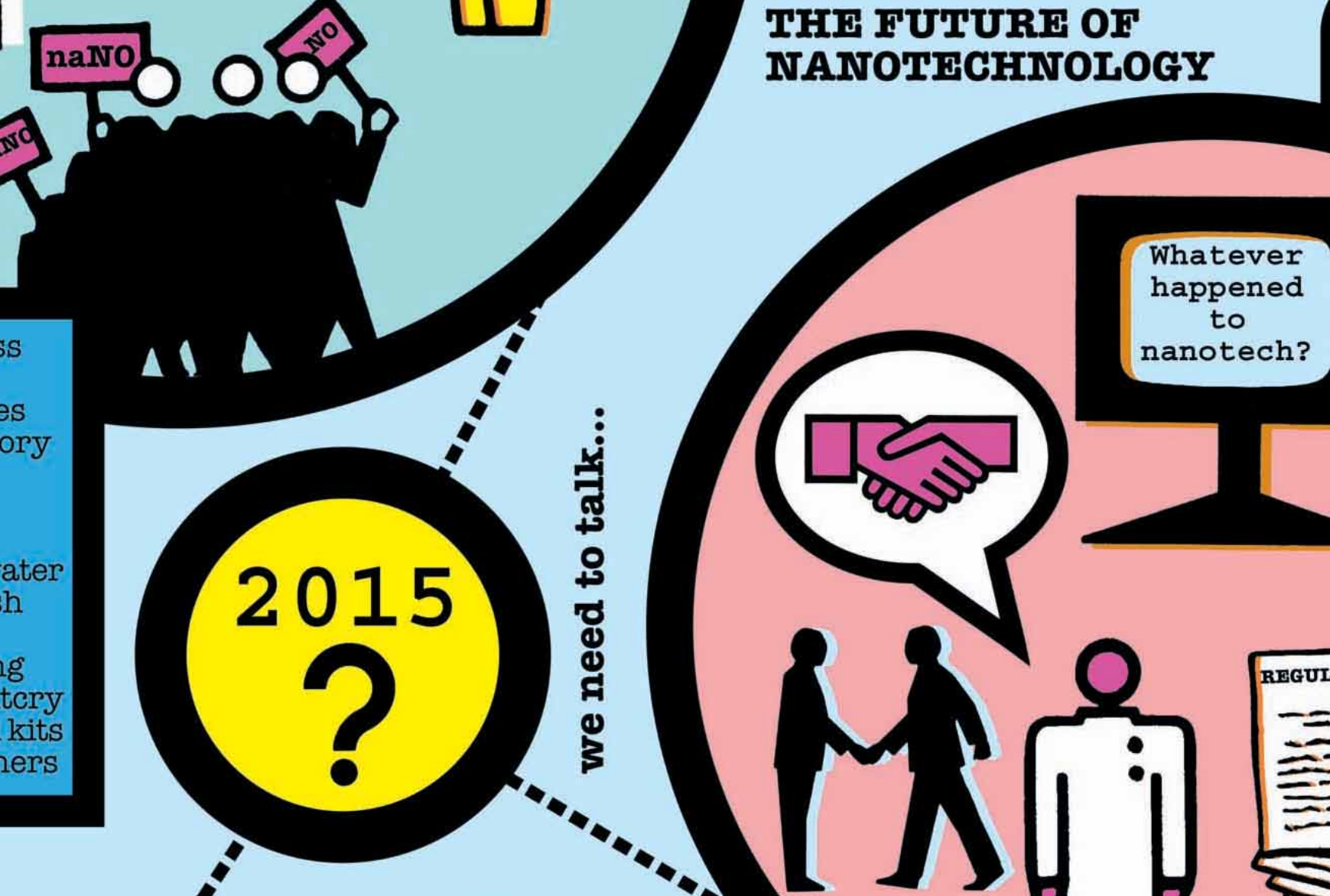
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THE FUTURE OF NANOTECHNOLOGY
Whatever happened to nanotech?
2015 ?
we need to talk...
REGUL

The future of nanotechnology:
We need to talk

Please remove the cover and use it as a poster

Nanologue is a joint project of:

Wuppertal Institute for Climate, Environment and Energy

Forum for the Future

triple innova

EMPA

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For more information about Nanologue, please see the contact details on the last page.

Introduction

ESRC (Economic & Social Research Council) 2003: 'The Economic and Social Challenges of Nanotechnology' →

"Nanotechnology is being heralded as a new technological revolution, one so profound that it will touch all aspects of human society. Some believe that these influences will be overwhelmingly positive, while others see more sinister implications."

Once again we are faced with the introduction of a technology that is polarising views, inspiring wild visions of transformation or catastrophe and stimulating some fundamental questions about how we develop and use technology. Yet nanotechnology is potentially a far more potent and disruptive technology than previous controversial technologies such as genetic modification and may deliver numerous positive benefits for our society. While the debate about the possible impacts intensifies, the technology is developing rapidly, supported by huge investment. Unfortunately very little of this investment is devoted to analysing the risk involved.

www.nanologue.net to find out more →

This pamphlet is a result of the Nanologue project, an 18-month European Commission-funded project designed to support dialogue on the social, ethical and legal implications of nanoscience and nanotechnologies.

The aims of this pamphlet are to:

- ➔ Disseminate a brief summary of the findings from the Nanologue project
- ➔ Provide a very short introduction to some of the risks and opportunities presented by nanotechnology
- ➔ Explore three possible futures in the development of nanotechnology
- ➔ Discuss how dialogue can be used as part of a process to ensure that society maximises the benefits from nanotechnologies and minimises the risks

Who should read this?

This document has been produced with a broad audience in mind. Written in non-technical language it will appeal to anyone interested in the ethical, legal and social implications of nanotechnology, from scientists to policy makers and students.

What is nanotechnology?

The term nanotechnology is an umbrella term that encompasses a vast range of technologies across a number of disciplines and as a result can be a handicap to any discussion about social and environmental implications that may be specific to particular applications.

The "nano" prefix derives from the Greek noun nanos, meaning dwarf. A nanometre (nm) is one billionth (1×10^{-9}) of a metre: the length of about ten atoms placed side-by-side, or 1/80,000th of the thickness of a human hair. Nanotechnology is commonly understood as a technology involving the manipulation and application of matter, based on its properties at the atomic scale. The term covers a family of technologies, including nanosciences and nanotechnologies.

The Royal Society (2004). 'Nanoscience and nanotechnologies: opportunities and uncertainties' RS Policy document 19/04. London, p.5 →

"**Nanoscience** is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale. **Nanotechnologies** are the design, characterisation, production and application of structures, devices and systems by controlling shape and size at nanometre scale."

The possible applications of nanotechnology are numerous and diverse. During the course of the Nanologue project we reviewed advances in the following areas: energy conversion and storage, medical diagnostics and food packaging. We chose these areas to demonstrate the potential impacts and our findings can be viewed on our website.

www.nanologue.net →

How will it affect us?

While there is much excitement over the potential for nanotechnology to provide solutions to some of the global challenges we face (eg increasing energy efficiency to combat climate change, improving nutrition and protecting human health), there are also a number of perceived risks. While some of these risks maybe dismissed or managed through future research and development, there are many gaps in our

knowledge about the potentially harmful effects of nano-materials on human health and the environment for example, which cannot be ignored.

www.nanologue.net for a more in-depth look at the issues →

The following is a summary of the main benefits and risks identified during the Nanologue project. It is not a comprehensive overview but instead provides an introduction to some of the ethical, legal and social implications of nanotechnologies.

Environmental performance

The application of nanotechnology may provide solutions to a number of environmental challenges such as energy conservation, pollution prevention and remediation.

At present there is a strong belief that there will be environmental benefits from the introduction of nanotechnology and improvements could be delivered in the overall environmental performance of products through:

- → efficiency gains in production due to miniaturisation effects, eg cleaner manufacture with less emissions and less waste
- → efficiency gains in use from the ability to build devices from the bottom up and improve efficiency and operation, eg better solar cells from molecular manufacturing
- → nanotechnology-based environment technology applications, eg devices for waste water treatment

However, there is the possibility that new environmental problems will emerge from the introduction of nanotechnology, such as the impact of the uncontrolled release of manufactured nanoparticles into the environment. Questions about the life-cycle impacts of the technology have also been raised with concerns that the manufacture of nano-materials could be energy and resource intensive and there could be further problems at the recycling and disposal phase.

Human health

Effects on human health are a major concern for most stakeholders. Nanotechnology is widely recognised as a great opportunity for disease prevention (eg improved food safety), early disease detection (eg sensors

for cancer detection) or medical treatment (eg controlled drug delivery by nanocapsules). However, the potentially adverse health effects of nanoparticles are widely debated and there is still a large amount of scientific uncertainty regarding the behaviour of nanoparticles in the human body.

Privacy

Because of the expected advances in medical diagnostics, the collection of increasingly sensitive data is likely to raise serious questions about information provenance and distribution. Convergence with information and communication technology (ICT) is also likely to cause the concern, with possible threats to civil liberties from increasingly advanced surveillance capabilities, enabled by nanotechnologies.

Access

There has been considerable discussion about the potential benefits of nanotechnology in tackling issues affecting developing countries. However, at the early stages of development there is concern that the technology will remain prohibitively expensive, limiting access to those who could benefit the most. Given the precedent of unequal access to recent technological development, eg advances in information technology, it is unlikely that access to nanotechnologies will be different without considerable intervention and guidance. There is concern that the development of this technology could just widen the divide between the industrialised and the developing world. It is also possible that high-end medical applications, for example, might also be restricted to those that can afford it within the industrialised world.

Access to technology can be a double-edged sword. Developing a "technical fix" to some of the social and environmental challenges we face might divert investment from cheaper, more sustainable, or low-technology solutions to health and environmental problems. It might also divert attention from the root causes of the original challenges.

Acceptance

As with all major technological breakthroughs, nanotechnology has stirred the imagination of the general public, reaching the news headlines and modern day fiction. However, the vast majority of people still have little or no idea of what nanotechnology is or its possible

implications. Despite this, members of the public have already expressed similar concerns to those associated with genetic modification (GM) and nuclear power, particularly around governance structures and corporate transparency.

Liability

One of the greatest difficulties in predicting impacts of new technologies is that once the technical and commercial feasibility of the innovation is demonstrated, subsequent developments may be as much in the hands of users as the innovators and could be used in ways not originally intended.

At present the main concern voiced by insurance companies is occupational exposure. Beyond this, the complexity of the product life cycle of nanotechnology applications may make it difficult to establish a causal relationship between actions of a company and any resulting impact. Are current liability frameworks sufficient for nanotechnologies?

Regulation and control

New technologies come with new possibilities and new problems. With a technology as potentially disruptive as nanotechnology there is a fundamental question over the need for new regulation.

The immediate issue is whether existing regulatory regimes are robust enough to deal with any special qualities that nanostructured materials may have, or whether new regulation is required.

On the one hand there is a possible risk that nanotechnology develops outside established regulatory bodies because of a wait-and-see attitude in government. On the other hand, an over-regulation of production or use of the technology could be an obstacle for the development of nanotechnology.

Like other emerging technologies that are tightly linked to basic scientific research, nanotechnology generates intellectual property that is perceived as valuable and thus protected by patents. There is an obvious trade-off between the various laws, regulations, and treaties that govern the relationship between the public good and the protection offered by patents.

Nanotechnology before 2006

1959	The word nanotechnology first appears in Richard Feynmann's lecture 'There's plenty of room at the bottom'
1964	Precedent set for patenting at the matter level – Glenn Seaborg "invented" americium 95 and acquired US patent #3,156,523
1965-71	Russell Young develops technology that is later used in the first Scanning Tunnelling Microscope (STM)
1985	Buckyballs (C60) discovered
1986	The Nobel Prize in Physics is awarded for the discovery of atomic resolution in scanning tunneling microscopy
	'Engines of creation' published by Eric Drexler
	Development of the Atomic Force Microscope (AFM)
	Foresight Nanotech Institute founded – first organisation to educate society about the benefits and risks of nanotechnology
1989	IBM scientist Don Eigler used an STM to spell out IBM in xenon atoms as an illustration of engineering capability at nano-scale
1991	Carbon nanotubes discovered
1996	Nanotechnologist Richard E Smalley of Rice University awarded the Nobel Prize in Chemistry for his discovery of buckminsterfullerenes
2000	Bill Joy's vision of the nano-assembler switched attention to the topic, which, in turn, raised public funding
	President Clinton announces the formation of the National Nanotechnology Institute
2002	'Prey', science fiction book on nanotechnology by Michael Crichton
2003	President Bush signs Bill authorising US nanotechnology programme
2004	'Nanotechnology: Small matter, many unknowns' report published by Swiss Re
	'Nanoscience and nanotechnologies: opportunities and uncertainties' report published by the Royal Society
	Prince Charles article speaks out against nanotechnology
2005	European Commission adopts Action Plan that defines a series of linked actions for the "implementation of a safe, integrated and responsible strategy for nanosciences and nanotechnologies"
	Research finds that Buckyballs may deform DNA
	Glass-treating spray containing nanoparticles recalled in Germany

THE FUTURE OF NANOTECHNOLOGY:

we need to talk...

Disaster recovery

- Workers organise mass protests on the health impacts of nanoparticles
- An explosion at a factory causes the release of nanoparticles into the environment
- Nanoparticles in the water cycle are blamed for fish deaths
- Contaminated drinking water leads to public outcry
- Self-diagnostic medical kits are available to consumers

2015 ?

we need to talk...

we need to talk...

THE FUTURE OF NANOTECHNOLOGY

Now we're talking

- There is open communication between scientists and the public about nanotechnology
- Strong regulation and accountability systems are in place
- Regulation slows down the development of the technology - but the world is a safer place
- A TV programme looks at the hype surrounding nanotechnology in 2006 and asks 'Whatever happened to nanotech?'

THE FUTURE OF NANOTECHNOLOGY

Powering ahead

- The introduction of new technologies results in dramatic changes in the energy market
- Spray-on solar cells turn the outside of buildings into energy factories
- Local energy facilities replace centralised energy production
- While industrialised countries benefit from the new technologies, the developing world is being left in the dark

we need to talk...

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THE FUTURE OF NANOTECHNOLOGY

www.nanologue.net

What could the future hold for nanotechnology?

www.nanologue.net to find out how these scenarios were created →

With so many unknowns it is difficult to have a meaningful discussion about the future of nanotechnology. The following scenarios are plausible, internally consistent, possible futures, which can be used to explore possible developments. They are explicitly not predictive, but should be used as qualitative planning and communication tools. A scenario-building exercise is not intended to create good versus bad scenarios or likely versus unlikely scenarios, but should reflect combinations of the desirable and less desirable outcomes that will be a feature of most future trends. Scenarios provide multiple perspectives on key areas of uncertainty and allow the development of robust strategies that can deal with multiple outcomes.

The three scenarios are written from the perspective of a researcher in 2015 examining the current state of nanotechnology, what the key concerns are and the pathway that led to this point.

Scenario 1 Disaster recovery

A lack of regulation resulted in a major accident. Public concern about nanotechnology is high and technology development is slow and cautious.

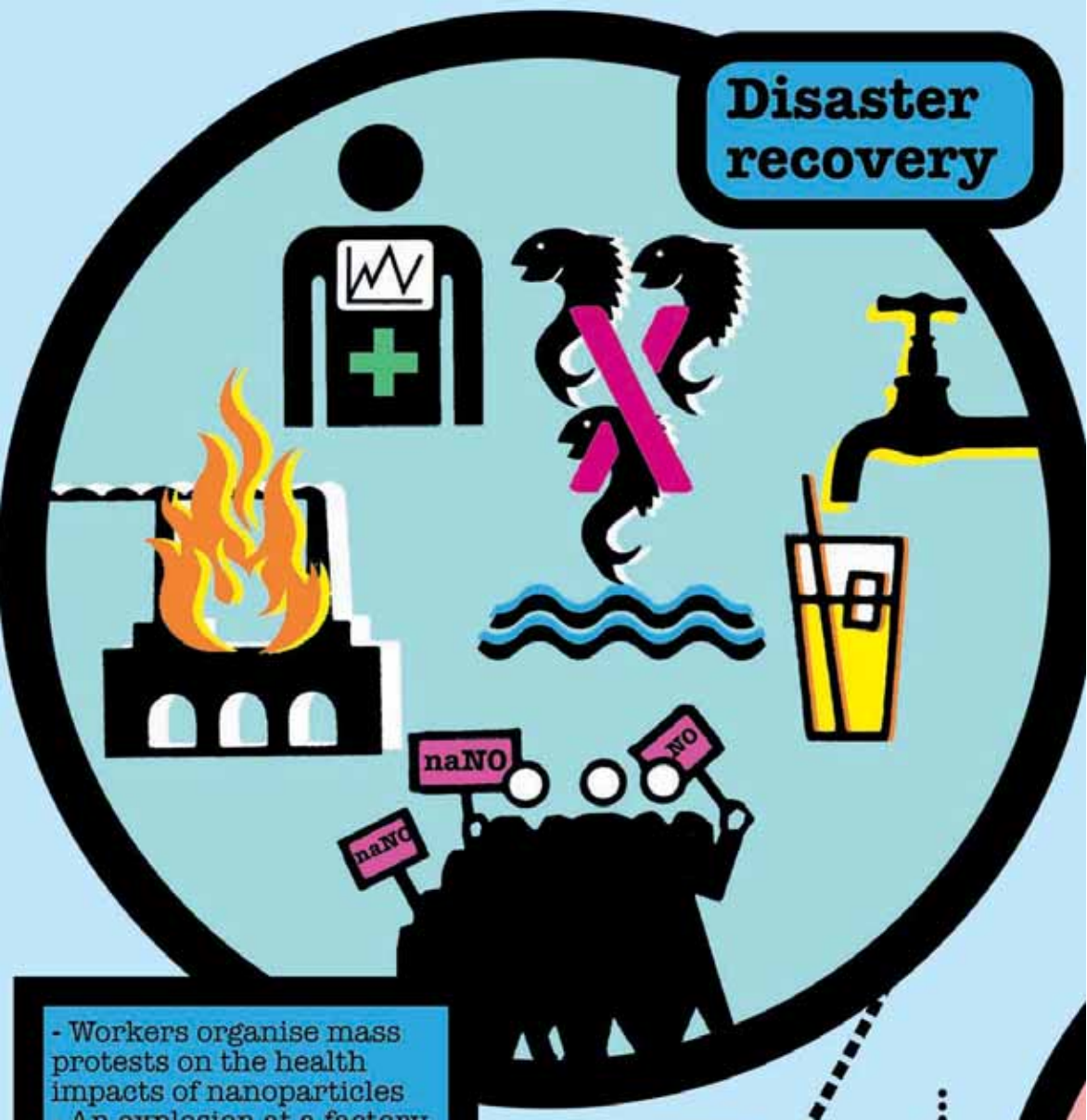
Scenario 2 Now we're talking

Strong regulation and accountability systems are in place. The technology has been shaped by societal needs and strong health and safety concerns.

Scenario 3 Powering ahead

Scientific progress has been faster than expected and nanotechnology is making a real impact, particularly in energy conversion and storage.

Disaster recovery



- Workers organise mass protests on the health impacts of nanoparticles
- An explosion at a factory causes the release of nanoparticles into the environment
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2015 ?

we need to talk...

we need to talk...

Scenario 1 Disaster recovery

Public institutions have been slow to plan for the possibility of health or environmental risks related to nanotechnology and private enterprise has been reluctant to self-regulate. This lack of regulation contributed to a major accident at a manufacturing plant in Korea in 2012. Public concern about nanotechnologies escalated and a cautious approach to technology development was adopted. Although the technology is still being used and the science is still developing, the term nanotechnologies is used less, and the prefix nano has all-but disappeared.

The story so far…

2006

A campaign by a mass membership NGO to alert the public to the potential risks of nanotechnologies was undertaken. At the launch event a speech by a major respected public figure warned against "the insidious danger of meddling at the nanoscale". The campaign received little public support.

The final reports of public-funded projects to promote stakeholder dialogue on the social, environmental and economic risks and opportunities of nanotechnologies were produced, but received little attention.

2007

Nanotechnology-enabled consumer products went mainstream. Household paint that changed colour according to temperature was one such product. Another was anti-ageing cream.

Later in the year an EU-funded study of the effects of nanoparticles on human health was published, showing some evidence for a negative effect. The report recommended more research to confirm the critical findings.

A public opinion poll of European citizens showed that, among the minority that had heard of nanotechnology, most had positive associations with the term, though didn't necessarily trust public institutions to govern the application of the science effectively.

2008

An international symposium on nanotechnologies took place, at which agreement was reached about the need for a Global Framework on Emerging Technologies to regulate the production and use of nanotechnologies. Work started on developing the Framework.

A brand of nanocoating for cars was recalled as it was found to peel off under extreme weather conditions and release nanoparticles into the environment.

2009

The combination of concerns around product safety and the lack of regulation meant that nanotechnology products were still peripheral in the marketplace. A major venture capital firm announced that it had embargoed all investment in nanotechnology-related products, citing a failure of the technology to deliver in the market as expected. Although a few other companies followed the lead, this decision was ridiculed by most in mainstream science. An editorial in 'Nature' magazine said the decision was "not only foolish, but dangerous."

2010

The UK Government publicly criticised the Global Framework on Emerging Technologies for moving too slowly and introduced its own, watered-down, guidelines. These were voluntary.

2011

Workers at a factory in Toulouse went on strike, refusing to work with nanoparticles following a number of medical complaints. Demonstrations spread across Europe. The number of occupational health related court cases increased.

A campaign by a major NGO was launched, calling for a moratorium on nanoscience and technologies until more was known about the health and environmental effects.

2012

In April, the process for delivering the Global Framework on Emerging Technologies broke down and efforts to create a level playing field internationally were abandoned.

A major explosion occurred at a plant on the outskirts of Seoul, which released several tonnes of nanoparticles into the environment.

2013

Routine monitoring of marine pollution in the Sea of Japan found high levels of nanopollutants in fish. This was traced to the Korean explosion. Further tests showed the particles in drinking water in Japan, leading to a public outcry.

It emerged that some athletes competing in the London Olympics 2012 were using nanotechnology-based performance enhancing drugs.

'Forbes' magazine stopped publishing its list of bestselling nanotechnology-related products.

2014

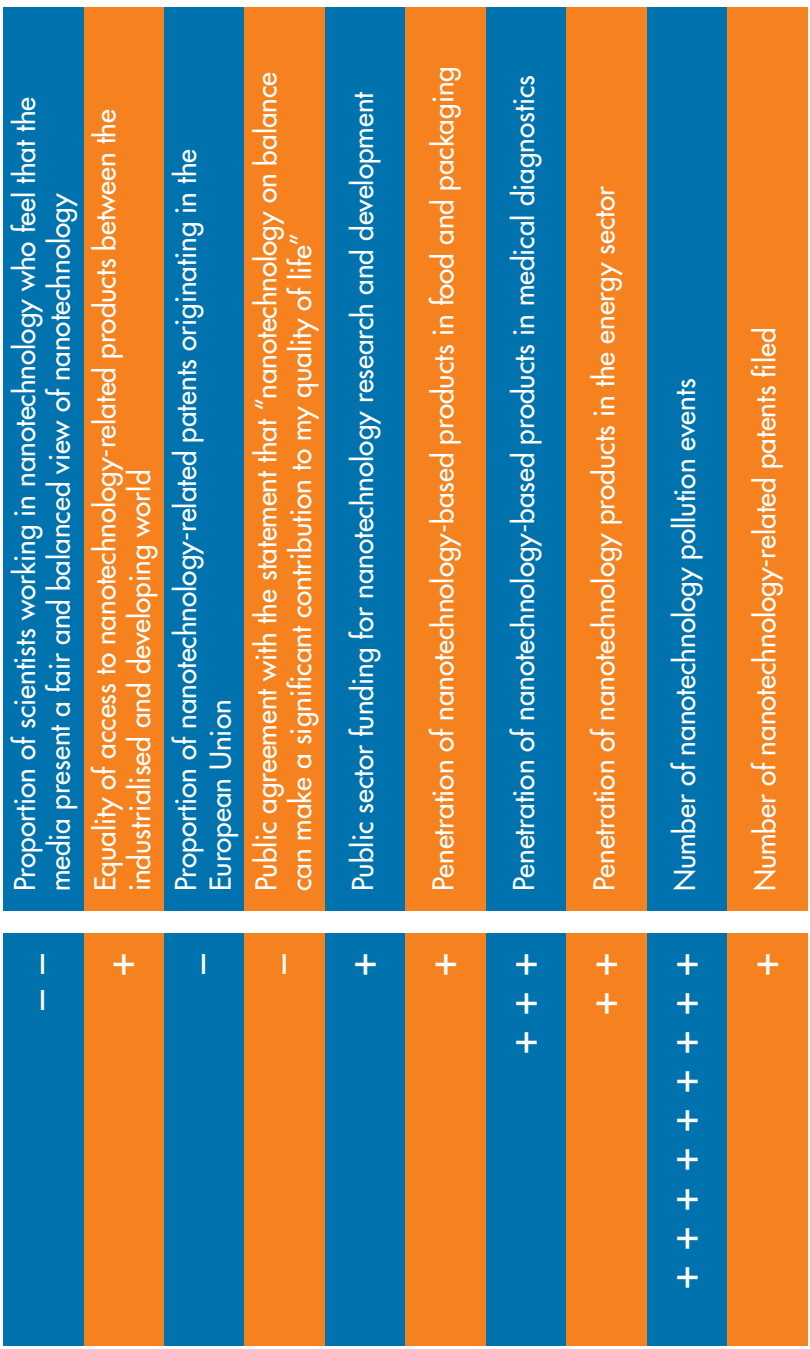
Residues of manufactured nanoparticles were discovered in Arctic sea ice.

A coherent EU regulatory framework for nanoscience and technology was finalised, based loosely on the UK guidelines.

2015

A consortium of European businesses published a report criticising the EU framework and committed to developing its own, stricter guidelines.

How things have changed since 2006



What's selling well?

Networked earring

This is a powerful computer, small and light enough to be disguised as jewellery. It acts as the network hub for embedded microchips in clothing and interacts with local area networks providing a constant stream of communication between the user and their environment. It also connects to personal communication devices.

Nose filter

This nose filter is a simple air-filter, capturing impurities using nanofibre mesh. It is worn inside the nose and is all-but invisible to the casual observer. The filter protects the wearer from allergenic spores and other particulate pollution.

Eezy-spy

A cheap and easy-to-use surveillance service has been the surprise nanotechnology product success in 2015. Making use of the extensive networks linking embedded computers in most European towns and cities (and increasingly in the countryside), network operators provide tracking services to the general public. Tracking is only available with permission, and is increasingly being used to monitor the whereabouts of pets.

Longevity cream

This popular anti-wrinkle and anti-bacterial cream is marketed as being able to extend the life of the user. The cream makes use of free nanoparticles, but the manufacturers have chosen not to market the cream as a product of nanotechnology.

Do-it-yourself medi-test

Available on supermarket shelves, this handy kit – employing lab-on-a-chip technology – tests the user for a range of medical conditions. It is easily networkable and comes with the optional extra of an automated on-line diagnosis and lifestyle advisory service.

What's worrying us?

Environmental pollution

Environmental pollution is a key concern among the public. Although it is widely known that nanoparticles exist naturally and can be found everywhere, the Seoul explosion of 2012 put manufactured nanoparticles high on the 'undesirables' list – on a level with asbestos and nuclear radiation. Within this atmosphere of fear, a struggle is ensuing as to how legislation can be improved to prevent environmental damage. With centres of nanoscience now spread out around the world, achieving consensus is a major challenge.

Health and safety

Health and safety for workers emerged as a key issue in 2011, when a spate of respiratory complaints and allergic reactions occurred among staff in a Toulouse factory. The symptoms were linked to the release of nanoparticles.

This has created a host of difficulties for the nanotechnology industry. Today the sector remains exposed to litigation by staff and union action, its reputation is suffering and this is feeding through to difficulties in recruitment. Of greater concern, however, is the appearance of similar symptoms in consumers. Although this hasn't yet occurred, the possibility can't be discounted.

Privacy

The rapid development of ICT means that monitoring technology is increasingly pervasive and available for use by the public in a range of products and services. The convergence of medical diagnostic technology and ICT has introduced the possibility that people can, legitimately or otherwise, gain access to all sorts of personal data that might have a major impact on a person's employability, their ability to get medical insurance or to pay premiums.

More in depth...

How is the science developing?

The lack of clarity on regulation, combined with public distrust of nanorelated products, has meant that **progress in the science has been slower than anticipated and some products that seemed just around the corner a decade ago are still on the drawing board**.

The trend now is for a greater emphasis in science and technology on understanding the potential risks of new developments, from a social, environmental and economic point of view, and a large amount of scientific funding is being diverted to precautionary studies of this type. The chief exceptions to this are in the area of medical diagnostics, driven by military and space research funding, and ICT – both areas that avoid the use of free nanoparticles.

In general **the term nanoscience has all but disappeared**. The "sciences formerly known as nano" are no longer grouped together for funding purposes, and general nanoscience-focused journals and websites have almost all folded.

Is the public sector investing?

Initially public sector funding was generous for nano-related research, on the basis that nanotechnology might provide solutions to many of the world's social and environmental problems. However, rising public concern, caused by events in Seoul and Toulouse, has led most European governments to adopt a more cautious approach and **no-strings-attached public sector funding for basic nanotechnology is in decline**.

Today public funding is increasingly focused on ensuring that the social, environmental and economic aspects of technologies are understood, and that there is an effective public debate about the role of science in society.

This approach is being encouraged at the international level, with the governments of the UK, Germany and Sweden putting pressure on other member states of the EU to restrict imports of nanotechnology-enabled products from less regulated markets by imposing high duties.

Is the private sector investing?

From the mid-1990s onwards, there was a huge increase in private sector investment into research related to nanotechnologies. Today, however, **private sector funding of science has reduced significantly**. The public sector is funding the majority of basic scientific research at the nanoscale.

While some companies have increased their investment in studies (of variable quality) of the ethical, legal and social aspects of the technology used in products, **there has also been a marked shift of investment out of the more regulated areas of Europe to other countries**, particularly in south-east Asia, where the regulatory burden is lighter, or where enforcement of regulations is laxer.

How has medical diagnostics changed?

Medical diagnostic technology has been in heavy demand from the public health sector, but the greatest advances have been pioneered in research funded by the Indian Space Research Organisation and the National Space Development Agency of Japan, as well as the US military. As early as 2009 astronauts were using devices for detailed self-diagnosis. In recent years **pharmaceutical companies have marketed self–diagnosis devices to consumers across the EU**.

How has ICT changed?

Because of advances in nanoscale engineering, computer microchip performance has taken enormous strides forward in the last few years. **Today, computers are more than a hundred times as powerful as they were in 2005**. This has led to many new products and applications, with most products and many buildings containing tiny computers. Even animals, from pets to pests and endangered species, are commonly tracked and monitored in this way.

How successful is nanotechnology in the market?

The Seoul disaster led to popular hostility to anything with the prefix nano. As a result, **products that rely on nanotechnology applications do not advertise the fact**.

Today, the concept of nanotechnology-enabled products doesn't really exist in the way that was anticipated a generation ago, causing 'Forbes' magazine to stop publishing its annual list of bestselling products. Nonetheless, nanotechnology is still used, as expected, in new product development and the industry remains profitable, though a long way from realising the expectations of early "nanoenthusiasts".

Progress in applications reliant on the use of nanoparticles has slowed because of the amount of controversy over their effect on human health and the environment. Despite this, the cosmetic industry worldwide has continued to use nanoparticles in products, especially in developing country markets.

The most successful products avoid the use of free nanoparticles and are from one of two areas: ICT based on engineering at the nanoscale and the field of medical diagnostics. Products from both areas have found success in a range of different markets, including consumer markets.

How is nanotechnology regulated?

Despite early attempts, **it has proven impossible to establish a level playing field globally for regulating the development of new technologies**. Instead, we have a piecemeal approach. In Europe, we have a legal framework, finalised in 2014 and based on voluntary guidelines established by a joint private-public working group in the UK. The USA has a different set of laws, as do the other main producers of nanoproducts, such as China, South Korea, Indonesia and Brazil.

Recently, concerns have been raised that the framework isn't tight enough. This, and the suggestion that European borders are porous to products developed with less emphasis on safety and the environment, has led to **individual companies developing their own codes of conduct that go beyond the regulatory requirement in a desire**

to be seen as responsible. However, the global picture is still very fragmented: it is difficult to see how one company's code of conduct aligns with another and to hold companies to account for their voluntary initiatives.

Have the anticipated risks occurred?

There **have been several major nanotechnology–related disasters** in recent years, including most notably the explosion at a plant manufacturing nanotechnology-based drying agents in South Korea in 2012. This caused fish deaths on a large scale in the Sea of Japan, polluted drinking water along Japan's west coast and led to street demonstrations. At around the same time in Europe there was a sudden spate of court cases brought by workers in plants producing nano-based products, provoked by an increase in respiratory complaints and chronic allergies.

These complaints should have come as no surprise, as studies as far back as 2005 suggested that the release of nanoparticles into the environment might be dangerous. Further evidence emerged in the following years, but the results were always inconclusive which meant there was no concerted response from business or government.

How have business ethics changed?

Initially, NGO campaigns to raise public awareness of the presence of nanotechnology in products largely failed, although the general anti-business feel of NGO campaigns won support.

It is only in recent years, with several high profile accidents pushing the issue into public consciousness, that business has truly begun to address the risks as well as the opportunities of nanotechnologies. Leading businesses are even going beyond what is legally required of them. All the signs are that these standards will raise the bar across the industry, at least in Europe.

How effective is public debate?

Early expectations of radical social, economic and environmental benefits flowing from nanotechnology-enabled products have practically disappeared. Today, **the dominant public discourse**

draws on a number of high profile health or environment–related scandals. Many in science and industry feel that this is holding back scientific progress.

The **media has adopted a sensationalist and adversarial approach to the issues** and is perceived by science as ill-informed, obsessed with scandal and continually returning to a series of iconic failures. The substantial number of lower-impact successes has largely been ignored and level-headed debate informed by scientific method is hard to come by. In a recent interview one prominent scientist stated "there is not one journalist I would trust to deal with nanoscience in a mature and nuanced manner."

Likewise, in attempting to draw attention to risks, the NGO sector has missed the opportunity of supporting socially or environmentally beneficial applications of the technology. NGOs have made the same mistake as the media in appearing to interpret nanotechnology as one monolithic entity, missing the fact that different nanotechnologies have different issues. This has played a part in **forcing the prefix nano out of the public space, which has undermed NGOs' attempts to campaign on it**.

In the past year there has been an improvement, though, and some companies are driving up standards of transparency and responsibility beyond the legal requirements. As a result, there are signs that a small amount of trust in nanoscience and nanotechnologies is being clawed back, but **the popular assumption that nano is bad is still felt to be a major impediment to new product development and competing for research funds**.

What does the public think?

Initially, campaigns by NGOs focused on the use of nanotechnology in products, but with little success as the use of nanotechnologies within supply chains was complicated and there was no shared definition of nanotechnology for governments to label or legislate on.

Today, as poll upon poll has shown, **the risks of nanotechnology are seen by the European public to outweigh the opportunities**. The very word nanotechnology has been demonised, and there is little appreciation of the fact that nanotechnology is a vast and diverse area.

The private sector has responded in part by abandoning the nano prefix. Although legitimate from a strictly scientific point of view, this has served to mask the use of nanotechnologies. As a result many of the ethical, legal and social issues that result from producing materials at the nanoscale are ignored.

Does everyone have equal access?

Decades ago NGOs expressed concerns that the benefits of nano-based products would primarily be available only to affluent consumers, opening up a "nanodivide" between the rich and poor. Today some of those concerns have been realised, due in part to the slow speed with which products have been developed and brought to market and because the anticipated economies of scale have not taken place. The result is that **nanotechnology–enabled products occupy the expensive end of product ranges**.

It is thought this is likely to change in the near future, however, as the geographical centre of production continues to shift eastward, and countries formerly thought of as developing begin to determine the sort of products that are released onto global markets. The untapped markets in these countries present innovative companies with a major opportunity. It is anticipated that as this opportunity is exploited, nanotechnology-enabled products will be available to a larger audience.

At present there are few organisations clamouring for private or public sector action to open up access to nanotechnology. If anything, despite the benefits that nanotechnologies could deliver, prominent NGOs are arguing that **it is the poor, with lower awareness and access to information about products, who have less freedom to avoid potentially dangerous nanoparticles**.

Have the anticipated opportunities occurred?

The slower-than-expected development of nanotechnology has meant that **fewer of the potentially transformative applications that were hyped in the early years have been launched onto the market**. That said, there is obviously some belief in the potential opportunities of nanotechnologies, not only from an economic point of view, but also from social and environmental perspectives. If this

did not persist, there would be even less money being invested in the science, given the known health risks. Not surprisingly, products that use applications not associated with the primary source of risk – nanoparticles – have proven to be more successful.

THE FUTURE OF NANOTECHNOLOGY

Now we're talking

- There is open communication between scientists and the public about nanotechnology
- Strong regulation and accountability systems are in place
- Regulation slows down the development of the technology - but the world is a safer place
- A TV programme looks at the hype surrounding nanotechnology in 2006 and asks 'Whatever happened to nanotech?'

THE FUTURE OF NANOTECHNOLOGY

Scenario 2 Now we're talking

Regulation of new technologies has been standardised internationally and strong accountability systems are in place, enabling transparent development of nanotechnology. Public sector incentives have directed research towards products that explicitly benefit society, supported by public participation. Local stakeholder forums debate issues that arise from the use of technology (such as privacy) and make decisions for their local area. The strong regulatory regime, especially around issues of toxicity, has meant that health and safety risks are spotted early on and are well-managed. The focus on products that benefit society and reduce environmental impact has paid off: growing resource stress means demand for these products is increasing around the world.

The story so far...

2006

The European Commission developed a platform for dialogue between scientists, product developers, NGOs, consumer groups and others on the social and environmental aspects of nanotechnology. Early progress was made with some quick wins including:

- ➔ Funding allocated for The European Centre for Environment, Health, Safety and Toxicology (ECEHST)
- ➔ Moves to include training on the ethical, legal and social aspects of nanotechnology into all higher education courses
- ➔ An immediate review to establish the extent to which current regulation covers nanotechnology specific risks
- ➔ Development of a protocol for the assessment of risk and implementation of moratoriums, if necessary
- ➔ A requirement for all funding applications to be accompanied with a completed ethical, legal and social aspects (ELSA) assessment
- ➔ Education programmes and funding to support development of skills and mitigate anticipated skills shortage in Europe

Media workshops and other communication on the potential risks and benefits of nanotechnology were successful in galvanising a balanced and informed public discussion.

2007

The European Commission's Framework 7 research funding programme began. Research funds for the following seven years were directed towards "nanosciences, nanotechnologies, materials and new production technologies" and the extent to which they contribute to addressing European social, economic, environmental and industrial challenges.

2008

An OECD process for developing standards on nanoparticles commenced.

The ECEHST was opened. The centre identified potentially harmful particles, provided guidance for regulation (eg where moratoriums were necessary) and advised on safety issues for workers and users.

2009

The OECD standards on nanoparticles were launched, hot on the heels of the Chinese standards.

An overhaul of the intellectual property/patenting system was announced.

2010

The first moratoriums were announced and a number of products were recalled, based on research from the ECEHST.

2011

The first local stakeholder debate took place after research linked a factory making metal oxide nanorods to cancer clusters.

2013

Privacy came to the forefront of the debate. Nanosensors tracked what people bought, where they went and even what they said. The media and civil rights groups branded this an infringement on civil liberty and the public took notice.

Stakeholder debates took place across Europe to discuss what was off limits. Clear signposts were required where the technology was in use,

and products that used this type of surveillance technology were labelled accordingly.

2014

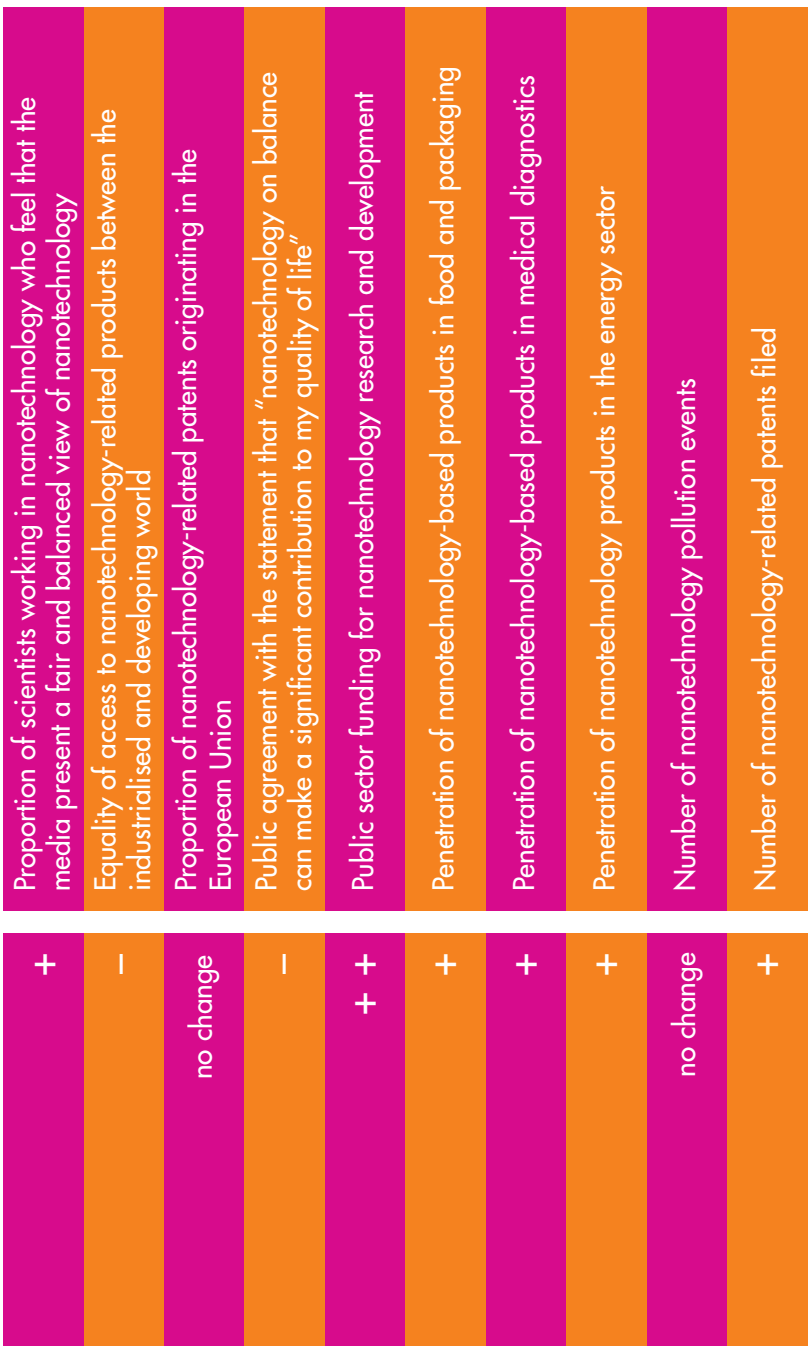
The nano tag was lost but this didn't mean the technology was not in abundant use. The science was everywhere, but not the name.

2015

BBC documentary 'Whatever happened to nanotechnology?' is broadcast. The programme revisits 2006, the fears of the time and looks at developments of the past ten years. The programme takes viewers back to some of the more radical predictions from 2006, such as curing blindness.

It becomes clear throughout the documentary that the technology has not developed as fast as was predicted by some in 2006. On the other hand, none of the disasters predicted have materialised either. So on the whole, the documentary concludes, we are better off, the ground work has been laid and the future looks brighter.

How things have changed since 2006



What's selling well?

Water purifier

This nano-enabled water purifier is now a mass-market product. Nanomembranes efficiently remove pollutants and bacteria. The biggest markets are in India and China. The African market is growing dramatically because of water stresses on the continent.

Rechargeable batteries

High capacity nano-enabled rechargeable batteries were initially recalled because of concerns at the disposal phase. They are now available again after strict regulation controls have been established to control their collection for recycling.

All-in-one household protection

A high performance material cladding for building protection. The cladding is water-repellent, self-cleaning and provides heat insulation, thereby reducing household energy use.

Nano food packaging

These unique packaging systems use nanosensors to change the colour of the packaging when the food inside is no longer edible, and alerts a networked monitoring system. This helps the retail industry to guarantee product freshness and helps consumers to identify microbial contamination in the food they have bought. Similar features are available for home food-storage systems.

Eco-packaging

A recent breakthrough in biodegradable polymers, made stronger with the use of nanocomposites, means that they can now be used in more types of packaging (not just plastic bags). Such packaging can be recycled in composting facilities where the polymers, as well as nanoparticulate matter, become biological nutrients.

What's worrying us?

Missed opportunities

Nanotechnology has been highly regulated. Potential risks have been flagged up early and a prudent approach has been developed which has enabled the continued success and acceptance of nanotechnology. Strong governance through the power and effectiveness of local stakeholder forums has contributed to nanotechnology's positive image in society. Some, however, are complaining about the resultant lack of innovation and mounting bureaucracy – nanotechnology has not progressed as fast as was predicted in 2006.

Privacy

Debates around privacy issues rage on. In food packaging, obligatory surveillance of food during production and distribution through radio frequency identification (RFID) tags is intended to protect consumer health, but some customers feel eavesdropped by the technology. Without deactivation, the RFID nanosensor continues to monitor and save data in the consumer's fridge. This data can be recovered by unauthorized third-parties once food-packaging is dumped.

Access

Although many products on the market have societal benefits, the high development costs (in part because of the highly rigorous approach to product testing and development) mean they remain out of reach to those that need them most. Belatedly, these issues are being addressed.

More in depth...

How is the science developing?

Today, in Europe at least, **new technology and applications must by law undergo rigorous tests to check for toxicity and other environmental impacts**. This is in order to ensure that products will be completely safe throughout their life cycle. However, **this has reduced the speed with which products are released onto the market**.

Public trust in nanotechnologies means that **once products are approved, they are taken up quickly, and competition between companies is strong**.

Is the public sector investing?

Following an extensive consultation (with scientists, product developers, NGOs, consumer groups and others), which began in 2006, the EU government made a strong commitment to the development of nanotechnology – maximising potential benefits whilst doing everything in its power to minimise potential risks.

Funding was allocated at this early stage for the European Centre for EHS and Toxicology (ECEHST) following calls from all sides for further research on the potential toxicological impact of nanotechnologies on humans and the environment.

Government incentives have directed research towards products that benefit society, particularly for use in developing countries, in line with the Millennium Development Goals. In addition to funding, governments play an important role in monitoring compliance and ensuring everyone is up to date on the latest requirements.

How has global economic power changed?

There is evidence that the relatively strong regulatory framework in the EU has driven investment overseas – where regulation is relatively weaker. However, **stringent EU guidelines are driving standards up globally and the time-lag between the appearance of regulatory innovations in Europe and elsewhere appears to be decreasing**.

Indeed, China has been recognised as a world leader in the standardisation of nanotechnology since 2006, and in 2008 was a key player in initiating the successful OECD (Organisation for Economic Co-operation and Development) standardisation process.

How healthy is the European economy?

Increasing environmental pressures have raised awareness and consumer demand for carbon cutting and resource saving products as well as for renewable technologies. As a result, the early government moves towards encouraging developments in nanotechnology towards products that benefit society has paid off. European companies are well positioned to respond to this increasing consumer demand, particularly from China and India – both huge markets with equally huge environmental and resource pressures.

Is the world a safer place?

Low-level conflict over resources such as natural gas and water, added to the continuing threat of global terrorism, has meant that security remains a top priority for all governments. Until recently, nanotechnology applications have been used widely to embed undetectable surveillance devices using RFID tags in the environment.

Then, a few years ago, an NGO campaign sparked off a heated public debate over the increasing encroachment on civil liberty. Nowadays **any area using this type of surveillance technology has to be clearly signposted or labelled** and **local stakeholder forums decide the extent to which the technology will be tolerated in their local area**.

Is the private sector investing?

Strong regulation has provided clarity for the private sector and focused the direction of its investment in nanotechnology. Although returns on investment aren't excessive, investors are confident and financial support for science and technology at the nanoscale has steadily increased over the years. **Many private–public partnerships have been initiated, manufacturing and distributing products with maximum social and environmental benefit**.

How is nanotechnology used with food?

There is still a degree of public concern about the use of nanotechnology in food itself. But there have been major developments in food packaging, and the use of nanosensors that can detect contamination is now compulsory during the food manufacturing process, including its transport and distribution.

There have been a few cases in the press recently where nanosensors have malfunctioned, suggesting food is fresh that has in fact gone off – which have led to some high profile class-action lawsuits. The courts granted those claims taking into account the food companies' product liability. There has been a back-to-basics movement reminding people also to "follow their noses" for the more traditional signs that food is not safe to eat.

How successful is nanotechnology in the market?

Back in 2005, predictions of a "nanoboom" as more and more nanotechnology-related products hit the market were matched by fears of a "nanobubble", created by avid investment of venture capital, leading to a painful "nanoburst". This has, so far, been avoided, and **nanotechnology is more a quiet success story than a consumer-led frenzy**.

This is largely down to the fact that the process of bringing new products to market is so carefully guided. Exhaustive testing is conducted on products in development stage and all potentially unsafe nanoparticles have been banned.

Nanotechnology is no longer used as a blanket term, as the technologies are so varied. As a consequence, companies no longer advertise the fact that certain products may be nanotechnology-related, and so it is difficult to track exactly how successful such products are. However, the environment, health and water sectors are all performing well and are intimately involved in nanotechnology. Affluent consumers in particular are willing to pay more for products that reduce their environmental impact and their exposure to carbon taxes.

One unfortunate side-effect of the deliberative approach to product development is that the products tend to be more expensive. There is a

danger as a result that the rich world benefits disproportionately from nanotechnology.

How is nanotechnology regulated?

A strict regulatory environment has evolved. International regulatory standards, promoted by the OECD, have been in place since 2010. Environmental and social impact assessments are now required for every new application that uses nanotechnology. Life cycle analysis is standard, analysing the impacts of each product from production, through use, to disposal. **There is also a legal obligation to publish the results of all clinical studies from both the public and private sector**.

Based on findings from the ECEHST, set up in 2013, there have been **a number of moratoriums put in place on certain applications of nanotechnolgy**, which are then investigated further. Past moratoriums have included the use of nanotechnology in cosmetics and food supplements. The extensive body of research from ECEHST has revealed that, once we started looking for them and had the equipment to find them, nanoparticles were everywhere. As a result, there have been legislative shake-ups in many industries that have not traditionally been associated with nanotechnology, such as plastics, food manufacture and construction.

There is a **central website resource from the ECEHST updated with all the information on the vast number of safety standards related to nanoparticles**. This is mainly used by scientists and product developers but can be accessed by anyone for free.

EU and government funded multi–disciplinary teams that include representatives from NGOs, companies, regional governments and delegates from local stakeholder forums, **advise on regulation and the direction of research funding**.

How effective is public debate?

Early mapping of key stakeholders enabled the European Commission to engage those with an interest in, those who might be affected by, or those who had a strong influence over, the development of nanotechnology – including scientists, product developers and other

representatives from industry, NGOs, consumer groups, the media and academia. **Effective dialogue at EU, national and regional levels has been key in directing nanotechnology towards more societal needs and building consensus over standardisation**.

Educated through a series of high profile media workshops early on, **the media has been key in providing informed and balanced information on nanotechnology and galvanising effective public debate**.

Today stakeholder debates are regularly convened around issues of public interest. Although nanotechnology itself does not have a high enough profile to warrant specific debate, issues related to the impact of nanotechnology, such as privacy, do.

NGOs have also become much more targeted in their campaigning around specific issues – to great effect. There was a move away from blanket campaigning against all things nano once it became clear governments were helping to direct development towards meeting societal needs. Working in close partnership with ECEHST they remain critical in highlighting main concerns for further investigation.

What is happening to the environment?

Pressures on natural resources are increasing rapidly as the population continues to grow and as economic development in China, India and elsewhere continues apace. The focus for new technology development on innovating products that alleviate social and environmental problems has made a major contribution to reducing the impact of resource scarcity and nanotechnology, in particular, is seen as a critical means of continuing global economic growth within tightening environmental limits.

Have the anticipated risks occurred?

Good regulation and strong governance have done much to prevent the scare stories of the early 2000s from materialising. **Risks are spotted early (during research and development or lifecycle assessments) and dealt with quickly, before the product in question is released to market where it could pose a danger to the general public**. There were some product recalls in the early days (nano food

supplements, for example) following research findings from the ECEHST. Since then however, there have only been minor nanotechnology-related pollution or health events.

How have business ethics changed?

For most of the last decade, the business community has been on the back foot when it comes to dealing with the ethics of nanotechnology. This is simply because the public sector in Europe has been so pro-active, and has pioneered regulation that guarantees a deliberative and precautionary approach to technology development. For example, legislation requires businesses to publish the results of clinical trials, and obliges businesses to participate in extensive stakeholder dialogue.

Business associations tend to complain about the amount of red tape and accuse governments of pushing up the price of goods through over–regulation. Individual companies, however, are keen to maintain a reputation for responsibility by publicly complying. **A small number of leading companies even seek market differentiation by going beyond compliance**, for example by applying high OECD standards in global affiliates.

What does the public think?

Today, the term nanotechnology is rarely used. Through open debate (for example, at local stakeholder forums) and education, the general public recognises that using the term nano as a prefix to anything manipulated at the nanoscale is not particularly useful in understanding the benefits and impacts of the technology.

That said, the early identification of potential risks and the lack of headline grabbing horror stories mean that **the overall impression of nanotechnologies is positive**. It is also widely acknowledged that developments in technology (at the nanoscale) have enabled a lot of products to become available that have a social benefit. Improvements in energy storage and water purification in particular are seen to have had a positive impact.

Does everyone have equal access?

An unintended consequence of the careful approach in taking new technologies to market has been to add a premium to nanotechnology-related products. **Consultation and dialogue cost money, and it is eventually the consumer that pays the price for this**. Although this hasn't affected the success of products in the market, **it has contributed to an emerging "nanodivide" in Europe and the developing world**. This is a matter of some concern in 2015, given that so many hopes for positive social and environmental benefits are pinned on nanotechnology.

Therefore, rather belatedly, significant effort is going into developing new mechanisms to broaden access, although this poses many difficulties. For example, some NGOs are entering into partnership with companies to deliver crucial products to "bottom of the pyramid" markets, often bringing in third-party companies based in the developing world. The continuing suggestion of public sector subsidy for the most important products, such as water purifiers and air filters, is hotly debated.

In 2009, international patent law underwent a significant overhaul in an attempt to prevent individual companies from wielding excessive market power and raising barriers to entry for new or smaller players, but fell short of limiting patents of novel materials. Today, there are renewed calls for further reform.

Have the anticipated opportunities occurred?

Although the regulatory requirements for the development of nanotechnology have meant that opportunities have not been realised as speedily as was hoped, the strong steer towards beneficial products means that any progress made tends to be in the right direction. **More and more of the products that enter the marketplace benefit society**. To realise their full potential, there is increasing recognition that more could be done to make these products accessible to all – particularly in developing countries where they are needed most.

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we need to talk...

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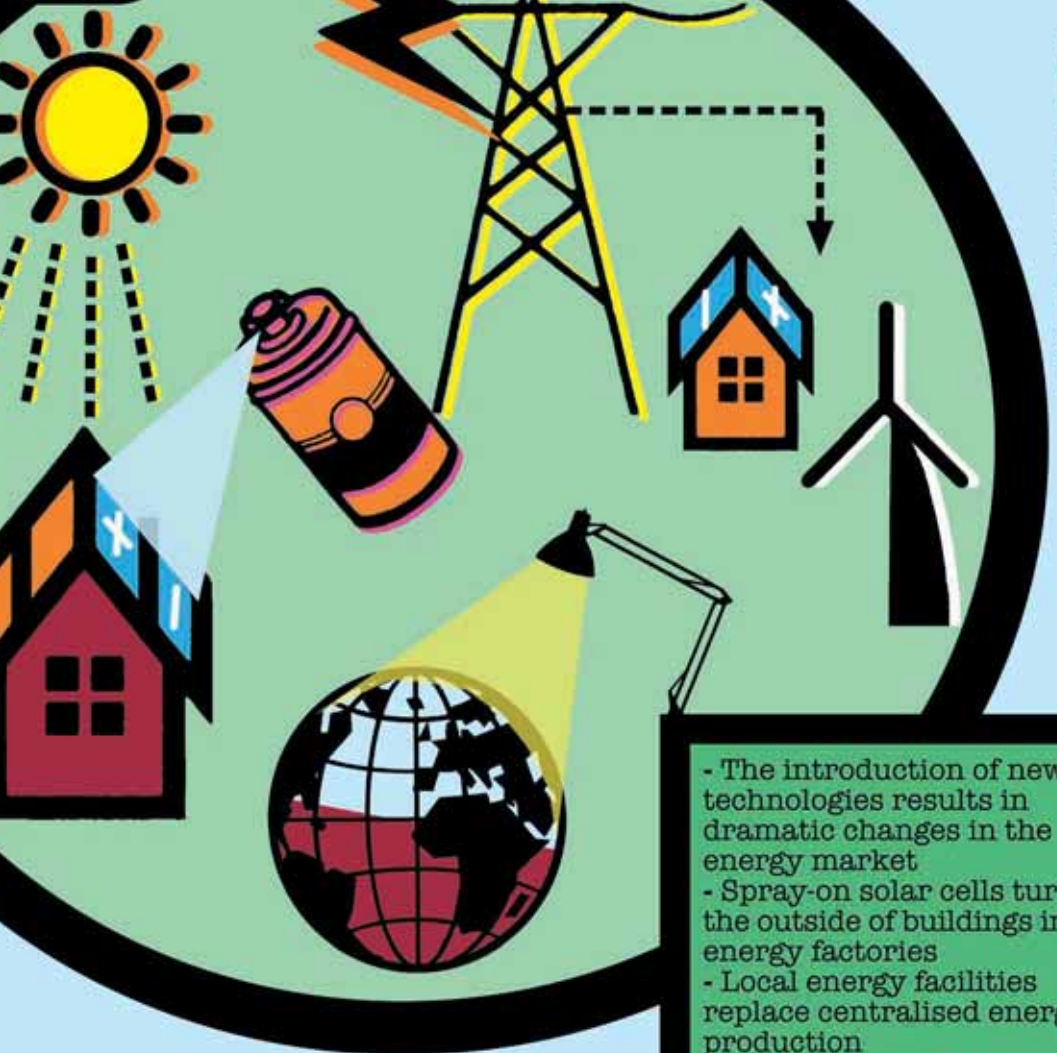


THE FUTURE OF NANOTECHNOLOGY

- The introduction of new technologies results in dramatic changes in the energy market
- Spray-on solar cells turn the outside of buildings into energy factories
- Local energy facilities replace centralised energy production
- While industrialised countries benefit from the new technologies, the developing world is being left in the dark

Scenario 3 Powering ahead

Scientific progress has been faster than expected and nanotechnology-related products are making a real impact on society and the economy. For example, there have been dramatic improvements in the efficiency of solar photovoltaic (PV) cells, with the result that applications expected to come into the market in the 2020s are already a reality. Long-term investments in fossil fuel resources are progressively losing value and new market entrants are growing quickly. The speed of change has left regulation behind. Although there has been discussion around the risks of novel materials, as far as public debate is concerned the benefits so far outweigh the risks.

The story so far...

2007

Small efficient fuel cells entered the market and replaced batteries in smaller electronic devices such as mobile phones and laptops.

Progress in this area drove research in other areas of fuel cell research and led to advances in larger fuel cell technology for transport use.

2008

There were dramatic improvements in PV – experimental solar cells were operating at 30 per cent efficiency. Prices began to drop.

2009

Rapid developments occurred with the first commercially available printable PV.

Governments across Europe struggled to keep up with the rapid pace of technological change. There was a lack of defined regulation. However, products were seen to have widely applicable benefits, so there were few objections.

European governments offered large subsidies to home-owners who invest in microgeneration.

2010

Printable PV was followed by spray-on solar.

There was an increasing shortage in engineers and researchers resulting in an increase in salaries.

There was a dramatic increase in the use of fuel cells in cars, at least ten years earlier than had been expected. Storage problems were solved by use of new composite materials and some houses were fitted with fuel cells as power sources.

2011

The entrepreneur, scientist and author of 'The Microgeneration Revolution' died under suspicious circumstances. Inevitably, conspiracy theories connected this to certain energy companies being left behind by the new technology.

Many of the old energy giants lobbied hard against the decentralisation of energy production.

Greenpeace produced a report on resource use, which highlighted the limits of platinum availability and concerns about the lack of recycling of nanomaterials.

2012

A Nobel prize was awarded to the team responsible for developing cheap, efficient spray-on solar cells.

Robotics started to kick off due to small, cheap and highly efficient batteries.

2013

The growth in nano-enabled products led to concerns over resource use and pollution. The recycling issue had still not been resolved.

The first major nanotechnology-related incident at a manufacturing plant highlighted the risks involved and forced a rethink from governments on regulation.

There was a worrying skills shortage in Europe.

2014

The rapid spread of spray-on solar cells led to a worldwide rise in renewable energy production. For the first time there were signs that major reductions in CO2 emissions might be achievable. The importance and timing of these developments cannot be overstated as atmospheric concentrations of CO2 had reached 400ppm.

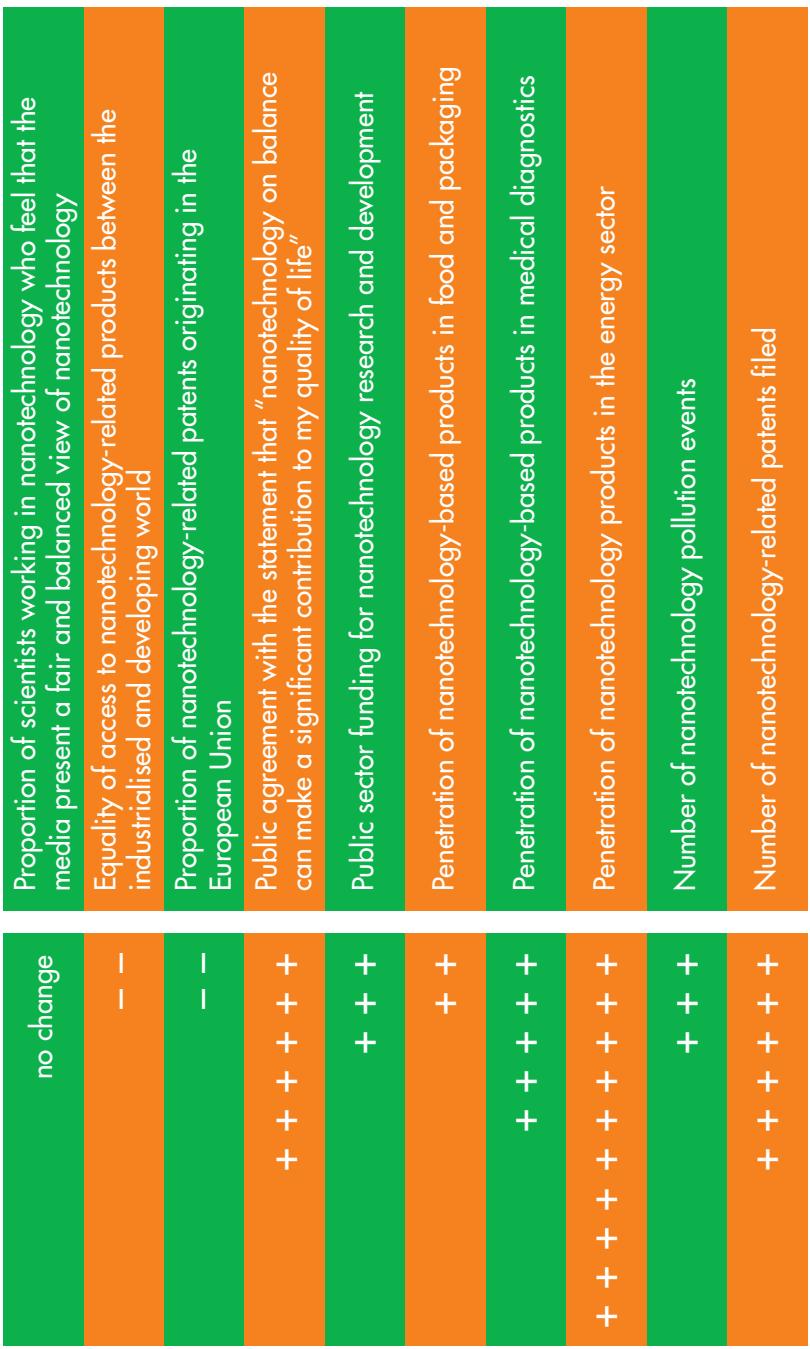
The religious right in the US scaled up its opposition to nanotechnology with a publication called 'The End of God's Children', which questioned the religious implications of the advancing science of human modification.

2015

In 2015 the disruptive nature of the developments has become apparent as centralised energy production begins to fall dramatically.

There is increasing unrest in countries that have no access to the technology and representatives are calling on governments and corporations to ensure wider distribution.

How things have changed since 2006



What's selling well?

Fuel cells for transport

Although miniature fuel cells have been used in personal products for some years, it is only recently that improvements in catalysts and hydrogen storage have enabled the commercial rollout of fuel cells for use in transport.

Sola-shelter

Increasingly extreme weather, resource shortages and the resulting conflicts have increased the number of refugees and homeless. Nanotechnologies have given rise to lightweight, strong materials with integrated photovoltaics. These have been used to construct a tough, re-useable, power-generating shelter.

The walking battery

Human clothing has integrated energy generation to supply increasingly power-hungry hi-tech personal devices.

Spray-on photovoltaics

Although the pervasive nature of this application is often questioned, the benefits of quickly applied flexible solar are huge. Any surface with a reasonable level of solar incidence can be turned to power generation.

Butlerbot

Advances in energy storage and computer processing have helped the development of semi-intelligent home assistants. Primarily built for simple tasks such as vacuuming, they have been adapted to help monitor energy consumption and provide basic surveillance.

What's worrying us?

Governance

Regulation and governance have been unable to keep up with the speed of technological development. While initially this did not have an impact, it is now evident that the energy divide and waste have to be addressed immediately.

Energy divide

Although cheap, clean energy is increasingly available to citizens of developed nations and emerging economies, there is still an energy underclass who do not have the capital or infrastructure to benefit from the advances. This has lead to an increasingly bitter dispute about access and distribution of technology.

Resource consumption

There has been a boom in cheap consumer goods and reliance on complex technological solutions has increased markedly. The question of recyclability remains unanswered and there is still enormous pressure on the planet's dwindling metal resources. Prices on the commodity markets are going up. For the countries rich in such resources, there is a temporary benefit from mining revenues. But for other poorer regions, the situation threatens to push the cost of transformative technology beyond reach.

More in depth...

How is the science developing?

Research in the energy field increased dramatically from 2007 onwards, driven by an increase in investment from venture capitalists keen to develop opportunities in clean technology. This, combined with increasing awareness of environmental and social pressures, increased interest in PV research and stimulated several crucial breakthroughs in the application of nanotechnology.

Today the speed of progress in PV has exceeded the expectations of most scientists, who had not anticipated competitive financial viability for solar technology until 2025 at the earliest. **Flexible thin film solar is on sale and is predicted to have a dramatic impact on the energy market within the next ten years**. Advances in PV have driven forward other areas of energy technology and a high number of energy-based applications using nanotechnology have been released onto the market. Super efficient batteries, ultra-capacitors and fuel cells of a variety of sizes are becoming increasingly common in developed nations. There are still problems with long-term storage of energy from renewable sources, but further progress is expected in the energy sector with a high number of scientific papers on energy developments published recently.

There have been considerable advances in other applications of nanotechnologies, which have to some extent ridden on the back of the energy sector wave. **The benefits of the advances in energy technology have also helped to allay fears of the impacts of nanotechnologies**. There has been good progress in medical applications with advances in diagnosis and drug delivery.

Is the public sector investing?

Riding on the wave of success, governments have continued to fund and support developments in nanotechnologies, although investment has started to wane in the face of take-up by the private sector. **The military continues to invest heavily in a wide range of nanotechnology applications**. It made considerable progress in energy conversion and storage in its pursuit for individual power supplies for troops and this

has spun out clothing with integrated energy generation to provide power for electronic devices.

The success of energy related products has driven EU government commitment in other areas such as medicine and materials science.

How has global economic power changed?

China and India moved swiftly into the high tech energy market from 2007–2008 and have established market dominance in this area. Both countries have a high use of PV and have started ambitious projects to push the use of fuel cells in transport. The investment in science and engineering graduates in Asia in the first decade of the 21st century has paid off and, unlike Europe and the US, the availability of a skilled workforce is not an issue. This has accelerated the shift in economic power and China is projected to overtake the US as the world's largest economy by 2020.

In Europe, despite calls from some politicians, business leaders and NGOs for increased investment in clean technology, **the EU is still playing catch up with Asia**. Thanks to the leadership of California and the massive investment there from venture capitalists, the US is in a slightly better position.

There are still a number of developing countries that have not been able to take advantage of the rapid development of technology due to lack of infrastructure and investment. There is growing demand for energy technology to be made more universally available.

Is the world a safer place?

The disruptive nature of developments in energy technology is becoming increasingly apparent and there has been a shift of power away from big oil since 2010. Many of the **oil producing nations in the Middle East have invested considerable resources into large-scale solar developments** and continue to sell energy to those countries without the infrastructure. But revenues are small compared to the golden era of mass oil consumption.

Even though the technology has the potential to provide cheap widely-distributed energy there is still an increasing divide between the rich and poor. This is due in part to the existence of a dramatic time lag between the introduction of the technology and its distribution to those who really need it. **Large multinational companies from America and China hold many of the patents** and there is **increasing resentment from developing nations that cheap and plentiful energy is largely available only to the richer nations** who now arguably need it less. To compound the impacts of the energy divide, many developing countries are suffering from resource shortages, with growing concerns over water scarcity and climate change. There is the threat of conflict over resources as the technology boom drives the demand for raw materials without rewarding the countries where the material originates.

Is the private sector investing?

The investment community's faith in clean technologies has really paid off. The heavy investment in PV that started in 2006 has yielded swift advances and good returns on investment. As a result **there is confidence that nanotechnologies will continue to deliver in other areas, as well as energy**. In 2007, private investment in nanotechnology-related research and development overtook the public sector contribution for the first time and in 2015 is many times the size. In 2015 the **PV market alone has revenues of $70 billion worldwide and is growing fast**.

How has the energy market changed?

New sources of energy have severely reduced the economic viability of older sources of generation such as nuclear, coal, gas and wind. PV began to compete seriously with these forms of generation in 2014. With pressure to develop renewable sources of energy, and concerns over security of supply, there has been rapid expansion in the roll-out of decentralised energy and microgeneration.

Recent developments are having a hugely disruptive effect on the energy market. Increased efficiency in solar cells and improvements in batteries and fuel cell technology are changing the nature of energy production and distribution. With the advent of flexible, economically viable solar, **surface area is increasingly viewed as real estate and entrepreneurial individuals have started to sell prime locations**

on their property. The roll-out of fuel cells has lagged behind solar cells because of the delay between the introduction of the technology and the development of the necessary infrastructure.

How successful is nanotechnology in the market?

The 'Forbes' top 10 list of nanotechnology products contains numerous energy devices and devices using nanotechnology-enabled power supplies. **The developments in energy are the basis for hundreds of new product lines** and nanotechnology enables many of these new products though local micro-power production. Used across the board, **nanotechnology has become the disruptive technology that it initially promised to be**. Products are often labelled "nanoenabled" as a marketing tool, even when the role of nanotechnology in their development has been relatively insignificant.

Are the necessary skills available?

The rapid pace of technological development has begun to open up a skills gap, particularly in the EU. Although investment in science and education has provided an increase in science and engineering graduates, **there is still some way to go to match countries such as India and China**. There is considerable concern that this skills gap will begin to affect competitiveness and across the EU there are initiatives to encourage education in this area. In response the US and EU have opened up overseas academies to try to recruit science graduates from abroad.

How is nanotechnology regulated?

The regulatory environment has struggled to keep up with the pace of technological change and there is still a massive discrepancy between spending on developing the technology and researching the impacts in order to minimise them. Health and safety at the workplace and **concerns over life-cycle impacts have recently made regulation a higher priority**. As the technology has a high profile in society and a huge market value there is resistance from business interests to any additional red tape. Regardless of this pressure, governments are finally starting to react to the rapid development of technology and new legislation has been introduced in the last two years concentrating on health and safety, producer responsibility, end-of-life impact and release of nanomaterials into the environment.

What is happening to the environment?

Although **many countries failed to meet their 2010 CO_2 reduction targets**, there have been significant reductions in CO_2 emissions across the EU. Progress since 2010 has been good and the **EU is expected to meet the new target to reduce CO_2 emissions by 35 per cent by 2020**. This was initially because of advances in energy efficiency, but increasingly it is the result of the rapid uptake of solar energy generation by businesses and households. The prediction is that energy will no longer be a limiting factor on economic activity by 2050.

More of a concern is the availability of raw material resources. Although manufacturing at the nanoscale is improving efficiency, the breakthrough in the energy sector has led to an explosion in the number of personal hi-tech products. **Because of the increasing complexity of these devices**, and the fact that they are often embedded in other materials (as with solar clothing), **recycling them effectively is extremely difficult**. Not only does this create a waste problem, it also means that precious materials cannot be recovered and reused. This has placed upward pressure on commodity prices, with the likely effect that the costs will be passed on to consumers in the medium term.

Have the anticipated risks occurred?

Dramatic scientific progress has led to greater speed of products to market and **society has struggled to define the implications of the advances in this technology**.

As the new range of products entered the market between 2009 and 2012, several NGOs voiced concerns over the environmental and social impacts of the rapid introduction of new and complex materials, with claims that the world could experience the effects of "another asbestos", but on a bigger scale. However, the **breakthroughs in energy technology have moved nanoproducts from the quirky to the real**.

Genuinely useful products providing cheaper cleaner energy – leading, for example, to the phasing out of toxic materials in batteries – have meant that such warnings have gone largely unheeded. **Until 2014 there was little discussion of the trade off between risk and benefit**, even from the more environmentally minded NGOs, as the

science began to deliver products that could help solve the energy crisis and reduce greenhouse gas emissions.

Initially the majority of the applications were deemed safe as the nanoparticles were fixed in the product. **Problems first arose when the first wave of products were replaced. This increased concerns about material use, resource management and the difficulties in recycling**. Minor pollution events also raised the concern about the life cycle impacts of the products. **In 2013, an accident occurred at a production site and staff suffered severe side effects from exposure to quantum dots**. This incident reinvigorated NGO activity on the dangers of rushing products to market without research on the possible impacts.

The social impacts of these developments are only now starting to be realised. For example, there are **concerns that reliance on hi-tech solutions will inevitably lead to problems of accessibility** for the poor and potentially divert funding from simpler, more universally applicable solutions.

How have business ethics changed?

Initially, those businesses involved in the development of energy products enjoyed unparalleled public support for delivering on a key environmental issue. These **businesses heralded their products as truly sustainable and only a small number of NGOs questioned the long-term social and environmental impacts**. The majority welcomed the advances in energy production and storage.

It was only once the first generation of devices reached the end of their life and the pervasive nature of spray-on solar became an issue, that the questions about material use and lifecycle impacts increased. NGOs began to raise the profile of the debate and those **businesses involved had quickly to move on the wider, long-term issues associated with the life cycle of their products** and major hurdles such as recycling. There are members of civil society who have accused business of ploughing ahead with progress without looking at possible impacts further down the road.

What does the public think?

In the years leading up to 2015, **most public opinion polls showed an overwhelmingly positive response to nanotechnology**. Nanotechnologies are seen by most to be delivering an obvious societal benefit. Nanoenabled products are increasingly widely dispersed and accepted within civil society. Technology for the individual is beginning to take off in 2015 and **there is a bullish view that nanoscience can deliver what was unimaginable just a decade ago**.

However, debate has intensified about the trade-off between rapid progress and the potential down-sides. Spray-on solar has raised awareness of the potential issues around how waste is dealt with when the product has reached the end of its useful life. The pervasive nature of the technology clearly exacerbates this problem substantially and there is **increasing pressure for biodegradable alternatives** to be developed.

There is increasing unease in religious circles about the path that the advances in technology are taking us. A multi-faith conference was held in early 2015 to challenge the technological progress and ask questions about the impacts on our society and our human nature. There is particular concern about the advances in the science of human modification.

How effective is public debate?

The unexpected advances in energy technology have meant that until recently there was little call for debate on the value and trade offs in using nanotechnologies in energy products. However, today there are calls for a dialogue on a variety of topics from accessibility to waste impacts of solar cells. There is **growing alarm around energy, social justice and the unfair distribution of technology**. A number of NGOs who have continually called for dialogue and a more precautionary approach are now championing the idea **that "the pursuit of technology for its own sake is a mistake"** and society has to learn that **"speed of development is not synonymous with progress"**.

What should we do now?

The scenarios show us what the future might hold for nanotechnology and what the risks and benefits could be. But what should we be doing now to ensure the best possible outcome from developments in future?

Many people expect nanotechnologies to deliver significant benefits to society. Many people also feel that nanotechnology poses enormous risks that must be negotiated carefully. We are at a relatively early stage in the development of the technology and so we have an opportunity to put systems in place that maximise the benefits of nano-related products and minimise the risks of manufacturing, using and disposing of them. Such systems must be developed through dialogue involving the key stakeholders.

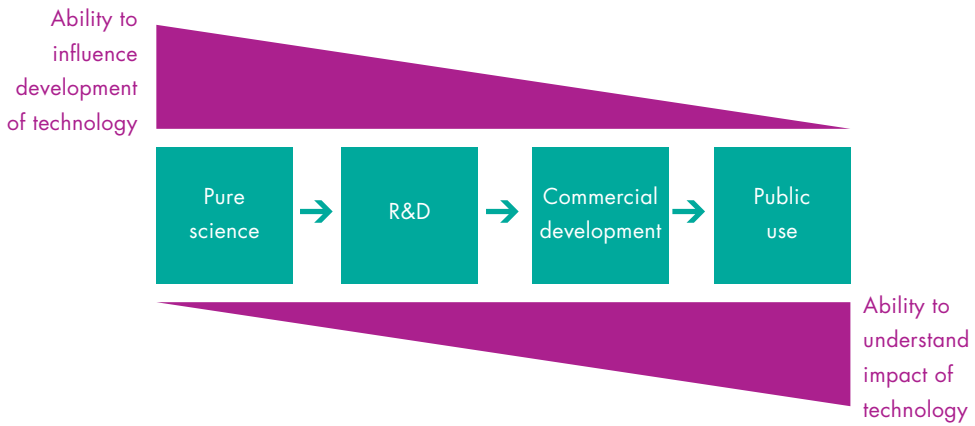
Nanotechnology may excite more enthusiasm and generate more opposition than most other areas of science and technology but, in essence, there is nothing different about this technology's place in society. The same basic questions are asked of nanotechnology as have been asked of biotechnology and information technology in the past – and they will be asked of other technologies in the future.

- ➔ Will the technology deliver for society and can this be done through established governance systems?
- ➔ Do we need to put market structures in place to ensure that we achieve maximum benefit from the technology and what kind of market structures would be needed?
- ➔ What roles should governments, businesses, civil society organisations and other stakeholders play in the process?
- ➔ How do we know if a new technology is going to have negative impacts and how will these be managed and prevented?

In the 21st century, we should be able to accommodate breakthrough technologies without having to endure the whole process of hype and controversy that often comes with them, as if we were going through it for the first time. Most people agree that we need new technology, so we need to learn how to deal with technological advance as a society. Any dialogue designed to do this should have the following features.

Begin the dialogue upstream

The diagram below illustrates that there is far more scope to influence the development of nanotechnology before commercial development begins. It can be difficult to include people who are involved in pure science or the early stages of research and development for specific applications, but dialogue will be much more effective if this can be achieved.



Focus the dialogue

Much of the discussion and coverage about nanotechnology-based applications does not differentiate between the very diverse array of applications captured under the term nanotechnology. At present the dialogue in the public domain tends to be quite generalised, lacking a specific focus on applications. Consequently, the risks of separate nanotechnology-based applications are often lumped together as risks of nanotechnology, masking important differences in potential impact. Dialogue and its communication should focus on specific applications rather than, or as well as, nanotechnology in general. And there is a strong argument for regulatory frameworks to follow a similar line, providing guidance on treating specific applications, as well as nanotechnology in general.

Frame the dialogue in terms of future goals

The dialogue should address the central question of where the technology is heading and relate it to accepted and shared societal goals. Currently there is no clearly articulated vision for what nanotechnology can deliver, and the closest we get to this is a discussion of risks and opportunities. Sustainable development, a concept that takes a holistic

approach to economic, social and environmental goals, is an ideal framework for understanding the technology's role and can be used to develop a vision of what we want nanotechnology to be delivering in 10, 20 and 30 years' time. Using scenarios is one way of promoting structured thought and discussion about the sort of context in which the technology will be operating in the future and how the technology itself will influence that context. This is an important step that can help prepare organisations, both strategically and operationally, for the challenges ahead (see 'Thinking ahead: Using the scenarios', p60).

Framing the dialogue in terms of future goals will improve the quality of dialogue but should also eventually influence funding criteria and policy, and would have the added benefit of maintaining a positive profile for the technology in Europe's media, making it easier to communicate positive stories about nanotechnology.

Finally, using sustainable development as a framework in this way might help to challenge the preconception that the speed of introduction of technology is synonymous with progress.

Inform the dialogue

We still don't know for certain in 2006 whether nanoparticles and other nano-based components pose a serious risk to human health and the environment, despite the publication of results from a number of studies. Other studies are currently under way, but in the meantime, discussions by both researchers and civil society representatives of such risks for the applications covered in this project have tended to assume that some of the potential risks will be realised. It is essential that up-to-date research is fed quickly into dialogue processes, so that the dialogue can be as informed as possible about the state of research and development and what sort of products and applications will be possible within the next decade.

The dialogue should also consider risks and opportunities through the entire life cycle of components and products. Discussions about the role of nanotechnology have often focused on how products and applications are manufactured, with less attention paid to how products are used, or how they should be dealt with at the end of their useful life. But inadequate disposal of nano-related products could release nano-particles into the environment, where they might accumulate and cause damage. Discussions should look at impacts throughout the life cycle,

from production through to end-of-life, enabling nanotechnology to advance with a fuller understanding of what the risks might be and how they should be managed.

Open up the dialogue

While doubts have been voiced about the value of public engagement in the current discussion, it is clear from previous situations (such as biotechnology) that the development of technology and the accompanying dialogue process must be as open and transparent as possible. While there might be a danger that too much information leads to confusion or disengagement from the issue, projects such as 'Nanojury' have demonstrated that the public can engage with the issue in detail.

www.nanojury.org ➔

Admittedly, these processes cannot be replicated for everyone but comprehensive communication and dialogue must take place. There is a far greater danger that a lack of transparency results in a lack of empowerment and a backlash from the public. The discussion about genetic modification raised serious questions about corporate transparency, and this must be overcome in the case of nanotechnology. It is essential that the relevant stakeholders respond to issues raised in dialogue and appreciate that, while this may slow down some aspects of technological development in the short term, it makes for a far better long-term prospect.

If stakeholders agree that the development of the technology should follow as sustainable a path as possible and the technology is clearly and consistently couched in terms of long term social goals, then public acceptance will be all the greater.

Communicate the dialogue

Even the most transparent dialogue will do nothing to avoid a backlash if people are unaware that it is happening, or cannot get access to the information easily enough to be involved. While many Nanologue project interviewees were aware of the large amount of information available, they felt it was not available in a central and, more importantly, accessible way.

Making this information available on the internet is an obvious choice, since the interviews showed that both target groups use it as a prime

information source. Some other suggestions raised during our research included:

- ➔ Setting up a clearing centre to collate and disseminate research into the risks and benefits of nanotechnology, hosted by an institution with high social legitimacy
- ➔ Activities could be initiated that involve the general public, for example via museums or science centres
- ➔ Makers of products that contain nanotechnology components should inform and engage with retailers
- ➔ Journalists and the media should be directly targeted with information both about benefits and risks

Check the societal impact of nanotechnology products

Researchers involved in the development of nanotechnology products are often not fully aware of the societal aspects that are, or will become, relevant to their application and often lack the time to explore further. Yet societal perception and demands can often affect the market success of new products (as can be seen from the GM debate). A high level of innovation and full legal compliance may not be sufficient if certain features of the product, eg the way it is manufactured or used, are questioned by civil society. In order to engage on the ethical, legal and social impacts of nanotechnologies, researchers need to have access to information on the potential implications of their research or products.

The NanoMeter

In order to help address this the Nanologue project team developed the NanoMeter.

www.nanologue.net/NanoMeter →

The web-based NanoMeter allows researchers and product developers to carry out an assessment of nanotechnology applications quickly during product research and development (R&D). It uses a series of questions or statements to help researchers explore the societal issues and concerns of their research. Unlike traditional product assessments, covering functions and user behaviour, the NanoMeter focuses on ethical, legal and social aspects and assists in identifying those areas that are critical for public acceptance.

The NanoMeter will:

- → Assist in identifying societal aspects that are critical for nanotechnology-based applications currently under development
- → Stimulate consideration of these aspects, which can be critical to success but are commonly not part of comprehensive early assessment
- → Help to consider additional benefits of nanotechnology-applications that can be further strengthened and communicated
- → Highlight potential risks and provide examples of where they can occur
- → Provide a good starting point to structure the internal discussion on societal issues
- → Serve as a meaningful framework to address societal issues that are increasingly relevant for the acquisition of public R&D funding
- → Provide a first indication of how the public might perceive and accept an application

How does the NanoMeter work?

The NanoMeter consists of a short but comprehensive series of guiding questions or statements that scrutinise relevant societal aspects of nanotechnology-applications, grouped under seven categories. The approach captures the enormous diversity of nanotechnology based applications while raising awareness for specific aspects and providing meaningful results.

Think ahead: Using the scenarios

It is important to prepare strategically for the challenges ahead. The scenarios have been compiled based on the opinions of more than 60 experts on how nanotechnology has developed and could develop in the future, and how society could react. The scenarios are not predictions, there is no best case or worst case scenario, and there is no business-as-usual scenario. Each scenario is a different picture of what is possible in 2015 and has both positive and negative features. They are tools to help people interested in nanotechnology and its place in society to think in a structured way about the future.

Below are some suggestions for how you could use the scenarios creatively to inform your policies, strategies, ideas or projects. In most cases, these activities will work best in a workshop, where people with different perspectives can share and discuss their views, but work with a colleague, associate or even individually would also be useful.

➔ Use the scenarios for strategic planning. What are the risks and opportunities presented by 'Disaster recovery', 'Now we're talking' and 'Powering ahead'? How can the risks be managed and the opportunities taken? What are the opportunities for you?

➔ How successful would your current strategy be in each scenario? Can you conduct a strengths, weaknesses, opportunities and threats (SWOT) analysis of your strategy for each scenario? How could the strategy change to make it more robust in 2015? How might you need to adapt it?

- ➔ Can you do the same with your policy, product idea or decision?

- ➔ Discuss what you would like to see nanotechnology delivering in 2015 from a social, economic and environmental point of view, set objectives and an action plan to achieve them, and then test the objectives and action plan against the three scenarios, perhaps using a SWOT analysis.

- ➔ Discuss what products might be successful in each scenario. How might they be developed? Can you draw a roadmap for the product idea that works for all three scenarios?

www.nanologue.net for suggestions on using the scenarios ➔

- ➔ Use the scenarios to help answer questions such as: What key events led to the emergence of each scenario? How do the different scenarios compare on key indicators? Which scenario is favourable and why? What is missing from the scenarios? What questions are left unanswered? What might their answers be?

- ➔ Use the answers to these questions to test your assumptions about nanotechnology applications and developments and where they are going in the future.

For a suggestion on how to structure a workshop with the objective to test the long-term robustness of a strategy (or policy, product idea, business plan etc) using these scenarios, please see the suggested agenda available on the website www.nanologue.net.

Where to go if you want to learn more

www.nanologue.net/ for downloads →

The scenarios and information provided in this pamphlet are just a snapshot of the materials available at www.nanologue.net.

Nanologue reports and projects results can be accessed conveniently in the 'download' section on the website www.nanologue.net. See 'general project documents' for insights into the project findings and methodology. You can find:

- → Nanologue project reports summarising a literature study ('Nanologue Mapping Study'), a background paper on societal implications of selected nanotechnology applications ('Background Paper') as well as results from a consultation with representatives from research, business and civil society ('Opinions')
- → Press releases and articles published by and about the Nanologue project
- → Presentations on the Nanologue Project
- → Topical introductions and specific results on societal aspects of medical diagnostics, energy storage and food packaging applications of nanotechnology
- → Assess your products: the NanoMeter and the business case of the ethical, legal and social aspects

Background to the Nanologue project

Commission of the European Communities (2005): 'Communication from the Commission to the Council, the European Parliament and the Economic and Social Committee. Nanosciences and nanotechnologies: An action plan for Europe: 2005-2006' →

In the Nanotechnologies and Nanoscience Action Plan for Europe, the European Commission underlines the importance of respecting ethical principles and integrating societal considerations in the R&D process. Public health, occupational health and safety, environmental and consumer risks should be addressed at the earliest possible stage, and a dialogue with citizens is encouraged. There is consensus among stakeholders that engaging in dialogue and reflecting broader public opinion is of vital importance to the continuing development of the technology.

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The project was led by Wuppertal Institute in Germany and features consortium partners EMPA (the Swiss Federal Laboratories for Materials Testing and Research) in Switzerland, Forum for the Future in the UK and triple innova of Germany.

Nanologue brought together researchers, businesses and civil society representatives from across Europe to support the dialogue on the societal opportunities and risks of nanotechnologies

The project comprised three main steps.

- ➔ A mapping study on recent developments regarding selected nanotechnology applications to lay a common ground for the subsequent discussions.

- ➔ Moderated dialogue sessions allowing for an inclusive and neutral platform for information and opinion exchange and discussion. Interviews with experts were used to substantiate findings and opinions.

- ➔ Scenarios based on the insights from the research, workshops and interviews to provide tools to explore some of the potential implications of these emerging technologies.

Acknowledgements

www.nanologue.net/ for credits →

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