Nanotechnology and Regulation within the framework of the Precautionary Principle

Final Report

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Main conclusions:

1. The study has its focus on nanotechnologies and especially on nano-particles. The behaviour of nano-particles deviates from matter at the macroscale, with sometimes adverse effects on environment and health. This might be a general rule and is especially important concerning new classes of matter as for example nanotubes and buckyballs. Some studies report surprising behaviour of nano-particles.

2. The approach of technology assessment (characterisation of technology) gives some hints about potential problematic effects of nano-particles „size does matter“. This shows that even before knowledge exists about potential adverse effects some hints might be derived.

3. The Precautionary Principle of the European Union (COM 2000xx) points out the scientific uncertainty is no reason for inaction if there might be immense adverse effects. If there is a decision to act there still remains a variety of potential actions. Ranging from a ban to further research projects as well as recommendations. Therewith, the question might be raised how to act concerning nanotechnologies.

4. Some elements of the Precautionary Principle exist in different regulation approaches. The regulation of Chemicals especially the proposal of the REACH regulation as well as the regulation of pharmaceuticals are examples for a precautionary approach with their prior approval procedures. In the case of chemical regulation this relates to new chemicals as well as new uses and with the enactment of REACH this will relate for “old” chemicals as well.

5. The existing regulations might be able to capture potential adverse effects of nanotechnologies especially of nano-particles. Further possible developments of nanotechnologies might be captured by approaches of the regulation of genetic modified organisms.

6. Still lacking is the adaptation of the existing regulations to the nano specifics. The difference between nano-scale and macro-scale is not caught in existing regulation. Furthermore, new materials are not classified in a systematic way. Furthermore, there might be an adaptation need concerning the measurement units of nano-particles. The current measurement in weight should be replaced by size and/ or surface size.

7. Beside the possible problems of adapting existing regulations our research made evident that the regulatory authorities so far took no action except horizon scanning.

8. Only limited general claims can be made regarding nanotechnologies
   There is a rather great need for further research concerning Nano-particles their behaviour and their potential effects in the case of release
   The magnitude of materials and their combinations makes general claims problematic, there is a huge need concerning the classifications of these materials.
   General guidelines for advice were mainly developed for the use of nano-particles in medicine: biodegradability of the materials seems to be one approach to avoid potential health problems. Furthermore the release of nano-particles in the environment should be avoided.
   The state of research concerning. The behaviour of nano-particles is actually rather limited, preliminary as well as contradictory. Nevertheless, the advice to avoid the release of nano-particles to the environment might be appropriate and would be in accordance with the Precautionary Principle.

A first look at the product life cycle of different products containing nano-particles makes evident that there might not be a general problem concerning nano-particles, as most processes do not use the gas phase but are in some form wet processes. In products containing nano-particles these nano-particles are usually fixed and there might be no release of nano-particles. This might also hold true for disposal, nevertheless there might be a need for further research.

Against the background of the increasing problem of air pollution by ultrafine particles caused by combustion processes, the problem of nano-particles might actually be negligible but is a problem of concern. This holds especially true against the background of the dynamics of technology development.
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1 Introduction

Assessment of environmental impacts of nanotechnologies has so far been viewed primarily in terms of opportunities. Risks have been mainly associated with the development of “self-replicating nanorobots” in the far future. Only more recently, partly in connection with the transition to industrial production (especially of nano-particles and nano-materials) have reservations been voiced w.r.t. certain aspects arising from the intrinsic nature of this technology.

The following report gives an overview of regulation of nanotechnology. Regulating nanotechnology touches a number of issues. Normative aspects of designing regulation under conditions of uncertainty and technology assessment are equally important as an evaluation of the potential effects and existing regulations as such. This study gives a detailed step-by-step introduction to all relevant issues. It firstly introduces the Precautionary Principle as a concept for action in conditions of uncertainty in policy-making. Secondly, it presents one way of assessing a new technology such as nanotechnology, called “Characterisation of Technology”. Thirdly the study presents the latest research results on possible hazardous effects of nanotechnology applications. Fourthly, areas of regulatory concern are discussed with reference to nanotechnology. Finally, a number of recommendations for future policy are presented.

1.1 The scope of the study

The study does not aim to develop an overall appraisal of nanotechnologies. The main focus is on nano-particles and the potential environmental and health effects of their release because nano-particles are one of the few nano-applications already in production and use.

Out of its scope are those applications which are sometimes described as "wet nanotechnologies" which might be interpreted as the convergence of nano and biotechnologies and their specific problems. Furthermore, the study does not focus on the possible contributions of nanotechnologies to environmental relief. Other studies of the IÖW make clear that nanotechnologies might have a positive environmental effect. Also, we do not investigate the wider societal implications of nanotechnologies or the question of innovation and possible distributional effects.

The main concerns of this study are nano-particles and their potential adverse effects on environment and health as well as what might be an appropriate way to handle nanotechnologies (nano-particles) against the background of the Precautionary Principle in general as well as the version developed by the European Union. Furthermore, the concern of the study is the regulatory framework and the need for development of this framework in the light of the emerging nanotechnologies.

1.2 The issue of nanotechnologies

Nanotechnology is defined as the production and application of structures, devices and systems by controlling shape and size at nanometre scale. In its broadest sense, it includes all technologies and processes which operate on the nanometric scale. Nanotechnology embraces a wide variety of sectors and we can expect that a number of different technologies will be integrated under the umbrella of nanotechnology.

The mere handling of materials of nano scale is not a fundamentally new phenomenon. Particles of nano scale, for example, have long been used in tyre manufacture. What is new are the basic “aspirations” of nanotechnology: actively controlling and shaping molecular architecture. Producing on the molecular scale ‘atom by atom’ could in principle lead to substantial improvements in the efficiency of resource use (with, for example, large reductions in waste production).

Notions of how nanotechnologies might develop have sparked a great deal of controversy, although it should be noted that most concerns relate to possible long-term trends (e.g. towards self-replicating nanorobots) not expected to take place before 2040.
Rocco (2002: 5) gives the following time frames for industrial prototypes and marketing in the field of nanotechnology:

Table 1: Time frames for the development of nanotechnology

<table>
<thead>
<tr>
<th>Time Frame</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanotechnology</td>
<td>Has - in the form of carbon black, for example - been used “inadvertently” for centuries</td>
</tr>
<tr>
<td>First generation</td>
<td>Passive nanostructures (around 2001) Fields of application: coatings, nano-particles, bulk materials (nanostructured metals, polymers, ceramics and ink-jet products)</td>
</tr>
<tr>
<td>Second generation</td>
<td>Active nanostructures (around 2005) Transistors, amplifiers, adaptive structures, etc.</td>
</tr>
<tr>
<td>Third generation</td>
<td>3D nanosystems (around 2010) With heterogeneous nanocomponents and different assembling techniques</td>
</tr>
<tr>
<td>Fourth generation</td>
<td>Molecular nanosystems (around 2020) With heterogeneous molecules, based on biomimetics and new design</td>
</tr>
</tbody>
</table>

Source: Rocco 2002

The distinction between the technology itself and the various contexts in which it can be applied means that a host of different questions, involving different timescales, arises w.r.t. ecological sustainability assessment. For current or short-term developments, conventional tools such as life-cycle analysis and (eco-)toxicological assessment can be applied. More difficult are attempts to assess the possible consequences arising from subsequent generations of nanotechnology applications. One main focus should be on the ecological sustainability of these conceived paths of development, and on the unintended side-effects. Further expected advances in nanotechnology, however, could entail risks similar to those of genetic engineering. These risks are typified by those inherent in the so-called “wet nanotechnologies”, which are involved mainly with cells (termed “nanomachines” in the jargon of nanotechnology). This also applies to the so-called self-replicating nanoro bots – the feasibility of which has been called into question – and are, in terms of the problems generated, the inorganic equivalent of genetic engineering. At the same time, it becomes evident that risk management and the assessment of opportunities and threats are approaches that need to be applied within different time frames.

2 The Precautionary Principle and the European Union

The Precautionary Principle is a highly debated issue in international politics. A superficial glance at the principle can give hints concerning the application of the principle in different policy arenas. The more detailed summary in the "Communication of the Commission concerning the application of the Precautionary Principle" focuses on understanding of the Precautionary Principle of the European Union. The aim of the study is to take the Precautionary Principle into account and using the approach of “Characterisation of Technology” to give advice on further action. By using both concepts, some steps can be taken to identify technology-inherent potential adverse effects, even before having knowledge of possible adverse effects on targets such as environment and/or health. This approach emphasises the early stages of innovations (especially R&D and design) in which adverse effects might be excluded or at least reduced.

The discussions regarding the Precautionary Principle are diverse. It has been pointed out that that the nature of scientific uncertainty is changing and international organisations exert increasing pressure to base governmental action on more "rational" schemes such as cost-benefit analysis and quantitative risk assessment instead of the Precautionary Principle. The Precautionary Principle is criticized as being both too vague and too arbitrary to form a basis for rational decision making. The assumption underlying this criticism is that any scheme not based on cost-benefit analysis and risk assessment is irrational and without secure foundation in either science or economics (Ashford 2002). The critics’ claim is that traditional risk analysis provides sufficient information for an effect-based regulation - other approaches are more or less arbitrary and ignore scientific assessments (Majone 2002, Sandin 2002).
Proponents of precautionary regulation on the other hand point out that the Precautionary Principle does not necessarily mean a ban of substances but that there is a need for a cautious step by step diffusion of risky activities or technologies until more knowledge and experience is accumulated (Bennet 2000) whereas risk-based regulation might have shortcomings in a background of scientific uncertainty.

2.1 Aspects of the Precautionary Principle

The most relevant aspects of the Precautionary Principle within this context are discussed in the following.

1. Use of the Precautionary Principle below the level of (known) acute danger.

Regulatory approaches related to this interpretation are “Best Available Control Technologies” (BAT) the minimization principle, and the ALARA principle (as low as reasonable achievable). With these criteria, tolerance levels might be reduced even where there is no or limited knowledge of the effects on environment or human health, but where adverse effects might be possible. Nevertheless these approaches contain some weighting of potential hazards as well as potential benefits of activities.

2. Precautionary Actions should not be postponed if the evidence is not yet conclusive.

In this case, regulatory action might be set in action to avoid irreversible damage and esp. long-term impact. While not having scientific certainty concerning dose-response relationships precautionary regulation might be set in place.

3. Precautionary Principle and the problem of coping with ignorance and system boundaries in assessing and evaluating risks.

Regulatory actions might be required if specific criteria of potential irreversibility and the extent of potential damages are met. “Regulation is based on the characteristics of hazards without considering exposure or effects. The major claim here is that specific characteristics of risks may serve as early warning signs for trouble to be expected later, even if the pathways of damage are yet unknown or unexplored. The most popular examples here are CFCs which were designed to be chemically stable (as a means to avoid toxic effects) but turned out to be destructive to the Ozone layer.” (Precaupri 2003)

4. A central concept in this context is shifting the burden of proof.

While in most legal concepts the regulatory agency has to prove that a new substance or activity poses an unacceptable risk to the public, this understanding of precaution places the burden of proof on the shoulder of the proposing actor. The proposing actor has to demonstrate that the planned activity or release of a substance will not harm the environment or human health.

5. The Precautionary Principle might encourage exploration of a wide range of alternatives to possibly harmful actions.

6. For reasons of legitimacy public participation in decision-making is required.

These elements of the Precautionary Principle are not mutually exclusive and might not always be appropriate to specific situations, they nevertheless give some hints concerning action and non-action, for example in the field of nanotechnology.

Elements of the Precautionary Principle are common in all national and international regulations but the degree of its use might be different in different regulatory regimes as well as specific circumstances (products) There is no general rule concerning the application of the Precautionary Principle in different states. Even shifting the burden of proof to the proposing actor might not be effective, as there may not be any proof that an action could harm the environment and human health, nor proof to
the contrary. Drawing on the Precautionary Principle is in most cases a question of weighing up risks and benefits. There is no test for possible, unknown damages. Nevertheless, the burden of proof might be shifted to the proposing actors in order at least to close information gaps. The shifting of the burden of proof is more or less an approach which is used in various regulatory regimes, especially in drug and chemical regulation.

In the case of nanotechnologies, a further question must be raised namely how to deal with new technologies and innovations. These always contain a lack of knowledge and uncertainty and it is quite obvious that even foresight activities might not help to identify possible consequent risks given ignorance and system boundaries - as in the case of CFCs. We think that rather a lot of knowledge exists (especially in the field of chemical regulation). This knowledge might be used to examine new technologies on the basis of the characteristics of hazards without considering exposure or effects.

2.2 PrecauPri

The EU funded project "PrecauPri" developed some criteria for interpreting and applying the Precautionary Principle within the European Union. The project defined “precaution” as a "prudent and sound choice of response in the face of uncertainty" and "uncertainty" as “a situation in which well-founded hypotheses of potential negative impacts are available, yet final empirical evidence of harm is missing”. Furthermore “prudent and sound choices” are characterized by using “substantive and procedural steps to evaluate potentials for harm.” This appraisal aims to identify specific characteristics of threats (including inherent hazards or social mobilization potential) and does not focus merely on the likelihood of consequences and damage potential.

The PrecauPri project developed a general model to cope with four central challenges of contemporary risks: seriousness, uncertainty, complexity, and ambiguity.

While not using this model in detail, we think that our approach might be based on these ideas: “Seriousness describes in particular the inherent potential of a risk agent to cause harm to the environment or to human health, e.g. exposure-based hazard criteria such as ubiquity, persistency, bio-accumulation or cause-effect related criteria such as carcinogenicity, mutagenicity and reprotoxicity. Criteria of seriousness may be an excellent guide for setting up an early warning system, if effects are still unknown or ignorance about potential impacts prevails.”

At this point in the development of nanotechnologies other factors such as uncertainty and complexity as well as ambiguity are equally important. The “characterization of technology” approach takes this as a starting point for a precautionary approach to nanotechnologies and with this the potential effects of the handling of nano-particles.

EU and the Precautionary Principle

The Maastricht Treaty added to Article 174(ex Art.130r) EC the Precautionary Principle. This principle was not mentioned in any of the EC environmental action programmes prior to 1991. Krämer points out that the clause was proposed by Belgium and adopted without much discussion. As EC law is autonomous it cannot be interpreted by recurring to national notions or concepts.

According to Krämer prior to the insertion of the Precautionary Principle in the EC Treaty all cases of scientific uncertainty now subsumed under this principle were subsumed under the notion of prevention (Krämer 2003). The best illustration for precaution is the landmark judgment of the Court of Justice in the BSE case. In that judgment, the Court upheld an export ban for British beef, because of the risk that British beef was infected with BSE and stated:

"Where there is uncertainty as to the existence or extent of risks to human health, the institutions may take protective measures without having to wait until the reality and seriousness of those risks becomes fully apparent. That approach is borne out by Article 130r(1) of the EC Treaty, according to which Community policy on the environment is to pursue the objective, inter alia, of human health. Article 130r(2) provides that that policy is to be based in particular on the principles that preventive
action should be taken and that environmental protection requirements must be integrated into the
definition and implementation of other Community policies". The same approach is adopted in Direc-
tive 2001/18 on the deliberate release of genetically modified organisms where considerant 4 mentions
the prevention and considerant 8 the Precautionary Principle.

The Precautionary Principle is still open to broad interpretation. While usually the wording of the Rio
Declaration (1992) is cited, "In order to protect the environment, the precautionary approach shall be
widely applied by States according to their capabilities. Where there are threats of serious or irreversi-
ble damages, lack of full scientific certainty shall not be used as a reason for postponing cost-effective
measures to prevent environmental degradation", the European Union refers to the definition in the
Convention on the protection of the marine environment in the North-East Atlantic (OSPAR 1992):
The Precautionary Principle is a principle)... by virtue of which measures are taken when there are
reasonable grounds for concern that substances or energy introduced directly or indirectly into the
environment may bring about damage to human health, harm living resources, even where there is no
conclusive evidence of a causal relationship between the inputs and effects".

EU - Communication
In 2000, the Commission issued a Communication on the Precautionary Principle in which it outlines
its approach to using the Precautionary Principle, establishes guidelines for applying it, tries to de-
velop an common understanding of the principle as well as underlining that there should be no misuse
of the principle as a “disguised form of protectionism”. The Precautionary Principle should come in
use “specifically where preliminary objective scientific evaluation indicates that there are reasonable
grounds for concern that the potentially dangerous effects on the environment, human, animal or plant
health may be inconsistent with the high level of protection chosen for the Community.” (EU 2000: 2).

This part of the study is mainly based on the EU-Communication, which pointed out that the applica-
tion of the Precautionary Principle is an eminently political task, based on the one hand on the definition
of what might be an ‘acceptable level’ of risk for society and on the other hand to the existing
scientific information especially concerning scientific uncertainty and possible ‘unacceptable risk’. The
Commission further points out that there exists a rather broad range of possible actions from
legally binding measures to ‘a research project or a recommendation’. Furthermore, the Commission
points out that when action is deemed necessary, measures based on the Precautionary Principle
should be:

- proportional to the chosen level of protection,
- non-discriminatory in their application,
- consistent with similar measures already taken,
- based on an examination of the potential benefits and costs of action or lack of action (includ-
ing, where appropriate and feasible, an economic cost/benefit analysis),
- subject to review, in the light of new scientific data, and
- capable of assigning responsibility for producing the scientific evidence necessary for a more
  comprehensive risk assessment.

With these elements the Commission underlines that before taking action there is a need for weighing
up the risks, and using a rather broad range of measures - from a total ban to more differentiated
measures - as well as the costs and benefits (not only in economic terms).
Furthermore, the application of the Precautionary Principle should not be unlimited but there might be
some periodically review about the available scientific information and especially about completeness
and inclusiveness.

Furthermore the Commission points out that the responsibility for producing scientific evidence is one
common consequence of these measures (reversal of the burden of proof). Substances are treated as
dangerous unless and until business demonstrates that the substances are safe (compare the regulation
of chemicals). Reservations were made in cases where there is no prior authorisation procedure, the
burden of proof might be shifted to the producer and/or importer but this cannot be made a general
rule.
2.3 **Dimensions of the Precautionary Principle**

The Commission Communication points out that the “The dimension of the Precautionary Principle goes beyond the problems associated with a short or medium-term approach to risks. It also concerns the longer run and the well-being of future generations.” With this approach the focus of the Precautionary Principle resembles the aim of sustainable development and points out that the well-being of future generations depends on decisions taken today. This approach widens the perspective in that sense, that the well-being might not only depend on the environmental and health effects but also on economic and social conditions in the future, which might be effected too by actions taken or not taken today. Against the background of the lack of knowledge concerning the preferences of future generations this is a rather difficult problem of balancing action or non-action today, especially because the wellbeing of future generations might not be evaluated or predicted by scientific knowledge but by “world views” of actors today.

**Aim: Politically chosen level of protection**

The approach of the Commission points out that there exists one main aim: the politically chosen level of protection which should not be put into question. There is a need for evaluating technological developments and their positive or negative contribution towards the level of protection. With this there is a need for methods to identify the risks and /or benefits for example of new technologies. The main point is therefore how to asses these risks often given a background of limited knowledge.

**Scientific knowledge and the need for taking measures**

The Precautionary Principle, as interpreted by the Commission, points out that there might be a need for taking measures even in the absence of the “all the necessary scientific knowledge”. Nevertheless the Commission takes into account that the Precautionary Principle should not be used arbitrarily but in balancing in a “proportionate, non-discriminatory, transparent and coherent” way furthermore “decisions require a structured decision-making process with detailed scientific and other objective information especially the three elements of risk analysis: the assessment of risk, the choice of risk management strategy and the communication of the risk.

Any assessment of risk that is made should be based on the existing body of scientific and statistical data. Most decisions are taken where there is sufficient information available for appropriate preventive measures to be taken but in other circumstances, these data may be wanting in some respects. The Precautionary Principle is exercised where

- scientific information is insufficient,
- inconclusive,
- or uncertain and
- where there are indications that the possible effects on the environment, or human, animal or plant health may be potentially dangerous and
- inconsistent with the chosen level of protection.

**The constituent parts of the Precautionary Principle**

The Communication points out that the Precautionary Principle reveals *two quite* distinct aspects:

(i) **the political decision to act or not to act as such**, which is linked to the factors triggering recourse to the Precautionary Principle;

(ii) in the affirmative, **how to act**, i.e. the **measures** resulting from application of the Precautionary Principle.

The Commission differentiates between a prudent approach and the application of the Precautionary Principle within risk analysis (risk assessment and risk management) and the role of scientific uncertainty in risk analysis. According to the Commission, the prudent approach is part of the risk assessment and therefore part of scientific opinion produced by the risk evaluators, while the application of the Precautionary Principle is part of risk management, when a full assessment of the risks is not possible because of scientific uncertainty and decision makers have to consider whether the chosen level of protection might be in jeopardy.
Factors triggering recourse to the Precautionary Principle

The use of the Precautionary Principle
The Precautionary Principle is relevant only in the event of a potential risk, even if this risk cannot be fully demonstrated or quantified or its effects determined because of the insufficiency or inclusive nature of the scientific data.

Identification of potentially negative effects
First of all a potentially negative effect of a phenomenon must be identified. Second the relevant scientific data has to be evaluated, which implies scientific examination.

Scientific evaluation
Scientific evaluation of the potential adverse effects should be undertaken based on the available data when considering whether measures are necessary to protect the environment. The risk assessment should be considered when deciding whether or not to invoke the Precautionary Principle. The result of this assessment should express the possibility of occurrence and the severity of a hazard's impact, the extent of possible damage, persistency, reversibility and possible delayed effects. While it might not be possible to carry out a comprehensive risk assessment, the available scientific information has to be evaluated. Where possible, a report should be made which indicates the assessment of the existing knowledge and the available information, providing the views of the scientists on the reliability of the assessment as well as on the remaining uncertainties. If necessary, it should also contain the identification of topics for further scientific research.

The limits of scientific knowledge may affect each of these components, influencing the overall level of attendant uncertainty and ultimately affecting the basis for protective or preventive action. An attempt to complete these four steps should be performed before the decision to act is taken.

Scientific uncertainty
Scientific uncertainty results usually from five characteristics of the scientific method: the variable chosen, the measurements made, the samples drawn, the models used and the causal relationship employed. Scientific uncertainty may also arise from controversy about existing data or lack of some relevant data. Uncertainty may relate to qualitative or quantitative elements of the analysis. Risk managers should be fully aware of these uncertainty factors when they adopt measures based on the scientific opinion delivered by the evaluators. However, in some situations the scientific data are not sufficient to allow one to apply these prudential aspects in practice, i.e. in cases in which extrapolations cannot be made because of the absence of parameter modelling and where cause-effect relationships are suspected but have not been demonstrated. It is in situations like these that decision-makers face the dilemma of having to act or not to act.

The triggering factor
Once the scientific evaluation has been performed as well as possible, it may provide a basis for triggering a decision to invoke the Precautionary Principle. The evaluation should identify if the "desired level of protection" could be jeopardised, include an assessment of the scientific uncertainties, a description of the hypotheses used to compensate the lack of the scientific or statistical data. Furthermore an assessment of the potential consequences of inaction should be considered. As a result the decision to wait or not for new scientific data and to act or not to act should be taken with a maximum of transparency.

The lack of scientific knowledge should not be used to justify inaction.\textsuperscript{1} According to the Communication of the Commission “even if scientific advice is supported only by a minority of the scientific community, due account should be taken of their views, provided the credibility and reputation of this fraction are recognised.\textsuperscript{2}

\textsuperscript{1} Scientific proof of the existence of a cause-effect relationship, a quantifiable dose/response relationship or a quantitative evaluation of the probability of the emergence of adverse effects following exposure
Precautionary Principle and the burden of proof

The application of the Precautionary Principle in different regulatory regimes is done by positive lists (principle of prior approval) before bringing products or substances onto the market. This is done to different degrees in chemical, drugs, cosmetics and other products. In these cases there is a shifting of the responsibility for producing scientific evidence. This applies in particular to substances deemed “a priori” hazardous or which are potentially hazardous at a certain level of absorption.

Where such prior approval procedure does not exist, it may be for the user, a private individual, a consumer association, citizens or the public authorities to demonstrate the nature of a danger and the level of risk posed by a product or process. Action taken under the head of the Precautionary Principle must in certain cases include a clause reversing the burden of proof and placing it on the producer, manufacturer or importer, but such an obligation cannot be systematically entertained as a general principle. This possibility should be examined on a case-by-case basis when a measure is adopted under the Precautionary Principle, pending supplementary scientific data, so as to give professionals who have an economic interest in the production and/or marketing of the procedure or product in question the opportunity to finance the necessary research on a voluntary basis.

In summary the Precautionary Principle is not really a new approach, there exist several approaches which might be at least first steps in the application of the Precautionary Principle within the environmental and health regulation procedures in the EU and elsewhere.

2.4 Nanotechnology and regulation and the Precautionary Principle

If technologies are to be designed and developed with a view towards both safety and sustainability, it is essential to carry out technology assessment at an early stage and to understand the different types of innovation process involved. The aim of this contribution is to help answer the following questions, which are important in the assessment, promotion and shaping of nanotechnology:

- What can we know? And what can we do?
- What methodology should we follow? How can the prospective assessment of an emerging technology be more than blind, haphazard guesswork?
- Is there a technology-specific reason for explicitly focusing on nanotechnology? Why is so much attention directed to the potential beneficial and/or detrimental effects of this form of technology? Just how potent and/or versatile is it, and does it qualify as a “power technology” and/or “key technology”?
- Which aspects require special careful consideration in the development and design of this line of technology? In particular, what role can guiding principles play in helping us adopt a precautionary approach in steering the course of nanotechnology?

3 New technologies and technology assessment

It is not the aim of this project to facilitate comprehensive sustainability assessment. The focus is on ecological and health effects, i.e. both on the intended opportunities and the unintended risks and side-effects; more on easily identifiable short-term effects and less on easily anticipated long-term consequences. Scientifically endorsed technology assessment is based on reasonably well-established and formalized assessment procedures, methods and criteria. The procedures include not only political discussion forums involving the public, consensus conferences, hearings and e.g. Inquiry Committees set up by a parliament, but also environmental impact assessments, approval procedures and legal proceedings. The key methods employed include risk assessment, ecotoxicological and toxicological testing, cost-benefit analysis and life-cycle analysis. Examples of assessment criteria are resource consumption, greenhouse potential, impact on habitats and biodiversity, water pollution class, and acute and chronic toxicity. Ultimately, the assessment methods used should - in conjunction with assessment criteria - provide rigorous (i.e. for the most part scientifically sound) arguments for economical, political and public debates about choices of technologies, processes and products.
Our knowledge of the potential effects of substances, techniques and application systems is limited by:
- the as-yet-unknown
This is knowledge that is basically attainable but not yet available, perhaps because certain tests have not yet been carried out or because experience is still lacking in particular areas. There may be many reasons for this, such as total unawareness of the potential problem (as with the ozone-depleting effects of CFCs) or lack of resources (e.g. time, money, and manpower). A typical example is the specific effects for which chemical substances not registered before 1982 have yet to be tested (e.g. acute toxicity, CMR, biodegradability, bioaccumulation, etc.).

- the unknowable
For fundamental reasons, the ways in which unstable, complex and dynamic systems respond to intervention cannot be predicted. The reasons for this “unknowability” lie primarily in the system’s intrinsic “architecture”, that is to say the unstable condition of the systems within which the intervention takes place. However, the “intensity” of the intervention, in terms of both quality and quantity, also plays an important role. Examples include the unforeseeable response of ecosystems to the existence of “gaps” in their food chains or the unpredictability of the isolated, spatially and temporally limited effects of climate changes (e.g. when and how will the Gulf Stream react?).

3.1 Managing the unknown

When predicting the impact of an emerging technology, the inescapable problem of predicting uncertainty becomes acute. Nevertheless, there is a need to create information about the potential behaviour of nanotechnologies and to reduce the “as yet unknown”. Furthermore neither the “novelty” of a technology, nor lack of knowledge about its potentially problematic consequences, constitutes good and sufficient grounds for “great concern” or even for a comprehensive “moratorium”. Newness and insufficient experience justify “circumspect behaviour” - which is true for any non-routine activity in everyday life.

In order to warrant such “great concern”, and in turn taking comprehensive measures in accordance with the Precautionary Principle, further reasons are required. These reasons are generally intrinsic to the technology itself (e.g. extremely high power and potential impact, considerable depth of intervention) or the specific application contexts (intervention within an especially vulnerable, unstable and important supporting system). The level of potential risks is usually determined by:

i) the quality of the intervention (identification of high-risk technologies);
ii) the quantity of the intervention (identification of cumulative effects); and
iii) the quality of the system subjected to the intervention.

The development of sensible (rational and value-oriented) ways of managing uncertainty, and especially ‘dealing with the unknown’, is among the core tasks of “reflexive modernization”. Important prerequisites are:

i) analysis and characterization of the technology (i.e. of the type of intervention); and
ii) analysis and characterization of the systems subjected to the intervention. Here, the systems directly affected are the technical application systems, with human health and/or ecosystems affected indirectly.

3.2 The “characterization of technologies” approach to technology assessment

In response to the opinion - still frequently voiced - that technology itself is neutral, and only its various applications can be subjected to value judgements, we can say that technology is always a “way of dealing” or “form of interaction” with something. It cannot, in consequence, be neutral. At the same time, however, the question “to what use is it put?” is important in terms of its assessment.

Knowledge about the impact of a technology (the central prerequisite of technology assessment) requires familiarity with three basic elements:
i) An agent (the technology, substance etc. whose possible effects are to be assessed);
ii) An impact model (i.e. a scientifically verifiable theory on how the agent acts on a potential target.);
and
iii) A target upon which the agent acts (e.g. climate, ecosystem, organism, or organ).

In the case of nanotechnology, it is the impact model and/or the target system that are actually the unknowns. The proposed approach to problem-solving in technology assessment is to change the focus by changing the view from the potential target systems towards a closer look at the agent, in our case nanotechnology, which is going to act upon them. The emphasis is therefore on the characterization of the agent. We have to address the question of what (potential) effects can be expected or deduced simply by virtue of the “nano-scale” of the interventions.

3.3 Technology-specific effects

Technology-specific effects: “Size does matter!”

Let us now take a look at what makes nanotechnology so interesting:

i) Its potency and depth of intervention (the possibility of controlling the smallest building blocks of matter or – conceivably - of living things). To what extent is nanotechnology a “power technology” and/or a “high-risk technology”?

ii) The “new effects” achievable through its use. Where does nanotechnology merely improve and enhance existing possibilities and effects - and where does it bring about qualities that are truly new and unprecedented?

iii) Its versatility in both possible effects and applications. To what extent is nanotechnology a key technology and/or a fundamental innovation?

The following list gives some immediately obvious nano-specific aspects and effects, together with some of the possible (or expected) properties and effects based thereon.

Nano-specific aspects/effects

- **Small size**: Mobility and perceptibility/detectability
- **Specific surface area-volume ratio**: Adhesion, cohesion, agglomeration; => Altered chemical reactivity and selectivity; Catalytic effects, Quantum effects
- **Self-organization**: Uncontrollable, autonomous developments, replication
- **Precision of the specification and substance quality**: Chemical purity Defined particle size; “Rare”, and perhaps problematic, elements and groups of substances
The following table lists some immediately obvious nano-specific aspects and effects, together with some of the possible (or expected) properties and effects based thereon.

Table 2: Nanoqualities and derived problematic ‘nanospecific’ effects

<table>
<thead>
<tr>
<th>Nanoquality</th>
<th>Potential effects/problems</th>
<th>Non-nano examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well defined particle size and purity</td>
<td>Material and energy streams, resource consumption recycling</td>
<td>Technical ceramics</td>
</tr>
<tr>
<td>Material quality</td>
<td>Health and environmental hazards, problematic (rare) elements or groups of materials in open use</td>
<td>Gallium-arsenide in semiconductors Heavy metals in catalysts</td>
</tr>
<tr>
<td>Smallness and mobility of particles</td>
<td>Dusting, mobile in the air, remaining suspended entering the lungs and even the alveoli passing through cell membranes, the blood-brain barrier</td>
<td>CFC’s (mobility and persistence) Ultra fine particles from diesel engines</td>
</tr>
<tr>
<td>Adhesion, cohesion, agglomeration</td>
<td>Fate of emitted nano-particles or fibres in environment, ‘intrinsic safety’ by tendencies towards adhesion, cohesion and agglomeration?</td>
<td>Metal-ions in soil with mobilising and piggyback effects</td>
</tr>
<tr>
<td>Changing chemical reactivity and selectivity</td>
<td>Altered ratio between surface and content leads to massive changes in catalytic reactivity, unexpected toxic and ecotoxic effects are highly presumable,</td>
<td>Problematic effects of ultra fine particles seem to be strongly dependent on size, and surface of the particle, perhaps less on the (main) substance</td>
</tr>
<tr>
<td>Changing and intensified catalytic effects</td>
<td>Altered ratio between surface and content leads to massive changes in catalytic reactivity, unexpected toxic and ecotoxic effects are highly presumable, also photocatalytic effects in inorganic (atmosphere) and organic areas</td>
<td></td>
</tr>
<tr>
<td>Quantum effects</td>
<td>Mostly depending on highly defined and purified conditions, where impurities are a source of technical failure. In the environment side effects in organisms or ecosystems are more or less unlikely</td>
<td></td>
</tr>
<tr>
<td>Self-organisation</td>
<td>On one hand highly promising for resource efficient technology, consistent with natural processes, on the other hand hazard of uncontrolable developments (self-replicating nanobots)</td>
<td>Self Assembled Monolayers, Bio mimetic materials</td>
</tr>
</tbody>
</table>

Source: IÖW

4 Characterisation of Nanotechnologies

Taking into account our present-day knowledge there is, with regard to nano-specific effects (excluding self-organization effects and cumulative effects of mass production) no reason for particularly great concern about global and irreversible effects of the specific technology ‘per se’, on a par with the justifiable apprehension concerning nuclear technology and genetic engineering. The nature and level of risk of nanotechnologies that can be anticipated is perhaps most akin to that associated with (synthetic) chemistry. If we are to avoid making the numerous mistakes seen in the field of chemistry, then it is necessary to assess and consciously shape technologies – and to adopt precautionary measures - at an early stage. The REACH system outlined in the current EU White Paper on Chemicals Policy prescribes risk analysis and management procedures which are probably also
adequate for most nanotechnological applications. With regard to risk management, too, much can be learned from the chemical industry and from the handling of chemicals. However, the risk management of chemicals still has shortcomings with regard to implementing the Precautionary Principle which is developed especially for chemistry but may be applicable to other circumstances (“inherently safe substances, techniques and application systems”). This includes the still widespread failure to incorporate available precautionary measures in the development of substances and technologies, and therefore the neglect of guiding principles as “instruments” of influence and design.

Thus a double-track approach may be the most promising concept for the “sustainable nanotechnology” project:

- Identify the technology-specific impact mechanisms of nanotechnology. It is especially important to establish more firmly the appropriateness of, and soundness of reasoning behind, the “characterization of technologies” approach and to improve its (differentiating) power to predict possible effects.
- Choose and justify particularly “interesting” application contexts, which may include:
  Those with a particularly high degree of intrinsic sensitivity (in terms of the quality and architecture of the affected systems). Here, risk assessment would be the method of choice.
  Those which exhibit a considerable social dynamic in any case (because of potential intensification, mass and cumulative effects, and level of input). The preferred instrument here is life-cycle analysis.

4.1 Environmental and health effects of nanotechnologies – overview over recent research

Diversity of materials

Engineered nano-materials must not be considered as a uniform group of substances. Instead there exists (or will exist) an extraordinary breadth of nanoscale designed materials, there are

- many different types,
- they can be of many possible sizes and possess different surface coatings,
- there is not one 'most important' class of materials to focus on,
- nano-materials are diverse and will be used in many forms and sizes.

Because of the sheer diversity of nano-materials, it is virtually certain that some examples will cause problems to our environment and human health with respect to whole life cycle. 'Nanoengineered particles' are a huge class of materials. They span sizes from 1 to 100 nm, with diverse compositions (ZnO to gold) and shapes. Moreover, the core inorganic species is only half or less of the major part of these materials - namely their surface. To consider only the core composition without concern for its surface chemistry and stabilization will surely lead to problems interpreting any data. There is not likely to be one simple answer when it comes to whether or not nano-particles are 'safe'. Differences in size, shape, surface area, chemical composition and bio persistence require that the possible environmental and health impact be assessed for each type of nano-material in its own right: closely similar compounds may induce substantially different health effects (Oben 2003, Hort et al 2004).

Furthermore engineered nano-particles present high surface areas in solution and can adsorb molecular contaminants. This coupled with their small size can provide such species access to areas of the body and cellular organelles not normally exposed. Facilitated transport of such impurities, exogenous or endogenous in nature, could be an even larger problem in biological systems than the nano-particles themselves.

4.2 Possible effects on health and environment

Translocation

When inhaled, nano-particles translocate within the body and might be found in liver, brain and even the fetus. Nothing is known about the effects of these translocations. At the conference Nanotox 2004
Vyvyan Howard described possible translocations of nano-particles to the fetus, while not having finished this research at that time he seemed to be convinced that he will be able to proof this evidence. Against the background of several studies Howard mentions that “once ultrafine particles have been internalized there appears to be a natural 'passageway' for them to travel around the body” (Woottlif 2004) Günter Oberdörster (University of Rochester, New York) tracked the progress of carbon particles that were only 35 nanometres in diameter and had been inhaled by rats. In the olfactory bulb nano-particles were detected a day after inhalation, and levels continued to rise until the experiment ended after seven days. Nevertheless little is known about what effect nano-particles will have when they reach the brain (Oberdörster 2004).

Smallness
Potential problems might arise from increased reactivity through the relatively larger surface area of nano-particles. Also, nano-particles entering the human lung via inhalation might not be filtered out due to their small size and be transferred into the blood stream causing problems and negative health effects. Oberdörster mentions, that agglomerated nano-particles might not be a problem (or not more a problem than other PM’s) individual nano-particles might cause severe problems. Conventional compounds which are normally considered to be harmless might therefore prove to be dangerous on a nanometre scale.

Adverse effects of new materials
Current research suggests that for example nanotubes might damage the lungs when inhaled. The related studies are however contradictory in their results. One study suggests that inhaled clumps of tangled carbon nanotubes caused the same effect as ordinary dust to the lung. Within another study, the exposition to individual carbon nanofibres the test animals (mice) provoked lesions of their lungs and intestines (Brumfield 2003).

Effects of nanotubes – different studies with different nanotubes and different results:
Nanotubes trigger the formation of granulomas (a combination of dead and live tissue surrounding the material) which is a significant sign of toxicity. Nevertheless different studies come to different conclusions regarding the seriousness of granulomas: While Lam (NASA) reports that the granulomas stay a problem, the study of Warheit (Du Pont) mentions that granuloma formation might be observed but that the inflammation trails off after three months. It has to be pointed out that both researchers used different nanotubes. The Warheit study used laser-evaporated nanotubes in rats. Lam used HiPco and Carbon arc NTs in mice (Lam 2003)

Same material different reaction
The same materials may behave in different ways. Carbon black as well as nanotubes consist of carbon. While carbon black produces in toxicological tests no reaction carbon in form of nanotubes (here single walled Nanotubes SWNT) produce reactions in lungs (granulomas). The main reason might be the different forms of carbon: individual tubes are ~ 1,5 nm diameter and several microns long, as bundles nanotubes are packed tightly and parallel to form rods. Nanotubes are structured as fibres while carbon black is amorphous. Also, the surface chemistry is different between SWNT’s and carbon black (Lam 2003).

Environmental effects
There are some worries about the ability of nano-particles and micro-particles to control heavy metal and radionuclide mobility in the environment. Brumfiel (2003) reports that researchers at the RICE University investigated the behaviour of buckyballs. They suspended buckyballs in water and then poured them through a soil-like material. The behaviour of these buckyballs changed with extremely different consequences. Where the buckyballs clumped together and formed particles of some micrometers, these were absorbed into the soil (as any other organic material). Where the buckyballs were dispersed it was observed that water formed a protective sheath around each buckyball with the consequence that these buckyballs might travel through the soil without being absorbed and therefore might pose a risk for groundwater. Furthermore there are hints that this material might enter the food chain. Brumfiel reports that nano-particles might be absorbed by earthworms (Colvin 2003).
Since nanoparticle research is still in its infancy, only general recommendations regarding research and treatment can be made:

- Differences in size, shape, surface area, chemical composition and persistence require that the possible environmental and health impact be assessed for each type of nanomaterial.
- There is a need for classification of nano-particles because not all nano-particles seem to cause the same degree of inflammation.
- A general proposal concerning nanoapplications in medicine is that they should be water soluble to avoid potential problems in the body.
- Avoidance of the open use of nano-particles, as long as there is limited knowledge concerning the behaviour (for example quick agglomeration to bigger particles etc.)

In general the environmental fate of nano-materials has to taken into account. The behaviour of nano-materials in different environmental mediums has to be observed. Research at the Rice University tries to identify the effects of nano-materials in soil (Bio persistency, Dissolution, Biodegradation, Aggregation (adsorption to environmental matrix) in aquatic environment (Dissolution and suspension in aqueous media, Sedimentation) and further raises the question on Bioaccumulation (Earth worms and Aquatic animals) (Tomson et al 2003).

The preliminary findings of this research are:

- States of aggregation of nano-particles may change in various aqueous environments.
- Adsorption of contaminants to the surfaces of nano-particles is very strong.
- Adsorption/desorption of organic compounds to nano-particles might be hysteretic.
- Adsorption/desorption of heavy metals onto/from nano-particles are predictable based on surface area normalized sorption isotherm.
- Nano-materials in natural aqueous environments may affect the fate and transport of contaminants substantially.

4.3 Ultrafine Particles and nano-particles

The limited knowledge of nano-particles is based mainly on knowledge about ultrafine particles. Research in this field made enormous advances in the 90s and showed that the success in the reduction in air pollution through more efficient combustion processes might have unintended consequences as the proportion of ultrafine particles increases. Ultrafine particles are suspected to have adverse effects on the human body and the environment. Ultrafine particles, unlike nano-particles, are the result of combustion processes. The comparability of the two particle types is therefore limited and nano-particles might trial additional and / or other problems (Kreyling 2004, Colvin 2003).

4.4 A life cycle approach to nano-materials

As pointed out in the previous sections nano-particles might cause problems especially in open use. A glance at the life cycle of nano-materials shows:

1. Production processes of nano-materials differ significantly. Engineered nano-materials are not necessarily produced by combustion processes (except CVD/DVD and Flame Assisted Deposition) but mainly in liquid or closed gas phase reactors. Therefore direct exposure to engineered nano-particles might be limited.

2. Products: Most nano-particles are enclosed or fixed in products, for example nanotubes in screens, particles in surfaces and coatings. The chance of nano-particles being released is limited.

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3. The behaviour in disposal and recycling is not yet well researched, but we think that the possibility of a release of individual nano-particles might be negligible. It has to be born in mind that currently very limited and preliminary knowledge concerning the questions above exists.

As a general rule we think that the main focus of research should ask questions like: Will there be an open use or a release of nano-particles. If this is the case precautionary measures should be undertaken, as long as there is a limited knowledge base concerning the behaviour of nano-particles (do they agglomerate? What are the potential environmental and health effects?).

**Manufacturing Processes of Nano-materials**

In the following section we give an overview of production processes of nano-materials esp. nano-particles. The list focuses on processes during which release of nano-particles might occur with possible adverse effects. Furthermore we look at some products containing nano-materials as well as nano-particles. No information is currently available concerning the disposal of products containing nano-particles. We should underline that these findings are preliminary and furthermore based mainly on assumptions. Sound knowledge concerning the effective release of nano-particles is not yet available.

1. **Vapour Phase Deposition (CVD, PVD)**

A very important procedure for the production of nanoscaled powders and thin layers from vapour-phase starting substances is vapour phase deposition, which is divided roughly into chemical (CVD) and physical (PVD) vapour phase deposition.

In the case of PVD, solid raw material in a vacuum environment is transferred into the vapour phase by physical effects (e.g. thermal energy). The particles condense on a substrate attached opposite and thus build up a thin film. The different processes of the PVD differ by the vapour deposition method, i.e. the way the material that is evaporated is heated. The conventional method for heating is thermal evaporation, further methods are sputtering, arc evaporation, molecular beam epitaxy (MBE) or ion plating.

CVD covers all processes, which lead by means of a chemical reaction of the gaseous starting substance on or near the substrate to a separation of solid products. The gaseous predecessor material is led into a reactor and chemically divided by energy input. The energy input takes place either thermally, via stimulation of the reactants in plasma or via electromagnetic radiation. A part of the formed intermediate products is absorbed at the substrate, where a film is formed by a heterogeneous reaction. Important CVD processes are: thermal CVD, plasma-activated CVD (PACVD), Photo-CVD as well as the catalytic CVD, which is used increasingly with the production of carbon nanotubes.
2. **Flame-Assisted Deposition**

Nano-particles can be synthesized by the decomposition of liquid or gaseous starting substances in a flame. Among the most well-known procedures are flame spray pyrolysis, flame hydrolysis (Aerosil-process) and flame synthesis. Hydrogen diluted with argon or hydrocarbons serve as fuels. A substantial advantage of these processes can be seen in the fact that the flame already brings in the necessary energy. Thus fine-grained powders without complex pre and subsequent treatment are producible. Furthermore, complex vacuum plants or reactors are not necessary with the production of oxides. Particle size and crystal structure can be affected by variation of the concentration of the reaction partners, the flame temperature and the retention time of the basic materials in the flame. However, particle size can be defined only inaccurately with these parameters. Nevertheless, these processes are already used extensively in industrial applications, due to their simple applicability.

3. **Sol-Gel Processes**

The sol-gel process represents an extraordinarily important wet-chemical process for the production of most diverse nanotechnological products such as powders, thin layers, aerogels or fibres. In the first step, nano-particles are synthesized in a solution by the reaction of the liquid components, this is called the sol. Subsequently, the transfer of the sol into the gel condition takes place. The molecules formed in the sol can grow together either over chemical reactions, until they represent one space-filling macromolecule, or individual sols are thickened, until a gel stabilized by electrostatic repulsive forces is formed. By destabilization of the sols and/or gels nano-particles of defined size can be precipitated. One of the most promising possibilities offered by the Sol gel process is to produce organically modified products by connecting organic and inorganic components.

4. **Precipitation**

Precipitation is a chemical procedure to synthesize nano-particles from solutions. Adding suitable substances activates the precipitation procedure. Thus, either a change in the composition of the solvent occurs, so that the precipitable material becomes slightly soluble and/or insoluble, or a new connection is formed, whose solubility is clearly smaller than the concentration in the solution. The formation of nano-particles runs gradually over crystalline germs or amorphous primary particles up to particle agglomerates. It must be ensured that germ formation and nucleation rate is larger than the growth rate of the particles. In the case of a continuous precipitation, particle size distribution and structure of the agglomerates can be procedurally adjusted by the correct choice of flow conditions and reciprocal effects between particles.

5. **Self Assembled Monolayers (SAM)**

Long-chained organic molecules form closely packed monolayer structures by adsorption on oxidic and metallic surfaces. Thus, ultra-thin layers can be manufactured, whose structure is given by the arrangement of the substrate atoms. Accumulated molecules enter a chemical connection with these substrate atoms and the emerging layers are called self-assembled monolayers. If the molecules separated in the monolayer carry a further functionality, besides the functional group for the connection to the substrate, this can be used, for example as a template for the selective separation of inorganic materials.

6. **Molecular Imprinting**

Molecular Imprinting is a procedure that allows synthesizing a highly interlaced polymer in the presence of a template molecule. A template can be understood as a molecule, that controls structure and arrangement of the system synthesized on it, by its defined geometry growth. Functional groups of the monomer are spatially fixed with those of the template and thus the outside form of the template is copied. Subsequently, the template molecules are removed by extraction. By this means cavities with binding sites of well-defined spatial arrangement remain in the polymer network. In order to select the
appropriate guest molecule the template is identical to it or resembles it strongly in its structure, so that it can be recognized and bound molecularly.

7. Lithography

Lithography processes used for the production of nanostructures can be divided into two categories: parallel methods structure the entire surface simultaneously, whereas the structure is written gradually with the serial methods. Parallel structuring methods are optical lithography, electron beam and ion beam projection processes atomic lithography as well as X-ray lithography. Serial processes are electron beam writing and ion beam writing, as well as scanning probe lithography. Optical lithography is the most commonly used process of all for the production of nanostructures. The semiconductor structures produced with this process finally generate the basis of the entire electronic industry. In optical lithography, light or X-ray is projected through masks with a certain structure and hits a sample surface covered with photoresist. After the formation of the resist, the mapped structure will usually be transferred to the substrate by etching processes. The smallest size of the attainable structures depends on the wavelength of the applied light.

When using electron beam lithography there are two ways of writing: directly with a focused beam on the substrate (electron beam writing), or the structure can be given through a mask (electron beam projection process). Ion beam lithography is very similar to electron beam lithography; however with this process direct structuring of a component is possible without photoresist and etching.

Use phase

Much less knowledge exists concerning the use phase and the emission of nano-particles. Particles are often fixed in products and therefore the release of nano-particles might be limited. There is, however, an explicit use of non-fixed particles for example in the case of sunscreen and the emission of nano-particles for remediation. Finally, the special effects of nano-particles are central to the economic value of nano-particles. They might have adverse effects in other than the intended applications as for example in catalytic converters. Taking into account the limited knowledge of the behaviour of nano-particles, our main advice is to avoid open use until safety is proven. Considering the main industrial application of nano-particles the hazards might be limited. An overview of some main products and the relating production processes as well as potential release of particles is given in table 3.

Summary

The production processes of nano-materials and/or nano-particles are diverse and so are the possible risks of release of nano-particles. While the main processes are based on wet procedures others are based on gaseous processes. While the gaseous processes might cause problems concerning the release of particles, the actual existing information illustrates that containment measures might be improved and that the emissions are relatively low compared to emissions produced by combustion processes especially by traffic. Nevertheless the specificity of engineered nano-particles should be taken into account. Procedures to reduce the potential risk of release of nano-particles and consequently the main problem might exist. They could be identified using the concept of “characterisation of nanotechnologies”, but of course must be put into action.
<table>
<thead>
<tr>
<th>Nanotechnology based products</th>
<th>Nanostructure</th>
<th>Manufacturing process</th>
<th>potential hazards</th>
<th>industrial sector</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application Area: New Surface Functionalities and Finishing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tribological layers: e.g. superhard surfaces</td>
<td>ultrathin layers; nano-crystallites; nanoparticles in an amorphous matrix</td>
<td>vapour phase deposition, PECVD</td>
<td>PVD/CVD production process: risk of disposal of nano-particles is small (process is running in a vacuum environment)</td>
<td>engineering, automotive</td>
</tr>
<tr>
<td>thermal and chemical protection layers</td>
<td>ultrathin layers; organic-inorganic hybrid-polymer; nanocomposites</td>
<td>vapour phase deposition; sol-gel/lithography</td>
<td>use stage: low scale disposal of nanoparticles possible</td>
<td>aerospace, automotive, ICT, food</td>
</tr>
<tr>
<td>self-cleaning and antibacterial surfaces</td>
<td>ultrathin (polymer) layers, nano-crystallites in an amorphous matrix</td>
<td>vapour phase deposition, sol-gel, soft lithography</td>
<td></td>
<td>textile, ICT, food, building, medicine...</td>
</tr>
<tr>
<td>scratch resistant and anti-adhesive surfaces</td>
<td>ultrathin layers; organic-inorganic hybrid-polymer</td>
<td>sol-gel; SAM</td>
<td>use stage: low scale disposal of nanoparticles possible</td>
<td>building, automotive, textile, consumer goods</td>
</tr>
<tr>
<td>products with &quot;nanoparticle effects&quot; : e.g. colour effects in lacquers</td>
<td>nano-particles, ultrathin layers</td>
<td>flame assisted deposition, flame hydrolysis, sol-gel</td>
<td>production: deposition possible; use stage: low scale disposal possible</td>
<td>building, automotive, consumer goods, textile</td>
</tr>
<tr>
<td><strong>Application Area: Catalysis, Chemistry, Advanced Materials</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>catalysts</td>
<td>nanoporous oxides, polymers or zeolites; ultrathin layers</td>
<td>precipitation, sol-gel, SAM, molecular imprinting</td>
<td>not known</td>
<td>chemistry, automotive, environmental, biotech</td>
</tr>
<tr>
<td>sieves and filtration</td>
<td>sintered nano-particles, nanoporous polymers</td>
<td>self assembly, colloid chemistry</td>
<td>not known</td>
<td>chemistry, environmental</td>
</tr>
<tr>
<td><strong>Application Area: Energy Conversion and Utilisation</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>fuel cells</td>
<td>ceramics from sintered nano-particles</td>
<td>div.</td>
<td>not known</td>
<td>energy, automotive</td>
</tr>
<tr>
<td>super-capacitors</td>
<td>nanotubes, nanoporous carbon aerogels</td>
<td>div.</td>
<td>nanotubes possibly toxic when inhaled</td>
<td>energy</td>
</tr>
<tr>
<td>superconductors</td>
<td>ultrathin layers</td>
<td>e.g. vapour phase deposition</td>
<td>production: risk of disposal is small</td>
<td>energy, medicine</td>
</tr>
<tr>
<td><strong>Application Area: Construction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nanoscale additives: e.g. carbon black in car tires</td>
<td>nanocrystals and nanoparticles</td>
<td>flame assisted deposition, flame spray pyrolysis</td>
<td>production process: disposal of nanoparticles possible, danger of inhaling for workers; use stage: low scale disposal of nanoparticles possible</td>
<td>building, automotive</td>
</tr>
<tr>
<td>nanoparticle reinforced products: e.g. temperature resistant components</td>
<td>(amorphous) nano-particles</td>
<td>flame assisted deposition, flame hydrolysis</td>
<td></td>
<td>automotive, ICT, consumer goods, medicine, aerospace</td>
</tr>
<tr>
<td><strong>Application Area: Information Processing and Transmission</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nanoelectronic components</td>
<td>ultrathin lateral nanostructured semiconductors</td>
<td>PVD, CVD, lithography</td>
<td>PVD/CVD production process: risk of disposal of nano-particles is small</td>
<td>ICT</td>
</tr>
<tr>
<td>Displays</td>
<td>ultrathin layers</td>
<td>PVD, spin-coating</td>
<td></td>
<td>ICT, automotive</td>
</tr>
<tr>
<td><strong>Application Area: Nanosensors and Nanoactuators</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sensors: e.g. GMR-sensors</td>
<td>metallic ultrathin layers; ultrafine tips</td>
<td>CVD/PVD/MBE; etching, SAM</td>
<td>PVD/CVD production process: risk of disposal of nano-particles is small</td>
<td>automotive, engineering, ICT, analytics</td>
</tr>
<tr>
<td>probes e.g. for scanning tunneling microscope</td>
<td>ultrathin layers, ultrafine tips and molecules</td>
<td>PVD, etching, SAM</td>
<td></td>
<td>analytics</td>
</tr>
<tr>
<td><strong>Application Area: Life Sciences</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>active agent carrier: e.g. drug carriers</td>
<td>organic molecules, nanoporous oxides</td>
<td>self assembly, anodic treatment</td>
<td>flame hydrolysis production process: disposal of nano-particles possible; use stage: particles might be absorbed dermally; very small TiO2-particles possibly toxic</td>
<td>Pharma, medicine</td>
</tr>
<tr>
<td>Cosmetics: e.g. pigments</td>
<td>ultrathin layers from nano-particles, (amorphous) nano-particles</td>
<td>wet-chemical separation; colloid chemistry</td>
<td></td>
<td>cosmetics</td>
</tr>
<tr>
<td>sunscreen</td>
<td>nanocrystalline titanium dioxide (TiO2)</td>
<td>flame hydrolysis</td>
<td></td>
<td>cosmetics</td>
</tr>
</tbody>
</table>

Source: IÖW
5 Existing and future regulatory frameworks for nanotechnology

We have seen so far, that the Precautionary Principle as understood by the European Commission advises policymakers to take specific action on two levels regarding the regulation of nanotechnology. The first is related to a better understanding of the technology and its effects. We have therefore presented an approach to assess technology and also discussed potential hazardous effects of nanotechnology. We have seen that serious concerns regarding toxic effects of nano-particles exist. They are however not grave enough to require immediate regulatory action. The Precautionary Principle however suggests a two-fold strategy to further investigate subject matter. On the one hand, the toxic effects of upcoming nano-applications should be better understood. On the other hand, the existing regulatory regimes should be investigated to understand whether they are suitable for future nanotechnology applications. Since the focus of this study is on the latter, we will pursue the second task in the following.

As stated before, specific regulation relating to nanotechnology or its applications do not yet exist. Different opinions exist as to whether new, specific regulations are/will be required or existing regulatory frameworks are sufficient. The debate about nanotechnology and regulation will intensify once more, applications of nano-technology will be available and some form of regulatory action will be inevitable. To establish the necessary framework, a reasonable basis has to be laid out. This basis consists for the most part in a better understanding of the nanotechnology effects on human health and the environment and on the suitability of existing regulatory frameworks. The following areas of regulation might be affected by future developments of nanotechnology.

- Emissions
- Chemicals
- Occupational safety
- Drugs/ pharmaceuticals
- Cosmetics
- Food and novel food

The current main concerns relate to:

- Particle size
- Form of nano-particles
- New properties of nano-particles

The main scientific difficulties in judging toxic effects of nano-particles relate to measurement problems and to determination of the full contribution of nano-particles to the overall amount of toxic emission.

5.1 Examples 1: Chemistry and cosmetics Regulation

The legal system of the Federal Republic of Germany has not yet produced any specific regulation regarding nanotechnology or its application. A discussion about the possible need of such regulation has been started however within expert groups. In the following, two regulatory frameworks, chemicals and cosmetics, are presented and discussed with hindsight to their adequacy for nanotechnology applications. The area of chemicals was chosen because this area shows the highest number substances subject to obligatory registration. Cosmetics regulation deserves closer scrutiny because a number of cosmetic products like suntan lotion or toothpaste already contain substances in nano-size.
**Chemicals**

The registration and admission of new chemical substances is laid down in the Chemical Law. The registration and admission of existing substances is regulated by Council Regulation (EEC) No 793/93 of 23.03. 1993 on the evaluation and control of the risks of existing substances.

Importers and producers of new chemical substances are required to register them. New chemical substances are all substances which are not listed in the European Inventory of Existing Chemical Substances. Whether a substance is a new substance depends solely on the chemical formula, a new size or new physical properties do not qualify as a new substance if the formula is already listed.

For the registration process, producers and importers have to provide information on physical, chemical, toxicological, and eco-toxicological properties as well as on the use of the substance (in the case of Germany) to the Federal Institute for Occupational Health and Safety (BAUA). The detail of the information depends on the intended production volumes of the substance. Basic toxicity, mutagenic etc. testing is required from a production volume of one ton upwards. The rule of thumb is the higher the production volume the higher the information requirements. The requirement to submit test results is purely based on production volume, not on particle size. If the particular information does not yet exist the producer is obliged to undertake the relevant testing to fulfil all information requirements.

The registration sheets are then distributed to several different evaluation authorities (occupational protection, environment, health) who evaluate the substances according to their properties. All information sheets are subjected to the authorities’ judgement. If they suspect any hazardous effects from the new substance, the authority is required to undertake a risk assessment. The result of the risk assessment then determines further action, which ranges from in-action to requiring further testing from the producer to classification or prohibition of the substance.

According to the judgement of authorities’ representatives, the existing regulatory framework is adequate to deal with the introduction of new substances in the nanotechnology domain. A producer wanting to produce nano-tubes would in the opinion of the expert interviewed for example be required to undertake inhalation testing. If there were any indication of hazardous effects, the authority would undertake a risk analysis. To detect hazardous effects of nano-substances, new testing methods and procedures might eventually be required.

There is however one area of concern which relates to the declaration. The producer is not required to declare the particle size of the substance. In the opinion of the Federal Institute for Occupational Health and Safety (BAUA), the producer might be obliged to declare particle size while describing the use of the substance. However, it is presently unclear if the existing regulation definitely obliges the producer to do so.

All substances which are listed within the European Inventory of Existing Chemical Substances do not have to undergo registration and can be produced and traded according to the rules found within the register. Existing substances which are re-manufactured to nano-size are not classified as such during registration but as micro-pedants to the original substance, if they are registered at all. According to the statements of a representative of the Federal Institute for Occupational Health and Safety BAUA, monitoring of existing substances which are re-manufactured to nano-size is difficult since a producer would not have to register them. Regulators are however aware of this problem and have started internal discussions to consider it.

Problems of current chemical regulation:

- Testing based on production volume, not on particle size
- Testing measures not adapted to small sizes
- Remanufactured substances fall through testing although they might be toxic (e.g. due to particle size).
- Possibility to treat nano as a product - then they would have to be registered and tested to fulfil information requirements during registration.
Cosmetics
The production and commercialisation of cosmetics is regulated by the cosmetics Directive 76/768/EEC. According to this directive there is no registration or admission procedure for cosmetics. Producers or importers are liable to due diligence and have to make sure that the ingredients of their products are harmless. A producer is also required to keep records of the documents on which the innocuousness is based. The cosmetics regulation lists substances which are prohibited for production, substances which are only to be used with limitations and substances which are suspected to be hazardous and need further testing to be declared as harmless. Also, a producer has to submit specific data about the contents of its cosmetics to a number of public agencies, who test the substances for their harmlessness.

The controversial case of the use of titanium dioxide illustrated problems of using nano-scale substances within cosmetic products. As an inorganic UV-filter, nano-scale titanium dioxide belongs to a category of substances which is suspected to have hazardous effects and had to be reviewed by the Scientific Committee of the EU-Commission to avoid possible negative effects. The substance in nano-scale has been added to suntan cream since the mid-nineties. Since its properties were considered equal to the long existing macro version of titanium dioxide and admission was based on chemical formula and not on particle size, no separate scientific review of nano-titanium dioxide was undertaken. Macro titanium dioxide was allowed as an additive to suntan cream up to concentration of 25 per cent.

Public concern about the risks of nano-particles and nano-scale titanium dioxide made the Scientific Committee for Cosmetic and Non-Food Products SCCNFP of the EU-Commission test the substance for toxic effects. The SCCNFP concluded that nano-scale titanium dioxide was safe to use within the existing limitation of a 25 per cent maximum concentration. This decision is however questionable since the review by the SCCNFP was purely based on industry studies and doubts about the safety of the substance are still raised within the scientific community (Christ 2003, Royal Society 2003) The increased surface in general might damage skin by free radicals as these materials are active photo catalysts. There are however ways to overcome this problem, for example by coating the nanoparticles (Royal Society 2003: 10). Furthermore, Colvin reports that the research on the effects of free radicals are based on micronised titanium. Information for particle sizes below 100 nm is not yet available. One other important issue might be the stability of the organic components in sunscreens that contain nanoscale titanium and zinc oxide particles. These materials are active photo catalysts and the free radical species they generate under illumination can degrade sunscreen formulations. These processes can also damage biological molecules which might pose some risk to consumers. Nevertheless the risks of sun exposure are more severe (Colvin 2003).

A number of other cases of equalising macro- and nano scale substances can be observed although reservations regarding the safety of the nano-version of the substance persist. The US Food and Drug Administration took the same stance regarding nano-scale titanium dioxide. A German administrative court concluded, in the case of a dispute over the approval of a production facility for nano-based materials that the emissions of the facility could be treated as emissions containing ultra-fine particles. Existing emission regulation was therefore, in the eyes of the court, suitable to protect against hazards and no further warranties were imposed.

Problems of cosmetics
Problematic within the regulation of cosmetics is the equalization of nanoscale substances with their macro pedants. They are either not tested at all, because they are considered equally safe as the same substance on a macro scale, or they are subjected to tests designed for known hazardous effects leaving hazards intrinsic to nano-sized substances unconsidered.

6 OECD Principles of good laboratory Practice and nano-materials and applications
The OECD Principles of Good Laboratory Practice (GLP) were adopted by the OECD Council in 1981 as an Annex to the Council Decision on the Mutual Acceptance of Data in the Assessment in
Chemicals. The background of this decision was that government and industry were concerned about the quality of non-clinical and environmental safety studies upon which hazard assessments are based and that in different countries different schemes of implementation were developed and with this there might be obstacles to trade as each country might insist that its own practice in testing standards is the pre-condition for market entrance.

By having a variety of laboratory standards two problems arise. Firstly, similar tests have to be carried out several times to comply with different standards. Secondly, testing might be costly and time consuming and might furthermore be used as an instrument of protectionism. To overcome these obstacles the OECD Principles were developed with the purpose of promoting the development of quality test data. Comparable quality of test data forms the basis for the mutual acceptance of data among countries.

According to the OECD, the scope of the Principles of good practice should be applied to the non-clinical safety testing of test items contained in pharmaceutical products, pesticide products, cosmetic products, veterinary drugs as well as food additives, feed additives, and industrial chemicals. These test items are frequently synthetic chemicals, but may be of natural or biological origin and, in some cases, may be living organisms. The purpose of testing these test items is to obtain data on their properties and/or their safety with respect to human health and/or the environment. The European Union established these principles in Directive 1999/11/EC of 8 March 1999 which have to be transposed into the national law of the member states.

The data quality should be ensured by Test Guidelines and the Good Laboratory Practice. By this the Mutual Acceptance of Data should be ensured. While the test guidelines prescribe the way the tests should be carried out, Good Laboratory Practice is a kind of quality assurance of the institution carrying out the test. The Principles of Good Laboratory Practice are mainly a managerial approach to develop transparency concerning the results of testing, which is the main point concerning the mutual acceptance of data as well as the pre-condition for the avoidance of non-tariff barriers.

The main point concerning the testing of nanotechnology (products) might not be the question concerning Good Laboratory Practice but instead the test guidelines which might have to adapted to the potential special effects of this new technology.

For example new knowledge about environmental and health problems has to be followed by new testing guidelines: The OECD has set up a Task Force on endocrine disrupters, which has as its principal task the development of new Test Guidelines:

- Enhancements and modifications of existing Test Guidelines
- Development of new Test Guidelines
- Management of validation work, as appropriate
- Development of harmonized strategy for the screening and testing of endocrine disrupters
- Sharing testing and assessments

This approach is used for newly-identified environmental and health problems. In the case of nanoparticles, potentially adverse environmental and health effects have been identified (for which at least for macromaterials test guidelines more or less exist). For currently unknown adverse effects, testing procedures are obviously not conceivable. But on the other hand there might exist problems of adequate testing of nano-particles, such as measurement problems (for example particle number vs. mass). Identification of some of the new effects of nano-particles might only be possible in special research institutions.

This shows the need for developing a metrology for nano-particles and the standardisation of testing. This example shows that new developments have consequences for test guidelines as well as for assessment and validation. This might not only be a task for national authorities but also for the EU and international organisations in this field. A main task in the future will be to emphasise the focus on nanotechnology and nanotechnology products and procedures. Currently, we think that there is a need for an international effort to catch up with the rather fast development of nanotechnologies.

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3 For this problem new test methods have to be developed as well as existing testing methods to be revised.
There might be a need for
- Grouping of nano-particles
- Tools for Screening and Testing
- Co-ordination of Testing
- Sharing Hazard/Risk Assessment Reports

The question concerning the test of nano materials or products and the GLP Standards are actually not to be answered: as our research reveals, there is actually no procedure for nano-materials or products and there has been currently no registration of nano-materials labelled as such with the competent authorities.

Considering the needs and new tools for sustainable chemistry as developed by the OECD, for example
- Collection and generation of data (e.g., release estimation methodologies; product registers) and also
- Risk assessments (e.g., life cycle assessment; toxicogenomics/proteomics, transgenic animals)
- Risk management (e.g., sustainable chemistry; green procurement; socio-economic analysis).

We think that these efforts will cover problems of nanotechnology as well.

7 The Toxic Substances Control Act, REACH and Nanotechnology

The following chapter illustrates the limits of existing regulatory frameworks regarding nanotechnology by summarizing the application of the U.S. Toxic Substances Control Act to nanotubes.

The Toxic Substances Control Act

The Toxic Substances Control Act (TSCA) is the US regulation act for chemical substances. It was passed in 1976 and is administered by the Environmental Protection Agency (EPA). Its aim is to regulate chemicals in commercial use with risk or potential risk to the environment. Chemicals can be produced and traded freely. If a chemical has to be admitted through the TSCA, the enforcing agency EPA has to demonstrate that the new chemical substance might entail harm to health and the environment. The TSCA provides six different regulatory mechanisms to be used by the EPA:

- Inventory of chemical substances
- New chemical review
- Testing of existing chemicals
- Direct regulation of chemicals
- Reporting/record-keeping requirements
- Import/export requirements

The TSCA Chemical Substance inventory is a list of all chemical substances exiting in U.S. commerce. New chemicals are reviewed within the pre-manufacture notice process (PMN). The testing of existing chemicals is guided by test rules outlined by the EPA to industry. Direct regulation means that the EPA has the power to prohibit or limit the manufacture of chemicals based on risk assessments. Manufacturers must keep records and reports of potential adverse effects. Finally, TSCA and the Treasury Department define import and export requirements (Wardak 2003).

The TSCA defines a chemical substance as “any organic or inorganic substance of a particular molecular identity, including any combination of such substance occurring in a whole or in part as a result of a chemical reaction or occurring in nature and any element or uncombined radical”. This definition excludes mixtures, articles, pesticides, tobacco products, nuclear material, food, cosmetics, and drugs.
The TSCA Chemical Substance Inventory is a database of about 80,000 chemical substances in commercial use. All existing chemical substances, around thirty million (which mainly exist within research laboratories), are listed in the Chemical Abstract Service (CAS) database, run by the American Chemical Society. Of the 80,000 chemical substances held in the TSCA database, only 50,000 have been reviewed and only 5,000 have been subjected to rigorous testing. The TSCA database provides information on the existence but to a much lesser extend on the risk of chemical substances (Wardak 2003).

The TSCA and the Precautionary Principle

The TSCA differentiates generally between existing and new chemicals. Within the regulations regarding existing chemical substances, no aspects of the Precautionary Principle were included while designing the regulation. If a chemical is already on the market, the EPA has to provide evidence that the substance might be hazardous. Regulatory action can only be taken if most scientific uncertainty about the effects of a chemical substance has been resolved (Wagner 2000). This highly contradicts the essence of the Precautionary Principle which suggests regulatory action in any form if the degree of uncertainty is high. Manufacturers on the other hand have little incentive to gather information on the toxicity of their existing products apart from possible reputation damage if harmful effects of the substance materialise.

Regarding new chemicals, some of the respective TSCA elements have been designed in accordance with the Precautionary Principle. If a producer wants to market a new chemical substance he has to file in most cases a pre-manufacturing notice (PMN) to the EPA. The EPA then has to determine from the information reported in the PMN whether the new substance might have hazardous effects. If any indicators for potential hazards are found in the PMS, EPA can subject the producer to further testing of the chemical substance. The burden of proof is in this case, in accordance with the Precautionary Principle, partly shifted to the manufacturer. If the new chemical belongs to a certain product class known for its hazardous effects, even stronger testing requirements are prescribed by TSCA regulation.

The first conceptual, un-precautionary gap in the TSCA model of regulating existing and most new substances is that they do not get tested if they are not suspicious. Also, the information requirements within the PMN relate mostly to the identity and the future use of the chemical rather than the possible effects. The producer is not required to include health- or safety related information on the new substance (Döhmann 2003). Health and safety information is only required if the new substance includes substances which already have been subjected to safety testing as components or if the substance belongs to one of 45 categories of known hazardous substances. Different regulations apply if the chemical is produced in very high quantities or its use exposes it to a high number of persons. In those two cases, the EPA has to provide evidence that the substance might pose some risk of substantial human exposure or release into the environment to require further testing by the manufacturer. The threshold for the EPA to require further investigation from the producer is, in other words, lower. The second conceptual and un-precautionary gap is that the agency has to provide all proof for possible hazards if the substance is already on the market.

The weaknesses of the TSCA outlined in the preceding paragraphs relates to all types of chemical substances. In the following, the TSCA will be reviewed with regard to nanotechnology applications.

Applying the TSCA to Nanotubes

Nanotubes are an already commercialised nanotechnology application, produced mainly by sixteen firms of which eight are located within the United States. The companies produce over 2.5 tons of nanotubes every day. Carbon nanotubes are used in semiconductor and metal applications and might replace the use of silicon in semiconductors within the next fifteen years (Wardak 2003).
is manufactured within or imported to the US, it is has to undergo the TSCA procedure. The following steps describe the application from the point of view of the producer of a new substance.

If the new substance falls within the TSCA definition of a chemical, the first step of the producer is to find out whether the substance is already listed in the TSCA Chemical Substance Inventory. The TSCA inventory as such indicates the general classification problems of new chemicals - which might become more difficult with nano-technology applications. Firstly, some existing types of nanotubes were not listed in the TSCA inventory although there are hints that they are commercial products. Secondly, some nanotubes were not listed in the categories where a chemical expert, according to their formula, would expect them to be listed.

If the substance is already listed and no rule or order regulates the substance, it might be manufactured straight away. The most important rule regarding existing chemicals in this context is the new use rule which will be discussed below. If the substance is not listed, the producer faces two options:

1. The producer can report under TSCA and apply for an exemption from the regular pre-manufacturing reporting
2. The producer can report under TSCA, not seek an exemption, and enter the pre-manufacturing reporting

Exemptions
In order to manufacture a new substance without having to undergo TSCA regulation, the producer may apply for three different forms of exemption. They are the Low Volume exemption (LVE), Low Release and Exposure (LoREx), and the Test-Marketing Exemption (TME). The LVE is probably the most important exemption in relation to nanotechnology. It exempts a manufacturer from full PMN reporting if less then 10 t of a particular chemical are produced per year. It is likely that many nano-chemicals will meet this exemption due to their relatively small production volume.

The second exemption is the Low Release and Exposure Exemption (LoREx). It states that the chemical must have no dermal or inhalation exposure to workers and consumers, must meet the low-volume exemption, and must not be released to groundwater and landfills. It is hard to meet this exemption and it is even harder to think of nano-applications which might qualify for this exemption.

The Test-Marketing Exemption (TME) can be applied if only small amounts of the chemical substance are produced to explore its market potential before going into mass production and distribution. It is also likely that nano-chemicals will qualify for this exemption since the number of nano products is expected to grow enormously in the coming years.

If the exemptions are denied or the producer does not apply for exemption in the first place, a pre-manufacture notice (PMN) must be filed. The PMN must be filled 90 days before start of production. In this part of the process, the problems of information provision and further testing for potential hazards re-appear. If the chemical is not subjected to further testing, it will enter the chemical substance inventory and production may succeed

New Use Rule
An additional problem of the existing TSCA regulation is the Significant New Use Rule (SNU). A producer might want to commercialise a chemical substance which already exists but will have a significant new use. If this is the case, the producer has to file a Significant New Use Notice (SNUN) which allows the EPA to consider and evaluate the new use of the chemical. Establishing and evaluating new uses might be difficult given to the property changing ability of nano-engineering. Establishing a “new use” is therefore a foreseeable problem. In addition to that, new substances might be compliant to TSCA regulation but might also have significant new uses entailing potential hazards.

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6 All new substances are exempted from TSCA regulation without application if they are used for research and development only.
The aspects outlined above highlights the problems of the TSCA regarding nanotechnology. This rather superficial view of the complex TSCA process has highlighted a number of problems and it is likely that more will arise if the process is reviewed in depth and new commercial applications hit the market. Already foreseeable problems relate to classification, exemptions from regulation, and the establishment of new rules (Wardak 2003).

7.1 REACH - the future chemical control regulation of the European Union

REACH stands for Registration, Evaluation and Authorisation of Chemicals and will be the future standard chemicals regulation within EU member states. REACH will regulate the commercial admission of new chemical substances and the testing regarding toxic effects of around 30,000 existing commercial chemicals which have not been subjected to systematic testing so far on the environment and human health. The aim of the REACH framework is better protection of human health and the environment without threatening the competitiveness and the innovative capacity of the EU chemical industry. It is highly likely that the REACH system contains a number of similar weak points regarding the regulation of nanotechnology applications as found above within the TASC.

The heart of REACH is an integrated system for registration, evaluation and admission of chemical substances which will replace around 40 existing, separate directives and orders. REACH has however not reached its final legislative stage. All following conclusions regarding the relation of REACH to nanotechnology are based on the revised proposal of the EU-Commission and are therefore tentative. A step by step review as undertaken in relation to TSCA is only possible to a more limited extend.

The first step of the REACH system includes already the most obvious problem - similarity to the TSCA. Generally, all new and already existing chemicals must be registered in a central database of a future European Chemicals Agency. However, if less then one ton of the chemical is produced per year they need not be registered with the chemicals agency. The producer is only obliged to pass on existing safety information to clients.

Although the required registration threshold is only a tenth of the TCSA threshold, due to the minimum weight of nano-applications and their yet unknown properties even a tonne of a hazardous nano-application might pose a serious health or environmental risk. Also exempted from registration are special materials groups like intermediates, polymers, and products which are included in other European regulation. This form of exemption might also turn out to be problematic due to the already indicated classification problems. New nano-applications might be classified and regulated under the wrong procedure might or not be classified or regulated at all.

Within the registration phase, the producer must provide the agency with a prescribed set of information and provisional evaluations on the intrinsic properties and hazards of the substance. The producer/importer must also provide information on the users and uses of the new substance. If the imported/manufactured volume exceeds 10 tons, information on risks for the identified uses for human health and the environment and how those risks are adequately controlled must be provided in a report. For lower volumes, safety information produced for the safety data sheets will be submitted as part of the technical dossiers. If the production volume of the chemical exceeds 100 tons extended information requirements have to be met.

Testing by the manufacturer is required already for registration if the existing knowledge on the substance cannot meet the information requirements for registration. It is not yet obvious whether the set of information requested also includes information on particle size. Also, the REACH system does not include a routine for significant new uses of existing chemicals.

Once the chemical is registered, the evaluation process commences. Central to evaluation is that the producer has to demonstrate that his new substance is innocuous. The evaluation process is carried out by agencies of the member states and includes dossier and substance evaluation. Dossier evaluation
means that the submitted dossiers will be reviewed for animal testing. They might be reviewed for compliance with the information requirements.

A substance evaluation may be undertaken if there are reasons to believe that it might be hazardous to human health or the environment. Submitted dossiers on new chemicals will only optionally be reviewed for indicators of potential hazards. As a result of the evaluation process the producer might be asked to provide more information on the substance to bring the registration dossier into compliance or clarify risks.

From a nanotechnology perspective the type of information requested by a future European Chemicals Agency is crucial to adequately evaluate potential health and environmental risks. Similarly to the TSCA, the likelihood of a new or old substance being subjected to further testing on potential negative effects increases with the level of certainty about potential harm. The more specific the type of information provided by the producer, the higher the chances of tracing negative effects. The EU-Commission declared: “It is expected that substance evaluations will focus on those substances that may pose the greatest risk to human health and the environment” (EU 2003). To avoid the conceptual no suspicion – no testing gap, information requirements for the producer should be adequately tailored.

All substances of concern will enter the authorisation process. Authorisations apply to particular uses of the substance in question and will only be granted if the producer demonstrates the adequate control of the substance or that socio-economic benefits outweigh the risks. Examples of substances that will be subject to authorisation are: carcinogenic, mutagenic or toxic to reproduction, persistent, bio-accumulative and toxic, very persistent, very bio-accumulative.

Registration and testing of existing substances under REACH

Chemical substances already in production or imported in volumes of 1 tonne or more per year, per manufacturer/importer, have to be registered in REACH. This means that around 30,000 marketed substances will need to be registered. Of these 30,000 around 20,000 are produced or imported in volumes of between 1 and 10 tonnes. Substances that are already on the market will be phased gradually into REACH. Substances produced in high volumes and known to be toxic will have to be registered first. Registration deadlines will be calculated from the year the legislation enters into force so that the new obligations will apply from:

- **year 3** for high production volume chemicals (1,000 tonnes or more/year/ manufacturer or importer) and highly toxic chemicals in volumes of 1 tonne or more
- **year 6** for production volumes in the range of 100 - 1,000 tonnes
- **year 11** for low production volume chemicals (1 - 100 tonnes)

### 7.2 REACH from a nano perspective

The current structure of the REACH-System has its focus on gradually testing all existing chemical substances. New substances will be only reviewed optionally. This is a reversal of existing regulation foci and is based on the fact that new substances constitute only around one per cent of all chemicals in commercial use. Evaluating the hazardous effects of existing chemical substances is, in the eyes of the EU Commission, more urgent then reviewing all new substances. This has a number of implications for nano-technology applications. The gaps in existing regulation regarding the re-manufacturing of existing substances to nano-size might be closed. This supposes however that manufacturers will not start declaring the remanufactured existing substances as new substances. New substances under the REACH system are only optionally reviewed. This is an area of concern, since new substances of the nano-domain might have toxic effects of yet unknown dimensions, which might not be discovered through registration. Also, as stated before, whether the toxic effects of a new substance under review
will be discerned depends strongly on the information requirements. Including the particle size into the information requirements could be considered.

8 Operationalising the Precautionary Principle

There is no life without risks. There is no way towards a sustainable economy and society without innovation. Innovation and risk are inextricably linked. The fact that a certain technology, procedure or substance is new, is insufficient grounds for far reaching measures justified by the precautionary principle. Additional causes for concern are required. In many cases there will be no other choice than to give things a try. But the method of ‘trial and error’ has its limits. It is appropriate only for small and more or less reversible steps.

If we may reasonably expect global and irreversible effects of certain projects, technologies or interventions the method of trial and error is just irresponsible. The production and deliberate release of CFCs was such a case. The precautionary principle has to be applied in cases of high technological potential and effectiveness, i.e. either extremely large steps by a single innovation (high depth of intervention) or high volumes and growth rates of little single steps (accumulative effects).

Thus cautiousness with regard to the quality and quantity (dynamics) of the innovative steps we make is the guideline for making the precautionary principle operational. Information about the quality of the steps can be obtained by ‘characterising the technology’. Information about the quantities and dynamics of application can be obtained by surveying the production.

8.1 Implementation of the Precautionary Principle in REACH

Within REACH (Registration, Evaluation and Authorisation of Chemicals) - the current concept for a new kind of regulation of chemicals and their associated risks – we can find both approaches to making the precautionary principle operative. On one hand, the quantities of an innovation (substance and/or application context) determine the risk analytical effort. The intensity of the tests, or the amount of required data, respectively, is determined by production volumes. For high volumes the most substantial data are required, for smaller volumes remarkably less and for volumes common in research and development nearly no data is required.

On the other hand, qualitative aspects of innovations and substances (in the sense of the amount of intervention) play an important role in this new approach to regulating chemicals. Certain properties of chemicals like carcinogenicity, mutagenicity or reproduction toxicity (CMR) determine the requirements of risk management to a large extent, even without an analysis of exposure, which is an equally important step within a complete risk analysis. An extremely interesting example of operationalising the precautionary principle is the planned handling of very persistent and very bio accumulative (vpvb) chemicals. These qualities give a high probability of irreversible exposure (and with the additional quality of mobility, for global exposure). This alone is reason enough for chemicals with these qualities to undergo authorisation, even without concrete indications of the probable occurrence of adverse effects. Measures of risk management are in this case direct consequences of a ‘characterisation’ of the technology or substance, even without any scientific model of cause and effects!

8.2 Learning from REACH for the Regulation of Nanotechnology

The two ways of applying the precautionary principle are transferable to any approach for regulating nanotechnology within REACH or within an independent form of legislation.

With regard to production volumes of nano particles gradually adjusted requirements for (eco)toxicological data are highly recommended. Furthermore, the requirements of risk analysis and risk management are dependent on the probability of exposure within the factories or, in case of release, dependent on the potentially global and irreversible range of exposure (requirement of containment, inherent safety etc.).

With regard to qualitative and quantitative aspects special attention is recommended towards the fate and possible adverse effects of nano particles due to their smallness, their mobility, their ability to

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7 Supposing that unified measuring standards for particle size exist.
reach the alveoli within the lungs, and due to the changing reactivity (compared to macroscopic particles) and catalytic effects.

On a larger time scale special attention is additionally recommended to the possibilities of self replication and self reproduction. There is a possibility of a shift from molecular self organisation, which is already utilised in many cases in nano technology, towards these more problematic dynamics.

8.3 Possible Measures

Actually there is a task to prove whether the procedures which are proposed for CMR- and vpvb-substances in REACH should be also applied to nano particles. We do not know enough about nano particles, but they seem to share a high probability of adverse effects with CMR-substances (still not equally specified). And they seem to share with vpvb-substances a high probability of unexpected inner (lungs, blood-brain-barrier) and outer exposure (mobility, staying suspended in air, piggy-back effects). But here, too, more knowledge is necessary of the qualities and the destiny of nano particles in the human body and in the environment – also in the sense of technology characterisation.

Furthermore, with regard to long-term trends it is essential to look at developments in the field of self organisation, self replication and self reproduction of nano molecules, organelles, assemblers, or robots. The attitude, present in many debates, that self replication and self reproduction of nanotechnological objects is just science fiction and will never happen is neither adequate nor responsible. Furthermore, there will be a loss of credibility, if actors do not impose these same limits on their hopes and expectations with regard to ‘positive’ effects of nanotechnology in future.

Finally we have to mention two additional possibilities of operationalising the precautionary principle far beyond the regulative approach of REACH. First, there is the development and design of technologies following guiding principles such as ‘inherently safe nanotechnology’ or ‘sustainable nanotechnology’. A second approach is the integration of safety, health and environmental (SHE) aspects into the intra-enterprise quality management and also the supply-chain-management. Risk minimisation and risk management is not only the task of the authorities. Especially scientists and developers (not to forget funding of R&D) and also the economic actors (enterprises) have the duty to tap their full potential.

Innovation and risk are inextricably linked. Innovation needs freedom. These socially granted liberties have to be applied in a very responsible way.

9 Innovation, Precautionary Principle and intervention

The main question in the case of innovations is when and where to take precautionary action. Our proposal is that in the case of nanotechnology, which is still in its infancy, the Precautionary Principle should be taken into account at a very early stage. This is because at the beginning of the shaping of technologies major action can be taken to avoid future problems and with this the Precautionary Principle in this stage of nanotechnology development might be the leitmotiv for inherently safe nanotechnologies. But of course the R&D stage is just one stage and might be complemented by the production, use and disposal stages where inherently safe handling has to be the leitmotiv. In an ideal case inherently safe nanotechnology would avoid the common problem of end-of-pipe regulations.

Graphic 2: R&D, Production, Life Cycle and potentials to avoid EHS threats
Graphic 2 shows the important stage of R&D as well as product design concerning the potential adverse effects of nanotechnologies. Ideally most of the potential adverse effects might be avoided in these early stages. The knowledge which might be derived from the characterisation of technologies approach might give important hints for design processes. As shown, the characterisation of technologies approach shows, given experience of chemical regulation, that there might be some unintended consequences of nanotechnologies. With this in mind, the design processes should avoid these obvious problems and make nanotechnologies inherently safe. Consequenlty, problems in the production, use and disposal stage might be avoided - otherwise adverse effects might be the consequence. The chance to reduce adverse effects in the following stages might be characterised as add-on strategies, usually involving high costs.

Of course even in the following stages inherent safety might be a strategy, as used for example in high risk chemicals.

However, technological developments are usually path-dependent. Once one way of development is successful other potential paths are not further developed, although perhaps preferable from an environmental point of view. Thus, with path creation, exit options become expensive and the stakes of a lot of persons are involved. This is not only a problem of environment but might become a problem of producers and users of nanotechnologies in case adverse effects are identified and cause an existential problem to producers.

So the main idea is that at an early stage of development main issues are at stake and some guiding principles as for example “inherently safe nanotechnology” might be one way to overcome some problems. While it is not necessarily clear if this will lead to some form of “sustainable nanotechnologies” it is at least a major step in this direction. We think that some preliminary problems might be identified and some advice developed concerning possible action (regulation as well as self regulation).

### 10 Regulation approaches in selected European Union member countries and the US.

The following section gives an overview of the regulatory activities regarding nanotechnology in the United Kingdom, Sweden, Denmark and the US. Several representatives of regulatory bodies, mainly in charge of the registration of chemical substances, were contacted and a number of interviews were held. The aim of the interviews was to gather information on current activity regarding the regulation of nanotechnolgy and to identify problems which representatives of public authorities associate with the regulation of nanotechnology. The states were selected according to their traditional role as lead countries regarding environmental and health regulation (Sweden, Denmark) or because of an advanced public discussion of nanotechnology within the country (US, UK). In general, one can distinguish a number of different regulatory approaches to the problem of nanotechnology and regulation.
• **Self regulation** before having scientific results. Cosmetics producer L'Oréal, for instance, dropped its research on the characteristics of buckyballs after outside researchers raised questions about toxicity. The Rice University found nano-particles from nanotubes on the research staff’s skin. Hence, an enclosed area was set up and nanotubes were converted into powder form, which might be easier to contain.

• **Changes in the Regulation** according to nano-specific requirements.

The main conclusion from our enquiries with representatives of national regulatory bodies is that in general the existing regulation has the capacity to handle present and future nanotechnology products and substances. Also, no specific form of nanotechnology regulation has been issued yet. Existing regulation might however need to undergo some changes regarding guidance and application as well as some nano-specific extensions. This conclusion is however only preliminary. Our research made evident that existing regulation has not yet been applied to nanotechnology applications and nanotechnology is only in rare cases part of the regulatory body’s agenda. Also, the awareness that future nanotechnology might have implications for health and safety regulation is limited.

**United States**

The United States is by far the most advanced country regarding the development of nanotechnology and the debate between government and industry on possible regulatory implications from nanotechnology. That is however not to say that the US debate has yet produced any substantial results or specific regulatory action. However, the awareness of potential problems is bigger then in the other investigated countries, possibly matched only by the awareness in the United Kingdom.

The US awareness is e.g. expressed in the initiation of dialogues between representatives of the nanotechnology business community and concerned regulatory bodies and workshops on the subject matter. The workshops for example transcend the subjects of effects of nanotechnology on the environment or health and explicitly address societal implications.

The main regulatory take on the problem of emerging nanotechnologies within the US Food and Drug administration is to communicate with the industry on the one hand and to hold internal discussions about the nature of nanotechnology applications on the other. If a manufacturer produces without communication or declaration, they stated, now regulatory steps can be taken. Since industry has a strong incentive, in their opinion, to communicate new contents of products. New regulation or a change of existing regulation is, following the judgements of representatives of the food and drug administration, not necessary.

At most, the use and the guidance of existing regulation and some toxicity tests might have to be changed. The most important step in the eyes of the experts is however to engage in a dialogue with manufacturers and decide on a product-by-product basis how to proceed. This regulatory approach assumes willingness to share information and cooperate as well as consciousness of potential hazardous effects from the manufacturers’ side. It also assumes an at least superficial understanding of the risks of a new product containing nano-materials to identify and evaluate risks. The approach requires from the regulators intensified information of the business community about the possibility of hazardous effects and on existing regulation to safeguard against them.

A particular gap in safety regulation could be identified regarding the use of nano-materials. In the US the material safety data sheets (MSDS) for most nano-materials list properties and restrictions which are identical to those given for the macro-scale bulk material. Thus workers using micro-scale substances have no formal requirement for or safety precautions beyond those adopted for bulk solids of identical composition.

**The United Kingdom**
The UK shows a similar public discourse on the relationship between nanotechnology and regulation. The last report of the Better Regulation Task Force, an independent institution advising the British government on regulatory issues, included a section on the subject. Also, comprehensive study on nanotechnology currently carried out by the Royal Society with results due to be published in spring 2004 prominently included the aspect of regulation.

The approach towards nanotechnology taken within the Health and Safety Executive, the authority responsible for the regulation of chemicals in the workplace and industrial areas, resembles the US FDA position. Their main activity regarding nanotechnology is currently to gain a deeper understanding of the technology’s effects and to persuade companies and researchers to undertake more research into hazardous effects. The agency’s representative underlined that the agency is still in an early phase of horizon scanning while being aware of potential implications for regulation of future nano-applications. The representative interviewed did not express the opinion that the British Chemical Agents directive might have to undergo change. However guidance might have to be changed. He expressed concern regarding the size of particles but concluded that before further steps to handle the subject could be taken, international standards for measuring particle size were needed. He also expressed concern regarding the re-manufacturing of existing chemical substances on a nano-scale. Whether those products should be treated as new materials should be decided on an EU-level.

A public stakeholder debate carried out by the Royal Society yielded the following statements by representatives of industry, science, and government regarding the regulation of nanotechnology:

- Strong pleas for more research on the toxic effects of various nano-particle groups and classification of these groups
- The view that existing regulation and legislation will cover all potential problems until self-replicating machines have become reality
- Toxic effects are expected to be similar to effects of existing substances and products
- Concern was expressed regarding size and reactivity of nano-particles
- Participants expressed the need for open debate about risks, risk assessment and risk governance
- Representatives of industry stated the need of self regulation for industry to avoid risk
- A generically new danger deriving from nanotechnology was not expected since all applications derive from the existing collection of technologies. Nano-sciences may have individual risks, but these should be dealt with separately, not collectively.
- Also, the fear of over-regulation before enough research was carried out to understand harmful effects of nanotechnology was expressed.

Sweden

The public debate on nanotechnology and regulation seems to be much smaller than in the US and UK. Swedish authorities have not yet been looking into the subject of nanotechnology and regulation. The cosmetics control department has not yet discussed the subject and no manufacturer in Sweden so far approached the department with a nano-product. It is however perceived as a problem within the department that cosmetics regulation covers the formulas of substances but not their size. The National Chemicals Inspectorate has not yet analysed the issue of hazards/risks from nanotechnology and nano-size particles/molecules and was therefore unable to consider the question of implications for regulation.

Denmark

As in Sweden, a public debate on nanotechnology and regulation does not seem to exist in Denmark. Also, public bodies currently do not address the issue. No relevant environmental or chemical regulation exists and the Danish Environmental Protection Agency considers the domain as a problem for the future. Questions on the implications of nanotechnology development on regulation could therefore not be addressed. The agency has, however, commissioned a report on future environmentally friendly design which includes nanotechnology which is due in spring 2005.

What can we say about regulation of nanotechnology?
• Awareness of possible implications of nanotechnology development for existing regulatory regimes is still limited
• No specific type of regulation has been issued yet within EU-member states
• USA, England and Germany lead in discussing the subject, Sweden and Denmark show much less awareness or action
• The current regulation of chemicals in the European Union is not adequate to cope with nano specifics, a new form of declaration might solve a number of problems
• Within the future REACH-System, detecting hazardous effects depends partly on design of information requirements and might perhaps not be able to cope with nano specifics
• Most experts consider existing regulatory frameworks as sufficient for nanotechnology. Possible changes might be introduced regarding guidance of regulation, introduction of new tests tailored to nano-scale substances and the stronger consideration of particle size
• The example of the TSCA shows that substantial gaps regarding the classification and registration of nanotechnology applications already exist.
• Our preliminary findings point to the fact that the situation within the EU might not be different
• Existing substances which are remanufactured to nano-size do not have to be registered

With regard to the potential risks and hazards which might be caused by nanotechnologies the following question must be raised: what might be the appropriate reaction towards this technology and especially in face of the limited scientific knowledge concerning the environmental and health effects of these technologies and their applications. This relates to the question of the level of precautionary action that should be taken: reaching from a total ban, a moratorium, strict regulation, regulation at all or enforcing scientific knowledge.

Representatives of regulatory bodies and academia hold to the majority the opinion that problems potentially caused by nanotechnology might not be so different to problems which already exist and that they are covered by the regulation of chemicals as well as genetically modified organisms.

The case of nano-particles on which the emphasis is put in this study, the regulation of chemicals and especially of hazardous chemicals might be appropriate, not at least because there exists knowledge about the problems of hazardous substances as well as dust and other potential hazards of materials. Especially interesting in this regard is the necessity of authorisation within the REACH-System for chemicals that are very persistent and very bio-accumulative even without any specific model of (eco)toxicological effects.

In general, registration and approval procedures for new substances and products are a good mechanism to evaluate the hazardousness of new products. Routines to examine existing substances, as within the REACH system, heighten protection against potential harm. Regulation areas which will be confronted with nanotechnology to the most extent within the near future are emission, chemicals, occupational safety, pharmaceutical, and food regulation.

Approval procedures exist for the main fields of nanotechnology applications. Nevertheless it has to be pointed out that there might be a need to adapt these regulations with regard to the potential special effects of nanotechnologies and what might be even more important, to initiate discussion processes within the regulatory community, which might be the adequate rules for the potential effects of nanotechnologies especially of nano-particles. Current regulation of particles is based on particle mass per unit, which might not be adequate anymore since toxic effects also result from the (small) size of particles. Our survey has shown that the regulators in different member states of the European Union actually have not taken action at all. In some member states first discussions have been initiated, but in general the problem perception seems to be still very low.
11 International Discussions on nanotechnology regulation

At the international level first discussions concerning the regulation of nanotechnologies are beginning. In general three approaches might be identified

- Foresight Guidelines, with the focus on molecular nanotechnologies and the aim of avoiding the release of self replicating nanobots by measures which might reduce the possibility of uncontrolled behaviour of these nanobots.

- The ETC-group pointing out that nanotechnologies are inherently unsafe and might pose a risk on the one hand for the environment and on the other hand for society as a whole - with this there is a call for a moratorium (etc group 2002)

- Pacific Research Institute, which discusses at least three options - a moratorium, a use only in military applications as well as some form of self regulation (Pacific Research Institute 2002)

All these proposals seem in one form or another not really applicable to the real world problems of nanotechnologies and nano-particles. While of course there exist dark sides of nanotechnologies main points are not really developed. On the one hand these proposals do not reflect the possibilities of the shaping of technologies and on the other hand they were only concerned with the technologies as such. With our focus on nanotechnologies, especially on nano-particles the question becomes more complicated: on the one hand we propose the possibility of the shaping of technologies (here nanotechnologies) with some guiding principles and on the other hand the question of regulation could not only be focused on the technology as such, but there is a need for the development and adaptation of the whole regulatory framework to the specifics of nanotechnologies.

Thus we will not discuss the need for the development of a regulatory framework fitted to the specifics of nanotechnologies, since a lot might be drawn from existing regulations in the field of chemicals as well of genetically modified organisms. Taking this in account there is an urgent need for some form of self regulation in industry, not at least in the interest of the industry itself, because a lot of investment is at stake.

Furthermore the question must be raised what might be the adequate level of the regulatory approaches given the great diversity of nanotechnologies: is there a need for a general regulation of nanotechnologies or might it be more appropriate to regulate at a more sectoral level as for example chemicals, food etc.

Some of these efforts are starting in the United States and might be considered as a cooperative effort to identify environmental and health problems and to find adequate solutions. In the following we give an overview of one effort in the description of the research needs and the possible action.

11.1 Need for research by the chemical industry – as seen by industry, regulatory authorities and researchers

In 2002 a workshop entitled “Nano-materials and the Chemical Industry – R&D Roadmap Workshop” was held (Vision 2020 2002). Its main aim was to identify the technical objectives and difficulties in the application and marketability of nano-materials within the chemical industry and the key requirements for R&D were derived. Further aspects - pertaining to safety, the environment and health – were also identified. It should be pointed out that discussions on these three areas were restricted solely to problems directly pertaining to them that could result from use of nano-particles and nano-materials. Longer-term problem areas were barely touched upon in this respect.

These other areas are referred to below, since these fundamental questions are of importance for further research efforts, in that they basically constitute a research agenda for nanotechnology.

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There are many possible impediments to market development that result from a lack of knowledge about the safety, environmental and health impact of nano-materials. They include:

- A lack of knowledge about the airborne dispersal of nano-particles
- A lack of knowledge about environmental concentrations of nano-particles (problem: measurement and quantification)
- Great uncertainty concerning the upscaling of production, as no environmental standards exist
- Insufficient knowledge about health risks of nano-materials
- A lack of data on toxicity
- Insufficient experience with regard to the safe handling of nano-particles
- Largely inadequate knowledge about the impact on health, safety and the environment

This led to the following research priorities being drawn up:

- Development of models to enhance understanding of the inhalation and uptake of nano-particles and their transfer to the blood circulation or tissue
- Investigation of the short- and long-term effects of health risks caused by nano-particles
- Investigation of the breakdown of nanocomposites / the release of nano-particles into the environment

**R&D requirements:**

- Studies on the toxicological properties of nano-materials which are adsorbed by microparticles, and on the aggregation of nano-materials
- Compilation of health, safety and environmental data on nano-particles in various composites
- Toxicity testing and studies
- Interaction of nano-particles with human physiology
- Life-cycle aspects of nano-particles
- Modelling aimed at designing environmentally-friendly nano-materials
- Development of rapid screening processes
- Methods and criteria for measuring the toxic effects of nano-materials under conditions of use
- Recycling / immobilization
- Commissioning of environmental impact studies and life-cycle analyses (LCA)

**Main output of this high-priority R&D work**

- Comprehensive understanding of human toxicity as caused by nano-materials
- Rapid results for new materials
- Adequate understanding of the environmental impact and the indirect effects on health

Overall, it can be noted that we currently have only minimal knowledge of the impact of nanotechnologies on safety, the environment and health, and that this - especially from the point of view of industry - may hinder the development and marketing of these technologies. It must be stressed, however, that the problems mentioned are not fundamentally new ones; the main problem issue surrounds the methods of assessment that need to be applied in, for example, the chemical industry. Actually, as far as our knowledge is complete, these efforts are not really well developed but this might be a starting point for further action to develop this field.

**12 Recommendations**

The IÖW recommends on the basis of this study the following regulatory steps to be taken by the EU.

- Release of nano-particles should be restricted due to the potential effects on environment and human health
- A ban of the production of nano-particles seems not to be justified, not least because the emission in production, use and disposal of nano-particles might be limited if open use is avoided
- There is a need for guidance of nanotechnology for example by developing “inherently safe” nanotechnologies
• Nevertheless there is an urgent need for further research on the potential adverse effects of nano-particles
• There is a need to develop knowledge of the behaviour of nano-particles, this for industry in general as well for medical applications and potential health effects
• There is a need for transparency and open public discussion of the bright as well as dark sides of nanotechnologies
• The discussion concerning sustainable chemistry might give some main hints concerning potential adverse effects and chances to avoid at least known problems
• Industry should undertake some form of self regulation to ensure safe production and safe nanotechnology applications
• New regulatory regimes are not yet necessary. EU should however encourage and support the examination of the adequacy of existing regulation.
13 Literature


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The Royal Society (2003): Nanotechnology: views of Scientists and Engineers Report of a workshop held as part of the Nanotechnology study, download at: http://www.nanotec.org.uk/


# New .eu Domain

## Changed Web and E-Mail Addresses

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