Nanotech: Early Lessons from Early Warnings

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Late lessons from early warnings for nanotechnology

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A new technology will only be successful if those promoting it can show that it is safe, but history is littered with examples of promising technologies that never fulfilled their true potential and/or caused untold damage because early warnings about safety problems were ignored. The nanotechnology community stands to benefit by learning lessons from this history.

Nanotechnology is the latest in a long series of technologies that have been heralded as ushering in a new era or even the next industrial revolution. Since 2001, nanotechnology has grown from little more than a gleam in the eyes of researchers to a technology projected to be worth $2.6 trillion in manufactured goods in 2014[1].

So as new nanomaterials move from the lab to the marketplace, have we learnt the lessons of past technologies, or are we destined to repeat the mistakes made with previous technologies? In 2001 an expert panel commissioned by the European Environment Agency (EEA) published a report, *Late Lessons from Early Warnings: The Precautionary Principle 1896–2000*, which explored 14 case studies, all of which demonstrated how not heeding early warnings had led to a failure to protect human health and the environment[2].

Covering topics as diverse as asbestos, chlorofluorocarbons, non-ionizing radiation and 'mad cow disease', the EEA report examined the delay between the emergence of scientific evidence of harm and action being taken to reduce risks in each case. The expert group identified 12 "late lessons" (see Box 1) on how to avoid past mistakes as new technologies are developed. These lessons bear an uncanny resemblance to many of the concerns now being raised about various forms of nanotechnology.

A comparison between the EEA recommendations and where we are with nanotechnology shows we are doing some things right, but we are still in danger of repeating old, and potentially costly, mistakes. This commentary explores these 12 lessons in the context of nanotechnology.

LESSONS 1–2: HEED THE 'WARNINGS'

According to the EEA report "No matter how sophisticated knowledge is, it will always be subject to some degree of ignorance [that is, inevitable surprises, or unpredicted effects]. To be alert to — and humble about — the potential gaps in those bodies of knowledge that are included in our decision making is fundamental."

We are still in danger of repeating old, and potentially costly, mistakes.

Perhaps more than any preceding technology, the early development of nanotechnology has been characterized by discussions of potential risks. Such discussions have always been an integral part of the government-led National Nanotechnology Initiative (NNI) in the US, for example, while a report published by the Royal Society and Royal Academy of Engineering in the UK in 2004 emphasized the need to address uncertainties regarding the risks of nanomaterials[3]. Currently, most economies investing in nanotechnology pepper discussions about future directions in research with questions concerning potential risks — and how to manage them.

However, despite some moves to respond to ignorance and uncertainty rather than simply discussing them, coordinated action seems slow in emerging. The EEA report recommends looking out for "warning signs" such as materials that are novel, biopersistent, readily dispersed or bioaccumulative, and/or materials that lead to irreversible action (for example, thousands of mesothelioma caused by the inhalation of asbestos dust).

These warning signs are clearly relevant to many nanomaterials, some of which have novel properties, are capable of being incorporated in highly diverse products, may be transported to places in new ways, and may be designed to be persistent. Too little is known to predict the environmental fate of nanomaterials, and feasible documentation of environmental dispersion through monitoring is not expected in the short term[4]. The extent to which specific nanomaterials are bioaccumulative or lead to irreversible impact is largely unknown, but the current state of knowledge suggests that the potential exists for such behaviour under some circumstances[5].

The global response to these warning signs has been patchy, with governments being slow to gather essential data on

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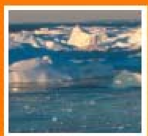

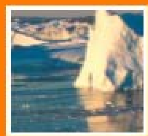

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21 Nanotechnology — early lessons from early warnings

Steffen Foss Hansen, Andrew Maynard, Anders Baun, Joel A. Tickner and Diana M. Bowman

Nanotechnology is the latest in a long series of technologies heralded as ushering in a new era of technology-driven prosperity. Current and future applications of nanotechnology are expected to lead to substantial societal and environmental benefits in regard to increased economic development and employment, improved materials using fewer resources and less environmental remediation, and to new ways of diagnosis and medical treatments (Roco and Bainbridge, 2005; RCEP, 2008; Hodge et al., 2010; Mikkelsen et al., 2011). Nevertheless, as new materials based on nanoscale engineering move from the lab to the marketplace, have we learnt the lessons of past 'wonder technologies', or are we destined to repeat the mistakes of our predecessors?

This chapter first introduces nanotechnology and provide some clarification on the terminology of nanomaterials, and elaborates on current uses of these unique materials. Some of the early warning signs of possible adverse impacts of some nanomaterials are summarised as well as the regulatory response of some governments. Inspired by the EEA's first Late lessons from early warnings report (EEA, 2001), a critical look is taken at what lessons may be learned now, considering that the development of nanotechnology is still relatively young ([1]).

21.1 What is nanotechnology and what are nanomaterials?

Nanotechnology is often described as having roots in a wide range of scientific and technical fields, including physics, chemistry, biology, material science and electronics. The field of nanotechnology is thus broad and covers a multitude of materials, techniques, scientific and commercial applications and products (RS and RAE, 2004). Originally the term nanotechnology, first used by Taniguchi in 1974, referred to the ability to engineer materials precisely at the nanometre (nm) level (Taniguchi, 1974). The term has since been framed and reframed by various actors over the decades and, despite the desire for a unifying all embracing definition of nanotechnology, many versions of the definition exist today. Here, we use the widely-accepted definition suggested by the United States National Nanotechnology Initiative (NNI):

> Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modelling, and manipulating matter at this length scale (NNI, 2009).

Chemistry typically deals with large numbers of atoms and molecules acting together. The behaviour of individual atoms and molecules can best be understood within a quantum physics-based framework, while the motion of massive collections of atoms and molecules such as physical objects under the influence of force are best described through classical mechanics or Newtonian physics. Nanotechnology falls between these two domains and holds the possibility of

([1]) This chapter is based on and in parts identical to Hansen, S.F., Maynard, A., Baun, A., Tickner, J.A. 2008. 'Late lessons from early warnings for nanotechnology', *Nature Nanotechnology*, 3(8):444–447.

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Chapter content

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- Current, future develop.
- Signs of early warnings
- (Lack of) nano-specific regulation
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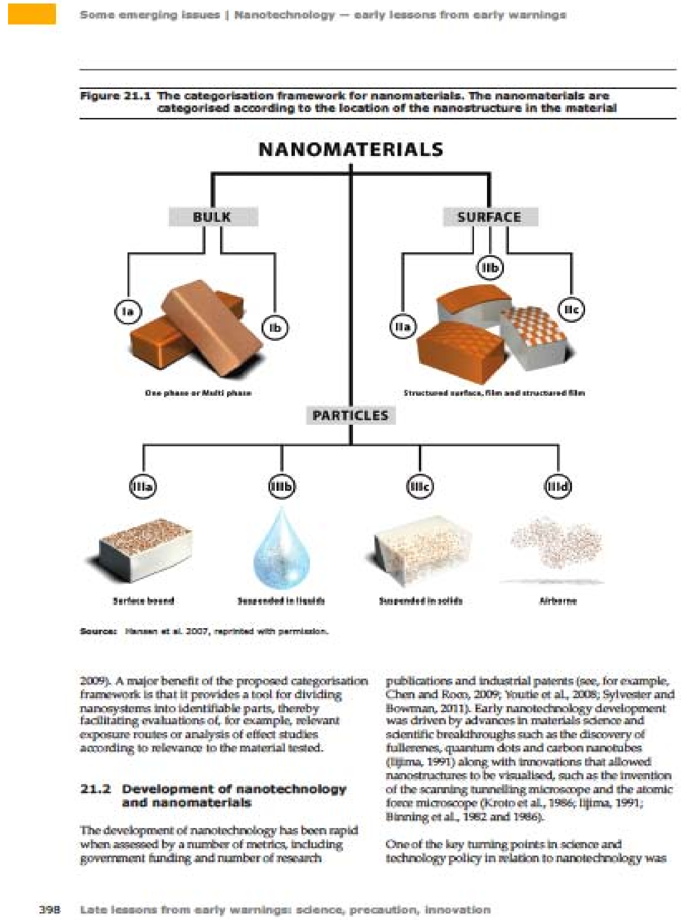
- So have we learned the LL1?
- Precautionary strategies for NT



Some emerging issues | Nanotechnology — early lessons from early warnings

Figure 21.1 The categorisation framework for nanomaterials. The nanomaterials are categorised according to the location of the nanostructure in the material

NANOMATERIALS
BULK
SURFACE
Ia
Ib
IIa
IIb
IIc
One phase or Multi phase
Structured surface, film and structured film
PARTICLES
IIIa
IIIb
IIIc
IIId
Surface bound
Suspended in liquids
Suspended in solids
Airborne

Source: Hansen et al. 2007, reprinted with permission.

2009). A major benefit of the proposed categorisation framework is that it provides a tool for dividing nanosystems into identifiable parts, thereby facilitating evaluations of, for example, relevant exposure routes or analysis of effect studies according to relevance to the material tested.

21.2 Development of nanotechnology and nanomaterials

The development of nanotechnology has been rapid when assessed by a number of metrics, including government funding and number of research publications and industrial patents (see, for example, Chen and Roco, 2009; Youtie et al., 2008; Sylvester and Bowman, 2011). Early nanotechnology development was driven by advances in materials science and scientific breakthroughs such as the discovery of fullerenes, quantum dots and carbon nanotubes (Iijima, 1991) along with innovations that allowed nanostructures to be visualised, such as the invention of the scanning tunnelling microscope and the atomic force microscope (Kroto et al., 1986; Iijima, 1991; Binning et al., 1982 and 1986).

One of the key turning points in science and technology policy in relation to nanotechnology was

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Early Warnings Triggered!!!

Carbon nanotubes introduced into the abdominal cavity of mice show asbestos-like pathogenicity in a pilot study

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Nanomaterials in the Environment

EFFECTS OF PARTICLE COMPOSITION AND SPECIES ON TOXICITY OF METALLIC NANOMATERIALS IN AQUATIC ORGANISMS

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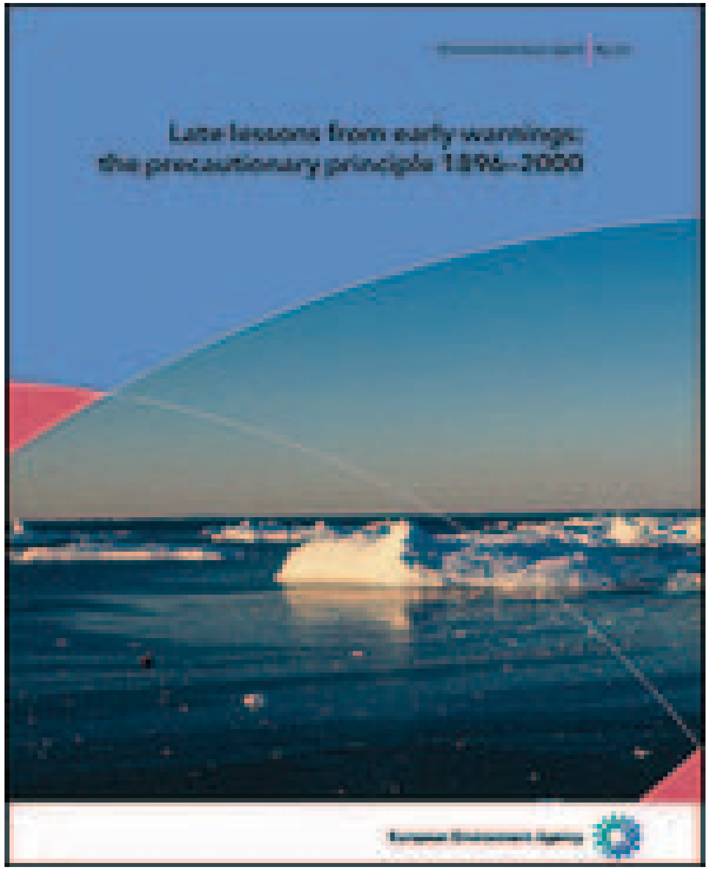
So How Are We Applying the 12 LL?



Box 1 The 12 lessons outlined by the EEA[2]

1. Acknowledge and respond to ignorance, uncertainty and risk in technology appraisal.
2. Provide long-term environmental and health monitoring and research into early warnings.
3. Identify and work to reduce scientific 'blind spots' and knowledge gaps.
4. Identify and reduce interdisciplinary obstacles to learning.
5. Account for real-world conditions in regulatory appraisal.
6. Systematically scrutinize claimed benefits and risks.
7. Evaluate alternative options for meeting needs, and promote robust, diverse and adaptable technologies.
8. Ensure use of 'lay' knowledge, as well as specialist expertise.
9. Account fully for the assumptions and values of different social groups.
10. Maintain regulatory independence of interested parties while retaining an inclusive approach to information and opinion gathering.
11. Identify and reduce institutional obstacles to learning and action.
12. Avoid 'paralysis by analysis' by acting to reduce potential harm when there are reasonable grounds for concern.

So Have We Learned the Lessons?

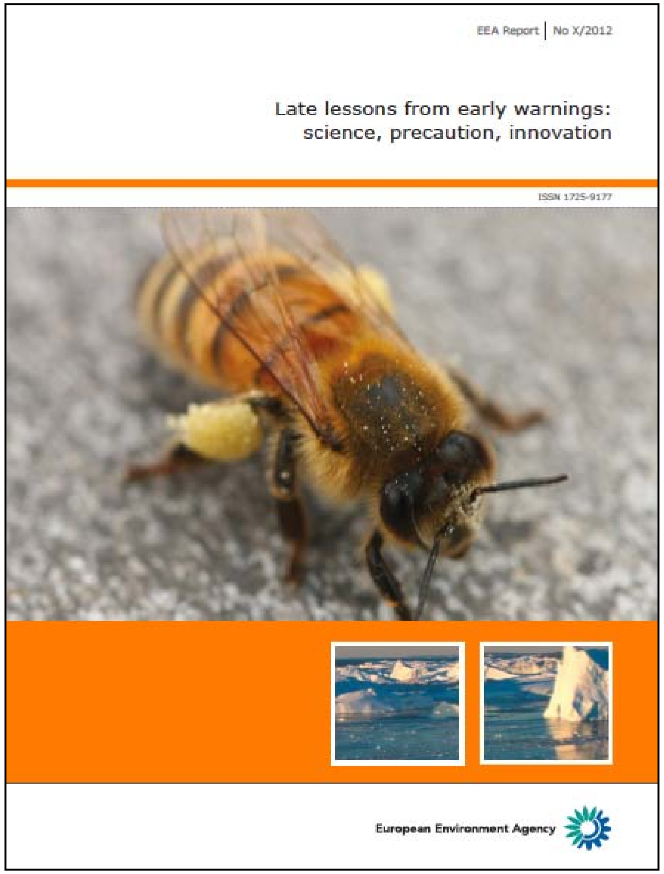
- Seems that we have, but that we are not applying them effectively
- Good start, now seems that we have become distracted
  - Nanotechnology is being overseen by the very government organisations that promote it;
  - Research strategies are not leading to clear answers to critical questions;
  - Collaboration continues to be hampered by disciplinary and institutional barriers; and
  - Stakeholders are not being fully engaged, or not being engaged early enough.
- Lots of bureaucratic inertia, claims that "risk research jeopardises innovation and "regulation is bad for business"

Table 21.1 Late lessons learned, as indicated in 10 EU Member State nanomaterials reports

Lessons (EEA, 2001)	Royal SA RAE (2004)	DG Sanco (2004)	Chaudhry et al. (2006)	IRGC (2006)	SCENIHR (2007)	RCEP (2008)	CEC (2008)	Stone et al. (2009)	RIVM (2009)	Aitken et al. (2009)	SCENIHR (2009)	Cosmetic Regulation	Biocides Regulation	Food Additives Regulation	RoHS * and WEEE **
Acknowledge and respond to ignorance, uncertainty and risk in technology appraisal	++	++	++	++	++	++	+	++	++	++	++	++	++	+	+
Provide long-term environmental and health monitoring and research into early warnings	++	++		++	+	++	+	++	+		++	++	++	+	+
Identify and work to reduce scientific blind spots and knowledge gaps	++	+		+	++	++	+	+			++	++	++	+	+
Identify and reduce interdisciplinary obstacles to learning	++			+	+	+									
Account for real-world conditions in regulatory appraisal		+										+	+		+
Systematically scrutinise claimed benefits and risks	+	+		+		+							++		
Ensure use of lay knowledge, as well as specialist expertise	++	+		++											
Evaluate alternative options for meeting needs, and promote robust, diverse and adaptable technologies															
Account fully for the assumptions and values of different social groups	++	+		++		+									
Maintain regulatory independence of interested parties while retaining an inclusive approach to information and opinion gathering	+											++			
Identify and reduce institutional obstacles to learning and action	++			+		+									
Avoid paralysis by analysis by acting to reduce potential harm when there are reasonable grounds for concern	+	+		+	++	+						+	+	+	+

Note: A emphty cell indicates no notice taken
+ mentioned in passing; ++ substantially discussed and/or analysed; +++ strategy suggested/implemented
* Restriction of Hazardous Substances Directive; ** Waste Electrical and Electronic Equipment Directive.

Thank U



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