggest societal problems, we 'just' have to enable the use of technologies already available today. The thinking is that simply by adjusting current and future research programmes' priorities we can easily meet the Grand Challenges within the time frame of 2020. However, this is not a reasonable expectation due to the time-to-market factor.

Every breakthrough invented within the next five years will be visible on the market only after 2025 (at earliest), and probably after 2030 if it follows the usual time-to-market pattern. In this context only large scale implementation of already existing technologies may reasonably influence the nearest future and catalyse expected global changes.

7.1 Challenges within health, demographic change and wellbeing

Optical sensors in health

- Optical sensors are well suited for systems whose purpose is not to restore an image to a final user but to analyse the content of a visual scene and make a decision. The main requirements for such a sensor are a wide intra-scene dynamic range and a data representation capability that facilitates processing. Currently used standard image sensors have a too narrow dynamic range to cope with the tremendous change of illumination occurring in natural visual scenes. The current state of the art is to perform the logarithmic compression in the analogue domain, which leads to a high pixel-to-pixel fixed pattern noise that makes them unusable for commercial applications. Future generations of visual front-ends, developed for robotic, medical or security applications, will have to resolve this issue.

Smart health-related systems

- Progress towards steadily shrinking structures will lead to situations where properties of devices can be defined by the presence or absence of a handful of doping atoms. Neither quality assurance, principally in mass production, nor manufacturing based on simulation seems to be possible in these circumstances. Other approaches to system design and manufacturing will have to be investigated.
- There is a need for low cost and high performance materials in this sector.
- The autonomy of smart systems depends upon their ability to scavenge energy from their environment, to

store it and to make efficient use of it. The limited life-time of batteries for implantable devices, e.g. pacemakers or implanted drug delivery systems, often necessitates surgical replacements after a comparatively short time (in relation to the scheduled system life time). Direct glucose fuel cells could be used as a sustainable power supply for long term implants, converting the chemical energy of the body's glucose into electrical energy — the energy supply of smart implants is a challenge as well as an opportunity for smart systems integration. Problems of implantable fuel cells are manifold. How to achieve fuel separation, because the body fluids contain fuel cell reactants, glucose and oxygen, simultaneously? How to guarantee a maximum of operation time? How to achieve exceptional system reliability?

- Vision systems: new sensor technologies still need to be developed. For example, terahertz imaging is quite new and the terahertz detectors that already exist require ultra-cooling and are still monolithic. For multimedia and domestic applications, cost and compactness are the key drivers.
- Medical Ultrasound: The ability to drive 100 - 200 volts at a frequency of several megahertz will improve the speed and performance of ultrasound scanners. The ability to process high-voltage signals using high-performance analogue integrated circuits with high linearity and high frequency stability is a key requirement for improving ultrasound image quality.
- Reliability: In principle two strategies can be approached to reach the needed reliability, being the avoidance of defects (zero-defect), and the identification and substitution of defective parts during operation (redundancy). Zero-defect requires a complete knowledge of ageing mechanisms within the circuits, enabling the modelling and simulation of the reliability gradient during operational life. Redundancy requires methods of estimating the number of expected failures, identifying defective parts and paths, and substituting them with new ones. For both approaches, however, today's tedious and expensive experimental reliability tests on processed silicon must, as far as possible, be substituted by intensive simulation methods.
- Electronic systems for health related mobile applications have to withstand very harsh environments, including high temperatures, humidity, vibration, fluid contamination and electromagnetic compatibility. While these problems have largely been solved for conventional integrated circuit (IC) style packaged devices, a whole new set of challenges will have to be faced when these packages also contain integrated sensors, actuators, mechatronics or opto-electronic functions.

Biosensors

- There is a need to ensure the bio-compatibility of the materials both for in-vitro and in-vivo applications.
- Ultra-low power consumption is required of wireless connected portable or implantable systems. These must stay within the maximum thermal loads that implanted devices can impose on the human body.
- Developing implants in bio-compatible packages will push miniaturisation to

the limits, while at the same time requiring the integration of many different types of device — for example, bio-sensors, nanoscale MEMS (microelectromechanical systems) devices, optical components, energy scavenging systems and RF (radiofrequency) interfaces. Many of these highly complex heterogeneous systems will also need to achieve life-support system reliability.

Micro- and nanoelectronic systems for everyday use

- This is a challenging research field that may boost or hinder technological developments. Issues include the development of structural in-line metrology (accurate 3D measurement of different patterns, overlays etc.), fast and sensitive defect detection and classification, structural off-line characterization (including morphological, physical and chemical analysis of 3D nm sized structures made of complex material stacks), and methods of assessing the sources of process variability.
- Challenges arise from the societal need to include sensors and actuators to nano- or microelectronic systems.
- Electronic imaging: Currently, pixel sizes for these applications can be as small as 1.4 x 1.4 micron. Lowering the pixel size is mainly driven by cost at the device and system levels. However, it is becoming a real challenge to detect photons while decreasing pixel size. For non-visible imaging, different technologies are needed for different wavelength ranges. In addition to performance improvements that are common to all imagers, such as better sensitivity, dynamic range, endurance, lower noise and pixel-to-pixel cross-talk, there is a definite need for multi-spectral analysis using a single sensor technology.
- The success of MtM (More than Moore[66]) will depend on a profound understanding of the properties and behaviour of materials and their interfaces under manufacturing, qualification testing and use conditions, and on the ability to tailor the material design for the requirements of specific applications. This issue is already acute for MtM technologies, where multi-scale size effects and multi-material compatibility, stability and reliability will be the key to success. Among the many challenges, characterisation and modelling of materials and their interface behaviour need more attention, especially for multi-scale, multiphysics and time dependent situations.
- Heterogeneous integration: Interconnection, packaging and assembly are major bottlenecks for future nanoelectronics technology.
- Equipment and materials: Historically, (poly)-silicon, silicon dioxide, silicon nitride and aluminium have been the materials of choice for semiconductor devices. In the last decade, however, it has proven impossible to further extend dimensional scaling with this set of materials alone. A multitude of new high-performance materials with specially engineered electrical, mechanical and chemical properties must be introduced to extend Moore's Law and allow fabrication of scaled devices that operate at higher speed and/or lower power. A huge material science effort is required to deliver the necessary properties, involving the selection,

[66] Moore's Law: The number of transistors on a chip doubles every 18 to 24 months

demonstration and integration of appropriate chemistries.

Sensors and actuators

- The integration aspects (monolithic/hybrid) of sensors and actuators onto CMOS platforms will be an important challenge and focus for the years to come. This will include the development of sensors and actuators based on materials other than silicon (for example, III/V or plastic materials) that offer new functionality or lower cost, as well as arrays of sensors and actuators of the same or different functionality. In addition, new sensor types such as nanowires and carbon nanotubes with potential for improved sensitivity need to be investigated. Fabrication processes have to be developed to integrate such new sensing elements into devices, systems and applications.
- The major challenge in the area of sensors and actuators is the support of huge amounts of input and output data envisaged in the application contexts with minimal power requirements and fail-safe operation.
- The technical challenges for smart systems and environments may be summarised as how to create a consistent architecture for smart environments. This is characterised by three equally important trends: multi-vendor interoperability, dynamic device configurations and extreme scalability.

Smart nano- and bio-materials for health

- Need to assess surface and bulk physico-chemical properties of engineered nanomaterials.
- Need to include sensitive or susceptible populations in assessing risk.
- Need to determine the most appropriate dose (a nanomaterial's mass may not be the most accurate way to evaluate health effects).
- Need to understand human health impacts of engineered nanomaterials: knowledge of molecular and cellular pathways, kinetics of absorption, distribution, metabolism and excretion critical to understand potential health hazards.

Integration

- Module integration: Future board and substrate technologies have to ensure cost-efficient integration of highly complex systems, with a high degree of miniaturisation and sufficient flexibility to adapt to different applications. Technologies for embedded devices such as MEMS (Micro-Electro-Mechanical Systems), passive or active components, antennas and power management will be the key for highly integrated modules. To reach this goal, new substrate materials, embedding technologies and encapsulation technologies have to be developed, such as high-K[67] and low-K[68] dielectrics, and tailored polymers (such as glass transition temperature -Tg, coefficient of thermal expansion - CTE and coefficient of moisture expansion CME) that correct the mismatch between dies and substrates.
- 3D integration enables different optimised technologies to be combined

[67] High-κ dielectric refers to a material with a high dielectric constant κ (as compared to silicon dioxide) used in semiconductor manufacturing processes which replaces the silicon dioxide gate dielectric. The implementation of high-κ gate dielectrics is one of several strategies developed to allow further miniaturization of microelectronic components, colloquially referred to as extending Moore's Law. http://en.wikipedia.org/wiki/High-k_dielectric

[68] Low-κ dielectric is a material with a small dielectric constant relative to silicon dioxide. http://en.wikipedia.org/wiki/Low-k_dielectric

together and has the potential for low-cost fabrication through high yield, smaller footprints and multi-functionality. In addition, 3D integration is an emerging solution to the 'wiring crisis' caused by signal propagation delay at board and chip levels, because it minimises interconnection lengths and eliminates speed-limiting intra-chip and inter-chip interconnects.

Construction industry

- The existing building stock has a long life-time, while solutions to retrofit existing buildings are lacking. For existing buildings, technical possibilities to create a more energy-efficient structure are poor and most of them remain to be invented. Low-intrusive retrofit techniques are lacking; affordability is still a major problem, and social demand and acceptance lag behind.
- Corrosion leads to an increased use of materials and energy, and to larger amounts of waste. Corrosion-resistant materials have a role to play here at the industrial scale.

7.2 Challenges in the context of food security and the bio-based economy

Food

- Require facilities, emerging technologies, industrial engineering concepts and new added value products and services to improve utilization of food raw materials and waste into new materials (food and non-food).
- Agriculture‘s automation for highly productive and efficient production processes will determine development trends of agricultural machinery.

Biofuels

- Largely driven by government support and high energy cost, biofuels need better efficiency in terms of biomass yield, nutrient and water use and energy conversion.
- Sustainable and reliable supplies of feedstocks will be a critical success factor for the long-term prospect of biomass-based technologies on a large scale. Factors include improving productivity in these sectors, developing reliable supply chains that open up the feedstock potentials, certification issues, and prevention of excessive disturbances in agricultural and forest commodity markets. These challenges, which are not specific to bioenergy and biofuels’ use of biomass, should be addressed in a coherent effort shared with the relevant stakeholders and initiatives.
- Because of the variety of potential biofuels feedstocks at global and EU levels, different conversion technologies are needed based on mechanical, thermochemical, biological and chemical processes.
- For algae biofuels, cost reduction and scale-up are the critical challenges.
- Natural photosynthesis is inefficient. Artificial photosynthetic systems, inspired by the natural system’s nano-components, are attractive alternatives Production of useful chemical fuels directly from sunlight with significantly higher efficiencies than the natural system is possible because such artificial systems need not devote captured energy to the maintenance of life processes. Artificial photosynthetic systems need increased scientific effort to understand structure-function relationships of components,

as well as develop basic principles for component assembly and integration.

7.3 Challenges for secure, clean and efficient energy technologies

Renewable energy

- The levelised cost of energy for many renewable energy (RE) technologies is currently higher than existing energy prices, though in various settings RE is already economically competitive.
- The costs and challenges of integrating increasing shares of renewables into an existing energy supply system depend on the current share of RE, the availability and characteristics of RE resources, the system characteristics, and how the system evolves and develops in the future. Wind, solar PV energy and CSP (concentrating solar power) without storage can be more difficult to integrate than dispatchable hydropower, bioenergy, CSP with storage and geothermal energy. The costs associated with RE integration, whether for electricity, heating, cooling, gaseous or liquid fuels, are contextual, site-specific and generally difficult to determine.
- As the penetration of variable RE sources increases, maintaining system reliability may become more challenging and costly.

Nuclear energy

- Nuclear power has unique technical challenges related to issues of material and fuel handling, fusion, fission and radiation damage as well as decommissioning and storage.
- Nuclear waste management is a keen issue. In particular, progress needs to be made in building and operating facilities for the disposal of spent fuel and high-level wastes. While solutions are at an advanced stage of technological development, there are often difficulties in gaining political and public acceptance for their implementation.

Solar energy

- Despite their cost-saving potential, the application of photonic integrated solutions has been restricted to a modest number of niche markets. The main reason for the slow market penetration is the huge fragmentation in integration technologies, most of which have been developed and fully optimised for specific applications. Due to this fragmentation most technologies address a market that is too small to justify further development into a low-cost, high-volume manufacturing process. And new technology development or optimisation is required for each new application, which makes the entry costs high. This is very different from the situation in microelectronics, where a much bigger market, larger by several orders of magnitude, is served by a smaller number of integration technologies (mainly CMOS[69]) which can address a wide variety of applications. This leads to extensive cost sharing for the large investments required to develop a powerful integration technology.
- PV systems lack cost efficiency. To stay competitive in the longer term, developers need to lower the cost of each unit of electricity generated, which requires more efficient cells, better

[69] Complementary metal–oxide–semiconductor (CMOS) is a technology for constructing integrated circuits. CMOS technology is used in microprocessors, microcontrollers, static RAM, and other digital logic circuits. http://en.wikipedia.org/wiki/CMOS

productivity. There is also a need for scalable low-cost fabrication and manufacturing technologies.

- The key technological challenge for the development of solar-heated buildings is to reduce the volume of the heat storage.
- For solar thermal, storage of heat is a major bottleneck. Further advances in seasonal and compact storage will have a major impact on the use of solar thermal energy.
- The main limitation to expansion of CSP (concentrating solar power) plants is not the availability of areas suitable for power production, but the distance between these areas and many large consumption centres. Challenge: efficient long-distance electricity transportation.
- Given the arid/semi-arid nature of environments that are well-suited for CSP, a key challenge is accessing the cooling water needed for CSP plants.

Wind energy

- Non-storability and energy loss prevent the wind electricity market from spreading globally. Large scale energy storage is the main challenge within this field.
- The manufacturing and installation of the cables represent a significant cost in offshore developments and have proved to be high-risk areas during installation and operations.
- The integration of offshore wind into the grid represents a major challenge. The current grid infrastructure will not allow the full potential of offshore wind to be realised. Its potential can only be realised through the construction of interconnected offshore grid systems and regulatory regimes that are better able to manage the intermittency and flexibility of wind power generation.
- Turbine developers need to address marine conditions, corrosion and reliability issues in the offshore sector. The key factors affecting the deployment of offshore wind are the current shortage of turbines, and their reliability.

Geothermal energy

- There are technical barriers to accessing and engineering the resource (especially drilling technology), geothermal heat use and advanced geothermal technologies. Geothermal has some health, safety and environmental concerns as well. Advanced materials technologies for offshore, geopressured and super-critical (or even magma) resources could unlock a huge additional resource base.
- The key challenge for widespread direct use of geothermal heat will be the ability to reliably engineer the subsurface heat exchangers (using technique known as 'EGS' – Enhanced Geothermal System) in a reproducible way to harness the heat flux at the required temperature.
- Fundamental research is required to bring about a significant breakthrough in compact, efficient storages.
- Since transport of heat has limitations, geothermal heat can only be used where there is demand in the vicinity of the resource.

Hybrid district heating and cooling

- To reach high penetrations of RE systems in district heating requires the development of source systems that can draw on a variety of heat and cooling sources to meet customer demand at any time.

- Control and automation of systems are major challenges that should be worked through. As a hybrid system is not simply an addition of two or more separate systems, specific research should be carried on the best way to control the combined system. This needs to take into account the stochastic nature of sunlight availability (if it is used in the hybrid system) as well as climate conditions, heating and/or cooling demand forecasting. This research should also address energy performance monitoring as well as early fault diagnosis for continued high performance over the system's lifetime.

Fossil energy sources

- Ultra-deep offshore oil reservoirs need new materials to alleviate platform structure, new technologies to guarantee flow assurance, new subsea robotics, a better understanding of well bore stability, sealing techniques, fit-for-purpose completions, high-temperature high-pressure sensors, imaging deep reservoir structure, etc. All of this makes innovation a necessary step.

7.4 Challenges of smart, green and integrated transport

- Electric vehicles need to store their electricity on-board in such way that it can compete with hydrocarbon fuels in terms of the required energy density.
- Maritime transport is vulnerable to future fuel oil shortage and rising prices because of today's oil-based propulsion systems. Existing long-life ships require retrofitting with new technologies to reduce fuel consumption and CO_2 emissions.
- Both current and near-term (that is, lithium-ion [Li-ion]) battery technologies still have a number of issues that need to be addressed in order to improve overall vehicle cost and performance. These include battery storage capacity; battery duty (discharge) cycles; durability; life expectancy, and other issues such as energy density, power density, temperature sensitivity, reductions in recharge time, and reductions in cost.
- In road transport, replacement of conventional gasoline or diesel by alternative fuel will cause high wear, friction and increased thermal loading in engines due to the lack of lubricating properties of bio-fuels, reduced compatibility with engine oils and seal material, as well as increased risks of corrosion. Existing solutions cannot cope with these problems, resulting in reduced engine reliability and component life time. For example, existing PVD coating wear out during component run-in phase (too thin) or do not possess resistance against fatigue (existing thick layers produced by thermal spraying).
- Fuel cells will play an important role in assuring the mobility of both vehicles and electrical devices (laptops and mobile phones, most commonly). One of the largest hurdles encountered in the development and production of fuel cells is their relatively low efficiencies. Naturally the catalyst plays a significant role in determining the efficiency of the cell, but the inability of the membranes to selectively transport protons between segments

of the cell also impacts on the performance.

- Air transport is currently characterised by high fuel consumption and many CO_2 and NO_x emissions. Manufacture, maintenance and disposal of aircrafts and related products have a negative environmental impact.
- R&D efforts in tribology (friction, lubrication and wear between surfaces) are inadequate. The lack of good solutions leads to inefficiency in energy consumption due to friction and reduced efficiency, maintenance costs, replacement of materials and components, machine and plant shutdowns and increased lubricant consumption.

7.5 Challenges in the context of raw materials supply

- Low substitutability of critical raw materials (high tech metals such as cobalt, platinum, rare earths, and titanium) will require extensive materials research in the years to come.
- Solar photovoltaic (PV) active layers, as well as coating and barrier layers, require too many rare metals.

7.6 Challenges within resource efficiency and climate action

CO_2 Capture and Storage (CCS)

- High costs and risks still outweigh the commercial benefits of CCS. Researchers need to further develop CO_2 capture techniques and reduce the energy consumption of oxygen production and CO_2 treatment. The aim is to increase the efficiency of both CO_2 capture and individual power plants in order to reduce energy consumption (which the capture process can increase).

Post-combustion technology CCS

- There is insufficient experience for power plant applications on a large-scale. Special requirements, due to flue-gas conditions, have yet to be resolved.
- There is a high energy demand/penalty for regeneration of the solvent and energy requirements for CO_2 compression.
- Systems do not yet have full process integration and optimisation for power generation.
- An absorption system with high-throughput under an oxygen environment is unavailable today.

Pre-combustion technology CCS

- There are scale-up issues in designing and developing a highly reliable industrial-scale power plant with CO_2 capture.
- Similarly, there is a problem with the scale-up of gasifiers.
- Highly efficient gas turbines are needed for hydrogen combustion.
- Energy losses by shift-reaction and the CO_2 capture process must be compensated.
- The goal is full-process integration and optimisation for power generation.

Oxy-fuel combustion technology CCS

- No commercial gas- or coal-fired power plants currently exist that operate under oxy-fuel conditions.

- The only tests being performed are in laboratory-scale rigs and experimental boilers up to a size of a few MWth.
- There are uncertainties as to what are acceptable impurities in the CO_2-rich flue gas.
- CO_2-rich flue gas treatment is not yet developed.

7.7 Technological challenges to solving the issues of secure societies

Satellite communication

- Satellite services need continuous development to provide more power and bandwidth in space, in order to enable cheaper, smaller user terminals, as well as lower utilisation costs, and enhanced, higher data rate services.
- Future satellite platforms will need to be flexible enough to support an evolving range and mix of traffic types. They must target a wide range of applications and allow reconfigurations to follow service demand and user behaviour, both in nature and in coverage.
- Currently there is a tendency for satellite technologies to compete with terrestrial technologies, rather than to cooperate.
- 'Security users' experience enormous difficulties because a lack of coherence in security research and a dispersion of efforts lead to enormous difficulties for interoperability between actors.

7.8 Innovation and the European paradox

- Nanomaterials, like any innovative material, can have high impact on the processing and manufacturing technologies of downstream industries. Process integration further down the value chains is a challenge which has to be overcome to ensure the deployment of nanotechnologies. Heavy investments with longer pay-back times should be supported along the value chains, as they are required for the uptake of nanotechnologies.
- Up-scaling is critical in the development of any new process. In order to achieve mass production of nanomaterials, multipurpose plants will have to be developed. Demonstration at industrial scale should therefore be supported in order to promote the deployment of nanotechnologies.
- European R&D needs to address the 'valley of death' question. Research and development is generally strong in new technologies, but the transition from device to product and scale-up demonstration is weak, associated with low levels of venture capital funding for KETs (Key Enabling Technologies).

Related issues

- The lack of agreed standards to reliably measure nanotechnology on-line during volume production creates co-ordination problems. There is a danger that every value chain, or chain segment, will develop their own heterogeneous standards based on secondary properties.

- Large initial investment costs in new plants and processes may lead to short-term lack of competitiveness.
- European technology experiences a shortage of engineering expertise.
- Product manufacturing processes need lengthy validation to meet regulatory approval.
- Researchers need to prove long-term safety and efficacy.
- SMEs (Small and Medium Enterprises) experience difficulties accessing the single market. .
- There is a lack of market-oriented public-private partnerships and programmes coordinating actions aimed at shortening the time to market.
- Venture capital funding usually requires a short exit horizon (about three years).
- In Europe, industry is negatively influenced by a lack of political commitment and vagueness about the support manufacturing will receive in the future. The predictability of regulatory regimes influences manufacturing companies' decisions whether to invest or not in Europe.
- There is a disconnection between patents share and manufacturing share.

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Study methodology

The most important aim for this study is to conduct solid research in order to create a precise overview and define perspectives of the various market segments for Value Added Materials.

The major study objectives are formulated as follows:

- definition and classification,
- analysis: VAM by segment,
- detailed current market analysis by segment and technology application,
- prediction of VAM market development by segment,
- current and potential technological market drivers by segment,
- analysis of potential economic and societal issues in the framework of grand societal challenges.

The study is based on four main work packages.

1. **Identification of information**

   This first work package dealt with preparation of the further stages of the research as well as with detailed analysis of available secondary sources. Using the relevant data gathered in this stage, we conducted a meta-analysis and systematic review. Combining the results of several relevant sources allowed the creation of a set of related hypotheses (therefore this integrated both qualitative and quantitative approaches), elaborated in more detail and verified in the following work packages.

   This part of the study also contained preparations of database of experts and interviewees to be engaged in further research.

2. **Collection of information**

   Analysts gathered primary information under this work package. The research team conducted a series of interviews with two groups of stakeholders:

   - materials experts,
   - investors and investment advisors from banks, venture capital and private equity companies.

   The first group of respondents, the materials experts, was also asked to participate in a Delphi group exercise in order to get a wide understanding of the challenges they face, and discuss their definition of VAMs. The main information gathered helped create further work packages.

   The detailed composition of the respondents groups is presented in Annex 2.

3. **Analysis and evaluation of data**

   When all relevant primary and secondary data were available, the team elaborated on market analysis and prognosis.

   The main challenge for this part of the study was to assess the sizes of markets for VAMs and their share in those markets. The difficulty of this task was intensified by the fact that respondents — materials scientists and private investors — gave their input in the form of interviews. Also the discussion on definition of VAMs within the Delphi Group exercise demonstrated that it would be difficult to establish precise and detailed information of current market shares of VAMs in each market segment.

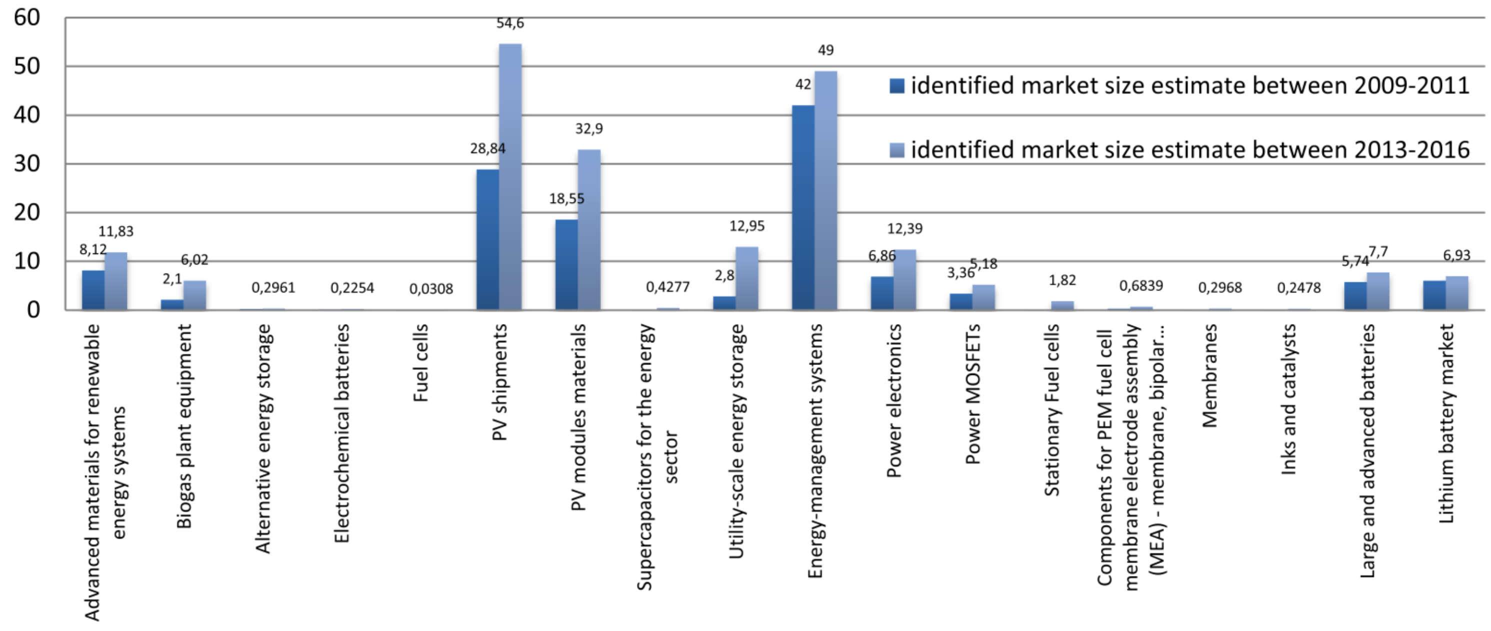
The only possible approach therefore was to analyse existing market size information and foresights for all sectors and subsectors (applications), then draw conclusions based on this analysis with support from qualitative information obtained and other secondary sources (roadmaps and foresights). We used triangulation to assure the data from interviews with market investors.

4. Conclusion

This part prepared the final report and disseminated the study outcomes.

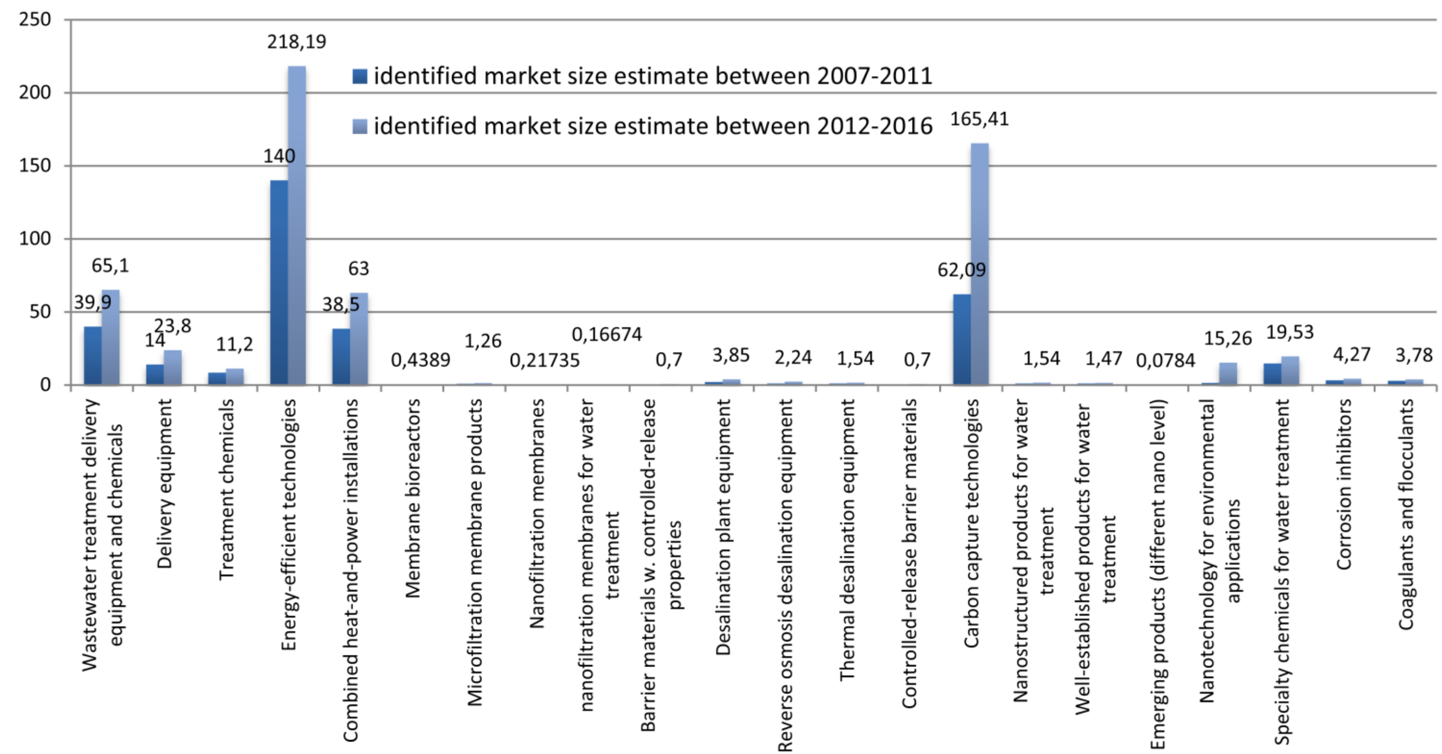
Annex 1. Market foresights relevant for Value Added Materials

Figure 18: Energy-related markets for VAMs — selected foresights overview



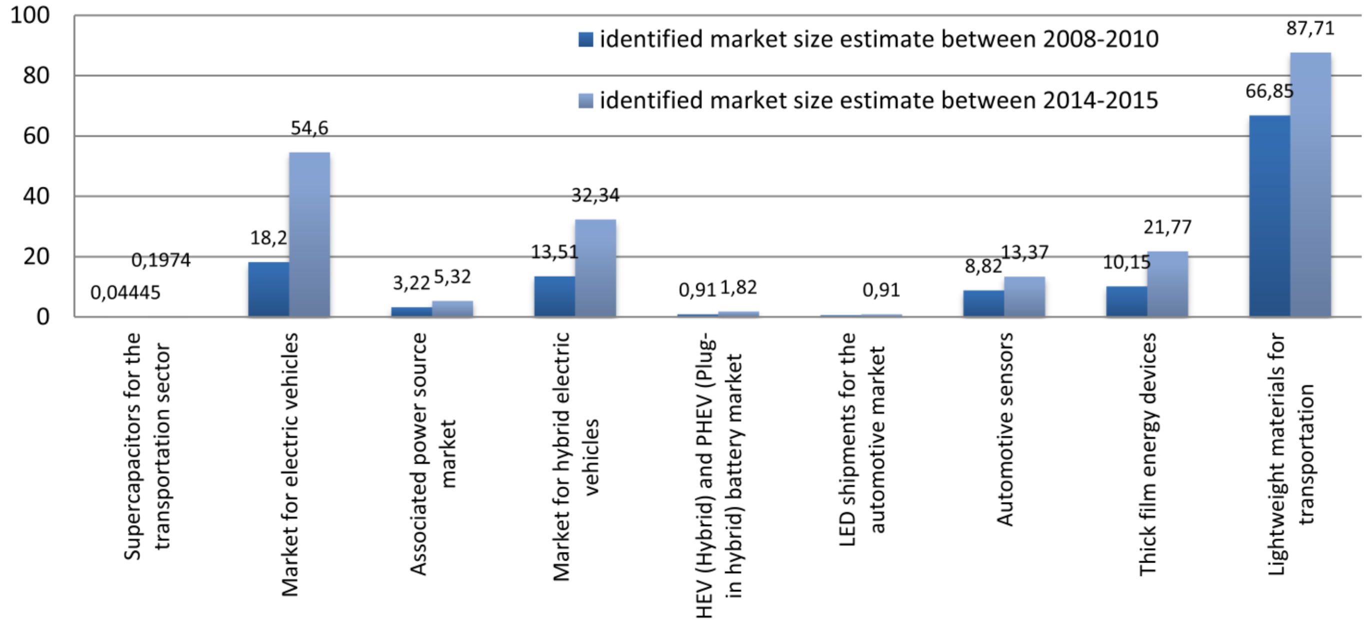
Source: selected BCC Research estimates. Design: Oxford Research AS. Unit: billion euro.

Figure 19: Environment-related markets for VAMs — selected foresights overview



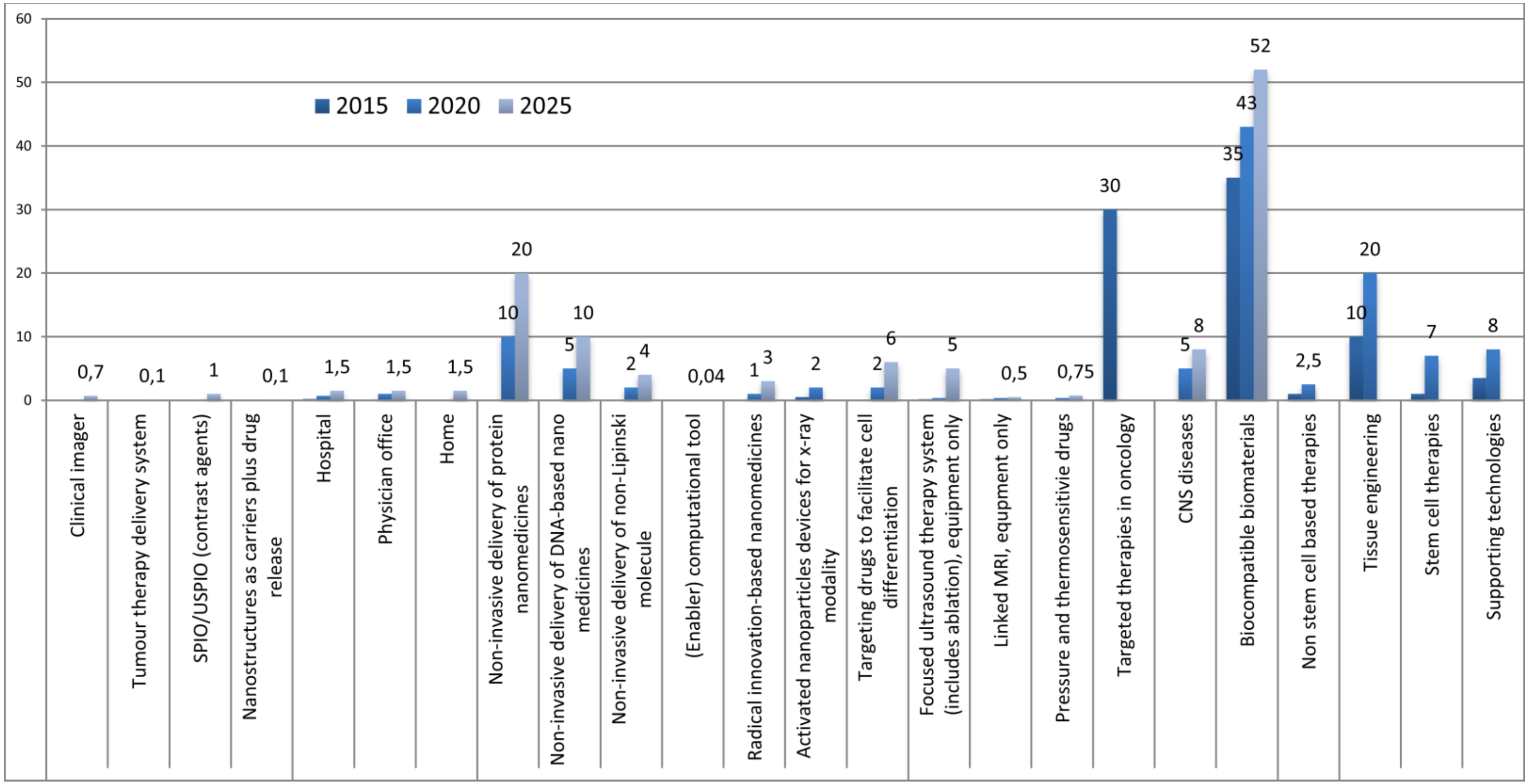
Source: selected BCC Research estimates. Design: Oxford Research AS. Unit: billion euro.

Figure 20: Transport-related markets for VAMs — selected foresights overview



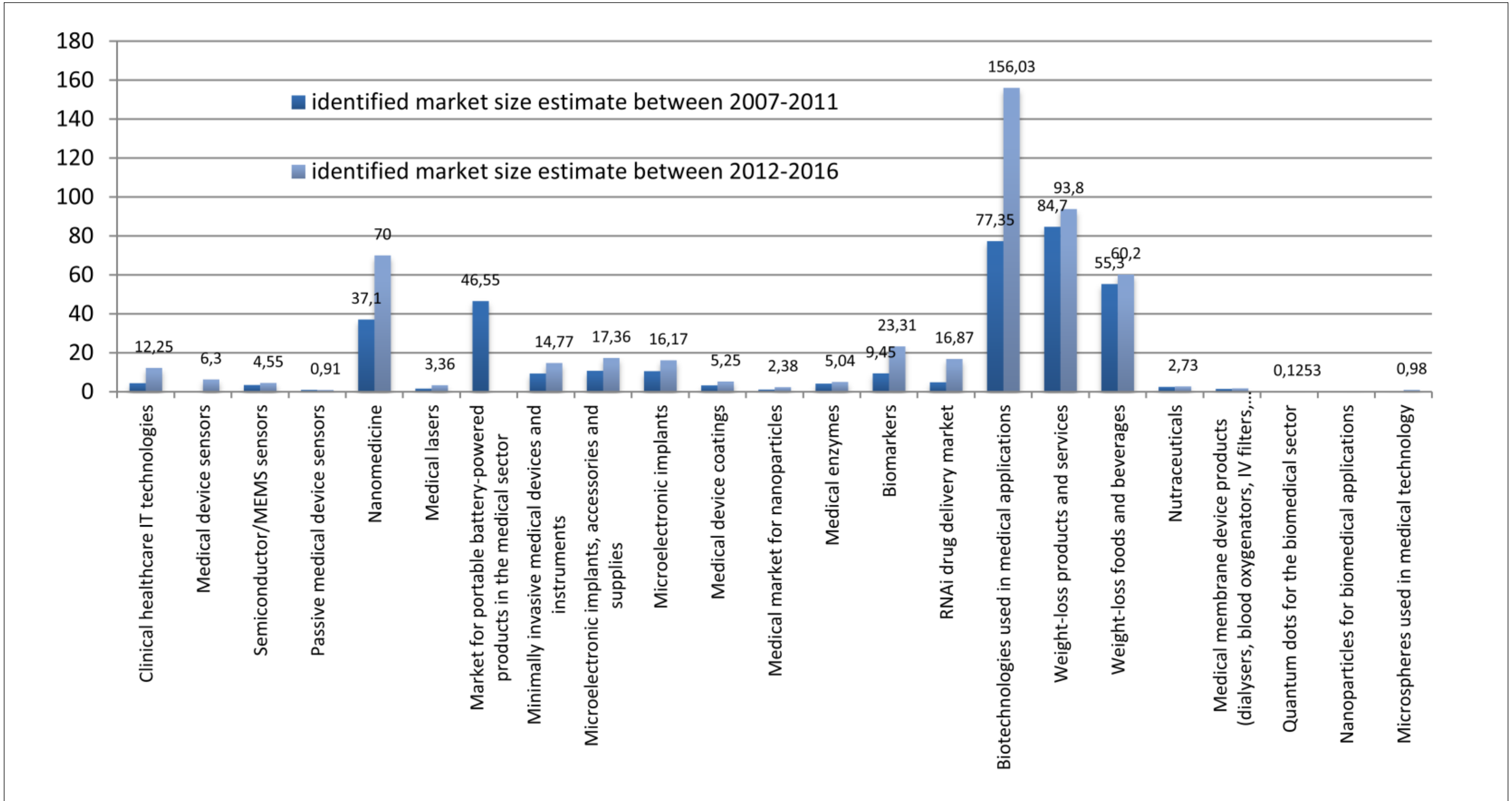
Source: selected BCC Research estimates. Design: Oxford Research AS., Unit: billion euro.

Figure 21: Health-related markets for VAMs — foresights from ‘Roadmaps in Nanomedicine’



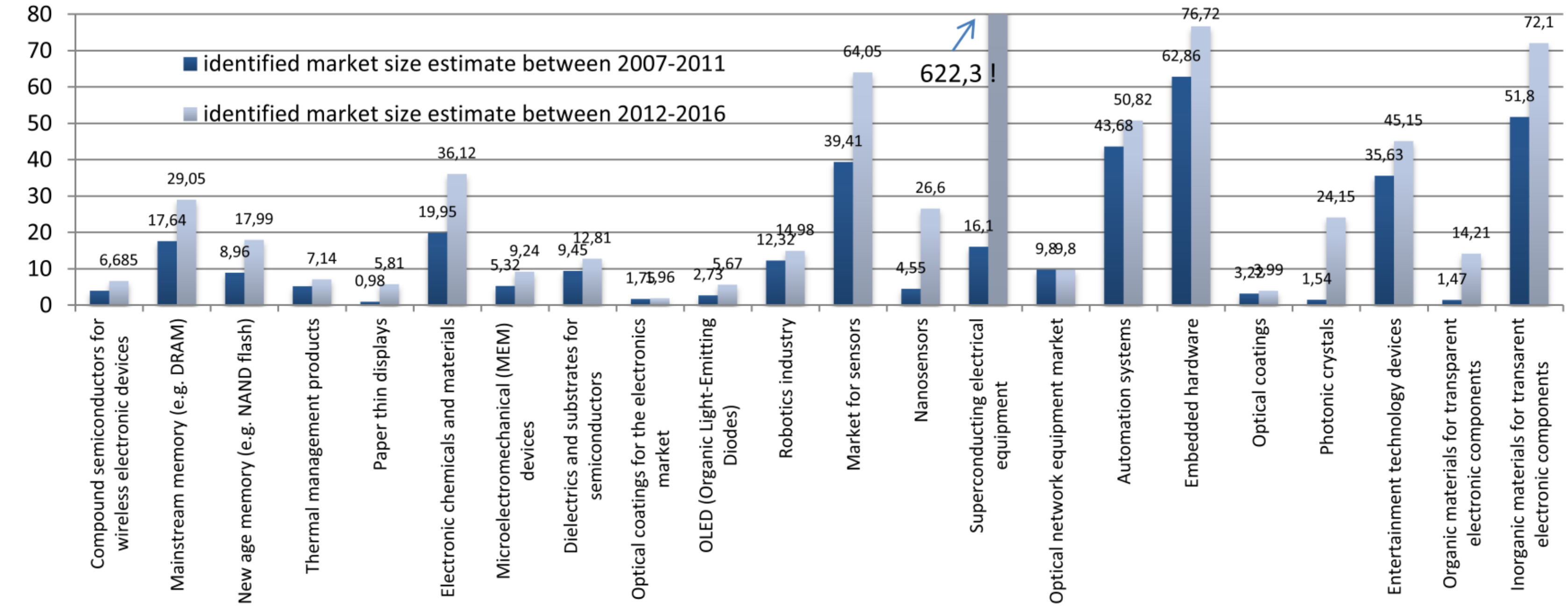
Source: ‘Roadmaps in nanomedicine: towards 2020‘. Design: Oxford Research AS. Unit: billion euros.

Figure 22: Health-related markets for VAMs — selected foresights overview



Source: selected BCC Research estimates. Design: Oxford Research AS., Unit: billion euro.

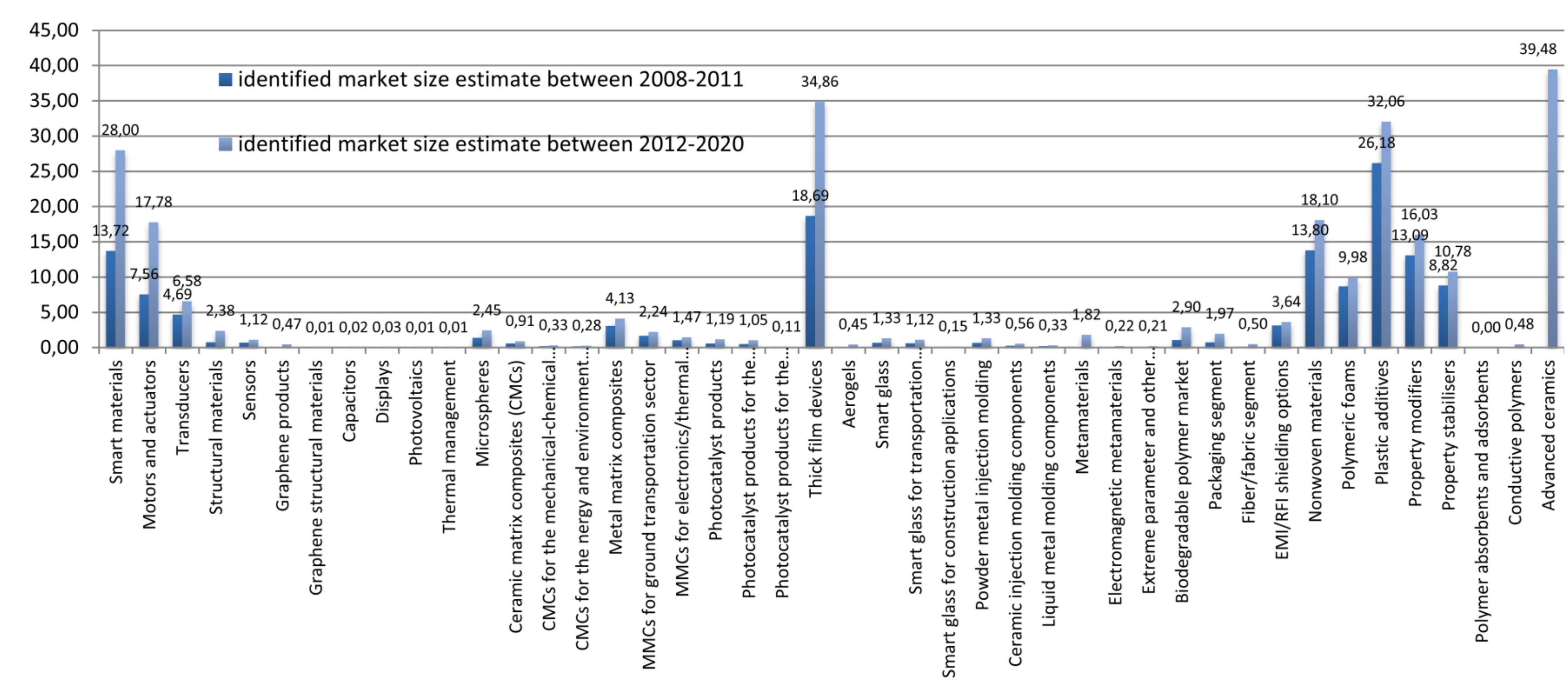
Figure 23: ICT-related markets for VAMs — selected foresights overview[70]



Source: selected BCC Research estimates. Design: Oxford Research AS. Unit: billion euro.

[70] The market for "'superconducting electrical equipment', reaching 622 billion euro, was presented within ICT sector following other sources and approaches. It can be of course also associated with the energy sector analysed in chapters above. This sector's expected growth has also influenced the total share of materials foresighted use in ICT sector discussed at previous page.

Figure 24: Selected cross-cutting markets for VAMs — foresights overview[71][72]



Source: selected BCC Research estimate., Design: Oxford Research AS. Unit: billion euro.

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[71] It is interesting that graphene products are emerging — from close to zero market up to a total of 472 million euro in 2020.
[72] Full record of 'long names' categories can be found in table below.

Table 9: Overview of identified market size values for sectors covered with the study[73]

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Energy		Market-Research.com	trillion €			4,235					7,87528								13 %
Energy		US EIA	quadrillion BTU	495,1								543,5			590,5	638,7	687	738,7	
Liquids		US EIA	quadrillion BTU	174,71								179			186	197	210	223,6	
Natural gas		US EIA	quadrillion BTU	112,13								129			141	150	155	162	
Coal		US EIA	quadrillion BTU	132,45								139			152	168	186	206	
Nuclear		US EIA	quadrillion BTU	27,1								32			37	41	44	47	
Renewables		US EIA	quadrillion BTU	48,83								64			73	82	91	100	
	Hydropower	US EIA	kwhours	2999								3689			4166	4 591	5034	5 418	
	Wind	US EIA	kwhours	165								682			902	1 115	1234	1 355	
	Geothermal	US EIA	kwhours	57								98			108	119	142	160	
	Solar (photovoltaics)	US EIA	kwhours	6								95			126	140	153	165	
	Other	US EIA	kwhours	235								394			515	653	733	874	
Advanced materials for renewable energy systems		BCC Research	billion €			8,12					11,83								8 %
Biogas plant equipment		BCC Research	billion €				2,1				6,02								30 %
Alternative energy storage		BCC Research	billion €					0,2275					0,2961						5 %
	Electrochemical batteries	BCC Research	billion €					0,1652					0,2254						6 %
	Fuel cells	BCC Research	billion €					0,0175					0,0308						12 %

[73] The market was gathered from various sources and denominated into euro using exchange rate being and average from 120 days before September 15th, 2011.
1 USD = 0,70 €; 1 GBP = 1,16 €O

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
PV shipments		BCC Research	billion €				28,84					54,6							14 %
	PV modules materials	BCC Research	billion €				18,55					32,9							12 %
Supercapacitors for the energy sector		BCC Research	billion €				0,0574					0,4277							49 %
Utility-scale energy storage		BCC Research	billion €				2,8					12,95							
Energy-management systems		BCC Research	billion €				42					49							3 %
Power electronics		BCC Research	billion €				6,86			12,39									22 %
	Power MOSFETs	BCC Research	billion €				3,36			5,18									16 %
Stationary Fuel cells		BCC Research	billion €				0,0860 3							1,82					55 %
Components for PEM fuel cell membrane electrode assembly (MEA) - membrane, bipolar plates, gaseous diffusion layers, catalyst ink and electrodes	BCC Research		billion €				0,2681					0,6839							21 %
	Membranes	BCC Research	billion €				0,14					0,2968							16 %
	Inks and catalysts	BCC Research	billion €				0,0721					0,2478							28 %
Large and advanced batteries		BCC Research	billion €			5,74					7,7								6 %
Lithium battery market		BCC Research	billion €			6,02					6,93								3 %
Nanoparticles used in energy, catalytic and structural applications		BCC Research	billion €	0,2554 3					0,91										29 %
Portable battery-powered products		BCC Research	billion €	297,71						323,05									1 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Transport		Datamonitor	trillion €						3,15										
Supercapacitors for the transportation sector		BCC Research	billion €				0,04445					0,1974							35 %
Market for electric vehicles		BCC Research	billion €			18,2						54,6							20 %
	Associated power source market	BCC Research	billion €			3,22						5,32							9 %
Market for hybrid electric vehicles		BCC Research	billion €				13,51					32,34							19 %
HEV (Hybrid) and PHEV (Plug-in hybrid) battery market		BCC Research	billion €			0,91					1,82								15 %
LED shipments for the automotive market		BCC Research	billion €		0,59465						0,91								7 %
Automotive sensors		BCC Research	billion €			8,82						13,37							7 %
Thick film energy devices		BCC Research	billion €			10,15					21,77								16 %
Lightweight materials for transportation		BCC Research	billion €				66,85					87,71							6 %
Environment		U.S. Department of Commerce	billion €	461,3			490												2 %
World market for water and wastewater		WSSTP 2010 SRA	billion €				300												
Wastewater treatment delivery equipment, instrumentation, process equipment and treatment chemicals		BCC Research	billion €					39,9		65,1									28 %
	Delivery equipment	BCC Research	billion €					14					23,8						11 %
	Treatment chemicals	BCC Research	billion €					8,4					11,2						6 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Energy-efficient technologies		BCC Research	billion €				140					218,19							9 %
	Combined heat-and-power installations and retrofitting	BCC Research	billion €			38,5						63							9 %
Membrane bioreactors		BCC Research	billion €			0,2359						0,4389							11 %
Microfiltration membrane products used in liquid separation		BCC Research	billion €				0,84					1,26							8 %
Nanofiltration membranes		BCC Research	billion €	0,06825					0,21735										26 %
	Nanofiltration membranes for water treatment	BCC Research	billion €	0,04963					0,16674										27 %
Barrier materials that impart controlled-release properties		BCC Research	billion €				0,42					0,7							11 %
Desalination plant equipment		BCC Research	billion €				2,03					3,85							14 %
	Reverse osmosis desalination equipment	BCC Research	billion €				0,98					2,24							18 %
	Thermal desalination equipment	BCC Research	billion €				0,98					1,54							9 %
Controlled-release barrier materials		BCC Research	billion €				0,42					0,7							11 %
Carbon capture technologies		BCC Research	billion €				62,09		165,41										63 %
Nanostructured products for water treatment		BCC Research	billion €				0,98					1,54							9 %
	Well-established products for water treatment (reverse osmosis, nanofiltration, ultrafiltration membrane modules)	BCC Research	billion €				0,98					1,47							8 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Emerging products (nanofibre filters, carbon nanotubes, nanoparticles)	BCC Research	billion €				0,0315					0,0784							20 %
Nanotechnology for environmental applications		BCC Research	billion €			1,4					15,26								61 %
Specialty chemicals for water treatment		BCC Research	billion €		14,7					19,53									6 %
	Corrosion inhibitors	BCC Research	billion €		3,22					4,27									6 %
	Coagulants and flocculants	BCC Research	billion €		2,87					3,78									6 %
Health		Photonics 21 report "Lighting the way ahead"	billion € data only for Europe		641,9														
Health market size		Plunkett Research®, Ltd.2006	trillion € in 2006	3,15			3,85												5 %
Pharmaceutical Raw Materials Industry		Plunkett Research®, Ltd.2006	billion €	3,22															
Dietary **Supplements**		Plunkett Research®, Ltd.2007	billion €																
Alternative Medication		Plunkett Research®, Ltd.2008	billion €	1,89															
Biotechnology		Plunkett Research®, Ltd.2009	billion €	35,49															
Healthcare Services		Plunkett Research®, Ltd.2010	billion €	35															
Pharmaceutical (drug market)		Plunkett Research®,	billion €	238			360												15 %

Sector / applica-tion	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Optical healthcare equipment		BMBF Optische Techno-logien 2007, used in Photonics 21 report "Light-ing the way ahead"	billion €	16,1								30,1							8 %
Biophotonics (including x-ray, PET and ultra-sound)		Photonics 21 report "Light-ing the way ahead"	billion €																
Nanodiagnostics in vivo imaging	Clinical imager	"Roadmaps in nano medi-cine: towards 2020"	billion €												0,05	0,7			70 %
	Tumour therapy delivery system	"Roadmaps in nano medi-cine: towards 2020"	billion €									0,001			0,02	0,1			38 %
	SPIO/USPIO (contrast agents)	"Roadmaps in nano medi-cine: towards 2020" (38)	billion €									0,01			0,1	1			58 %
	Nanostructures as carriers plus drug release	"Roadmaps in nano medi-cine: towards 2020"	billion €												0,01	0,1			58 %
Nanodiagnostics in vitro imaging	Hospital	"Roadmaps in nano medi-cine: towards 2020"	billion €									0,2			0,7	1,5			16 %
	Physician office	"Roadmaps in nanomedicine: towards 2020"	billion €												1	1,5			8 %
	Home	"Roadmaps in nanomedicine: towards 2020"	billion €													1,5			

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Nano pharmaceuticals	Non-invasive delivery of protein nanomedicines	"Roadmaps in nanomedicine: towards 2020"	billion €												10	20			15 %
	Non-invasive delivery of DNA-based nanomedicines	"Roadmaps in nano medicine: towards 2020"	billion €												5	10			15 %
	Non-invasive delivery of non-Lipinski molecule	"Roadmaps in nano medicine: towards 2020"	billion €												2	4			15 %
	(Enabler) computational tool	"Roadmaps in nano medicine: towards 2020"	billion €									0,015			0,02	0,04			15 %
	Radical innovation-based nanomedicines	"Roadmaps in nano medicine: towards 2020"	billion €												1	3			25 %
	Activated nanoparticles devices for x-ray modality	"Roadmaps in nano medicine: towards 2020"	billion €									0,5			2				32 %
	Targeting drugs to facilitate cell differentiation	"Roadmaps in nano medicine: towards 2020"	billion €												2	6			25 %
Nanodevices	Focused ultrasound therapy system, equipment only	"Roadmaps in nano medicine: towards 2020"	billion €									0,175			0,35	5			70 %
	Linked MRI, equipment only	"Roadmaps in nano medicine: towards 2020"	billion €									0,175			0,35	0,5			7 %
	Pressure and thermosensitivie drugs	"Roadmaps in nano medicine: towards 2020"	billion €									0,09			0,35	0,75			16 %
	Targeted therapies in oncology	"Roadmaps in nano medicine: towards 2020"	billion €									30							

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Anti-inflammatory diseases	"Roadmaps in nano medicine: towards 2020"	billion €																
	CNS diseases	"Roadmaps in nano medicine: towards 2020"	billion €												5	8			10 %
Regenerative medicine: smart biomaterials	Biocompatible biomaterials	"Roadmaps in nano medicine: towards 2020"	billion €									35			43	52			4 %
Regenerative medicine: cell therapies	Non stem cell based therapies	"Roadmaps in nano medicine: towards 2020"	billion €									1			2,5				20 %
	Tissue engineering	"Roadmaps in nano medicine: towards 2020"	billion €									10			20				15 %
	Stem cell therapies	"Roadmaps in nano medicine: towards 2020"	billion €									1			7				48 %
	Supporting technologies	"Roadmaps in nano medicine: towards 2020"	billion €									3,5			8				18 %
Clinical healthcare IT technologies		BCC Research	billion €				4,41						12,25						19 %
Medical device sensors		BCC Research	billion €								6,3								
	Semiconductor/MEMS sensors	BCC Research	billion €			3,5					4,55								5 %
	Passive medical device sensors	BCC Research	billion €			0,98					0,91								-1 %
Nanomedicine		BCC Research	billion €			37,1					70								14 %
Medical lasers		BCC Research	billion €			1,61					3,36								16 %
Market for portable battery-powered products in the medical sector		BCC Research	billion €		46,55														

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Minimally invasive medical devices and instruments		BCC Research	billion €				9,38						14,77						8 %
Microelectronic implants, accessories and supplies		BCC Research	billion €				10,78						17,36						8 %
	Microelectronic implants	BCC Research	billion €					10,57					16,17						9 %
Medical device coatings		BCC Research	billion €			3,29					5,25								10 %
Medical market for nanoparticles		BCC Research	billion €	1,12						2,38									13 %
Medical enzymes		BCC Research	billion €				4,2					5,04							4 %
Biomarkers		BCC Research	billion €				9,45					23,31							20 %
RNAi drug delivery market		BCC Research	billion €				4,9					16,87							28 %
Biotechnologies used in medical applications		BCC Research	billion €				77,35					156,03							15 %
Weight-loss **products and services**		BCC Research	billion €			84,7					93,8								2 %
	Weight-loss foods and beverages	BCC Research	billion €			55,3					60,2								2 %
	Nutraceuticals	BCC Research	billion €			2,52					2,73								2 %
Medical membrane device products (dialysers, blood oxygenators, IV filters, blood/apheresis filters)		BCC Research	billion €			1,400	1,464	1,532	1,602	1,676	1,753								5 %
Quantum dots for the biomedical sector		BCC Research	billion €			0,0336						0,1253							25 %
Nanoparticles for biomedical applications		BCC Research	billion €						0,3633										

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Microspheres used in medical technology		BCC Research	billion €				0,3367					0,98							24 %
Security and safety (equipment)		Photonics 21 report "Lighting the way ahead"	billion €																
Market for portable battery-powered products in the military sector		BCC Research	billion €		1,26					2,24									12 %
Surveillance equipment market		BCC Research	billion €			54,6						97,44							10 %
Mobile location technologies		BCC Research	billion €	16,24					34,16										16 %
	Vehicle navigation	BCC Research	billion €	11,06					26,74										19 %
Biometric technologies		BCC Research	billion €				3,5					8,4							19 %
Enzymes for textile processing			billion €																
Chemical industry		American Chemistry Council	billion €			2402,4													
Paints and coatings		BCC Research	billion €				69,79					81,62							3 %
	Powder coating and emerging technologies segment	BCC Research	billion €				12,6					16,1							5 %
	Waterborne technologies	BCC Research	billion €				43,82					47,6							2 %
Adhesives and sealants		BCC Research	billion €				28,56					36,47							5 %
Pesticides		BCC Research	billion €			30,1					35,7								3 %
	Biopesticides	BCC Research	billion €			1,12					2,31								16 %
	Synthetic pesticides	BCC Research	billion €			28,7					33,6								3 %
Agrochemical products		BCC Research	billion €			83,72					137,2								10 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Fertilisers	BCC Research	billion €			47,88					82,46								11 %
	Pesticides	BCC Research	billion €			35,84					54,81								9 %
Powder coatings		BCC Research	billion €			4,55					6,37								7 %
Total ICT sector		The World Information Technology and Services Alliance, DIGITAL PLANET 2010	trillion €	2,38	2,52	2,45	2,625	2,87	3,08	3,22									5 %
Hardware		Digital Planet	trillion €	0,315	0,343	0,336	0,336	0,364	0,392	0,413									5 %
Software		Digital Planet	trillion €	0,245	0,252	0,252	0,259	0,266	0,273	0,28									2 %
Services		Digital Planet	trillion €	0,49	0,525	0,49	0,525	0,56	0,595	0,665									5 %
Communications		Digital Planet	trillion €	1,33	1,47	1,435	1,575	1,68	1,82	1,89									6 %
Electronics industry		ENIAC 2007 SRA	billion €	773,5															
Market for electronics products (BCC)		ENIAC 2007 SRA	billion €	1400					2240										10 %
Materials and equipment		ENIAC 2007 SRA	billion €	56,7															
Semiconductors		ENIAC 2007 SRA	billion €	196															
Compound semiconductors		BCC Research	billion €	11,2					23,59										16 %
	Compound semiconductors for wireless electronic devices	BCC Research	billion €	4,004					6,685										11 %
	Compound semiconductors for optical data storage	BCC Research	billion €	1,155					2,401										16 %
	Compound semiconductors for fibre optics communications	BCC Research	billion €	0,805					4,249										39 %
	Compound semiconductors illuminations	BCC Research	billion €	1,33					1,631										4 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Compound semiconductors for solar cells	BCC Research	billion €	0,063					1,365										85 %
	Compound semiconductors for new markets	BCC Research	billion €	0,63					2,8										35 %
Transparent electronic components		BCC Research	billion €				53,48					86,1							10 %
	Organic materials for transparent electronic components	BCC Research	billion €				1,47					14,21							57 %
	Inorganic materials for transparent electronic components	BCC Research	billion €				51,8					72,1							7 %
Memory to semiconductor manufacturers and end users		BCC Research	billion €			32,34					55,3								11 %
	Mainstream memory (e.g. DRAM)	BCC Research	billion €			17,64					29,05								10 %
	New age memory (e.g. NAND flash)	BCC Research	billion €			8,96					17,99								15 %
Conformal coatings for electronics		BCC Research	billion €		4,62					1,61									-19 %
	Conformal coating materials	BCC Research	billion €		1,05					1,61									9 %
	Conformal coating equipment	BCC Research	billion €		3,57					4,83									6 %
Market for mobile telematics systems		BCC Research	billion €						36,4										
PVD equipment for the microelectronics industry		BCC Research	billion €			1,96					3,01								9 %
Thermal management products		BCC Research	billion €				5,25					7,14							6 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Thermal interface materials		BCC Research	billion €				0,273						0,43876						8 %
	Polymer-based TIM	BCC Research	billion €				0,23975						0,38451						8 %
	Metal-based TIM	BCC Research	billion €				0,02485						0,03766						7 %
	Phase-change TIM	BCC Research	billion €				0,00847						0,01666						12 %
Paper thin displays		BCC Research	billion €				0,98					5,81							43 %
	Paper-thin displays for electronic portable devices	BCC Research	billion €				0,91					5,67							44 %
	Paper-thin displays for advertising	BCC Research	billion €				7,7					30,8							32 %
Fibre optic connectors (FOC)		BCC Research	billion €				1,33						2,17						9 %
Electronic chemicals and materials		Electronics .ca	billion €				19,95					36,12							13 %
	Wafers	Electronics .ca	billion €				10,29					18,69							13 %
	Polymers and conductive polymers	Electronics .ca	billion €				1,33					4,13							25 %
Microelectronics **cleaning equipment, consumables and services**		BCC Research	billion €			2,03						5,6							18 %
	Cleaning chemicals, gases and other consumables	BCC Research	billion €			1,47						3,5							16 %
	Cleaning equipment	BCC Research	billion €			0,7						1,68							16 %
Atomic layer deposition		BCC Research	billion €		0,2226						0,6846								21 %
	Atomic layer deposition equipment	BCC Research	billion €		0,1617						0,4053								17 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Atomic layer deposition materials	BCC Research	billion €		0,0609						0,27965								29 %
Microelectromechanical (MEM) devices production and equipment		BCC Research	billion €			5,32					9,24								12 %
	Microfluidic MEMs	BCC Research	billion €			2,45					3,01								4 %
	Accelerometers	BCC Research	billion €			0,504					1,89								30 %
Dielectrics and substrates for semiconductors		BCC Research	billion €			9,45					12,81								6 %
	Substrates	BCC Research	billion €			8,4					11,2								6 %
	Dielectrics market	BCC Research	billion €			0,98					1,54								9 %
Optical coatings for the electronics market		BCC Research	billion €				1,75					1,96							2 %
OLED (Organic Light-Emitting Diodes)		BCC Research	billion €			2,73					5,67								16 %
	OLED for displays market	BCC Research	billion €			2,03					4,13								15 %
	OLED for lights market	BCC Research	billion €		0,7						1,54								14 %
Direct methanol fuel cells (used to make batteries)		Electronics .ca	billion €			0,04592						0,77							60 %
Strained silicon (used to make semiconductors devices)		Electronics .ca	billion €								2,45								
Robotics industry		BCC Research	billion €			12,32					14,98								4 %
Nanorobots and NEMs, and related equipment and materials		BCC Research	billion €	0,02821			0,58128												174 %
Market for sensors		BCC Research	billion €				39,41						64,05						8 %
	Biosensors and chemical sensors	BCC Research	billion €					9,1					14,7						10 %
	Image sensors	BCC Research	billion €					12,6					18,9						8 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Microsensors		BCC Research	billion €				3,64						8,4						15 %
	MEMs microsensors	BCC Research	billion €					2,24					4,55						15 %
	Nanosensors	BCC Research	billion €					4,55					26,6						42 %
	Biochips sensors	BCC Research	billion €	0,35						1,26									
Nanoparticles used in electronic, magnetic and optoelectronic applications		BCC Research	billion €	0,36533					0,77										16 %
	Electronic applications	BCC Research	billion €	0,2891					0,6097										16 %
Thick film display devices		BCC Research	billion €			0,84					1,96								18 %
Superconductors		BCC Research	billion €				1,4					2,38							11 %
	Super conducting magnets	BCC Research	billion €				1,33					1,68							5 %
	Super conducting electrical equipment	BCC Research	billion €				16,1					622,3							108 %
Information and Communication industry		EPOSS 2009 SRA	billion €			2350													
Telecommunications market		Photonics 21 SRA "Lighting the way ahead"	billion €		2380														
Optical network equipment market		Photonics 21 SRA "Lighting the way ahead"	billion €		9,8														
Optical component market		Photonics 21 SRA "Lighting the way ahead"	billion €		2,8														
Smart systems		EPOSS 2009 SRA	billion €												65				

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Monitoring and Control products and solutions		EPOSS 2009 SRA	billion €			188													
	Monitoring and control products and solutions for the vehicle market	EPOSS 2009 SRA	billion €	17															
e-health market		EPOSS 2009 SRA	billion €																
Market for portable battery-powered products		BCC Research	billion €		310,24				323,05										
	Market for portable battery-powered products in the communication sector	BCC Research	billion €	89,32						84									-1 %
	Market for portable battery-powered products in the computer sector	BCC Research	billion €		71,33														
Automation systems		BCC Research	billion €			43,68					50,82								3 %
Embedded systems		BCC Research	billion €		64,4					78,75									4 %
	Embedded hardware	BCC Research	billion €		62,86					76,72									4 %
	Embedded software	BCC Research	billion €		1,54					2,03									6 %
market for advanced intelligent wireless microsystems		BCC Research	billion €	0,0924						0,91									46 %
Fibre optic connectors for telecommunications		BCC Research	billion €					1,33					2,03						9 %
LEDs for display backlighting		BCC Research	billion €			0,6531					1,05								10 %
Photonics industry		Photonics 21 SRA "Lighting the way ahead"	billion €		270														

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Green photonics (photonics solutions that generate or conserve energy, cut greenhouse gas emissions, reduce pollution, yield environmentally sustainable outputs or improve public health)		Photonics 21 SRA "Lighting the way ahead"	billion €		20,23							70			182,7				20 %
Lighting market		"Lighting the way ahead" Photonics 21 SRA	billion €	58															
	Professional luminaires	"Lighting the way ahead" Photonics 21 SRA	billion €	20,3															
	Consumer luminaires	"Lighting the way ahead" Photonics 21 SRA	billion €	16,24															
	Luminaire market	"Lighting the way ahead" Photonics 21 SRA	billion €	36															
	Lamps	"Lighting the way ahead" Photonics 21 SRA	billion €	11,6															
	LED components	"Lighting the way ahead" Photonics 21 SRA	billion €	1,74															
	Lighting electronics	"Lighting the way ahead" Photonics 21 SRA	billion €	5,22															
	Automotive and special lighting applications	"Lighting the way ahead" Photonics 21 SRA	billion €	2,9															
	LED-based luminaires	"Lighting the way ahead" Photonics 21 SRA	billion €	3,71						10,43									19 %
	OLED-lighting	"Lighting the way ahead" Photonics 21 SRA	billion €								3,5								
Safety and security equipment using photonic sensors		"Lighting the way ahead" Photonics 21 SRA	billion €	22								48							10 %
	Safety	"Lighting the way ahead" Photonics 21 SRA	billion €	7															

Sector / applica-tion	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Air pollution detection	"Lighting the way ahead" Photonics 21 SRA	billion €	2															
	Automotive sector	"Lighting the way ahead" Photonics 21 SRA	billion €	5															
	Security	"Lighting the way ahead" Photonics 21 SRA	billion €	15															
	Biometrics	"Lighting the way ahead" Photonics 21 SRA	billion €	5															
	Videosurveil-lance	"Lighting the way ahead" Photonics 21 SRA	billion €	5															
Optical coatings		BCC Research	billion €				3,22					3,99							4 %
Quantum dots for the optoelectronics sector		BCC Research	billion €									0,217							
Silicon photonics product market		Electronics .ca	billion €								1,365								
	Wavelength division multiplex filter	Electronics .ca	billion €								0,434								
Photonic crystals		BCC Research	billion €				1,54						24,15						58 %
	Photonic crystals for displays	BCC Research	billion €										4,2						
	Photonic crystals for optical fibres	BCC Research	billion €										7,56						

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Food industry		CIAA (in KBBE 2010 report)	billion €				2800												
Food products containing nanotechnology		'Nanotechnologies and food', 2010 House of Lords report (UK)	billion €	0,287					4,06										70 %
Probiotic supplements, ingredients and foods		BCC Research	billion €	15,12					21,77										8 %
Active, controlled and intelligent packaging for food and beverage		BCC Research	billion €		11,83					16,52									
Entertainment industry		BCC Research	billion €		46,83					58,31									
Entertainment technology devices		BCC Research	billion €		35,63					45,15									
Enzymes			billion €																
	Enzymes for industrial applications	BCC Research	billion €				2,31					3,08							6 %
	Technical enzymes	BCC Research	billion €				0,7					1,05							8 %
	Food and beverage enzymes	BCC Research	billion €				0,6825					0,91							6 %
Biochips		BCC Research	billion €			1,82					4,13								18 %
	DNA microarrays (type of chip)	BCC Research	billion €			0,91					1,89								16 %
	LOAC (type of chip)	BCC Research	billion €			0,5719					1,47								21 %
Nanotechnology		Roco, Mirkin and Hersam. Sept 2010	billion €			177,8						700							26 %
Nano-enabled products		Roco, Mirkin and Hersam. Sept 2010	billion €			156,8													
Nano-intermediates		Roco, Mirkin and Hersam. Sept 2010	billion €			20,3													
Nano-materials		Roco, Mirkin and Hersam. Sept 2010	billion €			0,7													

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
Nanotechnology in the **manufacturing and materials sector**		Roco, Mirkin and Hersam. Sept 2010.	billion €			97,3													
Nanotechnology in the electronics and IT sector		Roco, Mirkin and Hersam. Sept 2010	billion €			53,2													
Nanotechnology in healthcare and life sciences		Roco, Mirkin and Hersam. Sept 2010	billion €			23,8													
Nanotechnology in the energy and environment sector		Roco, Mirkin and Hersam. Sept 2010	billion €			2,8													
Quantum dots (nanocrystals)		BCC Research	billion €				0,0469					0,469							58 %
Nanobiotechnology products		BCC Research	billion €				0,01351					20,79							334 %
	Nanobiotechnology products for medical applications	BCC Research	billion €				13,37					20,3							9 %
Carbon nanotubes grades (MWNTs, SWNTs, FWNTs)		BCC Research	billion €			0,07					0,7								58 %
	Multi-wall Carbon Nanotubes	BCC Research	billion €			0,0721					0,60585								53 %
	Few-wall Carbon Nanotubes	BCC Research	billion €			0,000553					0,04375								140 %
Nanotechnology		BCC Research	billion €			8,19						18,2							14 %
	Nanomaterials	BCC Research	billion €			6,3						13,72							14 %
	Nanotools	BCC Research	billion €			1,82						4,76							17 %
	Nanodevices	BCC Research	billion €			0,0217						0,16359							40 %
Nanofibre products		BCC Research	billion €			0,06279									1,54				34 %
	Nanofibre products for the mechanical/chemical sector	BCC Research	billion €				0,05201								0,98				34 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Nanofibre products for the electronics sector	BCC Research	billion €				0,00448								0,2261				48 %
Nanocomposites		BCC Research	billion €			0,322					0,966								25 %
	Clay-based nanocomposites	BCC Research	billion €			0,15883					0,48461								25 %
	Ceramic-containing nanocomposites	BCC Research	billion €			0,03374					0,10164								25 %
Nanocoatings and nanoadhesives		BCC Research	billion €			1,61						13,37							42 %
	Nanocoatings	BCC Research	billion €			1,47						12,53							43 %
	Nanoadhesives	BCC Research	billion €			0,1197						0,84							38 %
Manufacturing			billion €																
Physical vapour deposition (PVD)		BCC Research	billion €			6,3					10,36								10 %
	PVD equipment	BCC Research	billion €			4,48					7,35								10 %
Chemical vapour deposition		BCC Research	billion €		5,11					8,26									
Ion implantation		BCC Research	billion €								3,08								
Inorganic metal finishing technologies		BCC Research	billion €	29,61						42,77									6 %
Advanced protective gear and armour		BCC Research	billion €				2,8					3,64							5 %
Other \ Unclassified																			
Smart materials		BCC Research	billion €				13,72						28						13 %
	Motors and actuators	BCC Research	billion €				7,56						17,78						15 %
	Transducers	BCC Research	billion €				4,69						6,58						6 %
	Structural materials	BCC Research	billion €				0,77						2,38						21 %
	Sensors	BCC Research	billion €				0,714						1,12						8 %
Graphene products		BCC Research/electronics.ca	billion €									0,469			0,4725				0 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Graphene structural materials	BCC Research/electronics.ca	billion €									0,01225			0,0637				39 %
	Capacitors	BCC Research/electronics.ca	billion €									0,0182			0,238				67 %
	Displays	electronics.ca	billion €												0,03066				
	Photovoltaics	electronics.ca	billion €									0,00525			0,0245				36 %
	Thermal management	electronics.ca	billion €									0,0105			0,01575				8 %
Microspheres		BCC Research	billion €				1,4					2,45							12 %
Ceramic matrix composites (CMCs)		BCC Research	billion €				0,609					0,91							8 %
	CMCs for the mechanical-chemical sector	BCC Research	billion €				0,2205					0,3262							8 %
	CMCs for the energy and environment sector	BCC Research	billion €				0,1939					0,2758							7 %
Metal matrix composites		BCC Research	mln kg		3,08					4,13									6 %
	MMCs for ground transportation sector	BCC Research	mln kg		1,68				2,24										7 %
	MMCs for electronics/thermal management sector	BCC Research	mln kg		1,05					1,47									7 %
Photocatalyst products		BCC Research	billion €			0,5929					1,19								15 %
	Photocatalyst products for the construction sector	BCC Research	billion €			0,51821					1,05								15 %
	Photocatalyst products for the consumer market	BCC Research	billion €			0,0595					0,1106								13 %
Thick film devices		BCC Research	billion €			18,69					34,86								13 %
Rare earths		BCC Research	thousand tons			79,52					122,92								9 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Mechanical and metallurgic applications	BCC Research	thousand tons			25,76					39,48								9 %
	Glass and ceramics applications	BCC Research	thousand tons			22,75					34,23								9 %
Aerogels (2.6% of the market for microporous and nanoporous materials in 2008)		BCC Research	billion €		0,05803					0,45241									51 %
Market for metals (secondary and mined metals)		BCC Research	billion €		454,58					625,94									7 %
Smart glass		BCC Research	billion €		0,7					1,33									14 %
	Smart glass for transportation applications	BCC Research	billion €		0,6223					1,12									12 %
	Smart glass for construction applications	BCC Research	billion €		0,09709					0,15281									9 %
Powder metal injection moulding		BCC Research	billion €		0,68943					1,33									14 %
	Ceramic injection moulding components	BCC Research	billion €		0,27615					0,5607									15 %
	Liquid metal moulding components	BCC Research	billion €		0,22106					0,3255									8 %
Metamaterials		BCC Research	billion €		0,13349					1,82									69 %
	Electromagnetic metamaterials	BCC Research	billion €		0,08225					0,22134									22 %
	Extreme parameter and other metamaterials	BCC Research	billion €		0,05124					0,21098									33 %
Biodegradable polymer market		BCC Research	billion €					1,08112					2,9						22 %
	Packaging segment	BCC Research	billion €					0,76096					1,972						21 %

Sector / application	Sub sector / application	Source	Unit	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020	2025	2030	2035	CAGR
	Fibre/fabric segment	BCC Research	billion €					0,15544					0,5046						27 %
EMI/RFI shielding options		BCC Research	billion €					3,15					3,64						3 %
Nonwoven materials		BCC Research	billion €				13,804					18,096							6 %
Polymeric foams		BCC Research	billion €				8,7					9,976							3 %
Plastic additives		BCC Research	billion €			26,18					32,06								4 %
	Property modifiers	BCC Research	billion €			13,09					16,03								4 %
	Property stabilisers	BCC Research	billion €			8,82					10,78								4 %
Polymer absorbents and adsorbents		BCC Research	billion €		0,00294					0,0049									11 %
Conductive polymers		BCC Research	billion €						0,4756										
Advanced ceramics		EuMat 2006 SRA (for 2004); electronics.ca (for 2015)	billion €									39,48							

Annex 2 – Composition of respondents groups

Table 10: List of interviewed materials experts

Area	Institution	Name of the expert
Forestry	FTP sprl	Mr Johan Elvnert - FTP manager
Forestry	CEI-Bois chairman (European Confederation of woodworking industries) Stora Enso Wood Products	Jukka Kilpeläinen SVP of Corporate R&D
€ATEX and Biotex: a joint initiative by 2 ETPs: €ATEXT and (biotechnology)	Euratex	Lutz Walter– €ATEXT (SRA chief editor)
Net!Works: Converged fixed and Wireless Communication Networks (also called eMobility)	Alcatel-Lucent, Bell Labs Germany	Bernd Gloss
ECTP (European Construction technology Platform)	Heidelberg Cement - Head of Research&Development	Wolfgang Dienemann - Co-leader of the Working group on Cementitious within the Focus Area on Materials
EPoSS: The European Technology Platform on Smart Systems Integration	Microsystems Technology CSEM SA	Prof. Dr. Alex Dommann - Leader of the Key technologies Working Group within EPoSS
Food for Life	Food and Consumer Product Safety Authority (NL)	Dr Jacqueline Castenmiller - Facilitator of the working group on Food and Health within the ETP

ERRAC: European Rail Research Advisory Council	Network Rail (UK)	John Amoore - leader of the "Competitiveness" working group within ERRAC
Federation of European Materials Societies	FEMS - Executive officer, Consultant	Dr. Jean-Marie Welter President of the Société Française de Métallurgie et de Matériaux (SF2M) from 2005-2006. Currently a technical consultant to the copper industry.
Energy	National Renewable Energy Laboratory (NREL)	Prof. David Ginley Dr. David Ginley, Research Fellow/Group Manager Process Technology and Advanced Concepts
University/Research	National Institute for Materials Science (NIMS)	Sukekatsu Ushioda, Ph. D., President National Institute for Materials Science (NIMS), Japan
EuMaT: European Technology Platform for Advanced Engineering Materials and Technologies	MEGGITT	Wanda Wolny - Chair of the Working group on Materials for Information and Communication Technology at EuMaT.
Manutext: a joint initiative by 2 ETPs: Manufuture and Future textiles and Clothing.	ITA Aachen	Prof. Thomas Gries; Institute of Textile Technology at RWTH Aachen University and Chair for textile machinery (ITA)
SNETP: Sustainable nuclear energy Technology Platform	SCK-CEN (Belgian Nuclear Research centre)	Dr. Leo Sannen; Manager Nuclear Materials Science (NMS) Institute SCK-CEN Dr. Marc Scibetta, Deputy Institute Manager Nuclear Materials Science
FEMS (Federation of European Materials Societies) - President of the executive committee	Federal Institute for Materials Research and Testing, BAM, Berlin.	Dr. Ing. Pedro D. Portella
Manufuture	Daimler AG	Heinrich Flegel (chairman)
ECTP (European Construction technology Platform)	Advanced Composite group - technical director	Ebby Shahidi - Co-leader of the Working group on Composites within the Focus Area on Materials

FEMS (Federation of European Materials Societies) - Secretary	Rio Tinto Alcan, Engineered Products, T&I - CRV	Dr Hugh M. Dunlop, senior scientist, innovation programs
FEMS (Federation of European Materials Societies) - Executive officer	National Centre for Metallurgical Research (CENIM), Madrid	Prof. Juan J. de Damborenea
Photonics21	TRUMPF GmbH + Co.; KG Johann-Maus-Strasse 2 71254 Ditzingen Germany	Dr. Thomas Rettich, Research Coordination
TPWind	European Wind Energy Association	Athanasia Arapogianni, research officer EWEA - the European Wind Energy Association asbl/vzw
Nanomedicine	CEA (Commissariat à l'Energie Atomique)	Patrick Boisseau - chair of the nano-diagnostics working group within the ETP
Research Funding	Tekes, Finnish Funding Agency for Technology and Innovation	Ms Sisko Sipilä chief technology adviser
Research	European Spalation Source (ESS)	Colin Carlile
FEMS (Federation of European Materials Societies) - Vice-President of the executive committee	Fraunhofer Institute for Nondestructive Testing, Dresden	Prof. Ehrenfried Zschech
ECTP (European Construction Technology Platform)	Università Politecnica delle Marche	Gian Marco Revel - Co-leader of the ECTP Focus Area on Materials
ACARE: Advisory Council for Aeronautics Research in Europe	ASD	Mr Romain Muller (manufacturing industry contact)

Table 11: List of interviewed bank, private equity & venture capital investment specialists

Name of the company	Name of the expert	Sector
Intesa Sanpaolo, International Regulatory and Antitrust Affairs	Alessandra Perrazzelli	Cross - sector
Polish Investment Fund	Wojciech Szapiel	Cross - sector
JKIC -JOERG KREISEL International Consultant	Joerg Kreisel	Cross - sector
Incitia Ventures	Jens Petter Falck	Software / ICT Services, Electronics /Semiconductors, Life Science, Energy / Cleantech / Industrial
Beheer Flevoland Participaties BV	René Krijger	ICT, Life Sciences, Production
Zouk Capital LLP	Justin Mighell	Cleantech
Octadim GmbH	Mr Harald Fichtl	Chemical - Materials, Energy, Environment Industrial Products, Other
WHEB Partners	Dr. Aaron Small	Cleanteach, Software, Hardware, Energy Sensors, Chemicals
Gimv NV	Eline Talboom	Cleantech, Life sciences
NBGI Ventures	James Wong,	Medtech, Life sciences
NREL Process Technology and Advanced Concepts	Dr. David Ginley	Nanotechnology and nanomaterials; transition metal oxides; organic electronics;
Baltcap	Martin Kodar	Wide range
AB Chalmersinvest	Ingvar Andersson	Transportation; Cleantech; Chemicals and Materials; Energy and Environment; Life Sciences
Global Life Science Ventures	Dr. Hans A. Küpper	Life Science Medtech

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Our society and in particular, the modern industrial economy are profoundly influenced by new advanced materials and technologies, which will play a major role in determining our future well-being.

In the past, the traditional starting point in the development of new materials has been mainly influenced by their availability. Nowadays this is increasingly determined by their expected end uses and required in-service performance. The realization of materials by design benefits from recent progress in nanotechnology, converging technologies and modelling.

The aim of this study is to provide an overview and future perspective of the commercial market possibilities for value-added and value-adding materials and to set out the various technical and economic scenarios linked to their potential development and use. A major novelty is the sources and individuals consulted, which comprise as far as possible, those coming both from the materials fields and the financial sector, including investors and investment advisors that deal with venture capital and private equity investments.

The study is intended to be for the benefit of all stakeholders in the field of new materials.

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