Environment Agency

using science to create a better place

Technology roadmapping – An opportunity for the environment?

Science Report – SC050016

SCHO0407BMNT-E-P

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It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

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Science at the Environment Agency

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The work of the Environment Agency's Science Group is a key ingredient in the partnership between research, policy and operations that enables the Environment Agency to protect and restore our environment.

The science programme focuses on five main areas of activity:

- **Setting the agenda**, by identifying where strategic science can inform our evidence-based policies, advisory and regulatory roles;
- **Funding science**, by supporting programmes, projects and people in response to long-term strategic needs, medium-term policy priorities and shorter-term operational requirements;
- **Managing science**, by ensuring that our programmes and projects are fit for purpose and executed according to international scientific standards;
- **Carrying out science**, by undertaking research – either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen

Head of Science

Executive summary

Background

A roadmap is a plan that is made up of stages and set along a timeline. It sets out goals and defines the steps needed to reach them.

Motorola first coined the term 25 years ago. The company's chief executive saw the need to construct a plan to shorten the development time of new products, where getting new products to the market efficiently would increase company profits. Since then, many industries have adopted roadmapping as a tool to launch new products. But roadmapping has evolved, and the method is now used to plan wider technology developments such as nanotechnology, and industry futures.

Google provides nearly 200,000 hits on 'technology roadmapping' and there are now around 100 roadmaps freely available over the Internet, such is the popularity of the topic. The energy, manufacturing, materials and chemical industries all produce roadmaps, which track trends and drivers and identify roadblocks. They contain information about future developments, be it for a specific product, a technology or the path that an industry is intending to take.

Environmental considerations increasingly feature in roadmaps. However, the extent to which these are successfully incorporated is uncertain. What is certain is that the environment of the future - one that is moving away from reactive regulation - requires industries and companies to assess the potential impacts of their own developments. This assessment ideally needs to occur before developments reach the market, to mitigate adverse impacts wherever possible.

The Environment Agency needs to better understand this planning tool and to explore whether engagement with industry roadmaps could help protect the environment and reduce the need for reactive regulation.

Main objectives

The aim of this report was to assess whether technology roadmapping could help the Environment Agency achieve its objectives for greening business and improving the environment. The report describes the concept of technology roadmapping, including its history, development, methodologies and prevalence within industry. It looks at the usefulness of technology roadmaps as a source of horizon scanning information for environmental protection agencies, to provide early warning of products and services that could result in environmental problems, or reveal opportunities for improvement.

The involvement of other environmental agencies with industry roadmaps, particularly the US Environmental Protection Agency (US EPA), was examined to evaluate the potential of this process for the Environment Agency. Nanotechnology was used as a case study to illustrate technology roadmapping, where global nanotechnology roadmaps were reviewed and their main features drawn out.

Results

A survey of past roadmaps revealed a lack of involvement from environmental agencies around the world. Despite this, environmental considerations appeared to have become an increasing feature of many roadmaps.

Roadmaps developed in the energy, manufacturing and chemical industries tended to focus on energy efficiency, abatement of greenhouse gas emissions, cleaner production technologies, and residue and waste reduction. Materials-related roadmaps were more concerned with recyclability, improved infrastructure for recycling, design for recycling, life cycle analyses, and environmental modelling. Roadmaps for the medical and biotechnology sectors did not mention environmental issues as a strong driver, but did look at meeting current regulations, being cautious with GMOs and moving to disposable items. The roadmap reports for the electronics and devices sectors were much less concerned about environmental issues.

There was no reference to foreseeing potential environmental problems in the reviewed roadmaps. Instead, considerations appeared to be influenced more by the anticipated increase in environmental legislation and regulation.

International technology roadmapping experts were not aware of using horizon scanning as a means of identifying potential environmental problems early on, but they did see the benefits of such a procedure.

Many reports and technology roadmaps on nanotechnology emphasised environmental impacts. Nanotechnology roadmaps revealed that insoluble and poorly soluble nanoparticles are most likely to be of toxicological concern, and therefore research should concentrate on these nanomaterials to ensure safety in the workplace, for consumers and in the environment.

Conclusions

In conclusion, the report recommends a number of options for the Environment Agency to influence and benefit from technology roadmapping.   The Environment Agency should keep abreast of international roadmapping activities and liaise with environmental protection agencies in Europe, the USA and Canada. It should seek to have a stronger influence on industry roadmapping in the UK, possibly through the Department of Trade and Industry's Knowledge Transfer Networks (DTI KTN), which fund technology roadmaps. This involvement would provide foresight on environmental matters, and promote environmental considerations in industry's thinking on future developments. The goal would be to move away from reactive regulation and environmental clean-up towards preventative action.

For sectors which currently have relatively high environmental risks or impacts, such as chemicals and construction, the Environment Agency should consider encouraging the development of roadmaps. The US Department of Energy and The Canadian Department of Industry, also known as Industry Canada, have done this in many sectors.

The Environment Agency has the opportunity to take a leading role in horizon scanning for environmental issues that may emerge from the increasing number of roadmaps being produced by the EU. On nanomaterials, it is recommended that the Environment Agency become more involved in the OECD Working Party on Manufactured Nanomaterials, which has been established to address human health and environmental safety aspects of manufactured nanomaterials in the chemicals sector.

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1 Concept of technology roadmapping

1.1 Development of technology roadmapping

1.1.1 Background

Industry has never been under more pressure than at present, with trends towards:

- global markets and more intensive competition;
- rapid pace of technology change;
- high cost and risk of research and development;
- stockholder demand for near-term profits;
- increasing government regulation;
- customer pressures on costs;
- increasing technology/product complexity;
- greater environmental acceptability.

After the cost-cutting, downsizing and re-engineering of the late eighties and nineties, companies have now focused on what they believe to be their core competencies for the future. They have learned that cutting costs can only reflect on the bottom line (profit) for a short period. It might ensure a company's survival for a short while, but technological innovation is the only way to guarantee long-term growth and security.

Government *Foresight* exercises were an excellent way of stimulating organisations to think about the future, and enabled them to determine what was needed to stay ahead of their competition. This has now been overtaken, to some extent, by Technology Roadmapping. Just as President Bush's well publicised roadmap for the Middle East problems was a targeted strategy to solve the difficulties there, technology roadmaps are being drawn up by industry to set strategies for future growth, particularly through technological development. *Foresight* programmes set the scene for the future, but few detailed how to get there. Technology roadmapping not only offers a forward look, it also goes through the process of how to get there.

Technology roadmaps look at the trends and drivers of a particular topic, and the time horizons in which they are likely to be important. By linking market opportunities to product and technology developments, roadmaps can help support the communication of technology strategies and plans.

Technology roadmapping can:

- reduce technology investment risks;
- identify and capture market opportunities;
- respond to competitors' threats;
- identify the critical technologies, skills and core competencies needed;
- involve all of the supply chain in the planning process.

Motorola first coined the word "roadmapping" decades ago, but it is only recently that it has been adopted by other companies and industry sectors as an essential part of their strategies. Roadmapping is gaining popularity across the globe, although many of the technology roadmaps issued so far have come from the United States.

Nevertheless, in the last ten years it has become a common management tool, and a Google search for *'technology roadmapping'* provides nearly 200,000 hits. There are few industry sectors that are not covered by at least one technology roadmap. For example, over 70 technology roadmaps or strategy papers have been issued on 'materials', and nearly 30 of them deal specifically with nanotechnology.

1.1.2 Types of technology roadmaps

Of the roadmaps freely available through the Internet, there are three different types, as illustrated in Figure 1.1.

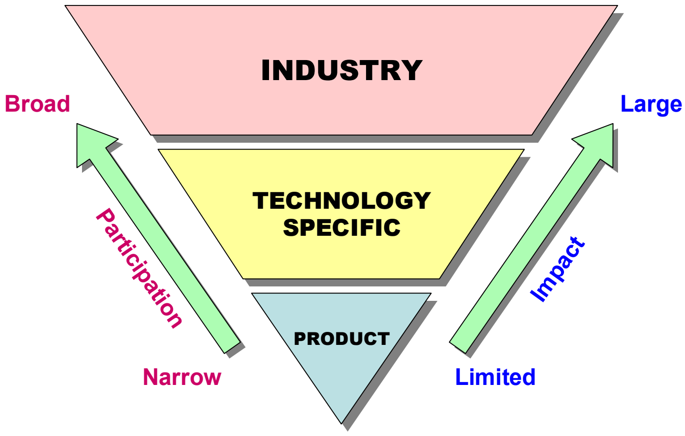

Figure 1.1: The three common types of roadmaps

1. Industry sector roadmap

The first type of roadmap covers a major industry sector such as glass or petroleum. Inevitably, its drafting will have involved a large number of people and it will tend to have a large impact on their communities, with users, suppliers and environmental groups all taking part.

2. Technology-specific roadmap

The second type of roadmap is technology-specific. Some recent examples include:

- nanomaterials
- bio-catalysis
- alumina technology
- alternative media, conditions and raw materials
- materials of construction, operation and maintenance in the chemical process industry
- new process chemistry
- colloid and interface science
- nanocomposites
- tissue engineering.

This roadmap tends to have fewer participants and does not have as large an impact as an industry sector one.

3. Product roadmap

The third type, a product roadmap, is much more specific. For example, it might be for a new washing powder or toothpaste for a consumer product company. The roadmap is usually confidential to the company and therefore is not widely distributed as are other types of roadmaps.

1.2 Roadmapping methods

1.2.1 Background

The method for arriving at a roadmap varies. Some simply rely on a Delphi-style questionnaire being sent out to people who are likely to be interested. Delphi questionnaires are named after the Oracle at Delphi, where experts were invited to give their opinions. Nowadays, however, most people have an aversion to questionnaires that often ask what seem to be irrelevant questions, and usually less than 20 per cent respond. Inevitably, experts whose input is most relevant are often too busy to reply.

However, it is crucial to engage experts in the particular field under consideration, by highlighting the benefits either to themselves or their establishments. Rather than using Delphi questionnaires, it is more acceptable to hold workshops to target those most knowledgeable in the field, and then receive input from other interested parties by putting a draft technology roadmap on a website.

1.2.2 Structure of typical technology roadmaps

Technology roadmaps tend to follow a very similar procedure, summarised in Figure 1.2.

Figure 1.2: The four stages in the roadmapping process

The process is logical and can follow the normal brainstorming practices used in industry.

1. Where are we now?

The first step is to establish where you are now relative to the competition, which might be within your country or throughout the world. This should be backed up with market research. This exercise might determine how far you remain behind your competitors, or identify gaps that might exist in your market areas.

In addition, prevailing trends and drivers need to be highlighted since they will have a major influence on the future direction and technology requirements. As a guideline, it is appropriate to use a STEEP process to assess trends and drivers. This follows the five steps shown in Figure 1.3, to examine the social, technological, economic, environmental and political trends and drivers. This process was previously known as a STEP or PEST procedure until the 'environmental' aspect became more influential.

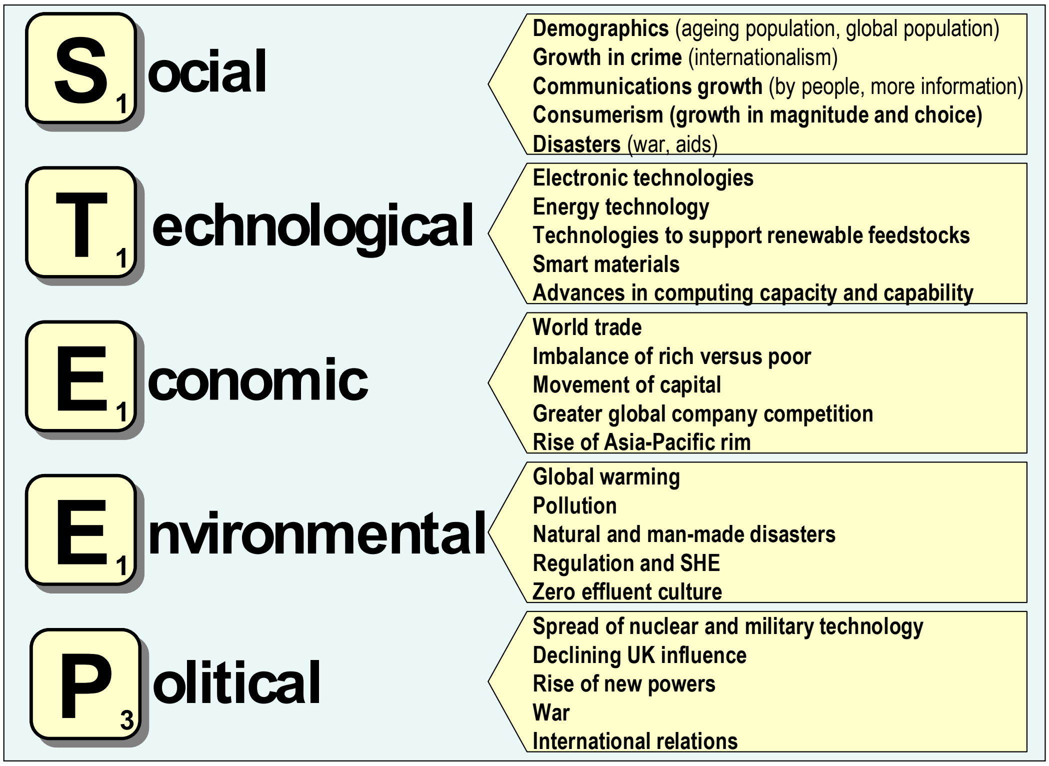

Figure 1.3: STEEP analysis to determine trends and drivers

2. Where do we want to be?

The second stage is to decide where you want to be in the future; not just short term and medium term, but also in the long term. Generally, long term is 10 to 20 years ahead, whereas short term can be up to two or three years, depending on the sector, and medium term can be up to 10 years.

This stage represents the organisation's aspirations for new products and processes as well as its services. However, it is prudent not to set targets that are unrealistic, since this can have a de-motivating effect on those concerned. Here, one has to balance the desire to set goals that will impress the most hardened of chief executive officers (CEOs), with targets that are not too outrageous. Governments appear to be going through a phase of setting targets that will never be achieved without considerable manipulation of the data.

3. What is stopping us getting there?

Having set ambitious but realistic targets, the third stage is to ask what barriers exist to getting where you want to be; that is, what is likely to stop you reaching your goals?

4. What needs to be done to overcome the barriers?

Finally, it is necessary to establish what is needed to overcome those barriers and in what timescale. This stage is perhaps the most important one to get right, and for a technology roadmap it is likely to be a list of research and development priorities.

It might be necessary to persuade non-technical leaders that a technology roadmap is going to play a key part of their strategy. Some of the benefits that may prove persuasive are that the roadmap will:

- enable the incorporation of new technology into the business;
- be the key support for the company's strategy and planning;
- identify new business opportunities for exploiting technology;
- provide top-level information on a business's technological direction;
- support communication and co-operation within the business;
- identify the gaps in technical knowledge as well as markets;
- support sourcing decisions, resource allocation, risk management and exploitation decisions;
- provide, through high-level integrated planning and control, a common reference or framework.

It is prudent to have people from all aspects of business involved in a technology roadmapping exercise, since the input from the marketing department is essential and the influence of the manufacturing department is also crucial. Once the technology roadmap has been agreed by all parties, the research and development programme can be drawn up and resources (capital investment, supply chain, staffing and skills) allocated.

1.2.3 Examples of recent roadmaps

The chemical and materials sectors have been particularly prolific at producing roadmaps. Those available in 2002 were listed in Materials World (Smith, 2002). By way of example, the procedures used for two materials-related roadmaps are summarised below.

Technology roadmap for materials of construction, operation and maintenance in the chemical process industry

(http://www.chemicalvision2020.org/pdfs/matconst.pdf)

This technology roadmap was instigated through the US Government's initiative *Vision 2020*, which was the US equivalent of the UK's *Foresight* exercise. The *Technology Vision 2020* for the US chemical industry highlighted construction materials as an important issue, and a decision was made to carry out a detailed investigation of what needed to be done to map out future requirements in this area.

The "Where are we now?" question was obvious, since most chemical plants are costly and subject to corrosion, as well as being energy intensive. The next step was to set targets to establish where the industry wanted to be by 2020. The targets that were drawn up appeared to be quite realistic.

In addition, the team of 25 experts explored the opportunities for industry and their customers' requirements, by carrying out a brainstorming exercise. Thoughts and ideas were gathered into related clusters. The most critical problem areas (where barriers existed) were marked with a priority 'dot'. For each cluster, the main opportunities for that cluster were drawn out. Experts were then able to list what they saw as high priority opportunities.

Using the same brainstorming procedure, the team looked at the barriers to the development of new construction materials. As before, these were grouped into a number of topics and under these, the barriers were listed and priority marks were added. The "basic science/knowledge" cluster, for example, prioritised "lack of understanding of materials" as one of the most critical barriers.

The final stage was to determine research needs, and this was carried out in a similar manner. The report shows the results for the near-term (zero to three years), mid-term (three to 10 years) and long-term (10 to 20 years) research requirements.

In addition, the priorities were allocated to the following categories: environment, productivity, safety or energy. The team then produced a number of bullet points to indicate the main research priority needs.

Chemical industry R&D roadmap in nanomaterials by design

(http://www.chemicalvision2020.org/pdfs/nano_roadmap.pdf)

A good example of a recent technology-specific roadmap is one on nanomaterials, which has now been published, having been on the Internet in draft form for a year. Entitled *Chemical industry R&D roadmap for nanomaterials by design*, the 98-page report, resulting from a series of workshops, was produced by around 100 people over three days. The health, safety and environmental issues raised in this roadmap are discussed in more detail in Section 4.3 of this report.

The goals set out in this roadmap were to:

- identify and exploit early commercialisation opportunities (catalysis, coatings, electronic and optical displays, medical diagnostics);
- achieve predictability and control of key building block properties (chemical composition, size, shape, morphology, surface chemistry);
- achieve predictability of life-time of nanomaterials under operating conditions;
- develop nanostructured materials to replace organic polymers in photonic devices;
- develop nanomaterials to increase energy storage in portable batteries by three times.

The general barriers were recorded as:

- insufficient understanding to enable prediction of needed properties, and of how to achieve them;
- inadequate characterisation capabilities;
- insufficient knowledge to synthesise complex heterogeneous structures;
- need to achieve directed self-assembly of building blocks and higher assemblies.

There was a great deal of detail in the draft report, but the priority research areas for nanomaterials were summarised as follows:

- develop capability to identify applications exploitable through properties offered by nanotechnology;
- develop capability to predict and control properties (modelling, synthesis and characterisation);
- expand the type and number of organic and inorganic nanomaterial building blocks to enable new applications;
- develop and incorporate self-assembly capability at the interface of building blocks;
- develop nanomaterial building blocks that enable self-repair of coating structures at the micron and millimetre level.

In view of the focus on commercialisation of nanomaterials, the priority areas for potential exploitation were highlighted as:

- catalysis (broad range, early opportunity);
- separations (sorbents and membranes);
- coatings (early opportunity);
- high performance materials (strong, lightweight, thermally and electrically conducting);
- energy conversion and storage;
- pharmaceutical and medical materials;
- sensors (chemical, environmental, bio);
- optical and electronic displays (early opportunity).

Following the workshops, the draft report was placed on the Internet to allow other parties to comment, and the full report was issued a year later in December 2003.

The procedure used to generate the report was as previously described:

- Where are we now?
- Where should we be?
- What is stopping us getting there?
- What is needed to overcome the barriers?

1.3 Examples of technology roadmapping procedures

As stated earlier, all technology roadmaps follow a similar procedure. Where they differ is in the number of people involved and the time taken to produce them. The topic being considered can, of course, influence both these variables. In view of the variety of roadmaps that are already available, a team under Robert Phaal at the Centre for Technology Management, part of the University of Cambridge's Institute for Manufacturing, devised an easy-to-use roadmapping process which incorporated the best points from previous roadmaps.

1.3.1 T-Plan

The procedure devised by Centre for Technology Management has been widely and successfully used, and is known as the *T-Plan fast-start method for technology roadmapping*. It follows the processes used for all roadmaps by looking at the present situation, determining what the targets should be and then filling in the gaps. The process follows three stages as shown in Figure 1.4.

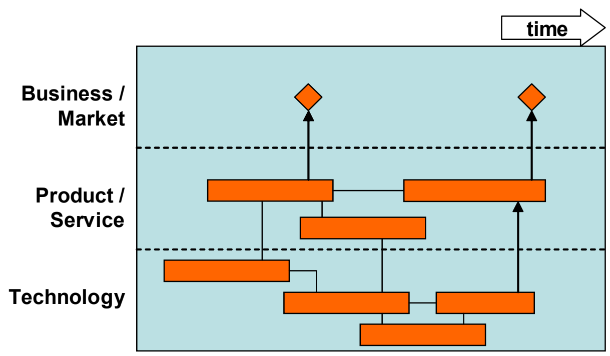

Figure 1.4: Three stages of the *T-Plan*

At different times, small teams sit in workshops to consider the topics shown in Figure 1.5.

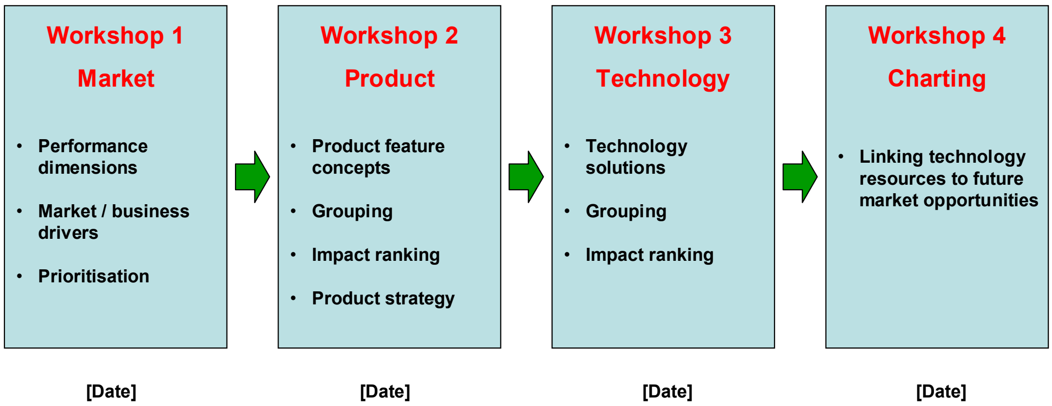

Figure 1.5: *T-Plan* workshops

Priorities are set by using analysis grids, as shown in Figure 1.6.

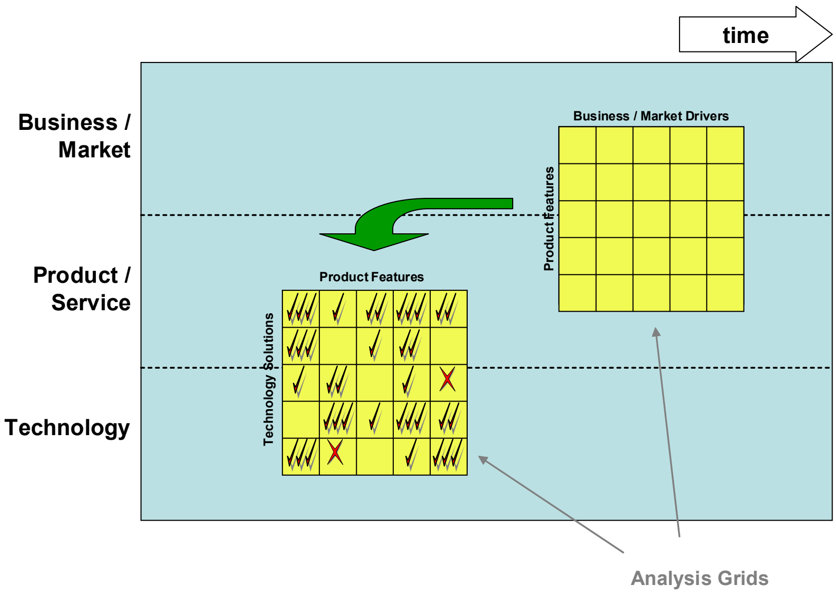

Figure1.6: *T-Plan* analysis grids

The whole process is, without question, very useful, and more details can be found on the University of Cambridge Institute of Manufacturing website: http://www.ifm.eng.cam.ac.uk/ctm/publications/tplan/.

1.3.2 Roadmapping made easy

Few establishments have been spared the necessity of cost-cutting, downsizing and re-engineering in order to remain competitive. As a result, companies are much more sensitive to how they spend their time and money, and are aware of the need for a strategy to remain in business or stay ahead of their competition. Most realise that they need technology roadmapping.

However, constraints on people's time and the cost of having large groups of experts tied up for several days on a roadmapping exercise, is not always seen as the most efficient way of achieving objectives.

The following procedure for technology roadmapping has proven to be a less time-consuming, way of establishing a technology roadmap in any field. Around 40 roadmaps have been completed in this way for the EU's SMART FP6 Programme, some of the UK's Knowledge Transfer Networks, and for the South African Government. The process needs only one day for a group to convene, and further input, as with most roadmaps, is sought through the Internet or trade journals.

As with all roadmaps, these working reports are reviewed and added to as situations change.

Participants

As described in Figure 1.1, technology roadmaps tend to fall into three groups: industry sector, technology-specific or product.

The type of roadmap will influence the number of people involved in the roadmapping session, but it must remain a manageable group. About 30 to 40 people can be managed, but any more is likely to prove difficult to handle! From experience, 25 is a comfortable number, though useful 'starter' roadmaps can be produced by fewer than 10 participants.

Participants need to be closely involved in the subject under consideration, and collectively cover all aspects of the topic. For example, a technology roadmap should not just have participants from research and development, but should include marketing staff and those involved in manufacturing and possible the supply chain. 'Buy-in' is crucial, so it is important not to miss out any key people who could destroy the exercise afterwards with adverse criticism. It is also essential that the CEO is on board with the event; not necessarily attending, but being kept informed, feeling part of it, and appreciating its importance.

Methodology

The meeting should begin with each participant giving a brief description of who they are and what they do. A facilitator should then go through the reasons for producing a technology roadmap and a summary of the process.

The methodology, which is colour-coded, is the same as that shown in Figure 1.2. However, Figure 1.7 indicates that the process is simply a variant of a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis. The strengths and weaknesses are identified in the first step, *Where are we now?,* and the opportunities are highlighted in the section on *Where do we want to be?* The threats come from the stage asking *What is stopping us getting there?* Finally, the actions arising emanate from the last question.

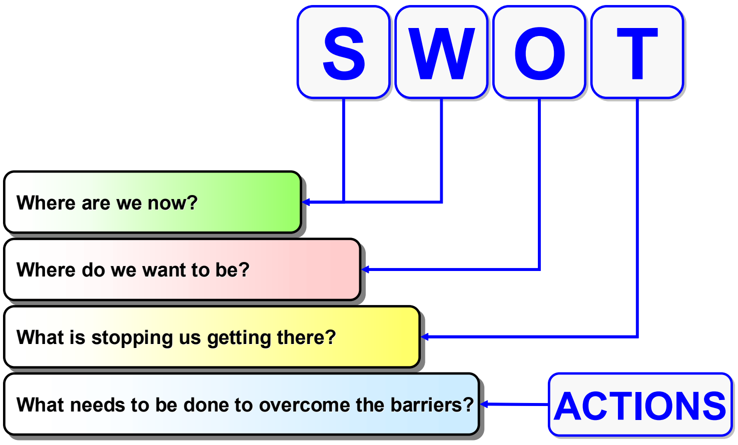

Figure 1.7: SWOT-type analysis

Where are we now?

With all the benchmarking exercises carried out in the last few years, it would be surprising if experts were not well aware of the current status in their area. However, all aspects of the current position need to be understood by all participants. It is helpful if one or more of the experts present gives a talk on the 'state of the art', but if not, the facilitator should draw out the main points, having carried out a survey of publications in the area being considered.

The team should then be split into small groups. For example, for 25 participants five groups of five would be ideal. Each group should be asked to come up with their thoughts on where the subject is at this time.

Typical questions might be:

- Who are our present customers?
- What are the current trends?
- What are the main drivers?
- What is the competition up to?
- What are our niche areas?
- Who are present leaders in the field?
- What are the gaps in technology?
- Do we have the right skills?
- Is capital investment sufficient?

Each group should record their thoughts on large hexagonal Post-its (shown in green in Figure 1.8). When the ideas of each group seem to be drying up, the facilitator should ask the scribe from each group to present their thoughts. The facilitator positions the hexagons in a honeycomb fashion around a central hexagon which might have one of the above headings on it. The scribe should write clearly and summarise each input in an understandable way, with only one thought on each hexagon. At this stage, the wall should include a large number of grouped hexagons (see Figure 1.8).

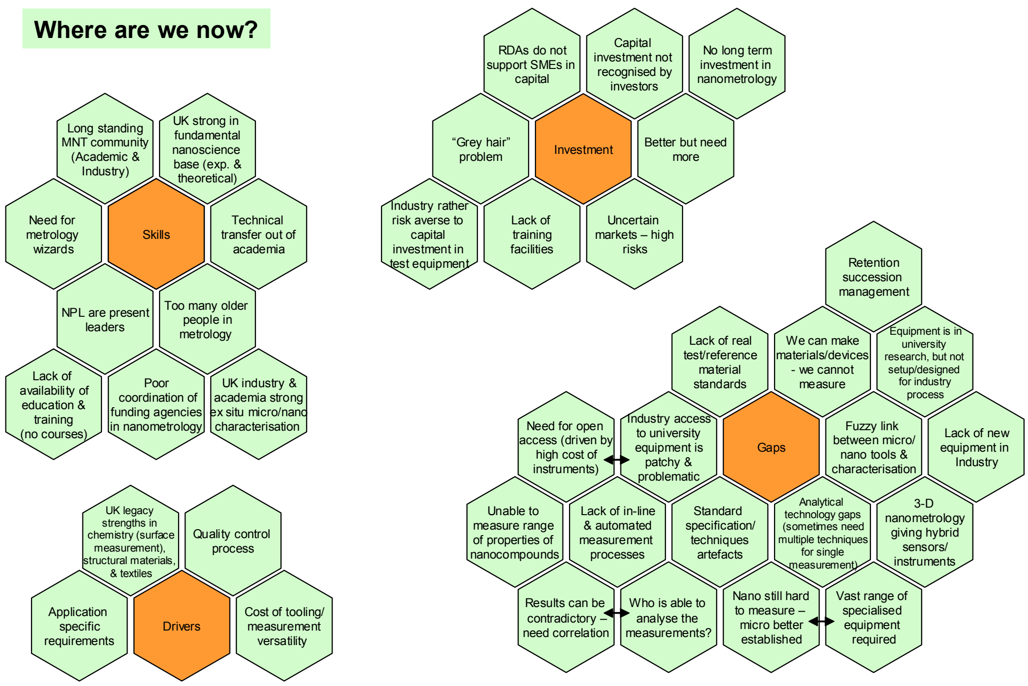

Figure 1.8: Use of hexagons to cluster ideas

This method of clustering ideas is just one method commonly used in brainstorming exercises.

Having agreed the thoughts from the whole team, it is necessary to assign priorities, and to do this each of the small groups should be given a limited number of adhesive dots to stick on the hexagons they feel are the most important. This sets the priorities for this section of the roadmap.

Where do we want to be?

For this stage of the procedure, it is important to gather the vision and aspirations of the team, and again this should be carried out with the brainstorming procedure, but this time with pink hexagons.

The types of questions that need answering are:

- What is our vision for the future?
- What should we be doing to maximise benefits?
- Are we doing something now that we should put more effort into?
- Are we doing something currently that we should drop?
- What technologies are going to make a real impact on our activities?
- What new areas should we be working in?
- Are there opportunities for creating spin-out companies?

Again, the facilitator's role should be to cluster the ideas and have the groups assign priorities to them. It is also helpful to allocate timescales wherever possible.

This is an important stage and the facilitator should be able to judge when to draw the session to a close. There is likely to be a lot of discussion when each group presents its hexagons.

What is stopping us getting there?

The procedure is the same for this stage, except that the facilitator may wish to ask participants to form different groups, to refresh the workshop and aid networking opportunities.

This stage is about looking at the barriers likely to prevent the team from reaching its goals. Anything that is likely to inhibit them should be extracted. Again, it is helpful to have prompts such as:

- What are the gaps in our technology?
- Do we have the skilled people we need?
- Is funding likely to be adequate?
- Do we have the necessary infrastructure?

All thoughts are, as before, gathered on hexagons - this time yellow ones. Again, the priority issues should be marked by each group, using dots for the more important points on the hexagons. In this way, it is possible to gain a consensus of views.

What needs to be done to overcome the barriers?

For this stage the hexagons are blue. Consideration should be given to both technical and non-technical solutions to overcoming the barriers. For this section, the timescales are particularly important.

It is helpful to ask participants to indicate the short, medium and long-term issues. The final hexagons might appear as illustrated in Figure 1.9.

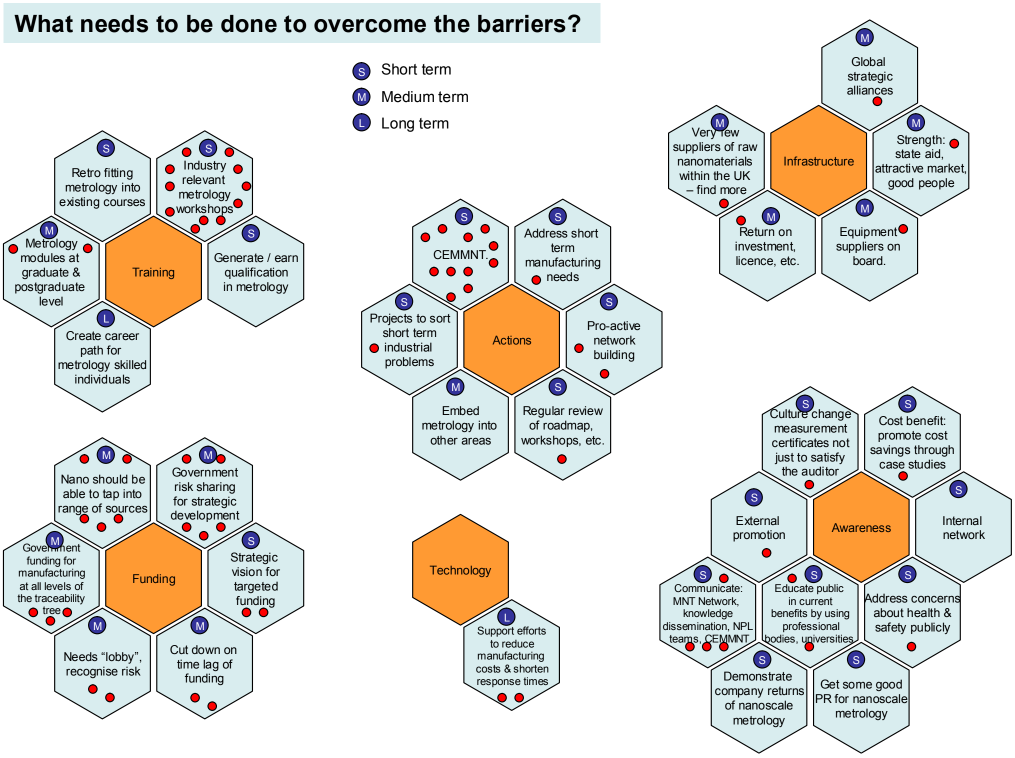

Figure 1.9: Clusters of main issues with timescales

From experience, most participants find the roadmapping exercise stimulating and useful. Before the team breaks up, the facilitator should outline what is going to happen next.

The conclusions from the meeting need to be recorded concisely. Usually, the facilitator will reproduce all the hexagons in the form of charts as an appendix to the report, but for non-participants who will be asked to add their input, it is best to present the conclusions in the form of tables.

For those who do not have time to read through all the issues raised, it can be useful to present the conclusions in the form of a single chart. A typical one from a European programme looking at materials for energy is shown in Figure 1.10.

Whatever format is agreed for the final report, it must be put to wider circulation. The team can, of course, have the first view of it, in order to add information or make corrections. The report should then be posted on the Internet and if there are any appropriate publications, such as trade magazines, it should be publicised in those as well.

As a working document, the report should be visited at appropriate intervals to update it as progress occurs. Responsibility should also be allocated to implement the proposals, and to keep the technology roadmap up to date.

This particular process has been used for around 40 roadmaps, and has proven to be an efficient way of producing useful technology roadmaps.

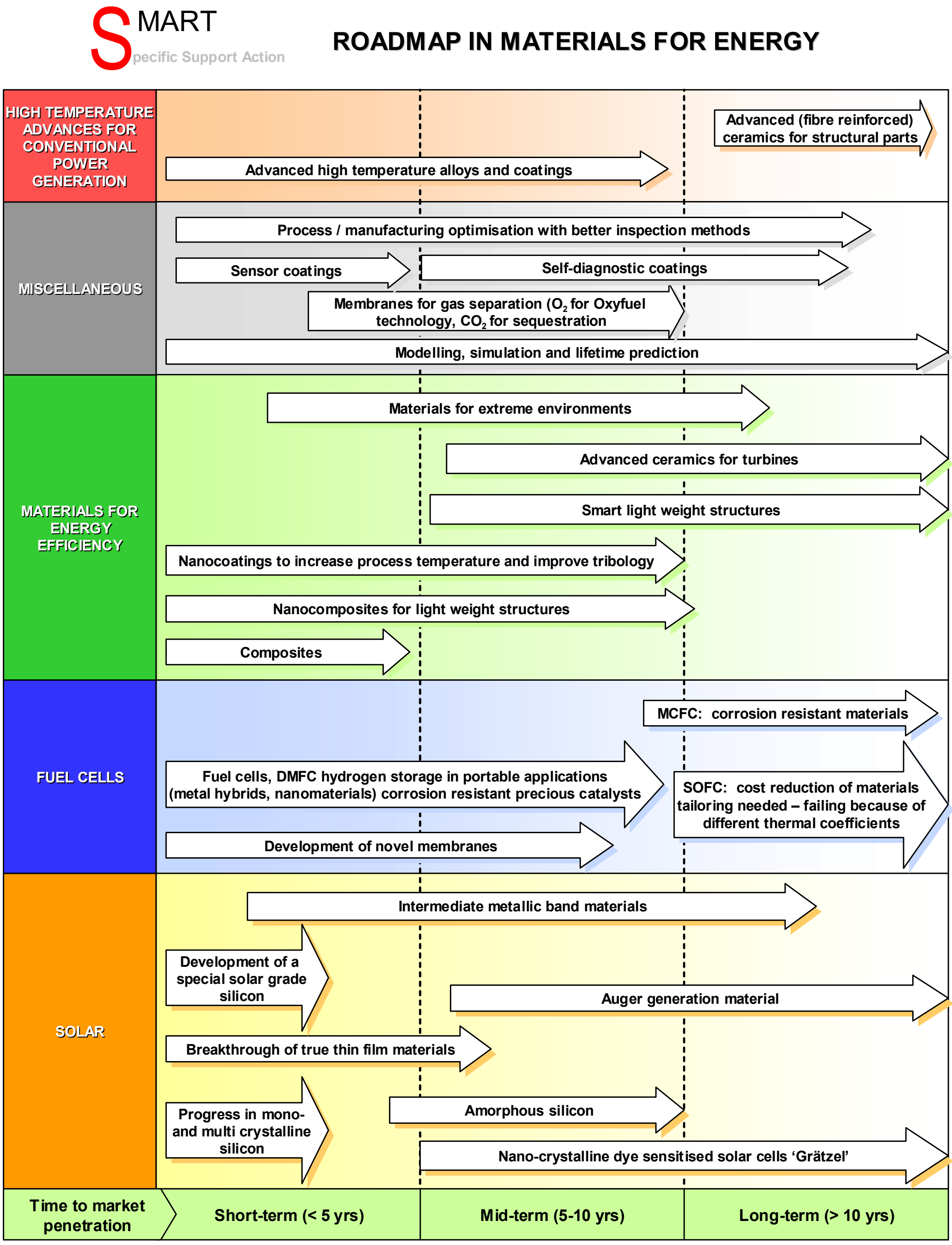

Figure 1.10: Typical timeline chart showing priorities

2 Early warning of environmental threats

2.1 Technology roadmaps for horizon scanning

2.1.1 Background

It is increasingly difficult to distinguish between reports and documents entitled:

- strategies
- plans
- technology platforms
- *Foresight* exercises
- forward looks
- research priority listings
- technology roadmaps.

Specifically, technology roadmaps look at the trends and drivers of a particular topic, and the time horizons in which they are likely to be important. By linking market opportunities to product and technology developments, roadmaps can help support the communication of technology strategies and plans. These roadmaps are not just a 'laundry list'; they also have a time frame.

The table in Appendix I lists the strategies and reports that are similar to, but do not follow, the main format of a technology roadmap. Those concerned with nanotechnology have not been included in this table (they are reserved for Appendix V).

Reports headed 'technology roadmaps' or clearly based on the roadmapping procedure are provided in Appendix II (the roadmaps relating to nanotechnology are listed in Appendix VI). This does not list all roadmaps that have been produced to date, but it does include the majority from sectors most likely to have an impact on the public and/or the environment. In addition, summaries are given for those roadmaps where environmental issues are crucial to future development.

2.1.2 Environmental issues in technology roadmaps

Roadmaps cover a range of sectors and in many of them, the environment is a key driver. Current or anticipated regulations tend to influence considerations. In the 10 years since roadmaps became commonly used, environmental aspects have gained increasing importance.

The following table (Table 2.1) highlights some recurrent environmental issues in roadmaps which raise concerns about impacts on the environment.

Table 2.1: Environmental themes running through technology roadmaps

	Gaseous Emissions	Recycling	Improved Processes	Reduction of Waste	Meeting Regulations	Stewardship	Energy Efficiency	Design for Recycle
Glass	✓	✓	✓					
Chemical Plants			✓	✓				
Wood Panels	✓		✓		✓			
Alternative Raw Materials			✓			✓	✓	
Petroleum	✓		✓		✓	✓		
Materials		✓			✓			✓
Advanced Ceramics		✓					✓	
Biocatalysts	✓		✓					
Aluminium	✓		✓		✓	✓	✓	
Lumber	✓			✓				
Combinatorial Methods		✓						
Steel	✓	✓						
Process Chemistry	✓		✓	✓				
Renewable Energy	✓						✓	
Aircraft Design	✓		✓		✓		✓	
Catalysis Immobilisation		✓						
Rubber					✓			✓
Process Equipment Materials	✓			✓				
Powder Metals	✓		✓		✓			
Magnetics	✓			✓				
Green Chemistry	✓			✓				

It is difficult to generalise, but common aims for certain sectors include:

Energy, manufacturing and chemistry-related roadmaps

- energy efficiency
- abatement of greenhouse emissions
- cleaner production technologies
- social performance
- improved health and safety record
- residue and waste reduction.

Concerns about the effectiveness of risk management, are always present with any product or technology from the chemical industry. This has led to calls for increased regulation of chemicals through European initiatives such as the Registration, Evaluation and Authorisation of Chemicals (REACH), a framework for chemicals regulation in the European Union. The downside is that companies move off-shore with their development and production, to areas where regulations are less punishing.

Materials-related roadmaps

- recyclability
- improved infrastructure for recycling (it is there for metals, but not plastics)
- design for recycling
- life cycle analyses
- environmental modelling.

In the above cases, environmental issues are paramount. However, roadmaps concerned with the medical sector do not mention environmental issues as being a strong driver.

Biotechnology and life science-related roadmaps

- meet current regulations
- adopt caution with GMOs
- move to disposable items.

For devices and microsystems-related roadmaps, environmental concerns are hardly mentioned. However, in consultation with the US EPA, the sector are looking at the use of brominated flame retardants, lead in solder, and what happens at the end of an electronic component's life.

3 Use of technology roadmapping by regulators

3.1 Involvement of environmental regulators in technology roadmaps

There are only a few roadmaps where participants have included government environment agency personnel. For these, all have been representatives from the US Environmental Protection Agency or Environment Canada:

1999	Alternative media, conditions and raw materials	Environmental Protection Agency Environment Canada
2001	New process chemistry technology roadmap	Environmental Protection Agency Environment Canada
2002	National hydrogen energy roadmap	Environmental Protection Agency

One technology roadmap was attended by the Food and Drug Administration in the US, but not by the EPA:

2003	Chemical industry R&D roadmap for nanomaterials by design	Food and Drug Administration

Government interest in technology roadmapping, in the past, has been exemplified by the US Department of Energy and by Industry Canada, both of whom have sponsored a large number of roadmaps of particular interest to their countries.

More recently, the European Commission has sponsored a number of roadmaps in the energy, materials and healthcare sectors. Those developed within the SMART FP6 Consortium are referenced in Appendix II as Energy, Safe Europe, and Better Life. Those in Appendix VI are from the FP6 Nanoroadmap Project, and are referenced as Materials, Health and Medical Systems, and Energy.

Technology roadmaps often have a strong emphasis on reducing industries' impact on the environment. Given this, there may be an opportunity for the Environment Agency to influence technology roadmapping exercises in order to help prevent or minimise environmental damage. In addition, an opportunity exists to use these roadmaps for horizon scanning, as an early warning system to highlight potential issues and opportunities. Clearly, if environment agencies were to be involved in roadmapping exercises, any potential problems which could have an effect on the environment could be picked up sooner rather than later

3.2 Survey of environmental regulators outside the UK

3.2.1 International roadmapping contacts

Communications have been held with roadmapping experts in a number of countries:

Australia: Professor Ron Johnston Australian Centre for Innovation Faculty of Engineering University of Sydney NSW 2006 Tel: 0061 02 9351 3934 E-mail: rj@aciic.eng.usyd.edu.au	Author of a number of roadmaps on behalf of Australian industries. One that is publicly available is a 2004 report, *Building Industry Technology Roadmap,* for the Copper Development Centre in Australia.

Canada: Mr. Geoffrey Nimmo Industry Canada Room 635D 235 Queen Street Ottawa Ontario K1A 0H5 Tel: (613) 954-3040 E -mail: Nimmo.Geoffrey@ic.gc.ca	Author of numerous roadmaps through the Industry Canada group.

Germany: Dr Gerd Schumacher Project Management Jülich Forschungszentrum Jülich GmbH 52425 Jülich Germany Tel: 0049 2461 61 3545 E-mail: g.schumacher@fz-juelich.de	Leader of the Framework Programme 6 SMART project to produce roadmaps for materials use in a number of different areas – energy, security and 'better life'.

Republic of South Africa: Ms. Pontsho Maruping General Manager Department of Science & Technology Building 53 CSIR Campus Meiring Naudé Road Brummeria Pretoria Tel: 0027 12 843 6461 E-mail: pontsho.maruping@dst.gov.za	Previously in charge of roadmapping for the Department of Science and Technology in South Africa, and now leading the country's nanotechnology activities.

United States: Jim Willis Director of Chemical Control Division Office of Pollution Prevention and Toxics Environmental Protection Agency Washington DC Tel: 202 564 0104 E-mail: willis.jim@epa.gov	

The experts were asked if they were aware of any government agencies responsible for the environment, who were interacting with industry through technology roadmapping to identify potential problems for the environment.

Comments worth noting were as follows:

"I have to report that horizon/early warning scanning, anticipatory intelligence, and whatever you might like to call it, is not established in Australia. I am sure some of it goes on, under one name or another, but it is very hard to locate. The closest item in the Department of Environment is a 'State of the Environment Report' issued every 3 to 4 years." – Ron Johnston.

"While it seems like a useful area for technology roadmapping, we have not been involved in such exercises. While the major US exercises in technology roadmapping such as Industries of the Future by DOE, and PATH [Partnerships for Advancing Technology in Housing – HUD] have had the environment as the driving force (prioritisation and development of technologies that would limit the amount of energy utilised, thereby assisting the environment and increasing productivity), I don't think they have done a roadmap of this type." – Geoff Nimmo.

Gerd Schumacher and Pontsho Maruping were aware that many roadmaps now consider environmental matters, though generally to ensure that environmental regulations are met. They were not aware of any roadmaps that could act as potential forecasts of future problems.

Specific issues regarding nanotechnology are dealt with in Section 4 of this report.

3.2.2 United States

In one nanotechnology report from the Woodrow Wilson International Centre for Scholars, entitled *Managing the effects of nanotechnology* by J Clarence Davies (referenced in Appendix III), there is a section calling for 'new institutional capabilities'. Commenting on 'foresight capability' (generally and not just for nanotechnology), Davies states that the US EPA , the National Research Council (NRC) and others have called for improved technology forecasting to identify potential environmental impacts of emerging technologies, in order to interact with business at an early stage to design out negative impacts and support environmentally positive applications (Olson and Rejeski, 2005; Brewer and Stern, 2005).

Davies suggests that the following initiatives may be required:

- EPA and other agencies should establish offices charged with forecasting and encouraging the use of forecast results;
- National Science Foundation (NSF), EPA and others should fund academic centres dedicated to research on improving forecasting ability.

Research has been carried out on how to improve forecasting (Brewer and Stern,2005; also Ascher, 1978), but because it is inherently interdisciplinary, this area has been neglected. Improved forecasting ability would increase lead times for making decisions, allowing for more careful analysis of various options, and would increase the opportunity for broad public participation in decision-making. The author states that the US Congress also needs the ability to foresee and evaluate new technological developments.

In discussions with Jim Willis, US EPA's Director of Chemical Control Division (Office of Pollution Prevention and Toxics), he was not aware of any activities within the US where roadmaps were being used for horizon scanning purposes to identify potential problems for the environment. Willis said it would be two years before a group might be put together to look at the environmental impact of emerging technologies.

4 Technology roadmapping for nanotechnology

4.1 Background to societal and ethical issues

4.1.1 Hype and definitions

A great deal has been written about nanotechnology and much of it is driven by the need to attract money. Businesses and scientists tend to exaggerate the market potential in order to persuade those with funding to invest in new and exciting technological opportunities while NGOs (non-governmental organisations) and lobby groups, along with the media, express their concerns in order to increase donations or provide more newsprint. With nanotechnology, social scientists have joined the fray to compete for a limited amount of funding.

The hype associated with nanotechnology has been charted in an excellent and amusing book, *Nano-hype*, by Professor David Berube (Berube, 2006a), who is the coordinator for industrial and government relations for the NanoScience and Technology Studies Group at the University of South Carolina. He has just been contracted to direct communications for the International Council for Nanotechnology (ICON), because of his informed and level-headed approach.

Summaries of some of the reports addressing the societal and ethical concerns are listed and referenced in Appendix III. The NGOs appear to have concerns about anything that can be tagged with the name 'nanotechnology', but such a broad-brush approach is misleading. The UK Government, possibly motivated by Prince Charles' comments about the 'grey-goo' issue, were the first to react to concerns raised about nanotechnology. They commissioned the Royal Society and the Royal Academy of Engineering to produce a report, *Nanoscience and nanotechnologies: opportunities and uncertainties*, in 2004. A response to that was given by HM Government in 2005, and in 2006 a further publication, *Characterising the potential risks posed by engineered nanoparticles*, was issued (all are referenced in Appendix III).

Figure 4.1: UK Government concerns

The message from HM Government is to proceed with caution, but that "*almost all concerns relate to the potential impacts of deliberately manufactured nanoparticles and nanotubes that are free rather than fixed in a material*."

Nanoparticles are not new. Nanoparticulate carbon black has been used in vehicle tyres for decades, currently at a rate of six million tons per annum. Nanoparticles can be found in nature, ranging from milk products (containing nanoparticulate casein) to the nanoparticulate pollution from volcanoes that causes spectacular sunsets (after Krakatoa exploded in the nineteenth century, there were bright red sunsets for decades). A recent article, entitled *Nanotechnology – lessons from Mother Nature,* lists other natural examples of nanotechnology (Appendix IV). Burning candles, or almost anything which burns, creates nanoparticulate material.

A report from the OECD International Futures Programme and Allianz, the German insurance company (Appendix III) states that we are surrounded by nanoparticles, where a room can have 10,000 to 20,000 nanoparticles per cm^3, while in a forest this rises to 50,000 nanoparticles per cm^3. In an urban environment, the number of nanoparticles can reach 100,000 per cm^3.

Clearly better definitions are required to prevent all of nanotechnology from being put under the spotlight. The British Standards Institution (BSI Group) has produced a publication with a vocabulary for nanoparticles, issued by their BSI/CEN/ISO Committee. It may be purchased from BSI giving the reference PAS 71:2005 at http://www.bsi-global.com/en/Standards-and-Publications/Industry-Sectors/Nanotechnologies/.

Small Times magazine correspondent Candace Stuart (Stuart, 2006) has also produced an illustrated guide to nanoparticles.

An analysis of some of the current applications already on the market offers guidance on risk issues (Figure 4.2). Four categories can be described as nanotechnology: thin films, organoclays, nanoparticles and carbon nanotubes.

Thin films include surfaces modified at the nanoscale, or thin films locked onto a surface.

Organoclays are treated clay products that are incorporated into plastics to improve a variety of properties. Such materials are described as nanocomposites. They are not nanoparticulate; it is the clay layers that are expanded and forced apart by the polymer used. This is not too different from the use of clays in solvent- and water-based paints, where the products are thickened by the clay layers being forced apart by the solvent. In the case of nanocomposites, the main drivers are replacement of heavy metal parts while retaining strength and flexibility, and barrier properties to preserve the integrity of products.

Nanoparticles tend to be nanoparticulate inorganic compounds or fullerenes. The main potential danger is in the production and incorporation of these into products. Some are clearly locked into the products, such as anti-scratch materials containing nanoparticulate alumina or silica, but concerns have been expressed about products where the nano-ingredients are not as 'locked in'.

In view of concerns and speculation that carbon nanotubes are the next asbestos, companies are dealing with this material with extreme caution. For all products containing carbon nanotubes, the tubes are firmly incorporated into the polymer matrix and are at low levels. However, given the potential of carbon nanotubes (50 to 100 times stronger than steel and one-sixth the weight), it is likely that these applications will grow dramatically.

Using a traffic light system, Figure 4.2 shows some of the products within these categories that are already available. Those closest to amber are most likely to come under scrutiny. In fact, the US EPA recently said that Samsung's imports of washing machines, which incorporate silver ions by 'nano-shaving' from silver plates to prevent mould, require registration as a pesticide. The use of titanium dioxide nanoparticles for sunscreens has been questioned, but available toxicological data indicates no ill-effects, and is, in fact, likely to be alleviating skin cancers. The use of silver nanoparticles in wound dressings is well established in markets round the world, and despite being in direct contact with open wounds, the risk is seen to be small. It has been known for centuries that silver had anti-microbial properties.

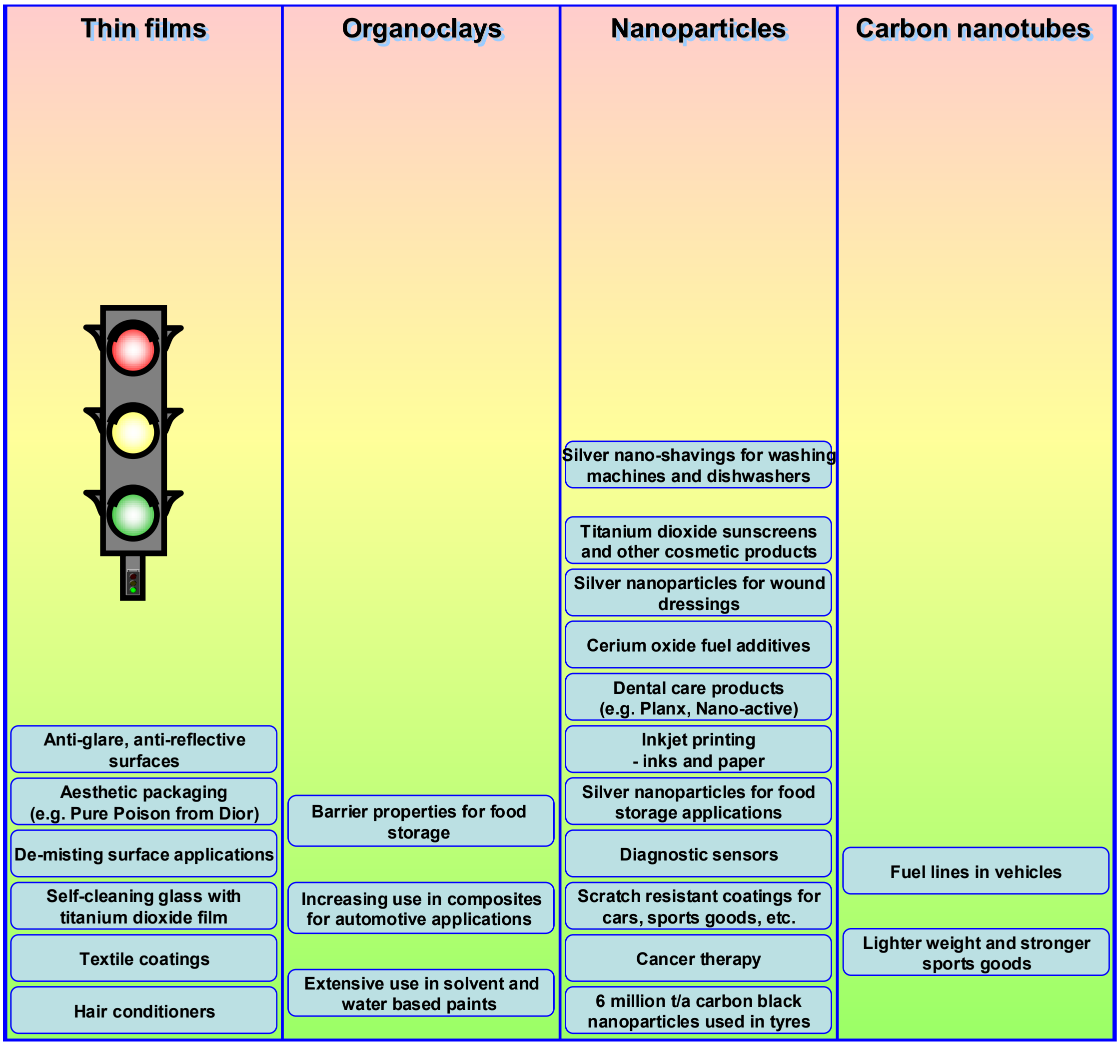

Figure 4.2: Applications of nanoscale materials

A possible upcoming issue for any nano-containing products will be life cycle analyses, and lobby groups are beginning to ask questions even though markets are very small at present.

A report from UNESCO entitled *The ethics and politics of nanotechnology* (see Appendix III) distinguishes between three types of nanoparticles:

- engineered nanoparticles (such as buckyballs and gold nanoshells);
- incidental nanoparticles (such as those found in welding fumes, cooking, and diesel exhaust);
- naturally occurring nanoparticles (salt spray from the sea, or forest fire combustion).

4.2 Benefits of nanotechnology

New products based on nanotechnology are emerging in a wide range of markets. Their use in cars and sporting goods has raised the question of how nanotechnology will help the poor. As with most new developments, high margin sectors are the first to benefit before the technology cascades down into more commodity-type uses.

Appendix IV lists several publications that have explored the beneficial effects of nanotechnology. Three of these have been produced by the US Meridian Institute, a non-profit organisation whose mission is to help people solve problems and make informed decisions on complex and controversial issues. The first paper, *Nanotechnology and the poor –*

opportunities and risks, raises awareness about the implications of nanotechnology for people in developing countries. Opportunities and risks are addressed in the following areas:

- safe drinking water
- energy
- healthcare
- information technology and communications
- food and agriculture.

Two other papers from the Meridian Institute will be of more interest to environmental agencies, since they deal with the provision of cleaner water and water management. Nanotechnology is seen as a high priority for water purification, since water treatment devices based on nanoscale technology are already available, and there is an increasing need for clean water throughout the world.

The first report, *Nanotechnology, water and development*, describes two case studies: a simple water filtration method for the prevention of cholera in Bangladesh, and a nanofiltration method in South Africa. The report goes on to consider nanotechnology applications that are already available or are in development, such as:

- nanofiltration membranes, including desalination techniques;
- attapulgite clay, zeolite, and polymer filters;
- nanocatalysts;
- magnetic nanoparticles;
- nanosensors for the detection of contaminants.

The second paper, *Water nano-based treatment technologies*, is a supplement to the first report, and enables comparisons of conventional and nanotechnology-based water treatment devices. It covers point-of-use water treatment methods at the household and community level.

All the Meridian reports are particularly well referenced, and the second one includes details for each application, recording the contaminants that can be removed, how much water can be treated, cost, and ease of use.

4.3 Nanotechnology roadmaps

A growing number of technology roadmaps have emerged in the field of nanotechnology, and following the ‘grey goo’ saga, there has been strong emphasis on health, safety, and environmental issues.

Appendix V lists the general strategies and reports on nanotechnology. These are not summarised since almost all take into account the social and ethical issues that have become associated with nanotechnology.

Appendix VI contains the actual roadmaps concerned with different industry sectors or areas within those sectors. These are summarised where the reports are freely available.

One report entitled *Chemical industry R&D roadmap for nanomaterials by design* is particularly detailed with regard to health, safety, and environmental issues. It was produced by the US Chemical Industry Vision2020 Technology Partnership and sponsored by the US Department of Energy, Office of Energy Efficiency and Renewable Energy.

Research priorities are reproduced here (Figure 4.3) with timeframes and likely impacts:

R&D PRIORITY – ENVIRONMENT, SAFETY, AND HEALTH	
Assess human health and environmental impact hazards	
Human health and environmental hazard identification are based on established health and environmental test guidelines of regulatory authorities such as the Organisation of Economic Cooperation and Development (OECD) / Environmental Program, Occupational Safety and Health Administration (OSHA), and Environmental Protection Agency (EPA). An understanding of how specific nano-sized materials may affect health and the environment needs to be established so that, if necessary, regulatory guidelines can be updated to consider novel chemistry, size, morphology, higher order structures (if any), and utilisation.	Priority: Top Timeframe: 20 years Impacts: • Compilation and survey of pertinent literature (year 1) • Identification of model systems to perform in-depth analysis (year 2) • Acute toxicity studies on model systems completed (year 5) • Exposure protocols and relevant testing established (year 5) • Chronic and developmental toxicology studies on model systems completed (year 7) • Environmental impact of model systems determined (year 20)

R&D PRIORITY – ENVIRONMENT, SAFETY, AND HEALTH	
Determine exposure potentials for nano-sized materials	
Understanding the make up of product, emissions, and waste streams and determining the existence and persistence of nanomaterials are essential to establishing exposure potentials. They are also required, along with the hazard potential for these materials, to prioritize control strategies, environmental testing, and a rationale for testing procedures (e.g. relevant route, concentration, duration).	Priority: Top Timeframe: 5 years Impacts: • Nanomaterial product / waste streams characterised (year 1) • Real-time monitoring incorporated into control / containment systems (year 5)

R&D PRIORITY – ENVIRONMENT, SAFETY, AND HEALTH	
Establishing handling guidelines for operations involving nanomaterials	
Safe handling guidelines for nanoscale materials are needed to supplement standard industrial hygiene practices. Industry, academia, and government will apply these approaches to R&D, product development, commercialisation, disposal, and transportation	Priority: Top Timeframe: 5 years Impacts: • Communication document providing safe work practices distributed (year 1) • Effectiveness of existing personal protection equipment (PPE) determined (year 2) • Best practices for exposure control of nanomaterials established (year 5)

Figure 4.3: Research priorities for nanomaterials (reproduced from the *Chemical industry R&D roadmap for nanomaterials by design* report)

Other nanotechnology roadmaps tend to have less detail but, like the *Chemical industry R&D roadmap for nanomaterials by design* one, respond to concerns raised about nanoparticulates.

4.4 Agencies' activities in nanotechnology

4.4.1 Germany

To date, the Federal Environment Agency in Germany (UBA – Umwelt Bundes Amt für Mensch und Umwelt) is one of the few that has published a research strategy for nanoparticles. Entitled *Nanotechnology: health and environmental risks of nanoparticles*, it has been produced in collaboration with the Federal Institute for Occupational Safety and Health (BAuA) and the Federal Institute for Risk Assessment (BfR). The strategy was published in August 2006 and is referenced in Appendix III.

The report begins by saying that, at present, nanotechnology is not yet linked to any major concerns about health and the environment, but over the next few years this could change. As nanotechnology grows, more workers and consumers will come into contact with it, so there is a need to monitor the development of this technology to weigh up the opportunities and risks. For Germany, it is recommended that the UBA, BAuA and BfR work in a coordinated manner to assess the toxicological and ecotoxicological risks, as set out by Adams and Smith (2003).

According to the report, current knowledge indicates that insoluble and poorly soluble nanoparticles are most likely to be toxicologically relevant, and therefore the report concentrates on their safety in the workplace, and for consumers and the environment. It states that further studies are essential, and recommends that complementary social scientific research should be carried out, with a transparent discussion of risks with all interested groups and organisations.

The report points out that nanoparticles are not new, and that humans have been exposed to naturally formed and unintentionally produced nanoparticles for a very long time.

Projects and areas requiring funding are identified below.

Exposure and metrology:

- voluntary reporting scheme for the production, further processing and open use of nanoparticles;
- company survey of workplace exposure and risk management;
- development, testing and standardisation of measurement methods for nanoparticles in the workplace;
- company survey on the use of nanotechnology in the production of foods, packaging materials, cosmetics, clothing and other consumer products;
- development of exposure scenarios and life cycle analyses of nanoparticles;
- development or adjustment of measurement methods for air, water and sewage sludge and for ecotoxicological testing;
- study of behaviour and fate (accumulation and persistence) in the environment.

Toxicological and ecotoxicological assessment of nanoparticles:

- development of methods to characterise nanoparticles in biological material;
- development of minimum requirements for information in publications.

Toxicological assessment:

- development of a test and assessment strategy;
- determining the sensitivity and specificity of *in vitro* methods or methods to determine the physico-chemical (PC) properties for the assessment of chronic toxicity and carcinogenicity of dust;

- assignment of nanoparticles to categories of different toxicity through *in vitro* studies and studies on PC properties;
- *in vivo* studies with widespread nanoparticles on chronic toxicity and Carcinogenicity, mutagenicity and reproduction toxicity (CMR) effects;
- studies on the mechanism of toxicity and the influence of particle size;
- studies on the toxicity of nanoparticles in the workplace;
- studies on the skin penetration of nanoparticles from cosmetics and consumer products;
- studies on absorption, systemic availability, accumulation and excretion of nanoparticles after oral exposure (foods and food packaging materials);
- assessment of the toxicity of nanoparticulate zinc oxide;
- assessment of the toxicity of nanoparticulate silicon dioxide.

Ecotoxicological assessment:

- grouping of nanoparticles by ecotoxicological effects;
- analysis of conducted studies for endpoints, elaboration of action hypotheses, identification of suitable test systems;
- examination and adjustment of ecotoxicological test methods and strategies, standardisation of nano-specific test systems;
- elaboration of an assessment strategy to determine the risk of nanoparticles in the environment.

Nanotechnology debate:

- creation of a joint nanotechnology discourse platform.

4.4.2 Europe

The EU Commission on Community Health and Consumer Protection has already produced a preliminary report (ably summarised by UNESCO in their paper, *The ethics and politics of nanotechnology,* referenced in Appendix III). The recommendations are to:

1. Develop a new nomenclature for nanomaterials
2. Assign Chemical Abstracts Service Registry Numbers (CASRN) to new nanoparticles
3. Advance science by collecting data and performing analyses on new nanoparticles
4. Develop new measuring instruments
5. Develop standardised risk assessment methods
6. Promote best practice in risk assessment
7. Create institutions to monitor development of nanotechnology
8. Establish dialogue with the public and with industry
9. Develop guidelines and standards for production, handling, commercialisation, and risk assessment of nanomaterials
10. Revisit existing regulations and change them where appropriate to reflect specificities of nanotechnology
11. Maximise the containment of existing free nanoparticles
12. Strive for the elimination or minimisation of the release of nanoparticles into the environment where possible.

The UNESCO report points out the political and cultural components that influence the attitudes of politicians and citizens towards risk and regulation. The EU has a more precautionary style than the US, which is much more market- and corporation-friendly. The EU precautionary approach assumes that the lack of data on the safety and efficacy of nanotechnology means that the marketing of products should proceed with caution, whereas the US market-friendly approach assumes no additional regulations are necessary before going to market.

The current situation is that if a substance is already on an existing substance database in Europe, it can be marketed. The marketing of existing chemicals in new nano forms has been recognised as a regulatory gap. The ‘no data, no market’ position shown in Figure 4.4 is what the EU is aiming for, via REACH.

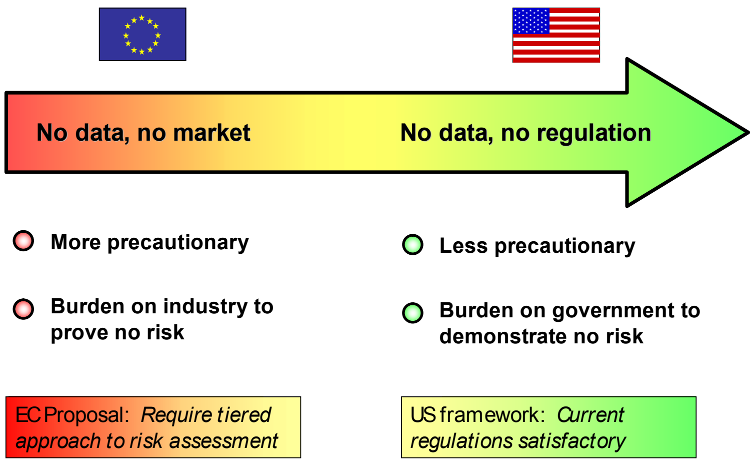

Figure 4.4: Attitudes towards risk

4.4.3 United States

Samsung washing machines

The most significant recent development in the USA has been the announcement by the US EPA that Samsung's silver ion-generating washing machine, which releases silver ions into wash water, is subject to registration requirements under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). This is a reversal of an earlier determination that the Samsung washing machine was a device rather than a pesticide, and therefore not subject to regulation. Samsung are still able to sell washing machines if they do not claim anti-microbial effectiveness in their advertising. In this case it is silver ions that are the active ingredient, produced by 'nano-shaving' silver plates.

No comment has been made about the use of nano-silver as a germicide in food storage containers, air fresheners, clothing, wound dressings, and shoe liners. Here, silver nanoparticles are incorporated into the polymer used to form the product. Their use in food storage containers and wound dressings comes under the Food and Drug Administration (FDA). There is little concern about this decision, but if the US EPA were to classify any new nanotechnology product as a 'new substance' under the Toxic Substances Control Act (TSCA), this would have serious repercussions, entailing a delay of months or years in bringing a product to market.

There are about 40 nano-silver based consumer products on the market, some of which make pesticidal claims or imply pesticidal effectiveness. One company, Sharper Image, has removed such claims from its products treated with nano-silver, which includes slippers, socks and food containers, and can thereby still market the products.

Davies versus Berube

J Clarence Davies of the Woodrow Wilson International Centre for Scholars authored a report in which he argues that nanotechnology is difficult to address using existing regulations (see page 52 of this report). He points out that the Toxic Substances Control Act, the Occupational Safety and Health Act, the Food, Drug and Cosmetic Act, and the major environmental laws (Clean Air Act, Clean Water Act, and the Resources Conservation and Recovery Act) all suffer from major shortcomings of legal authority, and from a gross lack of resources; they therefore provide a weak basis for identifying and protecting the public from risk. Davies suggests that a new law may be required to manage the potential risks of nanotechnology, along with new mechanisms and institutions which include research, tax breaks, acquisition programmes, and regulatory incentives.

This view was attacked by David Berube in an article, *Regulating nanoscience: a proposal and a response to J Clarence Davies*, in the December 2006 issue of *Nanotechnology Law and Business* (Berube, 2006b). Berube argues that Davies' recommendations are premature and potentially counterproductive; instead, a liability and insurance regime running concurrently with both the US EPA's voluntary pilot programme and other efforts would be more effective, according to Berube (2006b).

Professor Berube points out that there is no single nanotechnology industry, and that 'grey goo' science fiction has misdirected too many critics of nanotechnology for too long. Berube quotes from John Marburger, Presidential Science Advisor and Director of the Office of Science and Technology, who said that "*breakthroughs in nanoscience would occur at a pace that would enable the regulatory process to keep up with it in a responsive way*" (Gruenwald, 2004). Davies is unclear about which companies he is advocating for regulation, and even states that 80-90 per cent of nanotechnology products should be exempt from his proposal; he appears to believe that upstanding companies would risk their entire businesses and reputations on a short-sighted product line that opens itself up to liability.

There has been a great deal of criticism of Davies' proposal. As Clayton Teague (Director of the US's National Nanotechnology Coordination Office) put it, "*any additional regulations beyond what we already have would be burdensome to industry and the advancement of the field*" (Bridges, 2006). Another fear is that over-regulation will encourage firms to invest in areas other than nanotechnology or move their business overseas to a more accommodating regulatory environment.

Environmental Protection Agency

US EPA's Jim Willis (Director of Chemical Control Division, Office of Pollution Prevention and Toxics) has expressed some concerns about nanoparticles locked in plastics, since they might be sanded down and release dust containing, for example, carbon nanotubes whose effects are not known. The EPA has produced a White Paper on nanotechnology (published 15th February 2007) and is about to carry out its own tests on carbon nanotubes, which come in many different forms. The Japanese are running a programme to look at the risks and benefits of fullerenes, nickel oxide nanoparticles, and single and multi-walled carbon nanotubes. The EPA does not want to repeat this work, and would prefer to liaise with other international groups.

The main recommendations of the US EPA's White Paper are outlined below.

The EPA should continue to undertake, collaborate on, and support research to better understand the environmental applications and risks of nanomaterials, including:

- chemical and physical identification and characterisation;
- environmental fate;
- environmental detection and analysis;
- potential releases and human exposure;
- human health effects assessment;
- ecological effects assessment .

The EPA should conduct case studies to further identify risk considerations for nanomaterials. The Agency should also engage resources and expertise to encourage, support, and develop approaches that promote pollution prevention, sustainable resource use, and good product stewardship in the production, use and end-of-life management of nanomaterials. Additionally, the EPA should draw on 'next generation' nanotechnologies to identify ways to support environmentally beneficial approaches such as green energy, green design, green chemistry, and green manufacturing.

The White Paper recommends the setting up of a standing group to share information on nanotechnology science and policy issues, and the extension of nanotechnology training for scientists and managers.

The EPA sees the OECD Working Party on Manufactured Nanomaterials, which Jim Willis chairs, as the main voice to coordinate international efforts on nanotechnology. This Working Group also includes non-OECD countries such as China, India, Thailand, Argentina, and Israel.

Jim Willis warns that nanotechnology should definitely not come under REACH regulations; it must be avoided.

4.4.4 United Kingdom

In a Swiss Re report, *Nanotechnology: "small size –large impact"*, Paul Davies, Chief Scientist and Director of Corporate Science and Analytical Services at the Health and Safety Executive (HSE), gave a presentation entitled *Regulatory challenges with emerging technologies*. In it he described how the UK was attempting to stay ahead of the game as regulators, rather than having to play 'catch-up'. The ability to regulate can be compromised by the existence of already well-established practices.

Davies argues that horizon scanning can help by ensuring that the regulator is aware of changes in the medium to long-term future. The process must be systematic in anticipating and identifying new regulatory requirements, and should bring together back-room policy makers and frontline operational experts to identify emerging issues and evaluate their likely impact.

The DTI is one example of a horizon scanning initiative run via its *Foresight programme*, while the HSE has a more structured approach to horizon scanning for health and safety at work. The challenge is to spot 'runners', the technologies which will have a long-term future rather than become dead-ends.

Davies concludes that there is a need to:

- aspire to better regulation;
- be goal-setting rather than prescriptive;
- adopt a precautionary approach in the face of uncertainty about risks, with a view to easing controls if knowledge gained subsequently supports this;
- engage stakeholders, including the public, in constructing the regulatory regime;
- 'keep ahead of the game' through horizon scanning.

UK Government response to the Royal Society and Royal Academy of Engineering

HM Government, in this report, supports the findings of the commissioned report. In the final section, 'Ensuring the responsible development of nanotechnologies', the recommendation is that the Chief Scientific Advisor should establish a group that brings together representatives of a wide range of stakeholders to look at new and emerging technologies. The group should identify at the earliest possible stage areas where potential health, safety, environmental, social, ethical, and regulatory issues may arise, and advise on how these might be addressed.

Under this point, it is announced that the government will set up a new centre of excellence in science and technology horizon scanning, which will be based in OST and build on the work of the existing *Foresight programme*. HM Government believes that the centre will be most effective if it works with and alongside existing bodies such as RCUK (Research Councils UK), the Technology Strategy Board, CSAC (Chief Scientific Advisor's Committee) and CST (Council for Science and Technology).

5 Conclusions

Technology roadmaps offer industry, government and academia a means of working together to identify roadblocks and chart the path to commercialisation of technologies. The roadmapping procedure enables stakeholders to focus on the remaining challenges, identify public and private resources required to achieve those results, and implement a timetable with milestones to help measure success. To date, there has been little involvement by regulators in roadmapping.

Certainly, involvement should be welcomed by industry, since it would be unwise to invest in new technology that might pose a severe financial burden in the future. In addition, the industry would portray a responsible approach to environmental issues.

For the UK, it should be possible to gain the Environment Agency's input into technology roadmaps, since most are likely to be funded through government departments or organisations such as the DTI's Knowledge Transfer Networks (KTNs). An opportunity therefore exists for the Environment Agency and the DTI to set up an agreement for feeding their considerations into all future roadmapping activities.

Alternatively, the Environment Agency could organise roadmaps in specific sectors that currently have a high environmental impact. The US Department of Energy and Industry Canada have done this across many sectors, with a view to conserving resources.

New roadmaps are made publicly available, so it should be relatively easy for the Environment Agency to monitor developments in different sectors and assess the potential environmental impacts.

For roadmaps produced within Europe, it is suggested that the Environment Agency should press for more concern about the environment through the network of EPAs. .

The US EPA, the US National Research Council (NRC) and others have called for improved technology forecasting. This would identify potential environmental impacts of emerging technologies at an early stage, to help businesses design out negative impacts and work towards environmentally positive applications.

Close liaison with environment agencies in the US and Canada would provide a better perspective on emerging technologies, especially as new applications are often the product of multinational corporations.

For nanotechnology, there is already a great deal of interest and activity on the potential problems associated with this new technology. Many roadmaps indicate intentions to carry out toxicological testing and, in some circumstances, risk assessment. It is clear that international activities need coordinating. The US EPA has adopted the OECD Working Party on Manufactured Nanomaterials as the main expert voice for nanotechnology. This group also includes non-OECD countries such as China, India, Thailand, Argentina, and Israel. The Department for Environment, Food and Rural Affairs (Defra) has a seat on this group.

It is recommended that the Environment Agency should;

- keep abreast of roadmapping activities throughout the world, in liaison with other environment agencies, particularly in the USA and Canada.

- have a stronger influence in the UK during industry roadmapping sessions. This could be achieved by having an agreement with the DTI, which funds many of the roadmaps being produced by the Knowledge Transfer Networks.

- promote the development of roadmaps in specific sectors that currently have high environmental risks or impacts, for example the chemical and construction industry.

- take a leading role in horizon scanning for environmental issues that may emerge from the increasing number of roadmaps being produced by the EU.

- become more involved in the OECD Working Party on Manufactured Nanomaterials, which was established to address human health and environmental safety aspects of manufactured nanomaterials in the chemical sector.

6 Appendices

Appendix I: General strategies and reports (excluding nanotechnology)

Date	Title (source)	Reference
2001	Australia leading the light metals age (Department of Industry, Australia)	http://www.industry.gov.au/assets/documents/itrinternet/lmaa.pdf
2002	Life sciences and biotechnology – a strategy for Europe (European Commission)	http://ec.europa.eu/biotechnology/pdf/com2002-27_en.pdf
2003	Medical devices – the UK industry and its technology development (Prime Faraday Partnership)	Available through http://www.primefaraday.org.uk
2004	Thermoplastic composites in Europe to 2025 (Coronet – EU Research Infrastructure Network)	http://www.netcomposites.com/downloads/Coronet_Foresight.pdf
2005	The vision for 2025 and beyond – a European technology platform for sustainable chemistry (CEFIC, EU)	http://www.cefic-sustech.org/files/Publications/ETP_sustainable_chemistry.pdf
2006	Market analysis for microsystems III 2000-2005 (Nexus Task Force Report)	May be purchased through http://www.wtc-consult.de/english/report_e.html#other
2006	Technology development strategy – a report to the Language Technologies Research Centre (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/AbstractTRM_EN.pdf/$FILE/AbstractTRM_EN.pdf
2006	Second report of the Sustainable Farming & Food Research Priorities Group (Defra)	http://www.defra.gov.uk/science/documents/RPG/Papers/FinalRPGreport2.pdf

Where the reports are freely available, brief summaries are given below of those points concerned with environmental matters.

Australia leading the light metals age

Sustainability is important to the future viability of the light metals sector, which needs to be seen as environmentally and socially responsible. It is recommended that the sector's environmental performance is judged by:

- energy efficiency
- abatement of greenhouse emissions
- clean production technologies
- social performance
- improved health and safety record.

A target for 2020 has been set to reduce the overall environmental impact by a factor of at least four, but with a factor of 20 as the main goal.

Improvements in economic performance, which also impact on the environmental performance, are to decrease costs and increase productivity through more efficient processing methods, and to look at recycling and materials discovery. Further studies on the life cycle analysis (LCA) of light metals are recommended.

Life sciences and biotechnology – a strategy for Europe

The regulatory framework for the European Community has evolved over the last 25 years, and there have been major developments in recent years. The contained use, release and marketing of genetically modified micro-organisms (GMOs) in foods, feeds and seeds has been thoroughly considered. It is suggested that EU regulations should respect risk governance and product authorisation, while at the same time safeguarding the internal market.

Medical devices- the UK industry and its technology development

This report does not address the environmental aspects of the increase in disposable items. It focuses more on safety and regulatory aspects of medical devices, where the materials have to be carefully selected, and there is a trend away from sub-contracting in order to reduce risks.

Thermoplastic composites in Europe to 2025

The increasing use of thermoplastic composites versus thermoset composites is anticipated because of ease of processing, cost and especially recyclability. However, one drawback is the lack of any infrastructure for recycling thermoplastics.

Environmental issues are seen as both an advantage and a disadvantage. On the one hand, environmental legislation can open the door for thermoplastic composites in new applications with specific life cycle costing and recycling requirements. On the other hand, the industry is hampered by the lack of a clear recycling route (which is not the case for metals). It is anticipated that in the future, companies may have to take back their product at the end of its life cycle.

The vision for 2025 and beyond – a European technology platform for sustainable chemistry

The responsibility for managing risk to both human health and the environment has progressed markedly in the last 20 years within the chemical industry. By 2002, production had increased by 43 per cent compared to 1990, but energy consumption had increased by only one per cent while CO_2 emissions had fallen by nine per cent. The aspiration is for ever more sustainable production and consumption of chemicals in the future, increasing eco-efficiency and restoring confidence in the industry.

Technology development strategy – a report to the Language Technologies Research Centre

Not relevant to environmental impact issues.

Report of the Sustainable Farming and Food Research Priorities Group

Research priorities for sustainable farming and food are particularly focused on environmental issues. The report identifies constraints on and opportunities for the UK food and non-food chains resulting from various scenarios for climate change. It examines

- water requirements for keynote crops;
- crops that would flourish under changing climatic conditions;
- development of crop breeding programmes to identify ecologically adaptive populations;
- development of models to assess soil function and capability, and the impact of climate change on sustainable land use.

The report also looks at making better use of the resources we have, especially energy and water, and reducing waste. Particularly for the environment and landscape, research into land management is necessary to inform environmental assessments of new policies and the implementation of existing regulations.

Appendix II: Technology roadmaps excluding those relating to nanotechnology

Date	Title (source)	Reference
1997	Glass technology roadmap workshop (US Department Of Energy)	http://campus.umr.edu/iac/iof/industies/GLASS/glass_roadmap.pdf
1998	Technology roadmap for materials of construction, operation and maintenance in the chemical process industry (US chemical industry's Vision 2020 exercise)	http://www.chemicalvision2020.org/pdfs/matconst.pdf
1998	Wood-based panel products: technology roadmap (Industry Canada, updated 2006)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/Woodbasedpanelproducts.pdf/$FILE/Woodbasedpanelproducts.pdf
1999	Technology roadmap for computational chemistry (US Department Of Energy and the chemical industry)	http://www.chemicalvision2020.org/pdfs/compchem.pdf
1999	Technology roadmap for computational fluid dynamics (US Department Of Energy and the chemical industry)	http://www.chemicalvision2020.org/pdfs/compfluid.pdf
1999	Alternative media, conditions and raw materials (Technology Vision 2020: US chemical industry)	http://www.chemicalvision2020.org/pdfs/alternative_roadmap.pdf
2000	Vision 2020: 2000 separations roadmap (Centre For Waste Reduction Technologies For The AIChE)	http://www.chemicalvision2020.org/pdfs/sepmap.pdf
2000	Coatings on glass technology roadmap workshop (Sandia National Laboratories)	http://www.ca.sandia.gov/CRF/03_Reports/04_GlassCoatings/GlsCoatRptweb.pdf
2000	Technology roadmap for the petroleum industry (American Petroleum Institute)	http://roadmap.itap.purdue.edu/ctr/documents/petroleumroadmap.pdf
2000	Window industry technology roadmap (Department Of Energy, US)	http://www.eere.energy.gov/buildings/info/documents/pdfs/27994.pdf
2000	Technology roadmap for materials (Technology Vision 2020: US chemical industry)	http://www.chemicalvision2020.org/pdfs/materials_tech_roadmap.pdf
2000	Advanced ceramics technology roadmap – charting our course (Us Advanced Ceramic Association)	http://www.eere.energy.gov/industry/energy_systems/pdfs/ceramics_roadmap.pdf
2000	New biocatalysts: essential tools for a sustainable 21st century chemical industry (Chemical Industry Consortium, US)	http://www1.eere.energy.gov/biomass/pdfs/biocatalysis_roadmap.pdf
2000	Canadian aluminium industry technology roadmap (Industry Canada)	http://www.trans-al.com/Portals/15/carte_angl.pdf
2000	Canadian electrical power technology roadmap (Industry Canada)	http://strategis.ic.gc.ca/pics/ep/eleceng.pdf
2000	Canadian metalcasting technology roadmap (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/Metalcasting_TRM.pdf/$FILE/Metalcasting_TRM.pdf

2000	Lumber and added-value wood products technology roadmap (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/Lumber%20Roadmap%20English.pdf/$FILE/Lumber%20Roadmap%20English.pdf
2001	Technology roadmap for combinatorial methods (US chemical industry)	http://www.chemicalvision2020.org/pdfs/combichemroadmap2001.pdf
2001	Vision 2020: reaction engineering roadmap (Centre For Waste Reduction Technologies For The AIChE)	http://www.chemicalvision2020.org/pdfs/reaction_roadmap.pdf
2001	Steel industry technology roadmap (AISI, US)	http://www.steel.org/mt/roadmap/roadmap.htm
2001	Alumina technology roadmap (Aluminium Industry Consortium, US & Australia)	http://www.industry.gov.au/assets/documents/itrinternet/AluminaTechnologyRoadmap2004021017481 1.pdf
2001	A roadmap for recycling end-of-life vehicles of the future (US Department Of Energy/Argonne National Laboratory)	http://www.es.anl.gov/Energy_systems/CRADA_Team_Link/ELV%20Roadmap.pdf
2001	New process chemistry technology roadmap (Technology Vision 2020: US chemical industry)	http://www.chemicalvision2020.org/pdfs/new_chemistry_roadmap.pdf
2001	Microsystems technology standardisation roadmap (MEMSTAND)	http://www.memstand.org/microsystems-technology-standardisation-roadmap.pdf
2001	Powder metallurgy & particulate materials (pm^2) vision and technology roadmap (Metal Powder Industries Federation, US)	http://www.eere.energy.gov/industry/energy_systems/pdfs/pm_roadmap.pdf
2001	Medical imaging technology roadmap (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/MedicalImaging.pdf/$file/MedicalImaging.pdf
2002	The US small wind turbine industry roadmap (American Wind Energy Association)	http://www.awea.org/smallwind/documents/31958.pdf
2002	European roadmap for PV R&D (PVNET)	http://paris.fe.uni-lj.si/pvnet/files/PVNET_Roadmap_Dec2002.pdf
2002	Renewable energy technology roadmap (Department Of Industry, Tourism And Resources, Australia)	http://www.oemroadmaps.com/renewables.pdf
2002	A technology roadmap for generation IV nuclear energy systems (an international consortium)	http://gif.inel.gov/roadmap/pdfs/gen_iv_roadmap.pdf
2002	National hydrogen energy roadmap (US Department Of Energy)	http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/national_h2_roadmap.pdf
2002	Canadian technological roadmap on functional foods and nutraceuticals (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/SPEQM%20-%20FFN%20-%20Final%20report%20sections%201%20to%206.pdf/$FILE/SPEQM%20-%20FFN%20-%20Final%20report%20sections%201%20to%206.pdf
2002	Technology roadmap for intelligent buildings (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/TRM_English.pdf/$FILE/TRM_English.pdf
2003	Canadian aircraft design, manufacturing and repair & overhaul technology roadmap (Ontario Aerospace Council)	Available through http://www.strategis.gc.ca/epic/internet/inad-ad.nsf/en/ad03117e.html

2003	Roadmapping for the plastics industry (Faraday Plastics)	R B Simpson, , *Polymer Process Engineering*, 2003, p367
2003	Immobilisation in catalysis – a technology roadmap (BHR Solutions)	http://www.bhrgroup.co.uk/extras/immocat.pdf
2003	International technology roadmap for semiconductors (a world consortium)	http://www.itrs.net
2003	Rubber technology roadmap (Institute Of Materials)	A Tinker, *Polymer Process Engineering*, 2003, p373
2003	Product-technology roadmap for microsystems (Nexus)	May be purchased through http://www.wtc-consult.de/english/report_e.html#other
2003	Technical textiles technology roadmap (Technitex Faraday Partnership)	Obtainable from Technitex Faraday Partnership
2003	Roadmap for process equipment materials technology (Materials Technology Institute Inc, US)	http://www.chemicalvision2020.org/pdfs/mti_roadmap.pdf
2003	Innovation roadmap on bio-based feedstocks, fuels and industrial products (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/en_roadmap_book.pdf/$FILE/en_roadmap_book.pdf
2003	Canadian fuel cell commercialisation (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/FuelCellsen.pdf/$FILE/FuelCellsen.pdf
2003	Lean logistics technology roadmap (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/Lean%20Logisticsen.pdf/$FILE/Lean%20Logisticsen.pdf
2003	Marine and ocean industry technology roadmap (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/Marine%20and%20Ocean.pdf/$FILE/Marine%20and%20Ocean.pdf
2004	ICT technology roadmap (Department Of Science & Technology, RSA)	Available through http://www.dst.gov.za
2004	Powder metal sector technology roadmap (Powdermatrix Faraday Partnership)	http://217.118.138.78/powdermatrix/Powder_Metals_Roadmap_Dec04.pdf
2004	Hard metals technology roadmap (Powdermatrix Faraday Partnership)	http://217.118.138.78/powdermatrix/Hardmetals_Roadmap_Dec04.pdf
2004	Magnetics sector technology roadmap (Powdermatrix Faraday Partnership)	http://217.118.138.78/powdermatrix/Magnetic_Roadmap_Dec04.pdf
2004	Advanced ceramics technology roadmap (Powdermatrix Faraday Partnership)	http://217.118.138.78/powdermatrix/Ceramics_Roadmap_Dec04.pdf
2004	Green chemical technology 2004 roadmap (Crystal Faraday Partnership)	http://www.crystalfaraday.org/documents/GCT_Roadmap.pdf
2004	Building industry technology roadmap (Copper Development Centre)	http://www.copper.com.au/cdc/technology_roadmap/roadmap/index.html
2004	A technology roadmap for colloid and interface science in the UK (Impact Faraday Partnership)	http://www.impactfaraday.org/admin/documents/Roadmap.pdf
2004	Foresight vehicle technology roadmap (Society Of Motor Manufacturers & Traders)	http://www.foresightvehicle.org.uk/public/info_/FV/TRMV2.pdf
2004	A roadmap for high throughput technologies (Insight Faraday Partnership)	Available at Insight Faraday Partnership at http://www.insightfaraday.org/insight/default.aspx
2004	A European roadmap to hydrogen (Hyways – a stakeholders consortium)	http://www.hyways.de/docs/Brochures_and_Flyers/HyWays_External_Document_02FEB2006.pdf

2005	A roadmap for printable electronics (NanoMarkets IC)	Available through NanoMarkets at http://www.nanomarkets.net
2005	A European platform for sustainable chemistry – materials technology (SusChem, EU)	Available through http://www.suschem.org/content.php?_document[ID]=2049&pageId=3217
2005	Technology roadmap for low energy polymer processing (Faraday Plastics)	Available from Faraday Plastics
2005	Technology roadmap in recycling of plastics (Faraday Plastics)	Available from Faraday Plastics
2005	International roadmap for consumer packaging (Faraday Packaging)	Available from Faraday Packaging Partnership at http://www.faradaypackaging.com
2005	CO_2 capture and geological storage (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/ccstrm_e_lowres.pdf/$FILE/ccstrm_e_lowres.pdf
2005	Clean coal technology roadmap (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/cctrm_e.pdf/$file/cctrm_e.pdf
2005	Future fuels for the APEC region – an integrated technology roadmap (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/Future_Fuels-TRM_2006-EN.pdf/$file/Future_Fuels-TRM_2006-EN.pdf
2006	The canadian biopharmaceutical industry technology roadmap (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/Biopharmaceutical.pdf/$FILE/Biopharmaceutical.pdf
2006	A technology roadmap for the Canadian welding and joining industry (Industry Canada)	http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwapj/TRM-Canadian_welding_Final_Report_EN.pdf/$FILE/TRM-Canadian_welding_Final_Report_EN.pdf
2006	Roadmapping for medical devices (Technology For Industry Ltd)	http://www.devicelink.com/mdt/archive/06/06/014.html
2006	Roadmap of European technology platform for advanced engineering materials and technologies (EuMat)	http://www.mpa-lifetech.de/eumat/(ilr2dm55s5mppe55agmthqiu)/downloads/EuMaT_Roadmap_ver27b_Kj_08062006.pdf
2006	Materials powering Europe – energy workshop and roadmap (SMART FP6 consortium, EU)	To be published in early 2007
2006	Materials for a safe Europe – security workshop and roadmap (SMART FP6 consortium, EU)	To be published in early 2007
2006	Materials for a better life - workshop and roadmap (SMART FP6 consortium, EU)	To be published in early 2007

The technology roadmaps from Industry Canada are listed at http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/en/h_rm00051e.html.

Where the reports from the table are freely available, brief summaries are given below of those points concerned with environmental matters,

Glass technology roadmap workshop

This early roadmap was sponsored by the US Department of Energy's Office of Industrial Technologies and five multinational companies. One of the sub-committees for the roadmap focused on environmental protection and recycling. The highest priority for this sub-committee was to improve oxy-fuel firing technology to reduce air pollutants, the aim being to avoid creating emissions rather than cleaning up afterwards. The medium priority was to find alternative raw materials and improve batch preparation and pre-heating processes, as well as improve furnace design to reduce particulate and gaseous emissions.

Technology roadmap for materials of construction, operation and maintenance in the chemical process industry

With sponsorship from the US Department of Energy, this roadmap identified performance targets for a safer operating environment and reduced environmental impacts. Performance targets for 2020 were to:

- reduce capital cost and energy consumption by 30 per cent by 2020 by:
  - increasing uptime by 25 per cent by 2020
  - improving first pass first quality yield by 20 per cent by 2020
- increase asset productivity
- provide a safer operating environment with zero on-the-job injuries
- protect the environment by:
  - containing the process with zero fugitive emissions
  - eliminating toxic discharges to the ground by 2020
  - reducing hazardous wastes by 50 per cent by 2020.

Wood-based panel products: technology roadmap

A whole section of the appendix in the roadmap is given over to environmental issues such as:

- regulatory affairs
- emission sources and constituents
- best available control technologies.

The roadmap shows a clear concern for reducing the environmental impact of the industry.

Technology roadmap for computational chemistry

One of the applications listed in this roadmap is ‘environmental modelling and remediation’. Trends and drivers in government regulations and public policy are discussed.

Technology roadmap for computational fluid dynamics

Trends and drivers in government regulations and public policy are discussed, stressing the need for compliance with the Clean Air Act and its amendments, Toxic Substances Control Act, and the Resource Conservation and Recovery Act which together present serious challenges to the chemical industry in terms of capital expenditure and operating expenses.

Alternative media, conditions and raw materials

This roadmap was supported by the US Department of Energy’s Office of Industrial Technologies (OIT) and the Environmental Protection Agency’s Office of Pollution Prevention and Toxics (OPPT). The aim of the chemical industry was to find opportunities to improve energy use and environmental stewardship by conducting breakthrough research. Four workshops were held on:

- alternative media;
- the role of polymer research in green chemistry and engineering;
- electrotechnology and alternative process conditions;
- synthesis and processing with alternative resources.

Vision 2020: 2000 separations roadmap

All the separation technologies mentioned are aimed at improving yields and reducing waste. Techniques examined are: absorbents, crystallisation, distillation, extraction, membranes, separative reactors, ion exchange, bio-separations, and separations from dilute solutions. However, the potential impact on the environment is not considered.

Coatings on glass technology roadmap workshop

This roadmap workshop is again sponsored by the US Department of Energy, but there is little mention of environmental factors other than to say that trends to more environmentally friendly processes are being followed.

Technology roadmap for the petroleum industry

According to the industry, the main drivers linked to the environment are seen as:

- environmental regulations;
- increasing cleanliness of fuels;
- pressure to reduce emissions of CO_2;
- proactively dealing with public scrutiny, environment, global warming and other issues.

The report contains a chapter on environmental performance, and presents detailed statistics of the sources of air emissions in refineries from combustion, equipment leak, process vent, storage tanks and wastewater systems. Future criteria for environmental performance are given, and the performance targets are tabled. The main technical barriers to improved performance are discussed. along with the risk-based methods needed to guide the regulatory process as well as compliance.

Window industry technology roadmap

A further report supported by the US Department of Energy, it reveals a growing trend for industry to be involved in the regulatory process. The key points of the roadmap are improved energy supply and conservation. ‘Environmental harmony’ research activities are tabled.

Technology roadmap for materials

This roadmap is a subset of the *Technology Vision 2020* for the chemical industry in the US. It suggests materials development is being inhibited by the US tort system, which means that capital and operating investments are diverted to compliance, environmental regulations and standards. This is a particular problem for small companies.

A positive aspect, however, is that the roadmap encourages ‘design for recycle’. In the past, recycling has been inefficient because of the polymer mix and processing requirements. Designing products for post-use material recycling improves disassembly and recovery, and boosts the value of the recycled material.

Advanced ceramics technology roadmap – charting our course

With support from the US Department of Energy, this roadmap looks at processing and manufacturing with a view to extending equipment life, and reducing emissions and maintenance. The roadmap proposes to increase energy efficiency and recycling. The vision for environment, health and safety is the same as for other industries, but with emphasis on disassembly and recycling.

New biocatalysts: essential tools for a sustainable 21st century chemical industry

This roadmap is sponsored by interested parties from industry, and by the US Departments of Commerce, Defence and Energy. The programme includes traditional chemical industry goals to reduce material, water and energy consumption, and pollutant dispersal. Renewable resources are favoured over petroleum-based feedstocks. There is a focus on concerns about greenhouse gases, especially CO_2, which will drive new ‘closed carbon cycle’ methods. Government policies already favour the use of biocatalytic processes for producing fuel ethanol, but it is recognised that this could change.

Canadian aluminium industry technology roadmap

The aim of the roadmap is to help all parts of the aluminium supply chain to develop new technology to maintain a competitive position. The major challenges facing the industry are listed and those relevant to the environment are:

- reduce costs and increase productivity;
- respect regulations;
- reduce energy consumption;
- respect the environment.

A prerequisite is the health and safety of workers in the industry. For the environment, the main concerns are with CO_2 and greenhouse gas emissions, as well as global warming. The report discusses moves away from the use of chlorine, and to reduce waste. The industry is aware of its environmental impact and aims to alleviate problems. Over 50 new projects are described, many of which are likely to benefit the environment.

Canadian electrical power technology roadmap

Environmental issues covered in this roadmap include ground level pollutant concentrations, acid rain precursors, polychlorinated biphenyls (PCBs), liquid effluents and an initial approach to smog reduction.

Electrical utilities endeavour to be environmentally responsible, following regulatory requirements and championing various environmental causes. Environmental restrictions are anticipated to increase and become proactive to forestall greater environmental degradation.

As might be expected there is a strong emphasis on lowering environmental impacts throughout the report.

Canadian metalcasting technology roadmap

The roadmap aims to shake off the industry image of 3Ds: dull, dirty and dangerous. The desire is to move away from the view that the industry is old, low-tech and polluting, so there is considerable direction to reducing the impact on the environment.

Lumber and added-value wood products technology roadmap

Bark disposal is a problem for many mills since some are not allowed to burn it; instead, it is sent to landfill. Considerable efforts have already been made with the use of scrubbers to reduce emissions at various stages in the process. Volatile organic carbons (VOCs) are a problem and the roadmap proposes to address this.

It is mentioned that in some countries, restrictions are more severe than in Canada. For example, in Germany the wrappers used to protect dry lumber have to be recycled.

Projects are proposed to combat increasing concerns for the environment.

Technology roadmap for combinatorial methods

Topics mentioned in this roadmap are environmentally safe materials, and design for recycle or absorption – industrial ecology. Waste minimisation, remediation and environmental applications are mentioned, but there is no lengthy consideration of environmental issues.

Vision 2020: reaction engineering roadmap

Environmental drivers and trends play a large part in this roadmap, to use less energy and water and generate less waste. Some interesting metrics are provided on the size of problems and the improvements made.

Steel industry technology roadmap

As might be expected, one of the key drivers in this roadmap is to reduce the environmental impact of steel making. There is discussion of different processes, their energy use and the emissions they produce, and a large section devoted to the environment takes into account refining and casting, forming and finishing, coating, refractory recycling, and nitrogen oxides.

Alumina technology roadmap

This is a roadmap produced by US and Australian companies with support from the US Department of Energy. Environmental aims are for fewer energy-related emissions per ton of alumina, large reductions in residue stockpiles, and improved sustainability and environmental responsibility. The plans are also to reduce human interaction in potentially dangerous environments, and there are aims to reduce air pollutants and groundwater contamination. The report is a good example of an easy-to-read roadmap since it is set out particularly well.

A roadmap for recycling end-of-life vehicles (ELV) of the future

Sponsored by the US Department of Energy's Office of Advanced Automotive Technologies and Argonne National Laboratory, this roadmap focuses on identifying R&D needed to recycle automotive materials and components that will reach end-of-life status in 2020. The definition of recycling is given as any cost-effective use of automotive materials that would divert those materials from landfill, including reuse and re-manufacture of parts and components, materials recovery, chemical/thermochemical conversion (such as pyrolysis) and thermal energy recovery. Regulatory features are also taken into account.

Most of the ELV mass (more than 90 per cent) is expected to enter the shredding/sorting operation in 2020. In 2001, the ELV content by weight was predicted to be 75 per cent metal, 15 per cent plastics, and 10 per cent other (glass, fluids, dirt and so on) in 2020, but with the growth of nanomaterials fewer metal components are now expected.

New process chemistry technology roadmap

This report was supported by the chemical industry in the US, but with sponsorship from the US Department of Energy and the Environmental Protection Agency (EPA). Two members of the EPA were acknowledged for helping to produce the roadmap. The production and environmental goals for 2020, with performance figures, were:

- reduce feedstock losses to waste and by-products by 90%;
- reduce energy intensity by 30%;
- reduce emissions, including CO_2, and effluents by 30%;
- increase use of C1 compounds by 20%, and use of renewables by 13%;
- reduce time to market through the use of new R&D tools by 30%;
- increase the number of new products and applications annually by 15%;
- reduce production costs by 25%.

Microsystems technology standardisation roadmap

There is little mention of environmental issues in this roadmap, except in a section that highlights materials requirements. Concerns here are with biocompatibility, measurement methods for interaction of biomaterials with Microelectromechanical Systems (MEMS) materials, quantification of materials interaction and sensitivity to biomaterials.

Powder metallurgy & particulate materials (PM^2) vision and technology roadmap

Sponsored by the US Department of Energy, this roadmap does not consider the environment in any depth. Cost drives the search for more energy-efficient processes and recycling opportunities, and cleaner processing is only implied through improved processing techniques. However, the roadmap is well set out and provides a logical approach to clear R&D priorities.

Medical imaging technology roadmap

As with many medical-related roadmaps, environmental issues are not taken into consideration.

The US small wind turbine industry roadmap

Environmental impact is not discussed.

European roadmap for photovoltaics R&D

There is a clear advantage to the environment with new technology of this type, but it is not quantified. Recycling of modules is discussed.

Renewable energy technology roadmap

Considerations are given to the following sources of renewable energy:

- biomass energy
- cogeneration
- fuel cells and hydrogen
- geothermal
- hydro-electricity, tidal power, and wave power
- photovoltaics
- solar thermal energy
- wind energy.

Obvious targets are to reduce the effect of greenhouse gases.

Different Australian states had government environmental departments involved in the workshops which supported the roadmap.

A technology roadmap for generation IV nuclear energy systems

This report was issued by the US Department of Energy's Nuclear Energy Research Advisory Committee and the International Generation IV Forum (GIF). Of course, safety issues and environmental protection are paramount, but this roadmap looks in detail at all requirements for the generation of nuclear power. Despite an excellent safety record, the industry needs to increase public confidence and new systems should address this need with clear and transparent safety approaches that arise from R&D on advanced systems.

National hydrogen energy roadmap

This is another roadmap supported by the US Department of Energy, with contributions from an official from the EPA. Hydrogen is expected to become the premier energy carrier for the US and will reduce the country's reliance on imported petroleum energy. Key consumer demands will be for safety, convenience, affordability, and environmental friendliness. Existing production technologies can produce vast amounts of hydrogen, but they emit large amounts of CO_2 into the atmosphere. New methods of production are required and storage is also an issue.

Environmental challenges for hydrogen delivery, for example, are:

- lack of information on life cycle environmental impact
- liquefaction is energy- and greenhouse gas-intensive;
- environmental concerns with fossil carbon-based feedstock.

Canadian technological roadmap on functional foods and nutraceuticals

This is a large growth area and much of the interest comes from the US, Europe and Japan. There is a section dealing with the regulatory framework, within which GMOs are discussed. Environmental management of processes is mentioned but not addressed in any detail.

Technology roadmap for intelligent buildings

Lifespan of features is raised along with efficiency of maintenance. The slow response of the building industry to the growth in electronic devices is noted. There is little reference to environmental impact issues, except through the measurement of air quality.

Canadian aircraft design, manufacturing and repair & overhaul technology roadmap

This is an early roadmap that has been updated. Planes of the future will be expected to have:

- reduced structure weight by 15 to 20 per cent;
- lower powerplant weight;
- greater powerplant fuel efficiency;
- lower landing gear weight;
- reduced onboard systems weight by 20 per cent.

The regulatory environment is likely to be harsher, demanding less external noise and reduced emissions from engine exhausts, crankcases, transmission housings and fuel tanks (such as nitrogen oxide compounds, carbon monoxide and volatile organic compounds). There will also be a need to reduce or eliminate manufacturing processes that use or produce toxic waste products such as cadmium and chromium coatings.

Roadmapping for the plastics industry

This is simply an article explaining the activities of the Plastics Faraday Partnership.

Immobilisation in catalysis – a technology roadmap

Sustainable manufacturing is the main market driver for immobilisation in catalysis, which enables catalysts and reagents to be recovered and reused. A long term goal is for the supports to be manufactured cleanly from renewable sources, and reused along with the active ingredients. The potential to reduce environmental impacts of the chemical processes is obvious, but there is scant mention of this.

International technology roadmap for semiconductors

This is perhaps one of the most comprehensive roadmaps available. It receives regular updates and is greatly respected within the semiconductor manufacturing industry. Environment, health and safety are covered in a chapter of this report.

Rubber technology roadmap

Under a section on performance measures and targets, the need for increased and improved recycling techniques is called for. ELV directives from the European Commission will drive this, with targets by 2015 of 95 per cent recycled and five per cent to landfill. The need for design for recycling is highlighted.

Product-technology roadmap for microsystems

Nexus are on their second edition of this roadmap which may be purchased. It is very broad in its application domains and has a section on the environment.

Technical textiles technology roadmap

This roadmap is simply a timeline chart, although it does refer to environmental matters. Sustainability is important and should be applied in manufacturing, use during life, and end of life. Minimisation of waste and reuse of fibres and chemicals are stressed.

Roadmap for process equipment materials technology

Performance targets are set for materials of construction for 2020. Specifically for the protection of the environment, the following targets are given:

- containing processes and preventing unacceptable leakage and emissions;
- recycling 95 per cent of metallic materials of construction at the end of their useful life;
- striving to select materials that ultimately reduce environmental impacts from processing operations.

Innovation roadmap on bio-based feedstocks, fuels and industrial products

The objective of the innovation roadmap is to take advantage of Canada's abundant bio-resources in order to boost the economy while protecting the environment and quality of life. The roadmap report covers a number of chemical and bioconversion technologies and identifies both intermediate and future markets for the bio-based economy. Potentially renewable biofuels are cleaner and cheaper than fossil fuels.

Canadian fuel cell commercialisation

The fuel cell and hydrogen industries are poised to provide major improvements in efficiency, greenhouse gas emissions, urban pollution, and quality of life. Environment Canada's role in the roadmap is to carry out emission testing, life cycle analysis, and technology assessments. It is able to provide funding for a variety of demonstration projects.

Lean logistics technology roadmap

Fuel economy is the only environmental issue mentioned in this roadmap.

Marine and ocean industry technology roadmap

Traditional marine and ocean industries such as shipbuilding, fishing and water treatment are now being joined by others, including oil and gas, aquaculture, and recreational fishing. This roadmap is designed to protect Canada's interests in these areas. Global trends driving the industry are climate change, energy demand, food production and sustainability.

ICT technology roadmap

This report emanates from the Department of Science and Technology in South Africa, but does not mention environmental issues.

Powder metal sector technology roadmap

Increasingly stringent emissions legislation will drive refinements in internal combustion engines and other automotive systems. Workplace environmental and health and safety issues are the elimination of hazardous materials, reduced process emissions, and improved process energy efficiency. Cost-effective reuse of components is also a goal at end of life. It is intended that process energy consumption should be reduced by 50 per cent by 2020.

Magnetics sector technology roadmap

Commitment by the UK Government is requested to improve efficiency in aerospace and land-based power generation. Other concerns are the need to develop commercial magnet recycling capability for magnetic materials of high intrinsic value.

There is now intensive R&D effort on hybrid electric vehicles and fuel cell technologies, and a continuing race towards a lucrative low or zero-emission market. Political pressure to cut CO_2 emissions is also prevalent.

Advanced ceramics technology roadmap

There are no recommendations on environmental matters.

Hard metals technology roadmap

The use of cobalt as a critical component of hard metals is coming under scrutiny on safety grounds. The hard metal industry is characterised by a high level of recycling estimated at 80 to 90 per cent, but there is still room for new recovery and recycling processes.

Building industry technology roadmap

This is an Australian roadmap produced by their copper industry, but it covers all aspects of construction. In a section on security, safety and health, population pressures are predicted to see homes become smart havens using fail-safe data transmissions. Automated security systems, remote diagnostics, virtual community networks and germ management are mentioned. Energy generation, collection, and its efficient use are considered by the roadmap.

Green chemical technology 2004 roadmap

As expected, this green chemistry roadmap addresses a number of environmental trends and drivers with a vision of zero waste, zero emissions, and zero impact. Climate change, resource efficiency, recycling and sustainability are discussed. Items should be designed for recycling, and ultimately manufacturers should take responsibility for the entire life cycle of their products.

A technology roadmap for colloid and interface science in the uk

Low environmental impact is a feature of this roadmap. Issues such as durability versus disposability are covered, and in a cradle-to-grave analysis it is suggested that more attention should be paid to the ‘grave’ part. Triggered degradability is also commented on in view of the increasing responsibility being levied on the manufacturer to ensure recyclability of products.

Foresight vehicle technology roadmap

The UK has committed to the Kyoto protocol and will reduce CO_2 and other greenhouse gas emissions associated with road transport, as laid down in this roadmap. Overall, the vision is for an environmentally sustainable road transport system. Transport is presently responsible for around 22 per cent of UK greenhouse gas emissions.

There is a great deal of detail about environmental issues, addressing the manufacture of vehicles as well as their environmental impact while in use. Targets are established for CO_2, particulates, other gases, and manufacturing for up to 20 years. European directives for emissions, coupled with voluntary targets for CO_2 reductions, are setting the short-term agenda. For manufacturing, compliance with legislation (both emissions and waste regulations) without adding unduly to design and manufacturing costs is a priority.

R&D work is needed on a broad front to achieve a low carbon economy. Advances in the internal combustion engine emission characteristics, electrical machinery development, improvement in the efficiency of motors and other storage devices are required.

Specific technology targets are:

0-5 years	5-10 years	10-20 years
▪ Establish standards for environmental friendliness ▪ Development of polymer separation techniques ▪ ELV compliant composite materials ▪ Reduce vehicle weight ▪ Attachment strategies for dismantling ▪ Wider understanding of materials in the industry ▪ Overcoming energy savings vs. recycling perceptions ▪ Development of disbondable metal/composite interfaces ▪ National system for reuse of components ▪ Low cost CFRP panels and structures	▪ New magnetic materials for hybrid/fuel cell powertrain ▪ Develop reuse mechanisms/ methodologies ▪ Identify higher value markets for recovered materials ▪ National systems for material reuse and recycle	▪ Solve H_2 fuel infrastructure issues to enable widespread uptake and use ▪ Hardwearing, low friction coatings to eliminate lubricants from powertrains

A roadmap for high throughput technologies

The term high throughput technology (HTT) is used to describe a range of tools and techniques that enable rapid, intelligent, parallel experimentation, increasing the productivity of R&D by orders of magnitude over traditional approaches. Environmentally sustainable benefits which can be delivered by HTT are summarised as: reduce, reuse, and recycle. HTT is expected to have an impact on most industries, and for the environment high impacts are expected through bioassays and analysis, and medium impact on catalysis.

A European roadmap to hydrogen

One chapter looks at hydrogen storage, but environmental issues are not generally discussed.

A roadmap for printable electronics

Environmental issues are not taken into consideration.

A European platform for sustainable chemistry – materials technology

Other than a comment that future materials should have "*benign health and environmental attributes and should be recyclable with a focus on eco-efficiency*", there is no discussion of environmental issues. However, the report contains several proposals on nanotechnology.

Technology roadmap for low energy polymer processing

This roadmap is an update of one first carried out in December 2003, which obtained considerable funding from Europe (http://www.euRECIPE.com) to tackle some of the priorities set out in the roadmap. The general aim is to reduce wastage of energy and hence make processing much less expensive and subsequently have less impact on the environment.

Technology roadmap in recycling of plastics

This roadmap places a great deal of emphasis on environmental issues. The Environment Agency is mentioned in the report, being requested to take a leading role in legislative issues on recycling which appear to be vague or contradictory. There is a call for coordination of recycling research.

International roadmap for consumer packaging

As expected, this roadmap pays considerable attention to recycling and disposal and predicts that:

- there will be an increasing demand for biodegradable packaging;
- the cost of non-renewable materials will rise with a move to renewables;
- producer responsibility will drive waste minimisation through lightweighting, volume reduction, and use of recyclable materials;
- packaging will play a key role in making products more easily recyclable.

Timescales are given for progress in each of the above four areas.

CO_2 capture and geological storage technology roadmap

Canada is a major and growing exporter of energy and this roadmap sees the market becoming more competitive. The idea is to reduce the carbon intensity of fossil fuel energy by capturing the CO_2, transporting it and storing it in geological formations. The targets are ambitious but would have a marked effect on the environment.

Clean coal technology roadmap

Reduced emissions are the goal to minimise global greenhouse gases emitted. The proposal is to look at new technologies, provide commercial demonstrations and create export opportunities for the technology.

Future fuels for the APEC region – an integrated technology roadmap

There is a clear focus on renewable energy, and the roadmap, although produced by the Canadians, is an international one. The report examines unconventional hydrocarbons, renewable energy in the form of biofuels, and hydrogen. It contains considerable detail on each of these areas.

The Canadian biopharmaceutical industry technology roadmap

Environmental impact was not a major consideration in this roadmap, as is the case with other medical roadmaps.

A technology roadmap for the Canadian welding and joining industry

The image of the welding industry is that it is dirty and old-fashioned, so one of the priorities is to incorporate welding and joining considerations into product design, along with upgrading training in this area. There is also a call to increase the pace of innovation in advanced welding and joining applications. There is no comment about environmental impact other than an underlying conclusion that new technologies will be cleaner.

Roadmapping for medical devices

This roadmap provides little information about environmental issues, with some mention of removal of CFCs from inhalers. The report is more useful for its references to other roadmaps in the medical field.

Roadmap of European technology platform for advanced engineering materials and technologies

This report from EuMat discusses the environmental drivers and looks at the profound influence they have on the life cycle impact of new materials. Minimising wear, corrosion, and mechanical damage of plant components in the future is essential and entails less maintenance.

One topic covered is materials for energy supply and environmental protection, where environmental protection and minimising climate change are the most serious challenges, with the main focus on reduction of CO_2 emissions. A number of actions are put forward.

Materials powering Europe – energy workshop and roadmap

Generation of power by different routes is discussed in this roadmap. For all current and future work to produce energy, efficiency is paramount. Extension of the life of generators is a feature, with the need to prevent corrosion and produce materials that can survive longer in extreme environments.

Issues such as reuse and recycling are not considered in this roadmap.

Materials for a safe Europe – security workshop and roadmap

This roadmap looks at personal protection and proof of identity for both people and their property. The need for the development of sensors for a variety of conditions is recognised as being particularly important. The impact of developments on the environment is not discussed.

Materials for a better life - workshop and roadmap

The roadmap covers three themes: biomaterials, packaging, and technical textiles. The biomaterials chapter does not cover environmental impacts, as might be expected.   The packaging section does not raise any additional issues on the environment that have not already been raised in the Faraday Packaging roadmap on consumer packaging. The section on technical textiles does not cover what happens when textiles have reached the end of the period they were designed for, but fabrics that stay clean longer are likely to have less impact on the environment since they will need less detergent to wash them during their life time.

Appendix III: Reports on societal and ethical issues of nanotechnology

Date	Title (source)	Reference
2003	Future technologies, today's choice – nanotechnology, artificial intelligence and robotics. (Greenpeace Environmental Trust)	http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/5886.pdf
2004	Nanoscience & nanotechnologies: opportunities & uncertainties (Royal Society & Royal Academy Of Engineering)	http://www.nanotec.org.uk/finalReport.htm
2004	Nanotechnology – small matter, many unknowns (Swiss Re)	http://www.swissre.com/INTERNET/pwsfilpr.nsf/vwFilebyIDKEYLu/ULUR-5YNGET/$FILE/Publ04_Nanotech_en.pdf
2005	Nanotechnology: "small size – large impact" (Swiss Re)	http://www.swissre.com/Internet/pwswpspr.nsf/fmBookMarkFrameSet?ReadForm&BM=../vwAllbyIDKeyLu/mbui-6e7gdn?OpenDocument
2005	Response to Royal Society & Royal Academy Of Engineering (HM Government)	http://www.dti.gov.uk/files/file14873.pdf
2005	Informed perceptions of nanotechnology & trust in government (Woodrow Wilson International Centre For Scholars)	http://www.wilsoncenter.org/events/docs/macoubriereport.pdf
2005	Managing the effects of nanotechnology (Woodrow Wilson International Centre For Scholars)	http://www.pewtrusts.org/pdf/Effects_Nanotech_011106.pdf
2005	Opportunities & risks of nanotechnologies (OECD/Allianz)	http://www.oecd.org/dataoecd/4/38/35081968.pdf
2005	Charging into the valley of death? (O Cheema and S Kaushal, criticalEYE.net)	Available through https://www.criticaleye.net/review/january06B.phtml?login=688fb97e1b85daa6b9e848d75e265573
2006	Nanotechnology: a research strategy for addressing risk (Woodrow Wilson International Centre For Scholars)	http://www.pewtrusts.org/pdf/nanotech_071906.pdf
2006	The ethics & politics of nanotechnology (UNESCO)	http://unesdoc.unesco.org/images/0014/001459/145951e.pdf
2006	Results of the informal collection of inputs for nanotechnology R&D in the field of (eco)toxicology (European Commission, Research DG)	ftp://ftp.cordis.europa.eu/pub/nanotechnology/docs/inputs_nanoecotox.pdf
2006	Nanotechnology: health & environmental risks in nanoparticles (Federal Environment Agency/BAuA/Bfr, Germany)	http://www.baua.de/nn_47716/sid_B0AA05CB8FF8141A55EAC94DDDFCC809/nsc_true/de/Themen-von-A-Z/Gefahrstoffe/Nanotechnologie/pdf/draft-research-strategy.pdf
2006	Nanotechnology in agriculture and food production – anticipated applications (Woodrow Wilson International Centre For Scholars)	http://www.pewtrusts.com/pdf/Nanotech_agfood_090406.pdf

2006	Regulating the products of nanotechnology: does the FDA have the tools it needs? (Woodrow Wilson International Centre For Scholars)	Downloadable from http://www.nanotechproject.org/83
2006	Characterising the potential risks posed by engineered nanoparticles (HM Government)	http://www.nanoforum.org/dateien/temp/Characterising%20the%20potential%20risks%20posed%20by%20engineerednanoparticles%20-%20Government%20research%20report.pdf?05122005182041
2006	Review of safety practices in the nanotechnology industry (International Council On Nanotechnology, ICON)	http://cohesion.rice.edu/CentersAndInst/ICON/emplibrary/Phase%20I%20Report_UCSB_ICON%20Final.pdf
2006	Report on nanosciences & nanotechnologies: an action plan for Europe 2005-2009 (European Parliament)	http://www.europarl.europa.eu/sides/getDoc.do?language=EN&pubRef=-//EP//NONSGML+REPORT+A6-2006-0216+0+DOC+PDF+V0//EN

Future technologies, today's choice – nanotechnology, artificial intelligence and robotics.

This report was commissioned by Greenpeace Environmental Trust and written by Alexander Arnall, Department of Environmental Science and Technology, Imperial College. It compares the development of nanotechnology and artificial intelligence. Overall the report is not particularly controversial, and acknowledges that nanotechnology in electronic applications is likely to be more acceptable to society than applications involving nanoparticles. It concludes that acceptance of technological innovations will be a balance between their perceived usefulness and their associated risk.

Nanoscience and nanotechnologies: opportunities and uncertainties

This report was produced by the Royal Society and the Royal Academy of Engineering for the UK Government. It defines what is meant by nanoscience and nanotechnologies, and summarises current scientific knowledge. Applications are included, and a 'forward look' discusses how the technologies might be used in the future along with a rough timescale. The report identifies health, safety, environmental, ethical and societal implications or uncertainties that might arise. Areas are identified where additional regulation might be needed.

Twenty one recommendations are made, and those under the heading 'Possible adverse health, safety, and environmental impacts' are:

- Research Councils UK should set up an interdisciplinary centre to research the toxicity, epidemiology, persistence and bioaccumulation of manufactured nanoparticles and nanotubes. Liaison with regulators is recommended.
- Until more is known about environmental impacts, the release of manufactured nanoparticles and nanotubes should be avoided as far as possible.
- Factories and laboratories should for the time being treat manufactured nanoparticles and nanotubes as hazardous. It is also suggested that the use of free manufactured nanoparticles and nanotubes in environmental applications, such as remediation, should be prohibited until satisfactory research has been carried out.
- In the design process of products, industry should assess the risk of release of nanoscale components.
- Terms of reference of scientific advisory committees should consider safety of ingredients that exploit new and emerging technologies.

Nanotechnology – small matter, many unknowns

In the preface of this report, the Swiss Reinsurance Company (Swiss Re) claims to have dedicated teams of experts who track new or emerging risks, and nanotechnology is one of the topics currently in focus. For the insurance industry, it is vital to know what losses a new technology can give rise to and what the extent and frequency of such losses will be.

In view of the many benefits of nanotechnology, Swiss Re is working towards a transparent dialogue with the various stakeholders to discuss the inherent risks and opportunities. There is a large section on nanoparticles in the environment, and detailed information is given about the impact of nanoparticles from a number of applications.

Nanotechnology: "small size – large impact"

This report records some of the lectures at Swiss Re's first conference on nanotechnology held in 2004. At the end of the conference, a talk on regulatory challenges with emerging technologies was given by Paul Davies, Chief Scientist and Director of Corporate Science and Analytical Services at the Health and Safety Executive. In it he described how the UK was attempting to stay ahead of the game as regulators, rather than having to play 'catch-up'. The ability to regulate can be compromised by the existence of already well-established practices.

Davies argues that horizon scanning can help by ensuring that the regulator is aware of changes in the medium to long-term future. The process must be systematic in anticipating and identifying new regulatory requirements, and should bring together back-room policy makers and frontline operational experts to identify emerging issues and evaluate their likely impact.

The DTI is one example of a horizon scanning initiative run via its *Foresight programme*, while the HSE has a more structured approach to horizon scanning for health and safety at work. The challenge is to spot 'runners', the technologies which will have a long-term future rather than become dead-ends.

Davies concludes that there is a need to:

- aspire to better regulation;
- be goal-setting rather than prescriptive;
- adopt a precautionary approach in the face of uncertainty about risks, with a view to easing controls if knowledge gained subsequently supports this;
- engage stakeholders, including the public, in constructing the regulatory regime;
- 'keep ahead of the game' through horizon scanning.

Response to Royal Society and Royal Academy of Engineering

HM Government, in this report, supports the findings of the commissioned report described above. In the final section, 'Ensuring the responsible development of nanotechnologies', the recommendation is that the Chief Scientific Advisor should establish a group that brings together representatives of a wide range of stakeholders to look at new and emerging technologies. The group should identify at the earliest possible stage areas where potential health, safety, environmental, social, ethical, and regulatory issues may arise, and advise on how these might be addressed.

Under this point, it is announced that the government will set up a new centre of excellence in science and technology horizon scanning, which will be based in OST and build on the work of the existing *Foresight programme*. HM Government believes that the centre will be most effective if it works with and alongside existing bodies such as RCUK (Research Councils UK), the Technology Strategy Board, CSAC (Chief Scientific Advisor's Committee) and CST (Council for Science and Technology).

Informed perceptions of nanotechnology and trust in government

This report was issued by the *Project on Emerging Technologies* at the Woodrow Wilson International Centre for Scholars. It provides the results of a study on the public's perceptions of government, nanotechnology and regulation. Only a small sample of people was surveyed, and one has to question the relevance of this type of survey.

Opportunities and risks of nanotechnologies

This report was produced by the OECD International Futures Programme and Allianz's Centre for Technology. It is recognised that the catch-all term 'nanotechnology' is so broad that it is ineffective as a guide to tackling the issues of risk management, risk governance, and insurance. A more differentiated approach is needed. The report points out that epidemiological studies on ambient fine and ultrafine particles incidentally produced in industrial processes and from traffic show a correlation between ambient air concentration and mortality rates.

The report argues that more research is needed, but acknowledges that the exposure of the general population to nanoparticles from industrial processes is marginal compared to those produced unintentionally, for example via combustion processes. Exposure to manufactured nanoparticles at work is mainly concentrated on workers in nanotechnology research and nanotechnology companies. The report notes that studies on biopersistence, bioaccumulation, and ecotoxicity have only just started, and it calls for more independent research on risk.

Managing the effects of nanotechnology

J Clarence Davies of the Woodrow Wilson International Centre for Scholars authored this report, in which he says that nanotechnology is difficult to address using existing regulations. He argues that the Toxic Substances Control Act, the Occupational Safety and Health Act, the Food, Drug and Cosmetic Act, and the major environmental laws (Clean Air Act, Clean Water Act, and the Resources Conservation and Recovery Act) all suffer from major shortcomings of legal authority, and from a gross lack of resources. He claims that they provide a weak basis for identifying and protecting the public from potential risk.

Davies suggests that a new law may be required to manage the potential risks of nanotechnology, and that new mechanisms and institutions are needed. The paper describes several mechanisms to encourage beneficial applications of nanotechnology.

This paper has been heavily criticised recently by David Berube (Berube, 2006b).

Charging into the valley of death?

This article focuses on better management of new nanotechnology developments.

Nanotechnology: a research strategy for addressing risk

Andrew Maynard of the Woodrow Wilson International Centre for Scholars has looked at emerging nanotechnologies and concluded that they are unlikely to succeed without appropriate research on the potential risks to health, safety, and the environment. He calls for targeted and strategic research to fill the gaps in the current state of nanotechnology risk research.

Maynard claims that changes need to be made in research responsibility within the federal government. He suggests that federal government should assume top-down, authoritative oversight of strategic risk-based research, and that the research should be carried out by federal agencies with a clear mandate for environmental, health and safety issues. Maynard calls for adequate funding for highly relevant risk research, and says the appropriate lead organisations should be:

- Environmental Protection Agency (EPA)
- National Institute for Occupational Safety and Health (NIOSH)
- National Institute of Health (NIH)
- National Institute of Standards and Technology (NIST)

Maynard estimates a minimum budget of $100 million over two years.

The ethics and politics of nanotechnology

UNESCO views nanotechnology as being at a crossroads, but says that definitions are all important in this general review. There is a section on 'Toxicity and environmental implications of nanotechnology' which is referred to in the text of this report (page 27).

Results of the informal collection of inputs for nanotechnology R&D in the field of (eco)toxicology

This is simply a collection of thoughts on what needs to be funded in the EU Framework Programme 7 in the field of ecotoxicology.

Nanotechnology: health and environmental risks in nanoparticles

The Federal Environment Agency in Germany (UBA – Umwelt Bundes Amt für Mensch und Umwelt) has published a research strategy for nanoparticles in conjunction with the Federal Institute for Occupational Safety and Health (BAuA) and the Federal Institute for Risk Assessment (BfR). A summary of the main points is given in the text (Section 4.4).

Nanotechnology in agriculture and food production – anticipated applications

The report from the Woodrow Wilson International Centre for Scholars is in three parts:

- overview of ongoing research into the applications of agrifood nanotechnology;
- in-depth discussion of data from a database research project;
- detailed description of the methodology used to populate the database.

Regulating the products of nanotechnology: does the FDA have the tools it needs?

This is a further report from the Woodrow Wilson International Centre for Scholars and this one asks whether the Food and Drug Administration (FDA) has the tools to regulate the products of nanotechnology. The FDA will be charged with overseeing the safety of some of the earliest and most visible applications of nanotechnology (sunscreens, cosmetics, food packaging, drugs and medical devices). It will be expected to do so in a manner that protects public health, fosters beneficial innovation and provides the basis for public confidence in nanotechnology products.

The report recommends that the US Congress should address the gaps in FDA's legal authority and resources, and suggests steps to be taken under current law to address nanotechnology products that are already emerging.

Characterising the potential risks posed by engineered nanoparticles

The Department of Environment, Food and Rural Affairs (Defra) has produced this report which summarises government progress in coordinating research to address the potential risks posed by engineered nanoscale materials, as well as setting out the research necessary to gather evidence for an appropriate control structure. Five Task Forces are charged with progressing different aspects of this.

Review of safety practices in the nanotechnology industry

ICON's report reviews current health and safety practices in the nanotechnology workplace, and assesses product stewardship issues. Only the German Federal Institute of Occupational Safety Health (BAuA) has conducted large-scale surveys of industry.

Report on nanosciences and nanotechnologies: an action plan for Europe 2005-2009

The outcome of this report is that the European Commission envisages:

- boosting funding for nanotechnologies in the Seventh Framework Programme;
- developing world-class competitive infrastructure for research and poles of excellence;

- creating favourable conditions for EU industry to turn research into useful products and services;
- ensuring that ethical principles are always respected and citizens' concerns and expectations are taken into account;
- addressing public health, safety and environmental risks at the earliest possible stage;
- reassessing existing EU legislation;
- supporting the creation of an open archive of scientific publications in the field, promoting the inter-disciplinary education and training of researchers and engineers;
- strengthening international dialogue on common issues.

Appendix IV: Reports on the benefits of nanotechnology

Date	Title (source)	Reference
2005	Nanotechnology and the poor – opportunities and risks (Meridian Institute)	http://www.meridian-nano.org/gdnp/NanoandPoor.pdf
2005	Nanotechnology and the developing world (PLoS Medicine)	http://medicine.plosjournals.org/archive/1549-1676/2/5/pdf/10.1371_journal.pmed.0020097-L.pdf
2005	Big picture on nanoscience (for schools) (Wellcome Trust)	http://www.wellcome.ac.uk/assets/wtd015798.pdf
2006	Nanotechnology – does it have a sporting chance? (IUPAC, Chemistry International)	http://www.iupac.org/publications/ci/2006/2801/2_smith.html
2006	Nanotechnology, water and development (Meridian Institute)	http://www.merid.org/nano/waterpaper/NanoWaterPaperFinal.pdf
2006	Nanotech – the way forward for clean water? (Filtration & Separation, Elsevier, October 2006)	Available on subscription through http://www.filtsep.com
2006	Water nano-based treatment technologies (Meridian Institute)	http://www.merid.org/nano/watertechpaper/watertechpaper.pdf
2006	Nanotechnology – lessons from Mother Nature (IUPAC, Chemistry International)	http://www.iupac.org/publications/ci/2006/2806/2806-pp10-11.pdf

Appendix V: General strategies and reports on nanotechnology

Date	Title (source)	Reference
1999	Opportunities for industry in the application of nanotechnology (Foresight Exercise, UK)	http://www.foresight.gov.uk/Previous_Rounds/Foresight_1999__2002/Materials/Reports
2003	Nanoscale science & engineering for agriculture and food systems (US Department Of Agriculture)	http://www.csrees.usda.gov/nea/technology/pdfs/nanoscale_10-30-03.pdf
2003	Socio-economic report on nanotechnology and smart materials for medical devices (nanoforum.org, European Nanotechnology Gateway, EU)	Available through http://www.nanoforum.org
2004	Towards a European strategy for nanotechnology (European Commission)	Available through http://www.cordis.lu/nanotechnology/actionplan.htm
2004	Outcome of the open consultation on the European strategy for nanotechnology (nanoforum.org, European Nanotechnology Gateway, EU)	Available through http://www.nanoforum.org
2004	Cancer nanotechnology plan (US Department Of Health & Human Services)	http://nano.cancer.gov/about_alliance/cancer_nanotechnology_plan.asp
2004	Germany's nanotechnology strategy (British Embassy, Berlin)	http://www.britischebotschaft.de/en/embassy/r&t/notes/rt-note04.1011_nanotechnology_strategy.htm
2004	Nanoelectonics at the centre of change (European Commission)	http://europa.eu.int/comm/research/industrial_technologies/pdf/nanoelectronics_june2004_en.pdf
2004	Towards a European strategy for nanotechnology (European Commission)	http://ec.europa.eu/research/industrial_technologies/pdf/nanotechnology_communication_en.pdf
2004	Microsystems & nanotechnology in healthcare & life sciences - market sector report (Technology For Industry Ltd)	http://www.tfi-ltd.co.uk/reports/index.htm
2005	Nanosciences & nanotechnologies: an action plan for Europe 2005-2009 (European Commission, EU)	http://ec.europa.eu/research/industrial_technologies/pdf/nano_action_plan_en.pdf
2005	Nanotechnologies for car interiors (Institute of Nanotechnology, UK)	Available through http://www.nano.org.uk/reports.htm
2005	Nanotechnologies for the oil and energy industry (Institute of Nanotechnology, UK)	Available through http://www.nano.org.uk/reports.htm
2005	Nanotechnologies for composites, surface coatings and sensors (Institute of Nanotechnology, UK)	Available through http://www.nano.org.uk/reports.htm
2005	Nanotechnologies for novel optical effects (Institute of Nanotechnology, UK)	Available through http://www.nano.org.uk/reports.htm
2005	Nanotechnologies for perfume encapsulation (Institute of Nanotechnology, UK)	Available through http://www.nano.org.uk/reports.htm
2005	New processes and applications in nanochemistry (Institute of Nanotechnology, UK)	Available through http://www.nano.org.uk/reports.htm

2005	Micro & nanotechnology in healthcare & life sciences market sector report (Technology For Industry Ltd)	May be purchased through http://www.tfi-ltd.co.uk
2005	A strategy for European standardization for nanotechnologies (CEN/BT/WG 166, EU)	Submitted to CEN/BT for approval
2006	Nanomedicine – nanotechnology for health (European Commission)	ftp://ftp.cordis.europa.eu/pub/nanotechnology/docs/nanomedicine_bat_en.pdf

Appendix VI: Nanotechnology roadmaps

Date	title (source)	Reference
2003	Chemical industry R&D roadmap for nanomaterials by design (Chemical Industry Vision 2020 Technology Partnership, US)	http://www.chemicalvision2020.org/pdfs/nano_roadmap.pdf
2004	Senscope - strategic scoping study on the convergence of enabling technologies: microsystems, nanotechnology & sensors (Intersect Faraday Partnership)	Available through http://www.google.com/search?hl=en&ie=ISO-8859-1&q=senscope&btnG=Google+Search
2004	MNT Network roadmap in metrology (MNT Network, UK)	Access through http://www.mntforum.com
2004	MNT Network roadmap in integration (MNT Network, UK)	Access through http://www.mntforum.com
2004	MNT Network roadmap in silicon (MNT Network, UK)	Access through http://www.mntforum.com
2005	International MEMS/MST and nano roadmap (MANCEF)	Available through MANCEF at http://www.mancef.org/roadmap.htm
2005	Roadmap reports: materials - nanoporous materials; nanoparticles/nanocomposites; dendrimers; thin films & coating (NRM, FP6 Nanoroadmap project, EU)	http://www.nanoroadmap.it
2005	Roadmap reports: health and medical systems (NRM, FP6 Nanoroadmap project, EU)	http://www.nanoroadmap.it
2005	Roadmap reports: energy (NRM, FP6 Nanoroadmap project, EU)	http://www.nanoroadmap.it
2005	Nanocomposites technology roadmap (Faraday Plastics and Hybridnet, UK)	http://www.faraday-plastics.com/freedls/NanocompositesTRM170805.pdf?id=NanoTRM.doc
2005	MNT Network roadmap in design, simulation & modelling (MNT Network, UK)	Access through http://www.mntforum.com
2005	MNT Network roadmap in diagnostics (MNT Network, UK)	Access through http://www.mntforum.com
2005	MNT Network roadmap in gas sensors (MNT Network, UK)	Access through http://www.mntforum.com
2005	MNT Network roadmap in polymer manufacturing (MNT Network, UK)	Access through http://www.mntforum.com
2005	MNT Network roadmap in nanoparticle manufacture (MNT Network, UK)	Access through http://www.mntforum.com

Chemical industry R&D roadmap for nanomaterials by design

This is a particularly well-constructed roadmap that takes a serious look at environmental, safety and health issues associated with nanotechnology. For that reason, the R&D priorities for those areas are reproduced in the body of this report (Section 4.3).

SENSCOPE - Strategic scoping study on the convergence of enabling technologies: microsystems, nanotechnology & sensors

The environmental impact of the production of sensors is not discussed in this roadmap. However, the use of sensors for monitoring the environment is a feature. For example, MEMS pressure devices find wide application in the automotive, aerospace, marine, petrochemical, gas, power generation and water industries. Nanotechnology offers the potential of faster and more sensitive devices. Under a section on the environment, toxicity sensors, real-time pesticide monitors, carbon nanotube gas detectors, high performance miniature mass spectrometers, and single-wall carbon nanotube EM field sensors are all mentioned as development projects.

MNT Network roadmap in metrology

The environmental impact of nanotechnology is not a main issue but the ability to measure things at the nanoscale is, of course, crucial to examining the effects that it might have.

MNT Network roadmap in integration

Environmental impacts are not discussed.

MNT Network roadmap in silicon

Environment, safety and health are not seen as a major problem as devices increasingly go down to the nanoscale. It is felt that the situation will be the same as for larger scale devices.

International MEMS/MST and nano roadmap

Comments are the same as for the *MNT Network roadmap in silicon.*

Roadmap reports: materials - nanoporous materials; nanoparticles/nanocomposites; dendrimers; thin films & coating

This materials roadmap appears as a single booklet, but it is in fact four separate roadmaps on the above topics.

For nanoporous materials applications are as membranes and bulk material, and both have environmental applications for water treatment and remediation (see Appendix VI for three reports on nanotechnology and water). Other applications relating to the environment that are mentioned are their use in sensors.

For nanoparticles, the emphasis is on applications and environmental applications are listed as:

- water treatment (photo-catalyst treatments, for example using TiO_2);
- self-cleaning glass (for example, using TiO_2-based nanostructured coatings);
- anti-reflection coatings;
- sanitary ware;
- soil remediation (for example, using Fe);
- controlled delivery of herbicides and pesticides;
- anti-fouling coatings (reduce chemical use).

Health, safety and environmental aspects are covered and the following comment is made:

"Companies need to understand and clarify the current trends in both toxicology and regulation in order to ensure that they can reap the rewards of nanotechnologies while avoiding the risks, and this needs to be done immediately".

A final recommendation is to increase the risk capital for production start-ups which sell application-oriented research and technology development.

For dendrimers, the following environmental applications are listed: decontamination agents (trapping metal ions) and ultrafiltration. A dendrimer-based product from DSM is mentioned, which reduces the number of steps in the papermaking process, making it much more efficient and environmentally friendly.

Thin films and coatings applications include self-cleaning surfaces, MEMS devices, thermally insulated windows and friction-reducing surfaces.

Roadmap reports: health and medical systems

This roadmap is divided into the following sections:

- drug encapsulation/drug delivery/drug targeting;
- molecular imaging/biophotonics/medical imaging;
- biochips/high throughput screening/lab-on-a-chip devices;
- biomolecular sensors.

The need for awareness of environmental impacts in these areas is mentioned but not dealt with in any depth.

Roadmap reports: energy

Four topics are discussed: solar cells, thermoelectricity, rechargeable batteries and supercapacitors, and heat insulation and conductance. The benefits derived from applications in these areas are seen as outweighing any potential negative effects.

Nanocomposites technology roadmap

Increasing legislation such as the End-of-Life Vehicle Directive (ELVD) requires materials to be more recyclable and expend less energy during production and their lifetime. Nanocomposites, if used correctly, can help to overcome many of the problems associated with recycling and energy reduction. More specifically, nanocomposites have the potential to increase sustainability for a number of applications such as:

- reducing fuel emission in the transport sector through increased weight saving;
- enhancing properties of recycled materials;
- replacing halogenated flame retardants in polymer products.

In terms of health and safety, the report highlights the need to develop a research programme to look at aspects of nanocomposites that could be problematic.

MNT Network roadmap in design, simulation and modelling

Environmental issues are not covered in this roadmap.

MNT Network roadmap in diagnostics

The theme of this roadmap is diagnostics for medical applications, and environmental impact is not seen as an issue for these markets.

MNT Network roadmap in gas sensors

The original roadmap was updated in November 2006. Obviously, applications for gas sensors will have a major impact on the environment. The following markets are discussed:

- domestic carbon monoxide, flammables and fire
- automotive
- industrial health and safety
- process industries and process control
- air quality
- homeland security

- breath analysis and capnography
- niche markets.

Other than the applications, no comment is offered on health, safety and environmental points associated with nanotechnology.

MNT Network roadmap in polymer manufacturing

In view of the fact that clays in composites are likely to provide the largest initial markets, no account is taken of potential problems since they are not nanoparticulate. It is suggested that nanopolymers should be promoted as sustainable developments.

MNT Network roadmap in nanoparticle manufacture

Risk and regulatory issues associated with nanoparticles are discussed in this roadmap. There is a fear that some companies will not become active in nanomaterials because of the potential regulatory and toxicological momentum. In non-nanotechnology areas, many companies currently prefer to buy-in than develop new products that have to go though animal testing.

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List of Abbreviations

APEC	Asia-Pacific Economic Cooperation
BAuA	Federal Institute for Occupational Safety and Health
BfR	Federal Institute for Risk Assessment
CASRN	Chemical Abstracts Service Registry Number
CEO	Chief Executive Officer
CMR	Carcinogenicity, mutagenicity and reproduction toxicity
CSAC	Chief Scientific Advisor's Committee
CST	Council for Science and Technology
Defra	Department of Environment, Food and Rural Affairs
DTI	Department of Trade and Industry
DOE	Department of Energy
ELV	End-of-life vehicle
ELVD	End-of-Life Vehicle Directive
EPA	Environmental Protection Agency
EuMat	European Technology Platform for Advanced Engineering Materials and Technologies
FDA	Food and Drug Administration
FDCA	Food, Drug and Cosmetic Act
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
GMO	Genetically modified organism
HTT	High throughput technology
ICON	International Council for Nanotechnology
ISO	International Organisation of Standardisation
KTN	Knowledge Transfer Network
MEMS	Microelectromechanical Systems
NGO	Non-governmental organisation
NIH	National Institute of Health
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NRC	National Research Council
NSF	National Science Foundation
OECD	Organisation of Economic Cooperation and Development
OIT	Department of Energy's Office of Industrial Technologies
OPPT	EPA's Office of Pollution Prevention and Toxics

OSHA	Occupational Safety and Health Administration
PAS	Publicly available specification
PATH	Partnerships for Advancing Technology in Housing
PC	Physico-chemical
PCB	Polychlorinated biphenyls
PM^2	Powder metallurgy and particulate materials
PV	Photovoltaic
REACH	Registration, Evaluation and Authorisation of Chemicals
RCUK	Research Councils UK
STEEP	Social, technological, economic, environmental and political trends and drivers
Swiss Re	Swiss Reinsurance Company
SWOT	Strengths, weaknesses, opportunities, and threats
TSCA	Toxic Substances Control Act
UBA	Umwelt Bundes Amt für Mensch und Umwelt – German Federal Environment Agency
UNESCO	United Nations Educational, Scientific and Cultural Organisation

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