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# EuroNanoForum 2009

## Nanotechnology for Sustainable Economy

**European and International Forum on Nanotechnology**

**Prague (Czech Republic)**
**2 - 5 June 2009**

# CONCLUSIONS

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## Nanotechnology for Sustainable Economy

## European and International Forum on Nanotechnology

## *Conclusions*

Conclusions of the Forum organized by the Technology Centre of the Academy of Sciences of the Czech Republic, with the support of the Czech Ministry of Education Youth and Sports and the European Commission, held in Prague on 2-5 June 2009 as an official event of the Czech Presidency of the Council of the European Union

Directorate-General for Research
2009 Cooperation / Nanosciences, nanotechnologies, materials, and new production technologies

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It can be accessed through the Europa server (http://europa.eu).

# EuroNanoForum 2009: nanotechnology for sustainable economy

EuroNanoForum 2009 reflected the state of the art in European nanotechnologies and nanosciences. It highlighted the latest advances in fundamental research, as well as developments relevant to a wide range of industrial and societal needs. As the title indicates, there was a particular focus on sustainability and the environment

2-5 June 2009 The EuroNanoForum 2009[1] conference on nanotechnologies and nanosciences (N&N) took place in the Prague Congress Centre, as an event of the Czech Presidency and under the auspices of the Czech Ministry for Education Youth and Sports. About 800 delegates from industry and the scientific community attended the four days of plenary and parallel sessions, while an accompanying exhibition featured academic centres, special interest groups and suppliers of materials and equipment

As well as examining the contribution nanotechnologies are making to the transformation of European industry and society, the conference also considered the questions of governance, regulation and standardisation to be addressed in order to ensure a sustainable future for the technologies themselves.

In opening the proceedings, Miroslava Kopicová, Czech Minister of Education, Youth and Sports, observed that the current global financial crisis is adding new urgency to the search for radical innovation to spur industrial growth and stability in the EU. Nanotechnology, she considered, would play a major part in this process through its contributions in areas such as electronics, photonics and smart materials, as well as in health and pollution monitoring. However, she cautioned, introduction of the technologies would raise new ethical problems that would require early solution in order to win public approval for the emerging products.

Commission takes action

José Manuel Silva Rodrigues, Director General for Research at the European Commission, responded to the Minister by pointing out that the Commission has already taken timely action regarding the crisis, with its adoption of the European Economic Recovery Plan[2]. This aims to boost research investment by making provision for public-private partnerships in strategic industries most heavily affected by the downturn.

He went on to insist that human health, safety and ethical behaviour are matters that the Commission takes extremely seriously. “It is working to ensure that the public can benefit from the innovations that nanotechnologies may bring, while being protected from any adverse impacts,” he said. “Research on human and environmental safety has already seen nearly €50 million

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[1] Link to: http://www.euronanoforum2009.eu/

[2] Link to: http://ec.europa.eu/economy_finance/thematic_articles/article13502_en.htm

committed between 2004 and 2008. It is expected that the total budget will increase, reaching a figure of at least €100 million by 2013, thanks to the Seventh Framework Programme (FP7)[3] and the corresponding investments of Member States.

"To address the ethical issues, the Commission has made a recommendation on a voluntary Code of Conduct[4] to promote safe and responsible research and application of nanotechnology.

"In reaping the rewards of nanotechnology, we must make sure that excellent research is translated into tangible benefits," Rodriguez added. "And we must make sure that applications are not brought about without a meaningful involvement of society. The Nanotechnology Action Plan[5] has served us well in supporting Europe's integrated safe and responsible approach; we intend to continue this line."

## Pragmatism prevails

Throughout the conference, speakers expressed awareness of the need for sound governance, and highlighted the problems posed by the sheer diversity of N&N in gathering meaningful data as a basis for meaningful standards.

Matthew Nordan (Lux Research Inc. USA) underlines the importance of understanding that N&N is neither a sector in itself, nor an industry. Rather, it is a general-purpose toolkit that is contributing to product innovations in virtually all kinds of manufactured goods. It brings much positive news, but also frustration and scepticism.

A problem for the N&N protagonists, he notes, is that the impacts are broad rather than deep: as the 'nano-advantage' is often embedded at an early stage of the value chain (raw nano-materials – purpose-designed intermediates – finished products), where it can remain largely invisible to the end-user.

Moreover, as other presenters later remarked, there is a certain reluctance to broadcast the presence a nano-content. This is sparked by fears of public hostility, triggered by often ill-informed media comments, as occurred with the introduction of genetically modified plant species.

Future prospects nevertheless remain highly positive. Nordan describes a three stage pattern in the advance of N&N.
The initial adoption occurred in the period 2004-2007, with the emergence of a variety of materials and products, often accompanied by a considerable fanfare. During this period, there have been business successes, but also some notable failures.

Since 2008, the nanostructured materials and nanoparticles have been incorporated into a growing range of products and processes, but usually with a lower-key approach that will probably continue through 2011. Beyond that time, the continuing demand for energy saving, resource conservation and environmental protection will promote an explosive spread of applications and deeper

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[3] Link to: http://ec.europa.eu/research/fp7/index_en.cfm?pg=understanding
[4] Link to: http://ec.europa.eu/nanotechnology/pdf/nanocode-rec_pe0894c_en.pdf
[5] Link to: http://cordis.europa.eu/nanotechnology/actionplan.htm

penetration of nanotechnologies within each application area. The greatest profit potential will lie in the manufacture of intermediates, because a high level of know-how is needed to fit the basic materials to particular end-use requirements – such as functionalised nanoparticles for medicine, or CNT/polymer blended moulding compounds.

With healthcare and life-science leading the way, closely followed by electronics and information technologies, the total market size can be expected to pass the $3 trillion mark by 2015

Pekka Koponen (Spinvers, Finland) draws a parallel with the evolution of Internet-based business, in which the underlying impetus has been maintained despite early casualties from the bursting .com bubble. The so-called 'Web 2.0' is now bringing more efficiency in web browsers and new opportunities for interactive cooperation, pointing the way to a new wave of revolutionary products and entrepreneurial business start-ups.

Nanotechnology can be regarded as approaching the end of 'NT 1.0', Koponen believes. NT 2.0 will arrive within less than ten years, although recession will slow investment in the shorter term. Large companies are abandoning fundamental research to academia, so it will be necessary to build bridges between the two sides in order to realise innovation.

Additionally, particular attention must be paid to communication and dialogue with society on nanotechnology-related issues. This is desirable in order to produce two major effects: increasing the consensus between stakeholders, civil society and policy-makers on decision-making in nanotechnology; and simultaneously enhancing the image of the N&N community as impartial, transparent and trustworthy communicators on the risks involved, as well as the benefits.

According to Matteo Bonazzi (EC, Research DG) a clear shift in EU policy on communicating nanotechnology is emerging. Communication patterns are moving towards a more diversified approach, via dedicated projects prioritising web-platforms, social networks, communication multipliers, opinion-makers, science centres, multi-platform media, and open dialogue between experts and citizens. A dedicated workshop has been set up to promote collaborations between four recently launched projects, budgeted at around €5 million, involving all stakeholders – including NGOs and television networks from 27 EU Member and Associated States.

# Sustainable manufacturing

## Catalysis is prime application

The very high surface.volume ratio of nanoparticles makes catalysis one of the principal ways in which they can contribute to sustainable manufacturing. Particles with diameters of a few nanometres have huge specific surface areas, which makes them extremely effective as catalysts, the use of which can provide energy-cost reduction, improvement of selectivity and minimisation of waste streams in many industrial sectors. Nano-sizing also allows significant reduction in the required amount of precious metals such as platinum and palladium, which are extensively used as catalysts.

In chemicals production, for example, 80% of the manufacturing processes involve at least one catalyst-promoted reaction. Moreover, as energy consumption typically accounts for around 10% of the cost, and rises to as much as 40% for bulk chemicals, research to improve catalyst efficiency is a high priority.

A common problem in this industry is the loss of catalytic efficiency due to agglomeration and sintering of the particles at high reaction temperatures. Progress is now being made in the use of support materials such as carbon nanofibres and porous silica to immobilise the particles and thus prevent agglomeration. This also facilitates the recovery and recycling of catalytic materials, which in many cases can be extracted by simple filtration.

According to Dr Markus Pridöhl (Evonik Degussa, Germany), an interesting new field is the use of superparamagnetic metal oxide nanoparticles, which act simultaneously as catalysts and an energy source for chemical synthesis in microreactors. Heated by the application of an electromagnetic field, the particles deliver energy directly at the point of reaction, making processes such as rubber polymerisation and adhesive curing faster and more efficient. This precision, plus the fact that the heat dissipates rapidly due to the large surface area of the particles, opens the door to some intriguing possibilities. One example, currently being evaluated for mobile phone assembly, is the curing of adhesive tape joining delicate components that would be damaged by conventional heating.

Photocatalytic materials have massive commercial potential, e.g. in the construction and environmental sectors. Studies over many years have focussed mainly on titanium dioxide ($TiO_2$) because of its stability, commercial availability and ecological safety.

Akira Fijishime (Kanagawa Academy of Science and Technology, Japan) notes that two-thirds of Tokyo's buildings, as well as other high-profile constructions around the world, now incorporate 'self-cleaning' window glass coated with a 10-20 nm layer of $TiO_2$. This promotes the decomposition of pollutants such as $NO_x$, and acts as a wetting agent to facilitate the washing action of rainfall.

Other applications of this versatile material are in fog-resistant mirrors and self-disinfecting coatings on tiles used in hospitals, as well as in air- and water-purification. In Japan alone, the market size is estimated at around €750 million. Take-up in Europe remains slow, due to delays in the introduction of relevant international standards.

## High-performance composites

For the manufacturing industries, nanolayer coatings and the incorporation of nanoparticle fillers, even at low concentrations, into a variety of matrices can produce dramatic performance improvements.

Fillers such as layered silicates, silica, metals, carbon nanoparticles (fullerenes, nanotubes, graphene, etc.) have a particular influence on the mechanical and thermal properties of composites, as well as their electrical, magnetic and optical behaviour. Their effectiveness depends strongly upon the level of dispersion attainable, as agglomerated particles no longer display the nano-effects. Much research is therefore directed towards the development of processing methods that are able to ensure optimal dispersion and can be scaled up to an industrial level for materials ranging from metals and polymers to textiles and foods.

Photolithographic processes are well established for the manufacture of integrated circuits and other miniature devices with nanoscale surface features. While these are suitable for the production of planar structures with shallow relief, new methods are needed for products with high aspect 3D features. Several projects cited at the conference are seeking solutions. Among these, EUMINAfab[6], one of the EU's new I3 (Integrated Infrastructures Initiatives), is assembling a pool of high-end instruments and equipment into a 'tool box' that will be available to European researchers for structuring and characterising a multitude of functional materials.

# Industrial outlook

## Electronics

Progressive down-scaling of semiconductor devices, making equipment smaller, cheaper and less energy-consuming, has been the driving force of electronics development for many years. The remarkably robust CMOS technology has long permitted the manufacture of on-chip circuits containing thousands of individual transistors and other components at nano-scale dimensions.

But, as Walter Reiss (IBM, Switzerland) points out, feature sizes are now routinely approaching the quantum mechanical boundaries. At 1 nm, a feature would comprise just four Si atoms, so there is limited scope for further scaling of CMOS.

With decreasing scale comes increasing complexity. Today, a state-of-the-art 32 Gb flash memory contains around 30 billion transistors, each measuring just 40 nm (smaller than the common cold virus).

At the very smallest sizes, interference effects and connectivity problems assume greater importance. Furthermore, transistors become more power-hungry and consistent manufacture is increasingly difficult. To achieve further performance improvements and energy savings, it will be necessary to seek alternative solutions involving new architectures and new materials.

N&N are at the root of many possible solutions now being investigated. Carbon nanotubes (CNT) could serve as both conductors and heat sinks for tomorrow's dense circuitry, says Livio Baldi (Numonyx Italy). The use of metallic nanofibres and particles could also be used to achieve chip-substrate connections without need for soldering or gluing.

Carbon nanotubes (CNT) show great promise for other electronic applications, but their manufacture gives rise to a very inconsistent spread of sizes and properties. If a reliable extraction method can be devised to deliver large quantities of very uniform tubes, these could become the basis for exciting new products, since the components of complete circuits could be fabricated on the walls of a single tube.

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[6] Link to: http://www.euminafab.eu/

New kinds of device based on spintronics and III-V composite semiconductors have been proven at laboratory scale, but it remains to be seen whether their production can be scaled up to provide real competition for CMOS. Baldi observes that the development of CMOS to its present state has taken 50 years and an investment of $500 billion. Finding its successor could require a comparable effort.

## Automotive

The need to maintain personal mobility and the flow of essential goods in the Europe of tomorrow motivates a large body of research into alternative engine technologies. Electrical systems and hydrogen-burning fuel cells are the prime contenders to power the vehicles of the future, but face considerable technological and infrastructural barriers to widespread adoption. Photovoltaics and thermoelectrical systems for energy recovery are both under active development.

Meanwhile, the automotive industry will continue to rely heavily on the internal combustion engine. Improving the fuel efficiency and cutting emission levels for conventional engines therefore remain high on the list of goals over the next one or two decades.

At the same time, societal expectations of enhanced safety, comfort and reliability are tending to make vehicles more complex and heavier, countering efforts to save weight as a further means to reduce fuel consumption. A modern car contains 80-100 sensors and 50-80 processors, and is as much as 30% heavier than its 1980s equivalent.

Vito Lambertini (Fiat, Italy) sees a role for micro- and nano-technologies in up to 70% of all automotive applications, from tyres, power train and control systems; to structural components, styling elements and exterior finishes. Early examples are seen in the advance of economical and space-saving LED lighting from the rear to the front-end of cars, in pollution-reducing catalytic converters and particle filters, as well as in anti-friction coatings for both engine components and forming tools.

Further development of nanocomposites will bring smart materials simultaneously optimising weight reduction, mechanical and thermal properties. The convergence of electronic technologies will also allow the introduction of multifunctional systems for improved engine management, energy distribution and energy harvesting. CNT-based devices and printed electronics will greatly reduce the number of discrete components and wired connections.

Eventually, completely wireless electrical functionality will be built into fully integrated sub-assemblies that will be easier to manufacture and simply installed as ‘plug-and-play’ units. Smart additives will make production more efficient by allowing parts to be assembled using only local heating, while shape memory polymers will facilitate repairs and disassembly.

To maximise the impact of nanotechnologies on both present designs and future vehicle generations, a joint effort will be needed to scale up production and reach acceptable cost:performance levels, Lambertini believes. The European Green Car [7] initiative of the Commission's European Economic Recovery plan could provide the necessary impetus.

Construction

Transforming the construction industry into a modern knowledge-intensive sector is crucial, both to maintain the competitiveness of the EU and to meet its environmental commitments.

At present, construction activities, together with the transport of building materials and products, account for around 50% of all energy consumption in Europe – giving rise to a corresponding proportion of the region's $CO_2$ emissions. The industry also consumes billions of tons of natural resources, and produces 22% of total waste. Radical improvements must urgently be sought in all of these areas.

Objectives identified by the European Construction Technology Platform [8] are now incorporated into an Energy Efficient Buildings (E2B) [9] Joint Technology Initiative, which is part of the European Economic Recovery Plan.

A number of projects highlighted at EuroNanoForum are exploring areas such as energy storage and the incorporation of solar panels; solar-collecting and photochromic window glass, as well as nano-based air filters and insulation materials.

A study commissioned by the Commission's Enterprise and Industry DG confirmed that industrialised methods consume significantly less labour and materials than the traditional craft structures and processes. Emerging system concepts envisage greater ease of erection and maintenance, without restricting architectural design freedom.

Nanosciences are adding to the basic understanding of materials and pointing the way to nano-functionalised alternatives that will enhance performance and longevity, both for the new buildings and in the refurbishment and restoration of existing structures. Nano-devices will also play a part in the integration of ICT for control of the living-space environment – for example, using nanosensors embedded in prefabricated panels for 'plug-and-play' on-site installation.

# A healthier population

Huge strides in genomics and biosciences have brought a wealth of new knowledge about the molecular origins of health and disease. At the same time, nano- and micro-technologies are producing engineered materials, devices and tools on the same scale as the biomolecules themselves. This powerful combination has the long-term potential to transform the whole approach to healthcare.

[7] Link to: http://ec.europa.eu/research/industrial_technologies/lists/green-cars_en.html
[8] Link to: http://www.ectp.org/
[9] Link to: http://www.e2b-ei.eu/default.php

Nano-enabled techniques permit earlier, more reliable detection of diseases. Routine screening can even identify the propensity of individuals to develop life-threatening conditions, so that, where appropriate, preventive action can be initiated before any symptoms appear. Accelerated drug development will bring more effective pharmaceutical treatments for a growing range of disorders, while targeted delivery – e.g. by means of functionalised nanoparticles – will allow more precisely controlled dosage and minimise the risk of side effects. Miniaturised tools and observation devices will make surgery less invasive. Functional implants such as heart pacemakers will become smaller and less energy consuming. Longer-lasting and more biocompatible prosthetics will reduce the inconvenience and cost of premature replacement. And wearable nanosensors will turn long-term monitoring and aftercare into affordable, automatic routines.

In the medical sector, it is particularly essential to address societal, regulatory and ethical issues in parallel with the technological development. For industrial companies aiming to commercialise the results of R&D, rigorous approvals procedures and the need for lengthy trials add greatly to the cost and timescale for launching a new product. Developing a drug now costs around €600 million, and its value to the developer is limited by a relatively short patent life. An added complication is the need to ensure that the research leads to innovations that will not only benefit the patients, but also be acceptable under the reimbursement policies of increasingly stretched health authorities.

The European Technology Platform Nanomedicine[10] has defined a strategic agenda that takes account of these matters, and provides platform for continuing discussion between stakeholders, national administrations and the European Commission.

Several contributions to the Prague conference reported progress in detection and diagnosis, encompassing both in-vitro and in-vivo techniques.

For in-vitro testing, lab-on-chip devices incorporating various nanobiosensors allow rapid analysis of nanolitre-sized samples, with multiple results obtainable in a single pass. Their inherent simplicity and low cost makes the devices eminently suitable for high throughput screening – and could, in principle permit diagnosis in local surgeries or at patients' own homes. The possible need for specialist expertise in conducting tests and interpreting the data could limit the scope for such practices – although computer-based solutions may well emerge.

Nanoscale contrast agents improve the accuracy of in-vivo imaging in targeting specific biological sites, while hybrid imaging opens new avenues in both diagnostics and clinical interventions.

Case study

Magnetic resonance imaging is one technique that provides a non-invasive method to study the progress of transplanted cells in live animal subjects. Prof Eva Syková (Academy of Sciences of the Czech Republic) describes how labelling bone marrow and foetal stem cells (including human cells) with superparamagnetic nanoparticles of coated iron oxide enables their migration, differentiation, survival rate and eventual fate to be tracked.

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[10] Link to: http://www.etp-nanomedicine.eu/public

Animal models with stroke, spinal cord injury, cartilage damage and other conditions were studied to determine whether grafted cells would be capable of preventing scar formation and enhancing tissue regeneration. Positive results encouraged the researchers to look further into the potential of stem cell treatment for previously unrepairable brain lesions and spina l cord injuries.

Repeated imaging over a period of months showed that cells injected intravenously or close to the injury sites did migrate to the lesions, where up to 30% differentiated into neurons. If introduced sufficiently soon after injury, they wer e able to reduce the size of the wounds. For more severe spinal injuries, however, cell injection alone is not sufficient. A mechanical support is needed to bridge the defect and retain the cells in place during the period of differentiation.

After lengthy experimentation with polymeric hydrogels as scaffolds, Syková turned to nanofibres of similar polymers, which proved even more successful. Stem cells are cultured onto nanofibre sheets, which can then be rolled and inserted into the lesions. Studies with rats showed the growth of neural cells and blood vessels, bringing some return of mobility to formerly paralysed subjects. A small-scale human trial also provided evidence of a degree of healing.

The clinical viability of the present technique is restric ted by the need for timely surgical intervention. Further research could show the way to less invasive solution, for example using injectable nano- or micro-beads, which could perhaps be guided into place by magnetic steering

# Tackling pollution

EuroNanoForum presentations showed how nanocatalysts, nanoporous filter membranes and activated nanoparticles are all contributing to the battle against problems of air, water and soil pollution

## Climate change dilemma

Much of global environmental policy is based on attempts to counter the influence of human activity on atmospheric pollution and temperature variation. Increasing concentrations of greenhouse gases since the start of the industrial era regularly grab the headlines as a prime cause of global warming, and are the subject of stringent reduction targets. However, the situation is far from simple.

Nanoparticles have existed in the lower atmosphere since long before the dawn of the human race – from sources such as volcanic activity, sea spray and desert d ust. Today, the average number across Europe ranges from 1 000 to 100 000 per cubic metre, most of which now arise from combustion processes (diesel engine exhaust, flue gas pollutants, etc.).

As these are thought to be harmful to human health, air qualit y directives set more and more stringent limits for the reduction of emissions all over the world. But the particles also exert a cooling effect on Earth's surface by absorbing or scattering back part of the solar radiation and modifying the formation of clouds. This could offset the warming impact of increasing greenhouse gas concentrations since the start of the industrial era, which regularly grabs the headlines as the principal reason for global warming.

According to Jean-Philippe Putaud (JRC Institute for Environment and Sustainability, Italy), cleaner air could actually accelerate the predicted temperature rise from 1-2ºC to 8ºC or more by 2010! Using new methods that allow vertical profiling of the atmosphere at heights of up to 10 km, the institute is bidding to reduce uncertainties in modelling the eventual outcome, to provide policy-makers with a clearer reference for effective action.

Cleaner water

A workshop on water treatment addressed the desalination of ocean waters and the need to eliminate potential emerging contaminants like synthetic organic compounds, the concentration of which is on the increase. New technologies are being developed for the combined separation and decomposition of pollutants to eliminate secondary waste.

The use of nano-engineered or nanostructured materials can greatly enhance the efficiency and selectivity of processes such as catalytic oxidation or reduction and membrane filtration (process intensification, reduction of by-product generation), and reduce energy consumption (low pressure drop). This brings the prospect substantial improvements in cost-effectiveness, and could hasten the development of portable water treatment equipment.

Metal oxides such as $TiO_2$ and ZnO have been shown to be effective for the photocatalytic degradation of a wide range of organic pollutants in water and the inactivation of pathogenic microorganisms. $TiO_2$ is particularly suitable for water and wastewater treatment because it is: photoactive, insoluble under normal pH conditions, chemically and photochemically stable, non-toxic, inexpensive and readily available.

The FP6 project SODIS showed that $TiO_2$ nanoparticles can be used to enhance solar disinfection: a simple technique whereby contaminated water is placed in transparent plastic bottles and exposed to direct sunlight for several hours. Ideal for use in developing countries, this is effective against a variety of diseases, including cholera, dysentery, typhoid and diarrhoea

Novel functional materials with high selectivity for the removal of toxic chemicals and other contaminants are based on molecular imprinted polymer membranes, where the imprinted molecule is used as a template that can be removed to leave behind sites of appropriate size and shape to act as binding centres for pollutants.

# Energy alternatives

Securing a reliable and sustainable supply of energy to satisfy a growing world population is one of the major challenges facing mankind. The reserves of petroleum, coal, and natural gas are not inexhaustible; so it is imperative to explore alternative resources such as solar, biomass, wind, hydrogen and nuclear generation.

The sun delivers energy to the Earth's surface at a rate equivalent to several thousand times the present global consumption of electricity. Photovoltaic devices (solar panels) are widely deployed to tap this near-limitless resource, but the challenges are to optimise conversion efficiency and broaden the usable spectral range.

A photovoltaic cell comprises a light-absorbing surface electrode separated from a lower charge-collecting counter-electrode by an intermediate electrolytic transport layer.

In the 1990s, Michael Graetzel (Ecole polytechnique fédérale de Lausanne, Switzerland) introduced the concept of using an absorption layer of $TiO_2$ nanoparticles sensitised by coating with a layer of organic dye molecules. This material mimics the natural photosynthetic process of plants in converting sunlight to energy.

Organic cells are inexpensive, easy to produce and can withstand long exposure to light and heat compared with traditional Si-based solar cells. To date, conversion efficiencies of up to around 12% have been demonstrated, which remain well behind those of Si technology – but worldwide effort continues to seek further improvement. Closing the gap will bring the prospect of high throughput manufacture using reel-to-reel printing or spray deposition, while the use of ionic liquid as the transport layer also makes the processing solvent-free.

Organics will permit the production of ultra-thin and flexible devices, capable of being integrated into portable appliances, vehicles or building components, with the aesthetic appeal of tunable colour through variations in composition.

Fuel cells producing electricity from the hydrogen with very high efficiency are commercially available, but not yet competitive with combustion engines. Apart from the current high cost of manufacture, a barrier to their widespread use – particularly for mobile applications – is the lack of suitable $H_2$ storage materials and systems with adequate capacity.

Apart from high pressure tanks, which pose evident safety questions, other less developed methods include the use of metal hydrides and carbon nanotubes. Basic research continues into more promising new materials, such as Ti nanoclusters and mixed hydrides.

In order to make practical use of green electrical energy – particularly for mobile applications – it is necessary to store ample quantities of reserve power in rechargeable batteries and supercapacitors.

Lithium ion batteries are notable for their high energy:weight ratio and low stand-by discharge rate. This makes them particularly attractive in the portable consumer electronics market, but their capacity and output is not yet sufficient for use in hybrid vehicles. Supercapacitors fill the gap between batteries and regular capacitors by providing a power boost for short-term events – but again, they are not yet adequate for forthcoming automotive applications.

CNTs appear likely candidates as electrode materials and to increase the conductivity of polymer electrolytes used in both types of storage device.

Fundamental research is investigating processes for the manufacture of vertically aligned arrays of CNTs to maximise the electrode-electrolyte contact area, as well as the chemical functionalisation of CNT nanocomposites to further increase performance.

## The next steps

EuroNanoForum 2009 reinforced the prevailing consensus of heightened expectations that N&N offer to society. Nanomaterials are now making a positive contribution in a number of commercial markets, but other aspects of nanotechnology remain at the laboratory level. Moreover, experience shows that revenues are coming from existing applications: sometimes pushing the envelope, but seldom opening completely new areas.

Unlocking the full potential of nanotechnologies is as yet a more distant prospect. Poor up-scaling of nano-processes, and the difficulties in extrapolating existing technologies and tools to the nanoscale, are slowing progress. The high capital expenditure needed is another barrier, especially in present times of economic downturn.

Further obstacles to progress, says Marcel Van de Voorde (Delft University of Technology, The Netherlands) are the fact that different roadmaps are needed for each end-user sector, and the problems in framing meaningful standards and regulations.

With regard to the governance of nanotechnology, the issues of safety, education, standardisation, outreach, ethics, and infrastructures, as addressed by the Commission's strategy, were underlined. Demonstration that nanotechnologies are being safely and responsibly applied must be grounded on solid scientific evidence that potential risks have been identified and appropriate practices adopted.

In order to mobilise European resources behind a unified strategy to remove the bottlenecks and achieve the necessary research momentum, the conference concluded with a proposal to establish a new European Technology Platform, provisionally entitled ‘NANOfutures’. This will seek to shorten the path from research to technological innovation, bringing nano-based products and services more rapidly to market. NANOfutures would act as a framework, within which all stakeholders can join forces in carrying forward the industrialisation of N&N to benefit the European economy and all of its citizens.

For further information:
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http://cordis.europa.eu/nanotechnology