Nano & the Environment

Report from the workshop organized by

Nanoforum and the Institute for Environment and Sustainability, JRC Ispra

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CDMA Building, rue du Champs de Mars 21, Brussels

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Executive Summary

Nanoforum and the Institute for Environment and Sustainability, JRC Ispra organized a workshop on "Nano and the Environment" in Brussels on the 30th and 31st March 2006. This report describes the outcomes of the presentations and discussions from the workshop, and has been published on the Nanoforum website to broaden the input of ideas to this important topic. All interested parties are encouraged to read this report and provide feedback on the issues raised in it via the Nanoforum discussion board.[1] The culmination of this consultation process will be a final report delivered to the European Commission for consideration in future policy decisions regarding research funding.

The "Nano and the Environment" workshop was organized to reflect upon and discuss ways in which nanotechnology could be used for the benefit of the environment, while at the same time remaining fully cognisant of the risks associated with any new technology. It brought together approximately fifty different stakeholders drawn from academic research, environmental research, industry, industrial associations, regulators, and government agencies, each with differing experience and perspectives on the key issues facing the responsible implementation of nanotechnologies for the environment.

The workshop was divided into three consecutive sessions: monitoring, remediation and pollution, and resource saving. Each session consisted of short presentations from experts and an equal length of time for discussion of the broader issues. The discussions were wide-ranging and are summarised below:

- detection methods - nanotechnology offers improvements in detection of pollutants in air and water (through solid state sensors and biosensors), however there are as yet no appropriate systems available for the detection and characterization of nanoparticles. In particular those techniques capable of measuring key parameters related to surface area, shape and chemical reactivity are restricted to bulky, low through-put devices.
- life-cycle analysis (LCA)- new materials and products must be subjected to a full LCA, which is a methodology that is adapted and applied to different scenarios and takes into account all of the raw materials and energy consumption of a product from manufacture (including waste materials and their disposal), through use, to disposal or recycling. The LCA must also take account of different usage scenarios which will be dependent on societal impacts (e.g. will the introduction of a new product encourage people to purchase more of the same or similar item, or use it more extensively than an existing item on the market).
- sustainability- nanomaterials offer significant savings in raw material and energy requirements (e.g. nanofoams with higher insulation ratings, or more powerful and higher energy rechargeable batteries), however materials used for new products should be ideally sourced from renewable or abundant sources. If this is not possible then robust strategies for the recovery or recycling of materials must be put in place, ideally based on closed material loops and that take full consideration of the energy requirements. This is particularly important when rare materials are used in small amounts that are widely distributed in products, and which can consequently be widely dispersed in the environment (e.g. platinum in catalytic convertors through exhaust fumes, or indium in LCD screens and solar cells). Understanding these mobility issues is essential for the proper application of LCA.
- risk assessment- initially this should focus on the structure-function relationship of new nanomaterials and the mechanisms by which these might impact biological systems (i.e. building a predictive model of potential risks rather than assessing each nanomaterial individually: for example it is well documented that increasing the solubility of different nanoparticles decreases their toxicity). Risk assessments should take full account of both the hazard presented by a specific material as well as the probability of exposure of that material to humans or environmental species, and its possible release into the environment.

[1] http://www.nanoforum.org/nanoboard/comments.php?DiscussionID=10&page=1#Item_1

- remediation- nanomaterials have been shown to offer marked improvements to existing strategies for the removal of toxic materials from the environment (e.g. arsenic from ground water), however there are concerns over the use of free nanoparticles for remediation (for reasons of both sustainability and risk). Immobilising nanoparticles in a stable matrix or using nanostructured surfaces (where nanodomains essentially have the same functionality and activity as free nanoparticles) concentrates material in one place, thus decreasing dispersion, making recovery simpler and decreasing the probability of exposure.
- challenges for commercialisation- there is a gap between research supported by public funding and the extent to which the results of this research can be commercialised by industry. Several factors are involved. One is the difficulty of scaling up to pilot production which can require considerable volumes of materials (greater than can be easily produced by research labs) and the comparatively few facilities available to do this. Another is the creation of a market need for the technologies. New technologies must be benchmarked against existing ones to ensure that they live up to claims of improved functionality, energy consumption, sensitivity, efficiency, longevity, decreased environmental impact (e.g. increased water quality) etc. There is a need to involve SMEs in this process and to develop a far-reaching outlook on the development of new technologies, which can be facilitated by the European Technology Platforms (ETP).
- communication- this is seen as critical and should involve research scientists and technologists, life-cycle assessors, policy makers, and other stakeholders to ensure that identified needs are being met, that sustainability is built in at the start of product development, and that there is an adequate regulatory or legislative framework to support this. Communication is also essential between academic research and industry to improve technology transfer, and between industry and consumers to identify needs and market new applications. In respect of the latter, policy makers can assist by helping to promote a market for environmentally friendly products through regulatory and legislative frameworks.
- policy initiatives- these should encourage the development and uptake of environmental nanotechnologies. This includes issuing clear guidelines on environmental safety limits of particulates and pollutants (which would in turn drive technology development and commercialisation of the required monitoring devices), and the inclusion of environmental criteria in new calls for proposals.
- cooperation- both RTD scientists and those researching the impacts of materials on the environment and health must cooperate and share knowledge at the earliest stages of new developments, to ensure that new materials and technologies are developed to be both environment- and health-friendly.
- education- this is necessary to ensure that all stakeholders (from developers to regulators to consumers) understand the environmental impacts (both positive and negative) of existing and new products; so that they can make an informed choice for development, regulation, or purchase.
- societal implications- individual accountability could be increased by the development of ubiquitous sensor systems, however this also raises privacy issues. There is also the ethical question in relation to utilisation of materials from sources where there are welfare or civil rights concerns.

Background

Nanotechnology is the manipulation or self-assembly of individual atoms, molecules, or molecular clusters into structures to create materials and devices with new or vastly different properties. This can be achieved by reducing the size of the smallest structures to the nanoscale (termed the "top-down" approach) or by manipulating individual atoms and molecules into nanostructures ("bottom-up"), which more closely resembles chemistry or biology.

Nanotechnology is expected to be a major economic driver for this century, impacting virtually all industries including healthcare, agrifood, transport, energy, materials (construction, coatings, textiles etc), and Information and Communications Technologies (ICT). It also holds promise for improving the environment- both by reducing waste materials, energy consumption and our dependence on non-renewable natural resources, and for cleaning up existing pollution.

Introduction

On the 30th and 31st of March 2006, Nanoforum (an EU-funded thematic network under FP5) and the Institute for Environment and Sustainability, Joint Research Centre (JRC) Ispra, organized a workshop in Brussels to review and debate the potential impacts of nanotechnology on the environment. The aims of the workshop were to bring together stakeholders representing different interests in the environmental impact of nanotechnologies, to discuss what is known and unknown, what the priorities ought to be for future research and technology development (RTD), and ultimately to better inform EU policy decisions for RTD. This report represents the first product of the workshop. It has been posted on the Nanoforum website to encourage a wider debate of the issues and ideas raised and discussed at the workshop. Interested parties are invited to post their comments on the Nanoforum discussion board for the "Nano and the Environment" workshop.[1] The outcome of this consultation process will be the distillation of the submitted opinions and this document, into a final report to be submitted to the European Commission for consideration in future policy decisions.

The Commission produced an Action Plan on Nanotechnology (COM(2005) 243) in June 2005, which identified the need for nanotechnologies to "comply with the high level of public health, safety, consumers and workers protection, and environmental protection."[2] At the opening of the workshop Dr Renzo Tomellini of the Nanosciences and Nanotechnologies Unit, Directorate General (DG) RTD made the statement that more knowledge is needed on nanotechnology and the environment. Some research has been done. Nevertheless, it has been recognised that nanotechnology is a powerful tool to allow further improvements of our environment. The European Commission would like to invest more effort and resources in nanotechnology for the environment, and in FP7 there will be an opportunity for such funding. The environment is a political priority and therefore a priority for funding. The purpose of this meeting (from the Commission's perspective) is to maximise interaction among participants, to develop ideas and distil recommendations for the Commission. The relevant DGs responsible for research, regulation and environment, and health impact and safety of nanotechnology were invited and all participated in the meeting. The Commission has the framework in place to fund collaborative research with third countries and with NGOs. Dr Tomellini concluded by encouraging participants to "put everything on the table to allow the Commission to put together a strong nano-environment portfolio in FP7."

[2] http://europa.eu.int/comm/research/industrial_technologies/articles/article_2580_en.html

The workshop was divided into three consecutive sessions with approximately half the time allocated to presentations from experts in the relevant fields and the other half to general debate, on the themes of:

- Monitoring
- Remediation and Pollution
- Resource Saving

This report describes the outcomes of these presentations and discussions. Each participant was invited to pose questions or submit a statement of opinion prior to the workshop for inclusion in the workshop handbook. This material is appended to the report.

Monitoring

Monitoring of pollutant gases in the atmosphere and organic molecules in water were the topics of the four presentations in the monitoring session. Abstracts are appended to this report, and PDFs of presentations can be downloaded from the Nanoforum website.[3]

The key issues raised during the monitoring session fall into three main areas:

1. detection (limits and parameters)
2. application (functionality, longevity, commercialisation, life-cycle assessment)
3. integration (communication between stakeholders, need for new policy, regulation and legislation)

Detection

The need for detection methods is driven by the known toxicological effects of pollutants (gases, particulates, chemicals etc) and the established minimum permissible levels. For air pollution (gases) the allowed limits are set by European legislation and can be monitored using existing systems. However, the present air quality monitoring network consists of relatively large and expensive, fixed stations which are primarily limited to areas of highest pollution (cities) and even in these locations are widely dispersed (typically more than 1 km apart). These fail to meet the need of monitoring localised pollution peaks. In contrast, the use of solid state gas sensors allows: faster response times (real-time analysis); higher spatial resolution; simpler operation and cheaper running costs; possibility of integration with intelligent sensor networks. Tin oxide thin-film sensors have been developed which can reversibly and selectively detect carbon monoxide (CO) and nitrogen dioxide (NO_2), by measurement of changes in electrical conductivity due to adsorption. Efficiency and selectivity is dependent on: operating temperature, platinum doping, thin-film thickness, and crystal size. Detection limits for CO at 1 ppm levels and NO_2 at 10^{-1} ppm (at or below the existing legal limits) have been achieved with a device less than a centimetre in diameter and with low power consumption. Other target gases include methane, ozone, and benzene. Systems developed by another EU-funded project (NANOS4) have been based on indium, zinc and tungsten oxides that have been deposited in the form of thin films, nanowires, and nanocombs.

Linking such sensors with global positioning systems (GPS), allows data to be sent from remote locations to a central service centre for real-time analysis and allowing appropriate action to be taken (including early warning or charging polluters). However for this to be truly effective a high density of devices would be required (over one million are expected to be deployed over the coming years in fixed locations). Taking this a step further, such devices could be virtually ubiquitous (e.g. included in mobile phones, as standard equipment in cars) allowing a high level of detailed environmental information to be provided without

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3 http://www.nanoforum.org/nf06~modul~searchevents~eventid~1292~.html?action=longview&moreaction=&idauswahl=&

identifying individuals or their location. The long-term goal would be to make these devices both high capacity and mobile, however in the short term it is expected that fixed devices will be high capacity, with mobile sensors having a more limited capacity.

The EU-funded Automated Water Analyser Computer Supported System (AWACSS)[4] project coordinated by the University of Tübingen and involving nine partners has developed a remote sensor station that can send real-time data to a central computer on levels of organic pollutants (such as pesticides, antibiotics, natural toxins, carcinogens, industrial waste etc). Requiring only a pre-filtration step (to remove particulate matter), this device can analyse water from a variety of sources by means of an integrated optical chip, which uses immunoassay systems, to detect and provide information within 18 minutes on up to 32 different analytes. The attainable detection limits are at levels below the EU recommended safe limits, and the chip can be reused up to 500 times before the surface chemistry must be re-applied.

While there have been considerable advances in detecting pollutant molecules in air and water, there is still a gap regarding a robust, inexpensive and portable method for detecting and analysing nanoparticles. The properties of nanoparticles are not only determined by chemical composition and size, but also surface area and shape. There are currently no systems which can accurately and routinely determine all of these parameters on a single platform. Such monitoring systems would be useful not only for the accurate analysis of nanoparticles produced by combustion processes (and in particular diesel) but also for workplace monitoring for industries which are manufacturing engineered nanoparticles.

Application

There is a large potential market for devices to monitor pollution, as existing systems are large, expensive and do not provide the level of information necessary to accurately determine localised pollution. However there needs to be an improvement in time to market and better consideration of industry's needs. Manufacturing processes must be simple (requiring as few production steps as possible), detection methods must be based on verifiable standards (and there must be evidence that new sensor systems offer a substantial increase in sensitivity, spatial resolution, analysis time, etc). One of the obstacles is a lack of awareness from industry about RTD activities in this area. In this respect European Technology Platforms (ETP), which have their strategic research agendas driven by industry, could be a way forward. Moreover, the application of relevant ISO (International Organization for Standardization), CEN (European Committee for Standardization) and/or CENELEC (European Committee for Electrotechnical Standardization) standards for the validation of devices will also increase their acceptance by end-users.

Functionality, reliability and longevity of devices are key issues. While the distribution of sensors throughout the environment can provide much more detailed information, there is also the consideration of how long such devices can be left unattended without re-calibration or replenishing power supplies. Some studies on larger remote sensors indicate that these can be left in place for periods up to two years without loss of accuracy. Functionality must also include re-use e.g. dissociation of target molecule when levels/concentration decrease or photoactivation of sensor surface to remove bound materials. Markets must be analysed to see where there is a need and what revenues might be generated (e.g. the CO monitoring market is estimated at more than 25 M€).

At the other end of the spectrum, there seems to be a gap between support for EU projects to develop and demonstrate a functional prototype and the scale-up to full commercial device. There needs to be more communication between industry and the RTD community at the present stage and perhaps the ETPs, of which there are 28 at present, can fulfil this role. However there is limited involvement of small and medium-sized enterprises (SMEs), who might arguably be the most suitable candidates to take the technology forward.

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[4] http://barolo.ipc.uni-tuebingen.de/awacss/

Finally, there needs to be a life cycle assessment (LCA) of these sensor systems- i.e. the energy and material costs of their production, use over their lifetime and final retrieval , versus the savings in energy, materials, health, environmental impact, etc.

Integration

Communication between different stakeholders (e.g. academic researchers, industry, policy makers and civil society) is the first step in defining needs and integrating new technologies into market applications. The development is considerably influenced by policy makers, as they determine the structure of research funding schemes, and the legislative and regulatory framework. For environmental monitoring policy makers need to know what has to be measured, what the safe limits are considered to be, what existing technologies offer in terms of monitoring and what their limitations are, and finally what new knowledge or technologies are required to achieve the desired monitoring. In this regard ETPs and relevant ISO, CEN and/or CENELEC standards for validation are an excellent conduit. For example the Water Supply and Sanitation Technology Platform (WSSTP)[5] wants to use a sensor network for checking water quality. Workplace monitoring is one of the topics on the agenda of the Industrial Safety platform (which deals with different safety issues including in the workplace).[6] Emission reduction is an issue in two ETPs: Sustainable Chemistry (SusChem)[7] and Industrial Safety. The Strategic Research Agendas and the topics emanating from these ETPs are being used by DG RTD for developing priorities for calls in FP7. The European Commission is supporting these platforms, to promote the involvement of industry, improve innovation and dissemination, and the uptake of RTD results (and thus a quicker time to market). Nanotechnologies and manufactured nanomaterials can play a significant role here. Nanomaterials and nanotechnologies for energy and environment can provide important inputs to implementing the New Industrial Policy[8] and the different aspects outlined in the Energy Green Paper,[9] as well as a number of Thematic Strategies published by the Commission.

It should be considered whether monitoring systems should be linked with some form of automated penalty system for polluters. Already some industrial sites have installed sensor systems around their perimeters to warn of pollution. The widespread implementation of such systems could allow the detection of localised pollution above agreed EU limits, allowing local authorities to identify offenders more easily and issue warnings or fines as appropriate (the "polluter pays principal").

However, the implementation of ubiquitous sensor systems must also take account of privacy issues. It should be made clear that the data collected has the sole purpose of measuring pollutant levels and identifying hotspots, warning the population of these, and taking preventative action (such as limiting numbers of vehicles or charging polluters).

As far as ultrafine particle and nanoparticle pollutants are concerned, there is a recognised lack of data on the exposure-response function, and how best to measure the different types of particle. These aspects are fully taken up in the European Commission's proposal for a new Air Quality Directive for a three year strategy to measure $PM_{2.5}$ (airborne particulate matter less than 2.5 micrometres in diameter) that is currently before the European Parliament and Council for discussion. However, these measures may not go far enough, with policy makers in the US for example already looking at particle sizes smaller than 1 micrometre.

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[5] http://www.wsstp.org/default.aspx

[6] http://www.industrialsafety-tp.org/

[7] http://www.suschem.org/

[8] http://europa.eu.int/comm/enterprise/enterprise_policy/industry/index_en.htm

[9] http://europa.eu.int/comm/energy/green-paper-energy/index_en.htm

Recommendations

- new technologies must be compared with existing systems- are new ones more sensitive, more robust? This is being addressed in projects such as NANOS4 and AWACSS; however, this comparison must also include systems measuring in the liquid phase, not only in gaseous phase, e.g. using biosensors.
- analytical tools must be developed which can accurately determine nanoparticle shape and surface area.
- communication between RTD, policy makers, regulatory agencies, and industry needs to be strengthened.
- accordingly, the present directives and regulatory issues must be enforced to achieve a better positioning of new systems on the market which require a high number of samples to be measured.

Remediation and Pollution

This session consisted of two presentations on the use of nanomaterials for remediation and one on the toxicology of pollution particles. Abstracts are appended to this report, and PDFs of presentations can be downloaded from the Nanoforum website.[3]

The main topics presented and discussed during this session came under the following:

1. advantages of nanomaterials over their bulk counterparts for remediation
2. the need for risk assessments for different nanomaterials (particularly nanoparticles)
3. challenges for commercialisation

Advantages of nanomaterials for remediation

Access to clean drinking water is the main reason that average life-expectancy has increased and infant mortality decreased in the last century. However water-borne pathogens, pollution and increasing population are putting massive pressure on this resource. As a result it is estimated that 20% of the world's population have inadequate access to clean drinking water and that by 2025 the increased demand on our water supplies will mean that each person will have approximately 25% the volume that they would have had in 1960.[10] Although filtration and purification plants have been installed throughout the globe to provide clean drinking water, in some cases these have limited success due to the inefficiency of the active materials. As a result of their larger surface area (compared to bulk materials) nanomaterials are more active.

One example presented was of magnetic iron oxide nanoparticles for removing arsenic from ground water.[11] In this particular case, arsenic can be derived from both natural sources (minerals underground) and pollutants. This is a major global problem, particularly in countries such as Bangladesh, where it is estimated that between 46 and 57 million people are exposed to arsenic levels above World Health Organization (WHO) guidelines of 0.01mg/l.[12] There are no existing methods that effectively remove arsenic from groundwater and so there is a real need. The system described relies on the increased ability of iron oxide nanoparticles to bind arsenic irreversibly (5- to 10-fold higher than micron-sized particles) and the supraparamagnetic nature of the nanoparticles which allows them to be separated from water by the application of a magnetic field and the purified water to pass through. The nanoparticles with bound arsenic are subsequently released from the filtration channels by switching off the electromagnetic field. As a result there is no

[10] The World Meteorological Organization (WMO) http://www.wmo.ch/web-en/Wdwfea.html

[11] http://cohesion.rice.edu/centersandinst/cben/research.cfm?doc_id=5100

[12] http://www.who.int/mediacentre/factsheets/fs210/en/

need for high pressure filtration systems nor is there any risk of clogging or fouling equipment. In laboratory tests greater than 99% of the arsenic in water can be bound by 12 nm diameter iron oxide nanoparticles. This represents some 2500 to 25,000 fold higher efficiency than current systems (none of which are able to reduce arsenic concentrations below WHO recommended guidelines). Field tests of this system are being carried out in Mexico, however the costs of the materials and manufacturing on a large scale (particularly producing small diameter, unaggregated particles) are still obstacles to be overcome.

In addition to free nanoparticles, nanostructured surfaces can make excellent remediators. The EU-funded CONCORDE project[13] is developing nanostructured metal oxide catalysts for use in a variety of industrial applications. It is estimated that the world-wide market for oxide catalysts is over 3 billion euros, with an economic impact two orders higher (due to the use of catalysts in the production of many different chemicals- some 95% of materials will have undergone catalysed steps at some point during production). The understanding and control of metal oxide catalytic activities is seen as critical to the development of sustainable chemistry. Not only do they have applications in remediation or prevention of pollution, but they can also contribute to a more efficient use of energy and raw materials. However, many reactions employ mixed catalysts consisting of different oxides or noble metals, and the function of active centres is not only dictated by the constituent atoms, but also by the surrounding crystal or surface structures; so it is necessary to accurately control the synthesis of nanostructured catalysts. There is also a need to understand the chemical reactivity of the catalytic active centres and how this is affected by reactor conditions. The development to the full potential of such catalysts therefore requires effective interdisciplinary interactions between quantum theoretical chemists, solid state physicists, and chemical engineers.

Several systems are being developed to reduce the levels of combustion pollutants including metal oxide nanoparticles for the reduction of nitrogen oxides (NO_x), and titanium dioxide (TiO_2) for catalysed photo-degradation of volatile organic compounds (VOC). In each case different material mixes, particle sizes, and operating temperatures must be tested to ensure effective catalysis and the production of the expected compounds (and not other pollutants).

Risk assessment

There are four groups of nanoparticles that people can be potentially exposed to: combustion derivatives (e.g. diesel nanoparticles), bulk manufactured materials (e.g. carbon black), engineered nanoparticles (e.g. carbon nanotubes, CNT), and medical nanoparticles (e.g. dendrimers). A number of studies have shown that the ultrafine component of PM_{10} (airborne particulate matter less than 10 micrometres in diameter) is the main source of toxicological effects in humans, and that increased numbers of hospitalisations can be attributed to increased PM_{10} air pollution. Inhalation of such particles causes lung inflammation and endothelial dysfunction, leading to oxidative stress to the vasculature (resulting in increased risk of coronary disease). Both the surface area and the chemical composition of the particles are important in determining the physiological outcomes, for example ultrafine carbon black has a surface area of 253.9 m^2/g compared with 7.9 m^2/g for fine carbon black. It is estimated that 60% of environmental nanoparticles are due to road transport, a further 27% from other combustion processes (e.g. power stations), and the remaining 13% from non-combustion processes. There is mounting evidence that nanoparticles, due to their small size, can penetrate the lung epithelium, enter the vasculature and migrate to many different organs including the liver, spleen, brain, and peripheral nervous system.

The surface chemistry of nanoparticles is also a key consideration in determining their toxicity. For example the iron oxide nanoparticles used for arsenic sorption are not toxic to tissue-cultured cells, and the modification of fullerenes and single-walled carbon nanotubes (SWNT) to make them more hydrophilic decreases their toxicity. Another factor influencing

[13] http://www.cata.ucl.ac.be/jan2005.htm

potential toxicity is the ability of the nanoparticles to form aggregates. These on first consideration might be thought to be less hazardous than individual nanoparticles; however when aggregates are inhaled many will disaggregate when they encounter surfactants on the lung's surface.

Ultimately a risk assessment analysis must be performed for each individual nanomaterial. This should take into account the hazard posed by a material to human health or the environment and the probability that humans and/or the environment will be exposed to the material. One way of minimising the probability of exposure is to encapsulate the nanomaterial within an inert barrier (e.g. silicon can be used to coat quantum dots). Another method, employed by the CONCORDE project is to engineer stable nanostructures onto a surface. These nanodomains have effectively the same catalytic activity of nanoparticles without the risks associated with their freed counterparts owing to dispersion. Three dimensional nanostructured materials can also be manufactured using mesoporous materials (with pore sizes on the scale of tens of nanometres) that have been functionalised with nanoparticles, so that the nanoparticles line the pore channels, and as a result are also immobilised. Employing such methods can maintain the activity and functionality of the nanomaterial while minimising the probability of nanoparticle dispersion.

Challenges for commercialisation

More businesses are now recognising the need to include environmental measures within their strategic planning, however few industrial companies presently consider environmental technologies as a core business. The key is to link environmental issues with public health and to use this as a driver for creating markets. For example, in cases such as arsenic removal from groundwater there is obvious potential for market applications. However, cost will still represent a large hurdle. When devices or systems have been qualified and manufactured in large numbers, costs will decrease; however the initial cost of producing sufficient material (as much as several kg) for a pilot run can be prohibitive and in some cases the facilities simply do not exist to manufacture materials in sufficient quantities to undergo testing (without resorting to lab-scale production which can take several months just to provide the basic materials).

Recommendations

- fundamental studies into structure:function relationships should be supported to provide predictive models on the mechanisms by which these might impact biological systems (rather than safety testing of individual constructs, which is only necessary at a later stage). It is particularly important to relate both surface area and chemistry to functionality and toxicity.
- full risk assessments (i.e. hazard versus probability of exposure) should be performed on new materials that are to be incorporated into mass-produced products.
- mobility issues need to be assessed; on the one hand free nanoparticles can deliver a maximum catalytic effect, on the other dispersion in the environment can make it almost impossible to remediate if there are ensuing safety issues.
- by-products of nanomaterial production (e.g. solvent use) must be assessed.
- infrastructure must be provided to manufacture materials in sufficient quantities for pilot studies.

Resource Saving

The session had five presentations on topics including industrial innovation, sustainability, improved energy supplies, the distribution of materials through the environment, and life-cycle analyses. Abstracts are appended to this report, and PDFs of presentations can be downloaded from the Nanoforum website.[3]

The presentations and ensuing discussions are grouped under the following headings:

1. innovation
2. material distribution and sustainability
3. life-cycle analyses and socio-economic impacts

Innovation

Industrial manufacturers are trying to decrease the costs of various nanomaterials through innovative processes:

- Bayer A.G. is now producing approximately 2kg of CNT (Carbon Nanotubes) at its pilot plant in Leverkusen and aims to reduce CNT production costs from around 1000 € per kg to less than 50 € per kg which will make the widespread use of CNT in manufacturing economically practical;[14]
- Degussa expects the world lithium ion material market to grow from 1.2 billion USD in 2004, to 4 billion USD in 2015;[15]
- Ultradur high speed (produced by BASF) is a range of partially crystalline, saturated polyesters which incorporate nanoparticles to decrease melt viscosities (thus facilitating manufacture of different components) and increase strength and rigidity (thus reducing the thickness required for components)- the result is massive energy savings and reduction of CO_2 emissions;
- MOF (metal organic frameworks)-nanocubes (produced by BASF) have the highest surface area (3500 m^2/g) of any manufactured material and are potential applications in hydrogen (H_2) storage (three times the density and 100-fold faster uptake than current state-of-the-art systems);
- BASF are also developing nanofoams which will have the thermal insulation of aerogels, but at a much decreased cost and increased flexibility;
- the paint industry is incorporating nanomaterials to increase functionality and longevity, for example the use of TiO_2 nanoparticles for "self-cleaning" surfaces, the inclusion of iron oxide nanotubes as a transparent UV blocking preservative for wood products, silver nanoparticle containing paints for antimicrobial coatings on hospital walls, and electrically conductive coatings which could detect material stresses through changes in colour;
- energy is a main cost factor not only for energy-consuming production processes but also for processes where oil and gas are fundamental feedstock/raw materials.[16]

Academic research is also driving innovation. For example, the EU-funded ALISTORE project[17] aims to achieve a breakthrough in rechargeable battery technology by bringing together leading EU research labs in a virtual institute, with the goal of producing rechargeable batteries with power outputs of over 300 Wh/kg (existing materials yield less than 200 Wh/kg). The project has so far succeeded in increasing electron production per component electrode atom from 0.6 to 2 using nanostructured lithium cobalt oxide. Importantly, the nanostructured metal oxide is formed in situ during the first charge cycle; so there is no need to construct electrodes from free nanoparticles (in fact using compacted nanoparticles is more inefficient in the long-term due to loss of charge capacity). Further

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[14] M. Bryner & A. Scott, Chemical Week, Dec 14 2005, p.23

[15] V. MacDonald, Chemical Week, Dec 9 2005, p.32

[16] CEFIC, Horizon 2015 study report, www.cefic.be

[17] http://www.u-picardie.fr/alistore/

development has shown that other metal compounds (e.g. iron fluoride, cobalt chloride, rubidium oxide, nickel phosphide) can be used and are equally or more effective (up to 6 electrons per metal atom). The use of nanostructured electrodes also enhances discharge/charge rates, by shortening diffusion paths for lithium ions and electrons, and can better accommodate the migration of lithium ions during cycling (lithium is incorporated into the cathode during manufacture, migrates to the anode during charging, and back to the cathode when the battery is put under load). This means that the batteries are also safer (electrode volume changes due to lithium migration have been key safety issues in the past). Discharging and charging has been shown not to affect electrode integrity over 1000 plus cycles.

Material distribution and sustainability

While the EU as a whole has stabilised its material resource use over the last few years, its reliance on imports has dramatically increased. Many of the materials that we take for granted for use in high tech products have an extremely finite supply. For example platinum is only mined in four sites around the globe with an annual production of 200 tonnes. Indium production is similarly limited, with only 350 tonnes mined annually from six sites. Both materials are essential components for modern technologies (e.g. platinum for catalytic convertors in vehicle exhausts and indium for components of LCD screens and solar cells). When one considers the rarity of these materials and their widespread distribution in devices (for example an LCD screen may only contain 50 mg of indium), and that such materials may not stay contained within the product (e.g. platinum is lost from catalytic convertors through exhaust fumes) then it is clear that a strategy for controlled use and recycling is essential. Without this, such materials will become distributed widely within the environment making their recovery next to impossible.

There is a need to better control this distribution, and to seek ways to achieve the desired results with materials at fixed locations. For example TiO_2 can be produced as fibres and doped with iron to produce a photocatalytic filter for water purification (micron sized fibres, with nanoscopic active domains) and used in fixed installations, which limits the distribution of the material and also facilitates recycling.

Essentially we need to look closely at the material requirements of new technologies, and invest in those that we know will be sustainable i.e. utilise abundant materials, or have clearly defined recovery strategies for rare materials.

Life-cycle analysis and socio-economic impacts

A life-cycle analysis (LCA) measures the energy and raw material requirements for a product's manufacture, use and final disposal (or re-use). It is important to note that LCA is a methodology that must be adapted to different scenarios, rather than a strict application model. This analysis is essential to be able to claim that a new technology has environmentally friendly credentials. For example ICT was expected to reduce energy and material usage by delivering a paper-less office, and limiting the need to travel. While it has achieved this in some respects, there is also the consideration that each processor unit employs a substantial amount of raw material in its production (30kg for a 10g chip) and use, and that nowadays there are an increasing number of portable devices that consume relatively more resources than larger fixed devices.

To achieve minimal environmental impact and sustainability, material loops must be closed. This issue has been taken up by the SusChem ETP, and by integrating it into a technology platform (which has a long-term strategic outlook) it is believed that sustainability in manufacturing will increase (for example Philips have recently increased the number of its sustainable products from 120 to 180). Other industries are involved in other types of activities. For example, BASF has adopted the so-called "Verbund" strategy whereby waste from one industrial site is the feedstock of another. EU industry is also participating in several EU projects such as NANOSAFE2, as well as the ETPs.

This is not the only consideration however- usage must also be investigated e.g. will people use these new devices more often that existing ones? Does this mean that there will be higher power consumption (for electronic devices) as a result, or higher consumption of other materials that are used by the device? Will owning one item encourage users to purchase more of the same or similar? The ethical implications must also be considered, for example purchasing tantalum (used in mobile phones) that is mined in Congo essentially provides economic support for the civil war there. There are also issues regarding health and safety of workers in other mines (such as indium mines in Columbia and China). Social responsibility is not only the responsibility of industry and government but also consumers, however it is recognised that guidelines must be provided to encourage individuals to pursue a more environmentally friendly and socially responsible life-style.

There is a need for guidance from the European Commission regarding what is required- in terms of setting up RTD projects and for commercialising nanotechnologies. Currently the Commission is reviewing the structure of FP7 to include LCA, risk assessments etc; however it is clear that this information is not readily accessible to everyone, owing to the tendency for companies that produce this type of data retaining the information in-house. In this respect, it is also important to consider the current activities of the European Platform on LCA[18] and the LCA activities within the SusChem ETP.

The Integrated Product Policy (IPP)[19] and Resource Strategy[20] already offer some guidelines; however if increased assessment is required then investigators will need easier access to databases of hazards and LCAs of different materials. The integration of information from ISO TC 229 and CEN 352, which are respectively the international and European technical committees on standards for nanotechnologies, will also assist the decision making process.

Early interaction between RTD scientists and those researching environment and health effects is important to ensure that new materials and devices are developed with known environment, health and sustainability considerations built-in from the start. Education of all parties (RTD, industry, consumers) about their responsibilities, the potentialities of different actions and the long-term strategy for sustainable development, is also required.

Recommendations

- longer term outlook on material use, with full analysis of sustainability and where possible utilisation of abundant materials, and if not then a solid strategy for recycling/recovery of materials is required. Materials should have minimal toxicity built-in.
- a formalised structure which includes RTD, life-cycle assessors and policy makers should be established to ensure that technology developments meet commonly agreed goals.
- full life-cycle analyses should be performed for new products, which must include different usage scenarios. This will require new funding.
- guiding principles from policy makers are necessary.
- provision of a database of nanomaterial LCA and risk assessments.

[18] http://lca.jrc.it

[19] http://europa.eu.int/comm/environment/ipp/home.htm

[20] http://europa.eu.int/comm/environment/natres/index.htm

Closing Debate

The closing debate clarified some of the key issues that had been brought up during the workshop. These are summarized below.

It was recognized that the Commission includes LCA and sustainability criteria in current proposals, however the question was whether this should be strengthened, i.e. should it be an evaluation criterion? Most participants felt that it should be included for targeted projects- allowing projects that are orientated towards fundamental research to be distinguished from development and application based projects.

There is an urgent need to integrate the contributions of technology developers, life-cycle assessors and policy makers; so that common goals can be identified, understood and agreed upon. This will require specific funding for such analyses to be more commonplace. For example, in Denmark research awards now identify the environmental impacts of the proposed project. Inevitably this will require a more forward looking approach rather than focusing on immediate profitability. The lynch-pin is the policy maker, who determines the regulatory, legislative and funding frameworks and the strategy for their implementation. This framework must be in place before all stakeholders will agree to participate. An example is the Clean Air for Europe (CAFÉ) process that last year led to the Proposal on Ambient Air Quality, the culmination of discussions with a number of different organizations, involvement with many different technical committees and a web-based consultation.[21] European businesses have recently announced a new sustainable approach, which is now an EU strategy. However different sectors may well require different approaches, which will include combinations of voluntary, market, regulatory and communication approaches.

Markets and innovation are ultimately driven by consumers who choose what to buy; so any new strategies must take this into account and provide education and marketing for the relevant target groups. To be effective, evidence is needed that nanotechnology enabled products live up to their "green" credentials. This may require clarification (or sub-division) of nanotechnologies to dissociate hype from fact. It must also take account of the innovation needs of industry. In this regard it is essential to include SMEs, and there is a need for a strategy to assist transfer of environmental technologies to SMEs.

There must also be the recognition that risks and benefits go hand in hand; so the focus should be on making new nanomaterials safe, rather than manufacturing them first and then determining whether they are safe. Furthermore, hazards should not be the only consideration, although methodologies must be developed to identify nanospecific hazards, both the probability of exposure and the likely impacts of exposure to specific nanoparticles are more significant.

Eco-toxicology was discussed briefly in the closing debate; however this is the subject of another consultative process on nanoparticles carried out by SCENIHR (the Scientific Committee on Emerging and Newly Identified Health Risks).

It was re-iterated that from the Commission's perspective, the purpose of this workshop was to define research needs in the field of environment for FP7, rather than risk assessment (which is recognized as a crucial aspect and included in each call for proposals). The next step is to take the positive expectations of nanotechnology for the environment into consideration. The opportunities in this area need to be further discussed with the relevant DGs, in particular DG Environment and DG Enterprise and Industry.

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[21] http://europa.eu.int/comm/environment/air/cafe/pdf/cafe_dir_en.pdf

Appendix

The following pages are taken from the workshop handbook and list the questions sent to each participant before the workshop, submitted statements, and abstracts of presentations made at the workshop.

Monitoring

The ability to detect the presence of pathogens or toxic agents in our environment is the first step towards taking remedial action. While there are many monitoring devices for different agents, these are often expensive, bulky (or non-portable) or relatively insensitive. Advances in nanotechnology may be able to provide more sensitive detection systems allowing environmental changes to be detected earlier, and ambient sensor networks allowing multiple environmental parameters to be monitored continuously e.g. pollution levels, climatic conditions.

Questions to be addressed include:

1. How effective and close to market are monitoring systems being developed that use nanotechnology or that monitor the fate of nanosize particles in the environment?
2. What are the innovation processes used to develop these systems?
3. What supporting technologies and what infrastructure are these innovations dependent on and what still needs to be developed?
4. What scientific breakthroughs are necessary in order to develop the technology further and what social and organizational breakthroughs are necessary to make the technology actually work in society?
5. How sensitive will it be possible or practical to make such instruments?
6. What are the present/existing strategies to solve these problems today and how is the nanotechnology approach superior to these strategies?
7. What will be the long-term fate of remote sensors used to monitor air, water and soil?
8. Should "smart dust" be biodegradable?

Remediation and Pollution

Our reliance on fossil fuels for energy and transport, and the by-products and waste from manufacturing industries all have a major impact on the environment, in some cases leaving land and bodies of water unsuitable for any other use, and in worst cases destroying whole ecosystems.

Nanotechnology may offer solutions both for cleaning up polluted sites and to prevent pollution (filters etc). However we need to know whether our knowledge is sufficient to predict that the benefits outweigh any risks of such applications. In particular, the UK Royal Society and Royal Academy of Technology report in 2004 recommended that the use of free manufactured nanoparticles should be prohibited in environmental applications, such as remediation, until appropriate research had been undertaken to demonstrate that potential benefits outweigh the potential risks. Do we today have more experience or more knowledge to contradict this view?

The physical (size, shape, surface area) and chemical characteristics of nanoparticles determine their reactivity and ultimately their effect on living organisms; however it is still unclear how we can measure these parameters and how we can determine any potential environment and health impacts. The Scientific Committee (SCENIHR) report of October 2005 gives indications of major knowledge gaps and that modified test schemes are needed for materials in the nanoscale. In particular, there is a severe lack of knowledge concerning the environmental impacts. From a regulatory perspective, nanomaterials fall under legislation that was developed for their bulk materials, despite the fact that nanomaterials have novel properties which is likely to affect risk- or safety assessment methodology, standards etc.

It is important that nanotechnology applications for environment protection purposes are explored, but what exactly would be needed to pave the way for exploiting these new applications on a broader scale?

Questions to be addressed include:

1. What are, or will be, the most effective means of removing or preventing pollution (e.g. filters, particulates)?
2. How effective and close to market are materials or systems being developed for remediation that use nanotechnology? What research is needed to make it possible to fully exploit the potential of nanotechnology remediation applications?
3. What areas in pollution prevention technologies look promising and should be further explored?
4. Nanoparticles and fullerenes can be used to clean groundwater, but what happens to them following release into the environment? What do we know about the potential environmental impacts of nanomaterials?
5. What do we know about the impacts of nanoparticles on health and living organisms? What are the risks of using products containing nanoparticles?
6. What constitutes an environmental loss subject to remediation: the presence or accumulation of non-degradable nanoparticles in the environment; or are effects to the biosphere also required? If the latter, which effects?
7. Do we know enough to be sure that new technologies will improve the environment and resources without adding to the burden? Do current regulatory frameworks fully cover potential risk aspects?
8. What regulations/risk governance measures are needed, based on which nanomaterial-specific criteria?
9. Is there adequate funding for research on the environmental and health issues associated with nanotechnologies?

Resource Saving

Nanotechnology offers resource saving through improvements in efficiency for renewable energy sources (such as solar cells, thermoelectric devices, fuel cells); energy storage (such as rechargeable batteries and supercapacitors, hydrogen storage); reduced material consumption (e.g. providing lighter and/or stronger construction materials, or increasing the specific activity of functional materials); and the possibility of using alternative (more abundant) materials (e.g. using nanostructured metal oxides instead of rare metals for catalysts). Ultimately, this could mean fewer emissions, less waste, and a lower demand on limited resources. However, at the same time resource saving must also be viewed in terms of life-cycle assessment- will new products create a greater demand, will new materials have recycling issues?

Questions to be addressed include:

1. It is expected that total oil consumption will be 120 billion barrels in 2030. Are we doing enough to utilize renewable sources? Which areas should we focus on?
2. How long will it take new technologies to arrive on the market? Will this be in time before oil reserves are too low?

3. How might these advances be shared freely with developing countries to decrease their dependency on fossil fuels?
4. Will the use of nanosize key chemical elements be unsustainable and create a shortage of certain raw materials due to an unrecoverable dispersion in the environment (e.g. Indium, Gallium, Platinum)?
5. How can we ensure that materials/devices incorporating nanotechnology advances do in fact have a smaller environmental footprint? Should a more rigorous life cycle assessment approach be taken?

General Questions

1. What are other regions doing in these areas? (In terms of: R&D, commercialisation, risk research, risk government?)
2. How does European R&D compare with other regions?
3. Will these new technologies create a new economic boom?
4. What are the social and ethical concerns?
5. What are the roles for governments, scientists, companies and civil society organisations in dealing with the concerns of nanotechnology?
6. Do we have adequate regulation for nanotechnologies or do we need to develop new regulatory measures?
7. Is the European Commission doing enough regarding the safe and responsible development of nanotechnologies?
8. Are we engaging sufficiently with the public? What are the authorities doing to create a positive public perception? (a. Is this the public authorities duty? b. Is there any public risk perception so far?)
9. What are the communication difficulties? What is needed in the future?
10. What constitutes the borderline between nanotechnologies and their conventional counterparts, i.e. in which instances – besides size - must nanomaterials vary from their micro- and macrosized counterparts in order to be substantially different or riskier?

Programme

Thursday 30th March (13.00-18.00h)		
13.00h Introduction- Dr Renzo Tomellini		
Monitoring (13.15-15.30h) – chair, Dr David Rickerby		
Dr David Rickerby	JRC Ispra (IT)	"Development of Nanostructured Thin Film Sensors for NO_2 and CO"
Dr Andreas Skouloudis	JRC Ispra (IT)	"Microsensor Network for Air Quality Monitoring: Emphasis on Characterising Health Effects"
Dr Günther Proll	University of Tübingen (DE)	"Nanostructured Environmental Biochemical Sensor for Water Monitoring"
Dr Alberto Vomiero	University of Brescia (IT)	"The NANOS4 Project: a Breakthrough in Nanotechnologies for Innovative Metal-Oxide Gas Sensing Systems"
General discussion of issues (14.30-15.30h)		
Coffee break (15.30-16.00h)		
Remediation and Pollution (16.00-18.00h) – chair, Dr Eva Hellsten		
Dr Vicki Colvin	CBEN (US)	"Eco-Nano: the Impact of Engineered Nanomaterials on the Environment"
Dr Vicente Cortés Corberán	Inst. de Catalisis y Petroleoquimica (ES)	"CONCORDE Activities on Nano Metal Oxide Catalysts for Environmental Remediation"
Dr Rodger Duffin	University of Edinburgh (UK)	"Toxicology of Pollution Particles"
General discussion of issues (17.00-18.00h)		

Friday 31st March (08.45-16.00h)		
Resource Saving (08.45-13.00h) – chair, Dr Achim Boenke		
Dr Elmar Kessenich	BASF (DE)	"Innovation and Sustainable Development with Nanotechnology"
Dr Dietmar Eichstädt	Verband der deutschen Lackindustrie e.V. (DE)	"Applied Nanotechnology in the Coatings Industry"
Dr Armin Reller	Environmental Science Centre, Augsburg (DE)	"Spatial and Temporal Trajectories of Functional Nanomaterials"
General discussion of issues (10.00-10.30h)		
Coffee break (10.30-11.00h)		
Prof Jean-Marie Tarascon	Université de Picardie Jules Verne (FR)	"Towards the Next Generation of Li-ion Batteries Based on Nanomaterials"
Dr Volker Türk	Wuppertal Institute (DE)	"Nanotechnologies - Technological Means to Improve Resource Efficiency?"
General discussion of issues (11.45-13.00h)		
Lunch (13.00-14.30h)		
Closing debate (14.30-16.00h) – chairs, Dr Angela Hullmann, Dr Achim Boenke and Dr Mark Morrison Summary of what has been discussed, immediate feedback, priorities.		

Abstracts

Monitoring

Development of Nanostructured Thin Film Sensors for NO_2 and CO

Dr David G. Rickerby, Institute for Environment and Sustainability, European Commission Joint Research Centre, 21020 Ispra VA, Italy

Air pollution due to nitrogen dioxide and carbon monoxide from motor vehicle and industrial emissions represents a significant public health hazard. Current EU legislation limits the maximum concentrations of these gases to 200μgm^{-3} NO_2 and 10mgm^{-3} CO for the protection of human health. Solid state sensors based on nanocrystalline tin dioxide thin films can be used to monitor low concentrations of both gases in air. They have excellent response, operational simplicity and low cost in comparison with conventional analysis techniques such as gas chromatography, chemiluminescence and IR absorption. The sensor detects the presence of gases by measurement of the change in conductivity resulting from chemisorption of gas molecules at the surface of the film. The response is temperature dependent and the selectivity can be optimized by operating the device at the appropriate temperature. The performance is dependent on the microstructure of the thin film which is related to the deposition conditions. Sensitivity and selectivity can be further increased by doping the sensing layer with small amounts of Pt. It is possible to detect concentrations of NO_2 and CO at or below the existing legal limits. The fabrication of an integrated sensor, consisting of several miniaturized sensor elements on a single CMOS chip, allowing simultaneous detection of several gases, is also described.

Microsensor Network for Air-Quality Monitoring: Emphasis on Characterising Health Effects.

Dr Andreas N. Skouloudis, Institute for Environment and Sustainability, European Commission, DG of Joint Research Centre Ispra, T.P. 272, I-21020 (VA), Italy

The European Commission with the Environment and Health Strategy in 2003 (COM (2003) 338 final) and the European Environment and Health Action Plan in 2004 (COM (2004) 416 final) has set the objectives to reduce among others the human exposure by environmental factors in the EU and to identify and prevent new health threats caused by the environment. In order to strengthen the capacity for policy making in this area researchers are called upon to recognize the novel potential of smart technologies and in deployment of new technological tools.

These tools utilise advances in nanotechnology with innovative networking capabilities for monitoring the status of atmospheric pollution in way that is relevant for characterising the dangers to human health.

As described by preceding presentations, such sensors are becoming now commercially available and, as the convergence draws upon other technologies and enabling sciences, it would appear that nothing can escape the reach of social interactions and communication which can all be employed for assessing human exposure and to detect risks from chronic emission or abnormal events. Naturally there are many areas of application both for environmental monitoring as well as for immediate medical diagnosis.

This presentation focuses on how to extend our current understanding of the capacity of telematic architectures for identifying and classifying sensitive gases and/or even toxic substances and for coupling these with tools for assessing on "real time" environmental hazards which affect human health.

The deployment of such tools which use existing telecommunication infrastructures can change drastically the concepts of monitoring outdoor and indoor conditions and enhance the use of low cost nanotechnology applications. The main issues which will be addressed during this presentation are:

- Light, low-cost and low-power consumption, wireless micro-devices for hazardous gases in ranges typical for ambient monitoring.
- A movable terminal communication interface with processing capabilities with wireless communication for tracking and collection of data.

The advantages of applying such networks are:

- Plug and Play features and at sensor level permit an automatic registration without any necessary architecture adjustments.
- Easy integration in the network due to systems scalability. No need of a detailed previous network dimensioning.
- Maintenance is unnecessary except if a new communication protocol is used by a sensor. Flat jini network structures permits the integration of different subsystems into the architecture.
- A wireless communication could work via radio link or satellite and adapt itself automatically to all the communication mediums.
- Suitable for adequately monitoring the randomness of human activities and its relation with environmental hazards.

Nanostructured Environmental Biochemical Sensor for Water Monitoring

Dr Günther Proll, Prof Günter Gauglitz, Institute of Physical and Theoretical Chemistry (IPTC) Eberhard-Karls-University of Tuebingen, Germany http://barolo.ipc.uni-tuebingen.de

Within the European Union, a new water-related environmental legislation clearly defines the need for regular monitoring of organic substances down to low nanogram per liter levels (2000/60/EC, 2000; 98/83/EC, 1998). Therefore, it is necessary to develop fast, sensitive, cost-effective, and easy-to-use analytical systems capable of measuring a variety of small organic pollutants in aqueous samples. This trend in science is supported worldwide, including the 5th and 6th Framework of the European Community, and has resulted in numerous national and international research projects.

A novel analytical system AWACSS (Automated Water Analyser Computer Supported System) based on immunochemical technology carried out on a nanostructured optical transducer has been developed that can measure several organic pollutants at low nanogram per litre level in a single few-minutes analysis without any prior sample pre-concentration nor pre-treatment steps. Furthermore, nanostructures like Quantum Dots or the Nanotiterplate compared with chemometric methods are used to create a next generation set of analytical and bioanalytical methods.

The NANOS4 project: a Breakthrough in Nanotechnologies for Innovative Metal-Oxide Gas Sensing Systems

Dr Alberto Vomiero, Dipartimento di Chimica e Fisica per l'Ingegneria e per i Materiali Universita' di Brescia , Via Valotti, 9 , 25133 BRESCIA , Italy

The NANOS4 project is a 3M EUR EU-funded project under the 6th FP, lasting between 2004 and 2006, involving five academic and five industrial partners from five different EC Countries. Its main objective is a breakthrough in advanced micro- and nano-technologies for developing innovative metal-oxide gas sensing systems based on mesoscopic sensors.

The NANOS4 project is mainly driven by the following markets needs: innovative sub-system technology for increasing safety, comfort and economy of flying in large passenger aircrafts and in vehicles, early detection of smouldering fires, reliable and cost effective monitoring of environmental odour nuisances and workplace safety.

Nano-engineering techniques for materials synthesis and nano-manipulation of new materials are being developed in the framework of NANOS4.

New miniaturised, low-power consumption gas sensing systems are being designed and prototypically set-up based on gas sensing arrays of innovative nano-materials.

Achievement is planned of low power-consumption budgets comparable to a single commercial thick-film gas sensing element, featuring at the same time superior gas distinction, drift compensation as well as self-test functionalities.

Up-to-date results will be summarised both concerning the research and development of new materials and nano-manipulation technologies and the in field tests of prototypes gas sensing systems.

Attention will be focussed on the role of nano-dimensioned materials allowing superior performances of the new nanostructured sensors.

Remediation and Pollution

Eco-Nano: The Impact of Engineered Nanomaterials on the Environment

Dr Vicki Colvin, The Center for Biological and Environmental Nanotechnology (CBEN), Rice University, Houston, Texas 77005-1827, USA

Traditionally, nanotechnology has been motivated by the growing importance of very small (d < 50nm) computational and optical elements in diverse technologies. However, this length scale is also an important and powerful one for living systems. At Rice, we believe that the interface between the 'dry' side of inorganic nanostructures and the 'wet' side of biology offers enormous opportunities for medicine, environmental technologies, as well as entirely new types of nanomaterials. As part of our work on the potential biological applications, we also consider the unintended environmental implications of water soluble nanomaterials. Given the breadth of nanomaterial systems, we use a carefully selected group of model nanoparticles in our studies and focus on natural processes that occur in aqueous systems. We characterize the size and surface-dependent transport, fate and facilitated contaminant transport of these engineered nanomaterials. Models from larger colloidal particles can be extended into the nanometer size regime in some cases, while in others entirely new phenomena present themselves. We also consider biological interactions of nanoparticles and specifically address the interactions of a classic nanomaterial, C_{60}, with cellular systems. While the water-suspendable nano-C60 nanocrystal is apparently cytotoxic to various cell lines, the closely related fully hydroxylated, $C_{60}(OH)_{24}$, is non-toxic, thus producing no cellular response. Similarly, we have also found that functionalized single-walled carbon nanotubes are non-toxic to cells in culture. More specifically, as the functionalization density of the SWNT increases, the nanotube becomes more inert to cultures.

CONCORDE Activities on Nano Metal Oxide Catalysts for Environmental Remediation

Dr Vicente Cortés Corberán, Inst. de Catalisis y Petroleoquimica, CSIC, C/ Marie Curie 2, Cantoblanco, 28049 Madrid, Spain

Metal-oxide type materials are a main class of catalysts which play a key role in the production of petrochemicals, intermediates and fine chemicals, energy applications as well as in environmental protection. A great number of high level research groups on this field exist in Europe, but their efforts are disperse, and in most cases unconnected. The objective of CONCORDE is to boost the efficiency of these RTD at a European scale, and its transfer to the European industry, by means of the coordination of institutions and research centres which possess complementary and multidisciplinary expertise and know-how, covering the entire spectrum of catalysis by metal oxides. With a duration of 27 months, the co-ordination of RTD activities is focused on the major advanced topics of research on metal-oxide catalysts in five main areas: Advanced preparation methodologies, Improving development and identification of new metal oxide catalysts, New insight in the catalytic, structural and surface chemistry of metal oxide, Improving catalytic performances and discovering new applications, and Catalytic reaction and catalyst preparation engineering. CONCORDE activities include, among others, benchmarking, exchanges and training of researchers, preparation of a White Paper mapping of European competencies in the field, and the organization of three European Conferences and 4 Workshops on various topics related with the objectives.

Coordination of research activities is done through Task teams, several of them dealing with environmental protection issues. Examples in areas such as: Development of new DeNOx catalyst effective under lean burn conditions, new effective catalysts and photocatalysts for VOCs' elimination and catalytic combustion, as well as catalysts improvement for increasing efficiency of energy and raw materials use, will be presented.

Toxicology of Pollution Particles

Dr Rodger Duffin, MRC/UoE Centre for Inflammation Research, The Queen's Medical Research Institute, University of Edinburgh, 47 Little France Crescent, EH16 4TJ, UK

Prof Vicki Stone, Centre for Health and Environment, Napier University, 10 Colinton Road, EH10 5DT, UK

Elevated levels of particulate air pollution (PM10) are associated with increased hospital admissions and deaths due to both respiratory and cardiovascular causes. PM10 contains a mixture of components including nanoparticles, metals and endotoxin, all of which have been linked to the ability of PM10 to induce inflammation. It is proposed that by inducing inflammation, PM10 and nanoparticles exacerbate pre-existing inflammatory diseases. A number of studies show that both PM10 and low solubility, low toxicity nanoparticles (e.g. carbon black) induce inflammation in the rat lung. Both particle types clearly generate reactive oxygen species (ROS) in a cell-free system, and these ROS have been shown to induce intracellular signalling events leading to the production of pro-inflammatory cytokine proteins by macrophages. This suggests that both particle types are able to activate the signalling mechanisms that control inflammation.

Macrophages are the immune cells that are responsible for locating, ingesting and removing foreign material from the tissue. There are some suggestions that both nanoparticles and PM10 inhibit the ability of macrophages to ingest (phagocytose) other particles, but this work requires further investigation. PM10 also inhibits the ability of macrophages to migrate towards specific stimuli. The opposite has been observed for nanoparticles, but these studies were conducted at very high doses.

The effects of PM10 on the cardiovascular system appear to be extremely complex involving inflammation, humoral and neural factors. A wide variety of hypothese have been put forward to explain the cardiovascular effects of PM10 including enhanced blood clotting, altered neural stimulation of the heart and blood vessels as well as changes in the function of the blood vessel walls. Diesel particles have been shown to affect the ability of the blood vessels to respond to agents that normally induce dilation and increased blood flow. As yet the effects of nanoparticles on the cardiovascular system are unknown.

Resource Saving

Innovation and Sustainable Development with Nanotechnology

Dr Elmar Kessenich, Polymer Physics - Nanotechnology Coordination, BASF Aktiengesellschaft, GKP/N - B001, D-67056 Ludwigshafen, Germany

Sustainable development builds the basis for economic growth, longterm success and responsible care. Chemical nanotechnology and material technology is key to innovation, not only for the chemical industry, but for many other down-stream industries. Environmental aspects play an increasing role in future product development. Examples will illustrate how nanoparticles and nanostructured materials can save energy resources and reduce green-house gases.

Applied Nanotechnology in the Coatings Industry

Dr Dietmar Eichstädt, Director General, Verband der deutschen Lackindustrie e. V., Karlstraße 21, D-60329 Frankfurt, Germany

Nanotechnology sets up a technology leap for the paint industry. A new kind of coatings with special properties can be realised by this technology. A few coatings based on nanotechnology are already placed on the market providing functions which are not viable by conventional paints. Self cleaning paints can guarantee a brilliant surface without the use of cleaning agents, antibacterial coatings do not need conventional biocidal ingredients, nanotechnical pigments with catalytic properties can improve the indoor air quality and self healing coatings save energy and avoid re-coating after minor damages.

Further reinforcement in research and development on nanotechnology in the paint industry is necessary to reach innovative products but also on the impact of nanomaterials on human health and the environment. This needs financial help by the EU and the member states because the paint industry consists by 95 % of small and medium sized enterprises.

Spatial and Temporal Trajectories of Functional Nanomaterials

Dr Armin Reller, Environment Science Center, University of Augsburg, Universitätsstr. 1, 86159 Augsburg, Germany

The industrial production, implementation and distribution of nanoscopic functional materials is a fact, although many problematic and unknown features convoy this highly dynamic development. It is not only the potential of chemical and / or physical reactivities and interactions nanomaterials may undergo during their production and application. It is the whole life cycle which has to be considered and which poses unprecedented challenges. On one hand there is a need for analytical tools allowing the monitoring of the spatial trajectories, but also the dynamics of the distribution of mobile fractions. New methods and applications will be presented. The problem of resource and supply management will be discussed. The fact that strategic resources, in particular strategic metals, may be finely dispersed all over the earth´s surface when being implemented as nanomaterials in technical devices could imply severe shortages and economic risks for important technologies. Therefore a kind of a dedicated resource and supply chain management as well as of a resource geography or a materials geography are useful instruments allowing a better traceability and a more sustainable utilization of nanomaterials.

Towards the Next Generation of Li-ion Batteries Based on Nanomaterials

Prof Jean-Marie Tarascon, LRCS, Université de Picardie Jules Verne, UMR 6007 CNRS 33 rue Saint Leu, 80039, Amiens, France

ALISTORE network of excellence aims towards the development of the next generation of advanced energy storage Li systems through the use of nano-powders and nano-structured electrodes/electrolytes. Recent advances towards this goal involving 1) our ability to control as well as manipulate particles on a small scale so as to master new Li-reactivity mechanisms with high capacity advantages and 2) the fabrication of new nano-crystalline materials, nanoscopic or nano-structured electrodes through assisted template synthesis electro-deposition techniques or other chemical/physical means having high rate capabilities, will be presented. We will also stress that materials advances need to be parallel to the progress in characterization techniques. To illustrate this point, the key role of High Resolution Energy Electron Loss Spectroscopy in analysing electrode materials at the nanoscale will also be presented.

Nanotechnologies - Technological Means to Improve Resource Efficiency?

Dr Volker Türk, Wuppertal Institute, P.O. Box 10 04 80, 42004 Wupperta, Germany

Resources are the backbone of every economy. In using resources and transforming them, products are produced, infrastructures built up and values created. However, the current dimensions of resource use are endangering the chances of future generations and developing countries to have access to their fair share of scarce resources. Moreover, the level of resource extraction has serious environmental impacts beyond the carrying capacity of the environment.

Various initiatives on the international, national and regional level are trying to address this issue. Examples for policy initiatives are the Commissions 6th Environmental Action Plan, which called in its 3rd thematic strategy for the development of an strategy on the sustainable use of natural resources (Resource Strategy) or the Environmental Technologies Action Plan, that specifically mentions the important role Nanotechnologies might play. An example for the business side is the promotion of the eco-efficiency concept by the World Business Council for Sustainable Development.

Nanotechnologies appear to offer exciting new possibilities for increasing the resource and energy efficiency of industrial processes and products. But taking a life-cycle wide perspective, are these applications really contributing to an increase in resource efficiency? What are the lessons to be learnt from other cross- cutting technologies such as Information and Communication Technologies? And what is the current evidence base for Nanotechnologies?

Submitted comments from participants

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MONITORING AND REMEDIATION:

I think one of the challenges are how these sensors and remediation technologies are going to be used in society, including the picture the researchers and industry draw of the potentials of these technologies. I see a major risk that the combination of these two technology areas could be used to prohibit the further development of a preventive and cautious approach to environment, like the approaches of cleaner technology/cleaner production and environmental management. This could happen if monitoring and remediation is seen as guarantees towards pollution with statements like "we can always detect if sometimes goes wrong and we can always clean up if we get a problem".

POLLUTION:

It is important to see more than just nanoparticles as having potential environmental impact, The questions address more than nanoparticles although most focus seem to be on nanoparticles. Furthermore we should take a life cycle approach to nanotechnology (like it is done in the questions around resource saving), because there are also environmental impacts from the other parts of the life cycles which nanotechnologies are involved in. It can be from the processing of raw materials for nanotechnology manufacturing or it could be from the manufacturing of nanotechnology.

RESOURCE SAVING:

It is important to take a life cycle approach to resource savings, like I mentioned before and also to include questions around necessary supporting technologies and breakthroughs.

I like the focus on the relationship between developed and developing countries.

GENERAL QUESTIONS:

Question 8 and 9 build to some extent on the so-called deficit approach to the public: that they don't know and that we should ensure a positive perception. I more like the approach in question 5, which talks about roles and gives civil society a role in the framing of research and innovation and not just a role of receiving information. Seen within a governance approach civil society should have a role in the discussion of the legitimacy of those problems, benefits and impacts, which are addressed.

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Aspects for Discussion at the Resource Saving Session

1. Use of nano-materials/technologies to gain specific benefits for energy and environment providing input to the New Industrial Policy (NIP), Energy Green Paper and contributing to various Thematic Strategies (TS) linked to the 6th Environmental Action Plan:
    a. Capabilities offered by nano-materials/particles to further enhance storage capacity and to improve uptake/release kinetics in relation to hydrogen storage to positively contribute to current energy discussions => NIP, Green Paper & TS on Air Pollution;
    b. Nano-materials to adjust parameters such as electrical resistance and thermal conductivity leading towards Pb-and Halogen-free electronics and reducing environmental exposures =>NIP,TS Waste;
    c. Nano-material based remediation techniques for efficient water management linked water usages in, e.g., fabric preparation, dyeing processes, printing and special finishing of products in various industries (e.g. paper & pulp, textiles,

chemical, food, metal, leather, etc.) => NIP, TS on Marine Environment & Sustainable Use of Resources;

d. Improvements for water supplies and sanitation in Urban, Peri-Urban and Rural Areas by means of bio-nano-sensors in process monitoring => NIP, TS on Marine Environment & Sustainable Use of Resources;

e. Nano-structured layers for semiconductor layers to obtain a high efficiency of manufactured sensitised oxide cells, organic solar cells, and/or other nano-structured materials for photovoltaic => More effective energy use, Green Paper, NIP, renewable technologies and their applications;

f. Nano-materials achieving better catalyst performance, meeting engineering goals for new high performance materials in manufacturing, and lowering the material consumption level contributing to energy and feedstock efficient industrial processes => NIP, TS on Air Pollution & Sustainable Use of Resources;

g. Nano-materials providing high performance strength or temperature resistance, exhaust after-treatment and/or durability for reduced emissions from various transport means => NIP, TS on Air Pollution;

h. Nano-materials contributing to advanced computer systems, sensors, and methods of artificial intelligence within various stages of manufacturing processes => NIP, TS on Air Pollution & Sustainable Use of Resources;

i. Nano-materials generating scratch-proof and dirt-resistance surfaces, lower film and coating thicknesses to improve corrosion resistance and VOC emissions => NIP, Air Pollution&Waste TS;

j. Adoption of radically-advanced construction concepts such as integrated and intelligent agent systems, through programmable nano-materials, nano-constructors, bio-mimetic materials, structures and facility systems improving the indoor climate and energy consumption of buildings => NIP, Green Paper;

2. Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) Opinion on "The Appropriateness of Existing Methodologies to Assess the potential Risks Associated with Engineered and Adventitious Products of Nanotechnologies":

   Generation, application, distribution, persistence and toxicological characteristics of free nano-composites and their concerns over possible environmental risks:

   a. Physical, chemical or biological degradation of nano-composites releasing nano-particles;

   b. Life cycle evaluation of nano-composites (considering also benefits and stability (here: stability of quantum dots – see powerpoint slides) aspects from novel manufacturing processes and products);

   c. Free nano-particles: natural occurrence versus unintentionally generated ones, consideration of different environmental compartments air, water, soil and species including micro-organisms;

   d. Actual ranges of exposure levels for nano-particles to the environment linked to item c. above;

   e. Conventional and existing eco-toxicity tests versus adjusted and/or new ones linked to the setting of environmental quality standards including labelling aspects including characterisation of mechanisms and kinetics.

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Risk assessment of nanotechnology – support of sustainable technological development

Presently, nanotechnology is not regulated specifically. Risk assessment and regulations are based on existing procedures for chemicals, i.e. they consider the composition of the materials. Nanoscale size and surface structure are not yet considered factors by themselves. However, because size and structure determine the designed function, they might also influence the toxicological and environmental properties of nano-technological materials.

Therefore, it is important to evaluate the risk of nano-materials. We ought to consider, if present regulations are sufficient to cover this area, or if specific steps have to be taken to ensure safety of humans and the environment. Only a few nano-products are present on the market thus far, but within the next 10-20 years we will experience a huge number of new materials, with many new characteristics. Hence there is an urgent need for information about:

- What kind of nano-materials the environment and humans will be exposed to?
- Which are the most problematic nano-materials (e.g., regarding toxicity and fate in the environment)?
- How should society handle the new nano-materials to avoid adverse effects on humans and environment and which steps should authorities take to regulate them?

This information can best be obtained through collaboration of experts in toxicology, eco-toxicology and nanotechnology. Therefore, it is important that EU stimulate formation of expert forums for strengthening the development of new nano-materials, where human health and environment have high priority. Nanotechnology is still in its infancy and EU-society would greatly benefit from a technological development that from the beginning uses health and environment as one of its guidelines. This should prevent costly mistakes and secure public acceptance in the future. It might also contribute to the sustainability of nanotechnological development, as it may be more difficult to implement corrections at a later stage, when the main paths of nanotechnology R&D have reached a more rigid nature.

Nanotechnology is unique with respect to ability to design new constituents/materials with specific characteristics. Hence, there also is an opportunity to design the new nano-products with less impact on environment and human health. This issue deserves a higher priority in nanotechnology R&D.

But how can environment and human health benefit from nanotechnology? We need a strategy to ensure that we exploit the huge potential of nanotechnology for these purposes, such as reduced use of resources, designs for reduced environmental and health impacts, and optimized degradation profiles. Our imagination might be the limit of what is possible.

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There hasn't been much focus on understanding the implications of NT and resource use. The EU is working on a resource strategy, de-coupling economic growth is considered to be key for a more sustainable future, producers are increasing responsible for the entire life-cycle of products.

The Environmental Technology Action Plan tries to promote green technologies, and a closed- loop society is discussed but what is the role of NT in all of this? If e.g. metals like Indium (to take just one example) are used in Nano- Applications, will we ever be able to recover this material? Can the technology really live up to the claims of Nano = less resource intensive? Or will we come to similar findings like in the ICT debate, where digital was not necessarily less resource intense.

Having said this, I don't want to give the impression that the other questions are less important and I honestly do think that Nano offers a lot of opportunites in the environmental field that should be better explored, in particular also for SMEs.

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It is widely accepted that many benefits are expected from Nanoscience and Nanotechnology (N&N) approaches to research and development. Nevertheless, it has also been predicted that the exposure of nanoparticles is bigger than the one caused by pollution particles. It is therefore necessary to start considering the importance of knowledge with regards to the impact of nanotechnologies on human health, environment and social and ethical aspects.

Veneto Nanotech is involved in the establishment of ECSIN (European Center for the Sustainable Impact of Nanotechnology) in Veneto Region, Italy, aimed at satisfying the urgent needs of data on nano(eco)toxicology. The activities carried out by ECSIN follow the European Commission indications in N&N.

In fact the European Commission pushes towards the creation of 'poles of excellence': these kind of infrastructures are essential in order for the EU to remain competitive in N&N and to take into account the needs of both industries and R&D organizations. These centres are after international excellence and have to create a network of international cooperation in order to assure the sharing of data but also to intensify dialogue to adopt a code of good conduct for the responsible development and use of N&N. The Commission also calls for an interdisciplinary approach due to the complex and costly nature of the different applications in many fields.

The strengths of EU programmes are also related to the topics of the research proposed. In fact, every single one of the following aspects related to the protection of public health, environments and consumers is crucial: 1) risk analysis of the exposure of nano-size material during the production and transportation steps; 2) risk evaluation connected with the use of nanoparticles; 3) analysis of the nanomaterial polluting potentialities. In these kind of studies, it is fundamental to define common scientifically based systems for monitoring the presence of nanopollutants.

It is necessary to provide experimental and proved data to assure an evaluation on toxicity results to be agreed by the experts; this has to be assured by a methodical approach on the mentioned studies through protocols. These have to deal with all the steps of the testing process: the definition of nanomaterials to be analyzed, the procedures of the experiment and the rules in order to evaluate the toxicological results.

Moreover with regards to the topic of resource saving there is a part of the scientific world involved in green chemistry: it develops eco-compatible reagents and materials useful in industrial application and every day life.

The EU stresses the need for an analysis concerning the social impact of N&N. ECSIN has an interdisciplinary approach on the question by assuring the investigation on ethical aspects. There are two questions about the perception people have on new small side materials. The first question to raise is that of privacy, as the new nanotech applications while improving life style result in changes of social equilibrium (for example nanosensors). Moreover it is necessary to have the tools that support the changes of life due to nanotechnology applications.

It is also necessary to establish an effective dialogue with the public providing information regarding the progress, the expected benefits and the available results on potential toxicity. ECSIN aims at organizing informative and popular activities and it collaborates with other European centres to identify common guidelines towards the spreading of information.

In the development of a research project in the field of nano(eco)toxicology it is also very important to consider the management of the big amount of data the EU, ECSIN and other poles of excellence or research groups will have at their disposal. It would be suggestible to make a responsible use of data in order to predict the potential toxicity of unknown particles or nanomaterial in a short time and without the use of a large amount of lab animals. This is particularly true in the medical area.

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Aspects for Discussion at the Monitoring Session – Thursday 30th March 2006

1. Policy Dimension: The use of nano- and microtechnology sensors and biosensors for monitoring air and water quality and exposure to environmental stressors in support of the implementation of the Thematic Strategy on Air Pollution, the proposed Directive on Ambient Air Quality and Cleaner Air for Europe, the Water Framework Directive, and the Environment and Health Strategy and Action Plan.

2. Use of nanostructured solid state gas sensors to improve geographical coverage and provide higher spatial and temporal resolution, especially in pollution "hot spots", and allow real-time monitoring and rapid intervention. Evidence that adverse health effects due to air pollution (ultra-fine particles, ozone, nitrogen dioxide, etc) close to major roads are greater than those for the general pollution in urban areas. Presently it is not possible to assess the environment and health impacts due to lack of air pollution measurements at high enough resolution.
3. Application of sensors systems for monitoring of both outdoor and indoor air quality, particularly in public spaces (e.g. hospitals, schools, office buildings, aircraft cabins).
4. Improved water quality monitoring and control of chemicals and toxins with simple and cost-effective techniques. Diagnostic systems based on nanobiotechnology to monitor and detect all environmental contaminants and toxins. Principles of detection based on molecular recognition and other techniques.
5. Detection of pathogens and chemicals in water using biosensors and automated high throughput bioanalytical techniques. Identification of priority target substances and present technological capabilities and limitations (sensitivity, rapidity of analysis, detection thresholds, cost-effectiveness).
6. Sensitivity and selectivity of sensors and biosensors. Steps needed to be taken to ensure the reliability and reproducibility of data and to demonstrate that these are comparable with conventional instrumentation.
7. State of progress and closeness to commercialisation of air and water monitoring systems based on nanotechnologies. Demonstration projects to be set up in FP7 and the feasibility of these systems on the basis of results of projects already carried out or in progress.
8. Prospects for the development of low-power consumption sensors and miniaturised power supplies for sensor operation and data transmitter. Requirement for monitoring systems to be capable of operating autonomously for long periods or without attention or recalibration.
9. Interfacing of sensors with information technology and telecommunications networks for data processing and data transmission to a central monitoring station.
10. Potential risks associated with the dispersion of nanosensors in the environment and whether or not there should be a requirement for these to be biodegradable.
11. Methods for nano-particles/materials characterisation including also during production and recycling processes monitoring safety and health in the workplace and in various environmental compartments.
12. Ethical concerns, for example that ubiquitous sensor systems and informatics networks developed originally for environmental monitoring could also be employed for covert surveillance – privacy issues and respect for rights of the individual.

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Topics to be discussed:

- future potential of nanofoams for insulation
- innovations with nanoparticles: improved flow- and processing
- properties of thermoplastics will reduce energy consumption in production processes
- ecoefficiency analysis
- high porous materials for hydrogen storage (Fuel cells)
- innovative facade paints

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Topics to be discussed:

- circulation, pathways and accumulation of nanoparticles in the environment
- application of nanostructures for the benefit of the environment
- safety aspects
- use of nanostructures in agriculture

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Participant list

Name	Affiliation	Email
Aguar, Pilar	DG RTD (EC)	Pilar.AGUAR@cec.eu.int
Amond, Denis	Istituto nazionale per il Commercio Estero (IT)	bruxelles@bruxelles.ice.it
Boenke, Achim	DG Enterprise (EC)	Achim.Boenke@cec.eu.int
Bouis, Didier	DG Enterprise (EC)	Didier.Bouis@cec.eu.int
Bross, Michael	Verband der deutschen Lackindustrie e. V. (DE)	bross@vci.de
Chelmis, Helene	DG ENTR (EC)	Helene.chelmis@cec.eu.int
Colvin, Vicki	CBEN (US)	colvin@rice.edu
Corberán, Vicente Cortés	Inst. de Catalisis y Petroleoquimica / CONCORDE (ES)	vcortes@icp.csic.es
Degrand-Guillaud, Anne	DG Employment (EC)	Anne.Degrand-Guillaud@cec.eu.int
Duffin, Rodger	University of Edinburgh (UK)	rodger.duffin@ed.ac.uk
Eichstädt, Dietmar	Verband der deutschen Lackindustrie e. V. (DE)	eichstaedt@vci.de
Epprecht, Thomas K.	Swiss Re (CH)	Thomas_Epprecht@swissre.com
Feist, Steve	Cefas (UK)	s.w.feist@cefas.co.uk
Fellenberg, Ralf	VDI (DE)	Fellenberg@vdi.de
Genovese, Michele	DG RTD (EC)	Michele.genovese@cec.eu.int
Hellsten, Eva	DG Environment (EC)	Eva.Hellsten@cec.eu.int
Hullmann, Angela	DG RTD (EC)	Angela.HULLMANN@cec.eu.int
Johansen, Anders	National Environmental Research Institute (DK)	ajo@dmu.dk
Jorgensen, Michael Sogaard	DTU (DK)	Msj@ipl.dtu.dk
Jovanovic, Aleksandar	MPA Stuttgart / ETP EuMaT (DE)	Aleksandar.Jovanovic@mpa.uni-stuttgart.de
Kessenich, Elmar	BASF / Nanosafe2 (DE)	elmar.kessenich@basf.com
Krieg, Sabine	Fraunhofer Institute for Interfacial Engineering and Biotechnology	Sabine.Krieg@igb.fraunhofer.de
Lepape, Brice	DG INFSO (EC)	Brice.lepape@cec.eu.int
Lodato, Federica	Veneto Nanotech (IT)	federica.lodato@venetonanotech.it
Malsch, Ineke	Malsch TechnoValuation / Nanoforum (NL)	malschtechnovaluation@xs4all.nl
Marczewski, Artur	DG RTD (EC)	Artur.marczewski@cec.eu.int
Martin, Philippe	DG Sanco (EC)	Philippe.Martin@cec.eu.int
McDonagh, Gráinne	DG RTD (EC)	grainne.mcdonagh@cec.eu.int
Morrison, Mark	Institute of Nanotechnology / Nanoforum (UK)	mark.morrison@nano.org.uk
Olivato, Iolanda	Veneto Nanotech (IT)	iolanda.olivato@venetonanotech.it

Petschow, Ulrich	IOEW (DE)	Ulrich.Petschow@ioew.de
Proll, Günther	University of Tübingen (DE)	Guenther.Proll@ipc.uni-tuebingen.de
Rauscher, Hubert	JRC Ispra (IT)	hubert.rauscher@jrc.it
Reller, Armin	Environmental Science Centre, Augsburg (DE)	armin.reller@wzu.uni-augsburg.de
Rickerby, David	JRC Ispra (IT)	david.rickerby@jrc.it
Roesems-Kerremans, Gisele	DG INFSO (EC)	Gisele.Roesems@cec.eu.int
Schoupe, Michel	DG INFSO (EC)	Michel.schoupe@cec.eu.int
Scott, Janic	National Environmental Research Institute (DK)	jsf@dmu.dk
Skouloudis, Andreas	JRC Ispra (IT)	andreas.skouloudis@jrc.it
Tarascon, Jean-Marie	Université de Picardie / ALISTORE (FR)	jean-marie.tarascon@u-picardie.fr
Thomaes, Hendrik	Istituto nazionale per il Commercio Estero (IT)	bruxelles@bruxelles.ice.it
Tomellini, Renzo	DG RTD (EC)	Renzo.Tomellini@cec.eu.int
Tran, Lang	Institute of Occupational Medicine / PARTICLE_RISK (UK)	Lang.Tran@IOMHQ.org.uk
Türk, Volker	Wuppertal Institute / Nanologue (DE)	volker.tuerk@wupperinst.org
Veringa, Hubert	ECN / University of Twente (NL)	veringa@ecn.nl
Vomiero, Alberto	University Brescia / NANOS4 (IT)	vomiero@tflab.ing.unibs.it
von Schomberg, René	DG RTD (EC)	rene.von-schomberg@cec.eu.int
Vounakis, Irja	DG Environment (EC)	Irja.Vounakis@cec.eu.int
Wallin, Hakan	National Institute of Occupational Health / PARTICLE_RISK (DK)	hwa@ami.dk
Wong, Kim	Oxford Begbroke / NANOsafeNET (UK)	Kim.Wong@begbroke.ox.ac.uk

About Nanoforum

Nanoforum is a pan-European nanotechnology information network funded by the EC under FP5, to provide information and support to the European nanotechnology community. On the Nanoforum website (www.nanoforum.org), all users (whether they are members of the public, industry, R&D, government or business communities) can freely access and search a comprehensive database of European nanoscience and nanotechnology (N&N) organizations, and find out the latest on news, events and other relevant information. In addition, Nanoforum publishes its own specially commissioned reports on nanotechnology and key market sectors, the economical and societal impacts of nanotechnology, as well as organizing events throughout the EU to inform, network and support European expertise.

The Nanoforum consortium consists of:

The Institute of Nanotechnology (UK)	http://www.nano.org.uk
VDI Technologiezentrum (Germany)	http://www.vditz.de/
CEA-Leti (France)	http://www-leti.cea.fr/uk/index-uk.htm
Malsch TechnoValuation (Netherlands)	http://www.malsch.demon.nl/
METU (Turkey)	http://www.physics.metu.edu.tr/
Monte Carlo Group (Bulgaria)	http://cluster.phys.uni-sofia.bg:8080/
Unipress (Poland)	http://www.unipress.waw.pl/
FFG (Austria)	http://www.ffg.at/
NanoNed (Netherlands)	http://www.stw.nl/nanoned/

For further information please contact the coordinator, Mark Morrison: mark.morrison@nano.org.uk