Nano Dreams and Nightmares: Emerging Technoscience and the Framing and (re)Interpreting of the Future, Present and Past

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Abstract

Imagined nanotechnology futures are polarised between utopian dreams and apocalyptic nightmares. This paper provides an introduction to nanotechnology, a highly complex research and policy realm, and the contesting of "nano-futures". How the future and past are mobilised during the development of emerging technologies is of particular interest. Drawing on work in the field of Science and Technology Studies, which distinguishes between 'looking into' and 'looking at' the future, nanotechnology's intensely future-oriented dynamic is assessed. These dynamics have implications for the understanding of change processes and images of the future, as well as for constructive engagement with "nanotechnology".

Keywords: nanotechnology, sociology of expectations, imaginaries, nanoscience, converging technologies, images of the future

Introduction

The term nanotechnology was first used in 1974 to describe manufacturing that is precise down to the nanometre level. Today, it is 'the techno *buzzword de jour*' (Mekel, 2006) and has become synonymous with futuristic breakthroughs. Indeed, in the late 20th century, the 'quest to master the nanoscale' was said to resemble a global race (National Science and Technology Council, 1999); however, it is far from a settled, uncontested area. Whilst scientific research at this scale is nothing new (UNESCO, 2006), nanotechnology can mostly simply be considered a *collective* term for the myriad research, engineering and technology development activities focussed on the application of

a diverse, expanding set of techniques for manipulating physical and biological materials. It is often claimed that nanotechnology will be one the most significant technologies of the 21st century and that it will enable 'the next industrial revolution' (The White House, 2000).[1] As Anthropologist Chris Toumey (2004) has noted, 'landscapes of nano-hyperbole' currently abound.

While new technologies always stimulate visions of the future, "nano futures" are polarised between utopian dreams and apocalyptic nightmares. As Mekel (2006) puts it: the 'maelstrom of radical rhetoric swirling about nanotechnology includes two types of claims – those of "nanosalvation" (assertions based on the belief that nanotechnology is a technological magic bullet)... and their flipside, those of "nanodamnation"', which focus on technological risk and the potential for unanticipated consequences. This also highlights how technology is a double-edged sword (Mooney, 2006) and creates the need to manage expectations.

This paper aims to provide an introduction to nanotechnology and the shaping of emerging technoscience, describing key narratives and the contestation of "nano-futures". Initially, relevant frameworks, concepts and perspectives from field of Science and Technology Studies and sociology are outlined. Nanotechnology's past, present and imagined futures are then outlined. Of particular interest is how the future and past are mobilised and reframed. The contestation of emerging technoscience in the early 21st century is then discussed. With emerging technoscience becoming a central focus of futures thinking the paper concludes with some observations for practitioners and researchers in the futures field.

Theoretical Background: Technological Change, Expectations and Time Orientation of Modernity

The Science and Technology Studies field focusses our attention on the highly complex interactions between science and technology and society. Three key perspectives provide a broad theoretical framework: science and technology shape society (i.e. "technological determinism"), society shapes science and technology (i.e. "social determinism"), and the interactionist (two-way) perspective (Fuglsang, 2001). Although technological determinism is still highly prevalent in discussions about technology, and 'often easiest to capture and analyse pronouncements made about emerging technology' (Mody, 2004), overall there has been a shift away from linear notions of technological progress and the "science-push" model. Newer, more complex pictures highlight the roles of a wide-range of factors including expectations, social choices, and path-dependency, taking a 'co-evolutionary' perspective (Fuglsang, 2001; Jorgensen & Jorgensen, 2009; Jorgensen, Jorgensen, & Clausen, 2009; Salmenkaita & Salo, 2002; Stirling, 2007; Winner, 2001). That said, Winner (2001) has also noted the 'glaring disconnect' between the academic critique of technological determinism and 'the visions of run-away technology that prevail in society at large'. An excellent summary of these perspectives is provided by Fuglsang (2001) in Table 1.

Table 1
Three perspectives on science, technology and society (Fuglsang, 2001)

	Science and technology shape society	Society shapes science and technology	Interactive approaches (co-evolutionary)
Time	1950s-60s	1970s-80s	1990s-
Definition of technology	Cause	Consequence	Cause and consequence
Independent variable	Technology	Society	Social group
Relation of actor to technology	Beneficiaries (or victims)	Negotiate interests	Seamless web
Role of policy	Protect or reject science and technology	Empower actors, create networks	Democratise
Power structure	Technological regime	Negotiation	Frames, discourses
Methodological approach	Study impact of technology	Follow the artefact	Follow the actors

In this paper we recognise co-evolution: 'on the one hand, technology changes and challenges social patterns and, on the other hand, the governance structures and values of the society affect progress in developing the technology' (Keller, 2007). Additionally, Science and Technology Studies scholars have recently developed a sociology of prospective technoscience (Brown, Rappert, & Webster, 2000) and of the "promises" made about what scientific research will mean for society (Kearnes & Macnaughten, 2005), to assess how images of the future influence the development of new technologies and scientific fields.

This new sociology assesses how actors try to 'create "direction" or convince others of "what the future will bring".' That is, it is a move from 'looking *into* the future' to 'looking *at* how the future as a temporal abstraction is constructed and managed, by whom and under what conditions' (Brown, Rappert, & Webster, 2000, p.4). In particular, STS scholars have theorised the role of "expectations", which are defined by Borup et al. (2006) as 'real-time representations of future technological situations and capabilities'. A major claim is that expectations and visions in technoscience have become more significant in late modernity (Borup, Nik, Kornelia, & Van, 2006), something van Lente and Rip (1998) attribute to the 'general phenomenon of science and technology becoming strategic'. Borup et al. (2006) note that technological expectations 'link technical and social issues, because expectations and visions refer to images of the future' and become embodied. Empirical studies demonstrate that expectations can play decisive roles in establishment of new technological fields – such as nanotechnology – at three levels: the *macro* (e.g. creation of government policy), *meso* (e.g. in innovation networks and industry sectors), and *micro* (e.g. in research groups).

An important related concept is "sociotechnical imaginaries". Macnaghten, Kearnes and Wynne (2005) define imaginaries as the 'implicit assumptions, values and visions driving scientific development' and 'projected "future worlds"' which dissolve 'the opposition of the imagined and the real'. They argue that sociotechnical imaginaries influence research and innovation trajectories by shaping expectations, being

mobilised in public discourse, and becoming enacted in everyday practices. For example, Kearnes et al. (2005) reviewed governance practices in the recent UK genetically modified organism (GMO) plants controversy and found that GMO plants 'were justified in terms of positive projective visions, often utopian', which was not "opened up" for authentic and inclusive debate.

Adam (2005) argues that the key gain made by the sociology of prospective technoscience is the increased emphasis on the *materiality* of future-orientation. That is, 'recognition that intense expectation mobilises resources, produces incentives, creates chains of obligations, silences (or at least sidelines) dissenting voices, justifies certain actions in preference of others and produces new networks'. This appears highly relevant to an assessment of nanotechnology, which is 'set in the context of a proliferation of performative expectations, hopes and promises' (Anderson, Kearnes, & Doubleday, 2007) and is mobilising significant amounts of resources and creating new networks.

The final theoretical area considered is analysis of the future-orientation of modernity. Again, much has been written about this topic outside of futures studies. Two aspects will be noted. The first is regarding how the future is seen. Influential sociologist Anthony Giddens contends that a central factor separating modern society from earlier forms is future-orientation. It sees the future 'as a territory to be conquered or colonised' (Giddens, 1999). Further, it is the most preoccupied with the future because, unlike traditional societies, it has no sense of control over the future (Giddens, 1998). Similarly, Carvounas (2002) argues that modernity's unique temporality is fundamental to understanding it. He asserts that 'with the birth of modernity the past became undermined and the future valorised to such a degree that temporality became dominated by an open future' (Carvounas, 2002, p.12). Consequently, argues Carvounas, the problem of "temporal coordination" emerged creating the need for "temporal continuity" through 'new narratives connecting the modes of time'. The second aspect is how the future consequently must be managed. For Giddens (1999) this future-orientation creates the issue of *risk* and further asserts that 'our very attempts to control the future tend to rebound upon us, forcing us to look for different ways of relating to uncertainty'. More recently Adam and Grove (2007) have critically analysed Western society's relationship to the future, arguing that the West suffers from "structural irresponsibility", producing long-term futures through innovation and technology development and without the capacity for adequate forethought.[2]

An Introduction to "Nanotechnology"

Emergence through invention and futurism

Nanotechnology's emergence stems from two contrasting developments. First, advances made in scientific instruments for scanning and probing at the "nanoscale" (the scale of nanometers, or one billionth of a metre), which later became commercially available in the 1980s, led to new efforts and capacities to understand and exploit it. Indeed, many of threads that came to be known as "nanotechnology" long pre-date the use of the term (Kaiser, 2006). In 1989 Donald Eigler famously arranged Xenom atoms to spell "IBM" and this achievement was given the cover of *Nature*. The IBM

scientists involved claimed 'many new avenues of investigation are open to us... it should be possible to assemble or modify certain molecules in this way [and] we can build novel structures that would otherwise be unobtainable'.[3] Such moments give Schmidt's (2007b) definition of nanotechnology as 'domesticating atoms and harnessing them to serve our needs' meaning. This history is led by advances in equipment and research, informed by the convergence of scientific disciplines – see Figure 1 below.

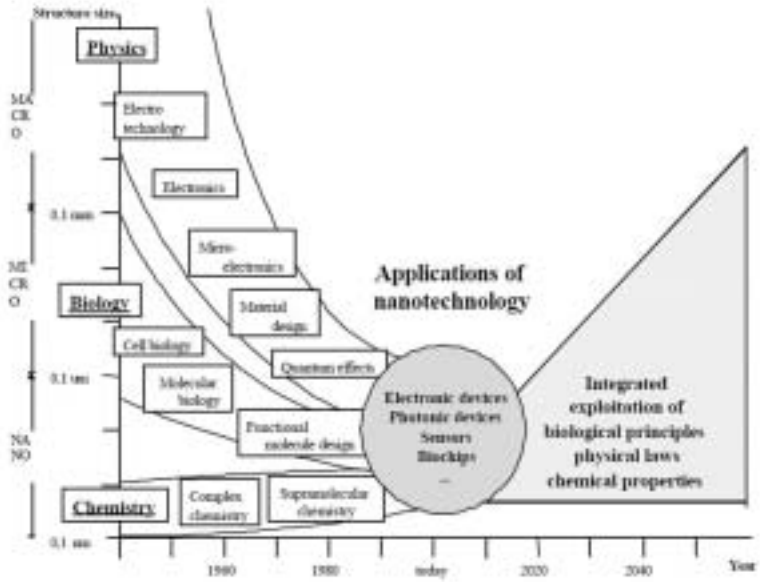

Figure 1. Physics, biology and chemistry meet in nanotechnology (as presented in Tegart, 2002)

Second, futuristic writings and pronouncements massively led tangible advancement. Early nanotechnology literature, as well as policy announcements supporting related research, is full of futuristic claims about its likely future development and consequences (e.g. see Clinton, 2000; Drexler, 1987; Drexler & Kling, 1991; Jones, 1995; National Science and Technology Council, 1999; Regis, 1995; Roco & Bainbridge, 2002). Eric Drexler's seminal *Engines of Creation: the Coming Era of Nanotechnology*, published in 1986, outlined a controversial "molecular manufacturing" vision. This well-read book outlined a speculative, distant future technological vision of theoretic possibility which Drexler interchangeably termed "molecular technology", "molecular engineering" and "nanotechnology". Drexler forecast the engineering of tiny "nanomachines" and "nanosystems" that 'will allow the fabrication of complex objects to atomic precision'. This version of "nanotechnology" has ever-since been associated with futuristic concepts such as tiny medical nanobots in human arteries, or "nano-assemblers" creating materials from the "bottom-up" (i.e. atom-by-atom).[4] Although this vision is usually discounted as ill-conceived and unlikely to ever

be fully realised by scientists (Wood, Geldart, & Jones, 2008) proponents of other nano-visions are 'not shy about saying that current research will inevitably generate a brave new world' (Mody, 2004).

Two political examples make this clear. When former US President Bill Clinton introduced the National Nanotechnology Initiative (NNI) in 2000, he drew on the futuristic imagery that Nobel Laureate physicist Richard Feynman outlined in his now famous speeches 'There's plenty of room at the bottom' (1959) and 'Infinitesimal machinery' (1983):

> *Just imagine: materials with ten times the strength of steel and only a fraction of the weight; shrinking all the information at the Library of Congress into a device the size of a sugar cube; detecting cancerous tumours that are only a few cells in size' (Clinton, 2000).*

In his speeches Feynman playfully speculated about all the possible ways in which miniaturisation, computer and information technologies could be used to explore the sub-microscopic world and elaborated on ideas for tiny machines which could find application in medicine and self-cleaning surfaces, among others. Today, the NNI's vision for 'a revolution in technology and industry' echoes Clinton's address. It states that 'some scientists think they can combine carbon nanotubes with plastics to make composites that are far lighter, yet stronger than steel' and confidently asserts that 'properly structured gold nanoparticles... start absorbing light and can turn that light into heat, enough heat, in fact, to act like miniature thermal scalpels that can kill unwanted cells in the body, such as cancer cells'.[5]

Second, huge promises have also been part of recent efforts to establish new nanotechnology programs in the Australia and the European Union. For example, the independent working group for the Australian Prime Minister's Science, Engineering and Innovation Council (PMSEIC) 2005 report that championed nanotechnology contained a key cartoon sourced from the European Commission's 2004 report *Nanotechnology Innovation for Tomorrow's World*. Figure 2 and figure 3 below incorporate a combination of predicted advancements in materials science, computing and energy technologies, among others:

Figure 2. 'Nanotechnology in future everyday life' (PMSEIC, 2005)

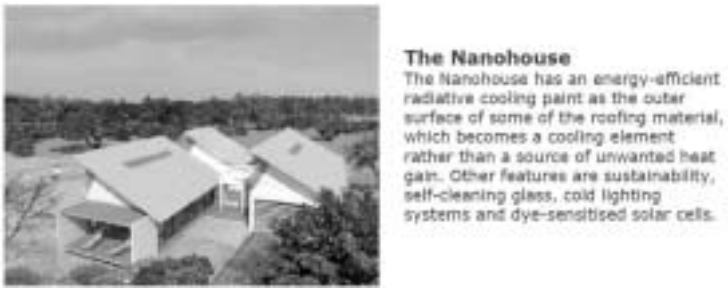

Figure 3. The "nanohouse" (presented in PMSEIC, 2005; see also http://www.nano.uts.edu.au/about/australia.html)

Today, nanotechnology is considered to deserve special attention because *converging* and *emergent* technologies at the nanoscale are expected to have enormous consequences. They are also developing fast, with many billions of dollars being invested in research all around the world by governments and business (Lux Research, 2007).[6]

Nanotechnology's complex present

Nanotechnology is today generating a lot of attention, all around the world, and building great expectations in the academic community, and amongst governments, investors and industry. Lakhtakia (2004) argues that nanotechnology is increasingly being seen as 'the solution of any problem afflicting humanity' in the minds of many researchers as well as those who control research funds and is, thus, shaping up as a "megaideology". But it is a hard area to define and understand. Attempts to define the nanotechnology typically focus on scale. Much of the enthusiasm arguably stems from

the lab observations of the properties of materials at the nanoscale, which is then extrapolated into potential applications. The authoritative UK Royal Society and Royal Academy of Engineering (2004) study asserted that 'the only feature common to the diverse activities characterised as "nanotechnology" is the tiny dimensions at which they operate'.[7] Similarly, UNESCO (2006) notes that 'perhaps the broadest definition of nanotechnology is research conducted at the nanoscale'. It has already been noted, however, that a scientific focus on this scale is nothing new. To further explore nano's complex present it is necessary to first further identify nanotechnology's specificities.

In this emergent area science, technology and society are tightly interconnected. 'Familiar distinctions between "applied" and "basic" research are troublesome' and there are dozens of definitions of what nanotechnology is or could be (UNESCO, 2006). Definitions typically focus on *control* (i.e. the ability to precisely manipulate matter at the nanoscale) and new tools and approaches which make it possible to *exploit objects at the nanoscale* such as the fabrication techniques used to make nanomaterials and/or nanostructures such as carbon-based nanotubes. Some define nanotechnology according to how it may be applied, e.g. as a *'platform technology'* (Walsh, 2007)[8] or *'enabling set of technologies'* (PMSEIC, 2005). Current definitional issues highlight the breadth of activity, fuzzy boundaries, and flux that characterises nanotechnology (Porter, Youtie, Shapira, & Schoeneck, 2008).

Scholars from the Manchester Institute of Innovation Research (Loveridge, Dewick, & Randles, 2008) suggest three conditions distinguish the production of "nano-artefacts":

- *Dimensional scale* (focusing at the nano-range of 1-100 nanometres [nm]);
- *Properties* and behaviours of particles that come into affect when molecules attain a critical (small) size, i.e. molecular disaggregation; and
- *System integration* of nano-artefacts (e.g. nanoparticles, fabricated nanomaterials and nano-engineered structures, etc.) to make new nanotechnologies and products.

As part of this new production the enormous, and increasing, aspiration for ambitious, commercially-deployed application is an important development. This, and a mainstreaming view of "converging technologies" at the nanoscale, has led to a rapidly growing belief that nanotechnologies may be the beginning of a "new world" within a notional time horizon of 2030 (Loveridge, Dewick, & Randles, 2008). Further consideration is informed by three main "types" of nanotechnology identified by Wood et al (see Table 2 below):

Table 2
Three "types" of nanotechnology (adapted from Wood, Geldart, & Jones, 2008)

Type	Description	Examples
Incremental nanotechnology	Scientific and technological developments that, essentially, are a continuation of the research directions of the past 50 years.	Includes much colloid science and materials science, focus is on materials that have superior/new properties as a result of their controlled nanoscale structure. Also includes bulk production of nanoparticles and their inclusion in consumer products (e.g. sunscreens).
Evolutionary nanotechnology	The scaling down of existing technologies towards the nanoscale.	Includes developments in information technology (e.g. new semiconductors, memory devices) and molecular delivery (e.g. drug delivery).
Radical nanotechnology	The creation of fully functional nanoscale machines and the engineering of systems (not simply materials and devices).	Embraces the proposals of Drexler and his followers for “molecular manufacturing” (e.g. new “bottom-up” approaches to fabricating materials), and other approaches that may lead to this outcome (e.g. bionanotechnology).

Further, Wood et al. identify key perspectives based on actors' views of Drexler's vision (that is, whether or not it is considered to be technically flawed) and the expected impact and effects of nanotechnology (that is, incremental or revolutionary). To *Drexlarian advocates*, for example, many new technologies and more mundane work is currently simply being branded as "nanotechnology" – it is a label mainly used for marketing purposes which should be reserved for applications of 'principles of mechanical engineering applied to chemistry'. Most nanotechnology scientists and the nano-business community, in contrast, believe the Drexler vision of "molecular engineering" is technically flawed *and* that 'the products of incremental and evolutionary nanotechnology will themselves have profound and potentially revolutionary impacts.' These perspectives clearly see the core issues very differently.

Overall, there are two main sides of the nano-debate – the skeptics and the believers, which inform the two long-term visions of "nano-optimism" and "nano-pessimism" (Arnall & Parr, 2005). On the skeptical side of the debate, Ball (2003), a consultant editor for *Nature*, asserted that 'those working in the field know that nanotech is not really a discipline at all, that it has no coherent aims and is not the sole concern of any industrial sector'. Similarly, Mody (2004) commented that 'for many practitioners, nano is still a bit of a put-on, a bandwagon whose content they do not quite understand but which they are trying to make the best of ... sticking to relatively uncontroversial play'. For some Science and Technology Studies scholars nanotechnology is above-all a "political project" to raise finance and channel this to particular privileged projects (Randles, Dewick, Loveridge, & Schmidt, 2008). An American nanoscientist explains: 'the scientists and engineers are desperate to maintain funding levels, maintain government support...the stuff that people are doing today they have been doing for years' (Berne, 2006, p.69). Fuller (2009) bluntly describes nanotechnology as a "rebranding exercise for chemistry".

On the other side of the debate, it is passionately argued that what is new and potentially transformative about nanotechnology is its interdisciplinary nature (Berne, 2006; PMSEIC, 2005). Rosalyn Berne author of *Nanotalk: Conversations with Scientists and Engineers about Ethics, Meaning, and Belief in the Development of Nanotechnology*, believes it represents a new, still-forming, partnership between science and engineering:

> *Under the umbrella of 'nanotechnology' flourishes an intriguing diversity of formerly distinctive and often fractious fields of science and engineering research... Biologists; chemists; physicists; biochemists; theoretical and applied mathematicians; materials scientists; mechanical, civil, chemical, biochemical, and biomedical engineers; and researchers from other specialized and distinctive fields exchange a plethora of findings and engage fascinating problems to take on under the rubric of nanotechnology. (p.32)*

Professor Richard Jones, Chair of the recent UK *Nanotechnology Engagement Group*, has articulated a related view, commenting that 'what is less disputed [about nanotechnology] is that it is essentially a goal-oriented activity' (Jones, 2007). These goals are extremely far-reaching and, in their most radical forms, exhibit a large dose of techno-utopianism. It is to these "nano-imaginaries" we now turn.

From experiments to imaginaries: glimpses of the desired nano-future

Science and Technology Studies scholar Cynthia Selin argues that 'the future of nanotechnology has become overburdened and has overshadowed the present' (Selin, 2006b, p.199). The intensity of "nano-hype" that has been quickly building over the past decade is well captured by *The Power of Small*, a public education initiative funded by the US National Science Foundation and Department of Energy.[9] The initiative's supporting website asserts that 'nanotechnology will change your life' and, among the various forecasts of nanotechnology development, confidently predicts that:

> *Nanotechnology is certain to provide solutions for some of our worst environmental problems and lead the way to a more sustainable future.*
> *Nanotechnology will allow convenient sensor surveillance and tracking technologies anywhere in response to our desire for security.*
> *The solutions cover the spectrum ... new solar power technologies, lighter and stronger construction materials for cars and other vehicles for improved fuel efficiencies, and processes to inactivate and/or remove a wide range of toxic substances from water and soil; all may be possible.*

Similarly, a major European public engagement exercise, *Nanologues* (Anon, 2006), featured scenarios looking out to 2015 where nanotechnology enables all sorts of amazing things such as: a 'nose filter... capturing impurities using nanofibre mesh'; computers '100 times as powerful as they were in 2005'; and 'unique packaging systems using nanosensors to change the colour of the packaging when the food inside is no longer edible, and alerts a networked monitoring system'. Nanotechnology even enables use of 'spray-on photovoltaic' solar power generation in one scenario. Likewise, in *Nanotalk* scientists discuss their ambitions: more efficient solar power

via 'artificial photosynthesis'; the manufacturing of generic elements via 'nanoscale material manipulation', rather than via traditional mining and processing systems; and one nanoscientist would like have the encyclopaedia, or maybe all the books ever written, stored in a certain cubic centimetre of his brain (Berne, 2006). This desire for technical mastery is well expressed by one nanoscientist (Berne, 2006, p.62):

> *Wouldn't it be wonderful if one understood the design rules for building things that you could pick and choose what functions you wanted to place into the material and design it from first principles. And I don't care what the application is, I just want to be able to do that. I want to be able to have that kind of control.*

IBM's Head of Physical science, Thomas Theis (as quoted in Berne, 2006, p.23), further elaborates this nano-future:

> *Materials as superior to existing materials as steel was to iron, and iron was to bronze in earlier eras. Nanostructured materials hold the promise of being stronger and lighter than conventional materials. This would have innumerable beneficial impacts from more fuel efficient and safer airplanes and cars, to luggage that can withstand baggage handling at airports! But strength is just one property. Designing materials with atomic precision allows unprecedented control of their electronic, magnetic, optical and thermal properties – in fact, any property that we want to enhance.*

Two goals are central to nano-imaginaries: solving the problems of the *industrial* age, such as climate change, and enhancing capacities gained during the *information* age. Indeed, Roco (2006), a major architect of the NNI, has asserted that 'nanotechnology promises to extend the limits of sustainable development.' With a complex set of challenges facing humanity, including the 'terrawatt challenge' of energy generation (Smalley, 2005), and environmental limits in the early 21st century, some techno-prophets promote nanotechnology – in concert with other emerging technologies – as the ultimate solution. The nano-vision, thus, speaks of unprecedented human mastery and transcending limits. The emerging technologies agenda, in particular nanotechnology, is argued to involve a related shift from a *physical* worldview to a *chemical* worldview: that is, a shift from seeking to 'discover the ultimate nature of things' to seeking to 'construct the most efficient means to our ends' – a focus on the "functional" and on matter in terms of instrumentality in bringing about humanly relevant ends (Fuller, 2009).

Further, utopianism permeates much of the nanotechnology literature. It can be seen as part of a shift from 'Liberation Theology' (struggle for social justice) to 'Liberation Technology', in which governments seek technological, rather than political, solutions to social problems (Mooney, 2006). It can also be likened to the utopianism that accompanied computerisation (Dunlop & Kling, 1991). Just as Kling and Dunlop (1991, p.5) outlined a 'seductive equation' of computerization, 'Technological Progress = Social Progress', "nano-ization" suggests that humanity can solve its major challenges through accelerating technological advancement. Indeed, as Kearnes and Macnaughten (2005) observe, forecast 'possible applications of nanotechnology appear so broad as to construct nanotechnology as a cure for more or less all human ills, and as the sustainer of future growth, prosperity and human happiness'.

Clearly there are various layers to the promised nano-future which need to be interpreted. A large amount of potential has come to reside in nanotechnology, with a wide range of Western governmental and non-governmental of actors creating hope for specific nanotechnologies and the emergence of nanotechnology as a "disruptive event" (Anderson, 2007). Further grasping of this new field is aided by considering temporality and narratives in nanotechnology.

Temporality and Narratives in Nanotechnology

Grounding discussions about nanotechnology in the present and in reality is a daunting task (Mitchell, 2007). Aside from the field's obviously intense future-orientation, this emerging area is characterised by a broader "non-presentism" (Mody, 2004), integrating narratives, and multiple temporalities in actor networks (Selin, 2006a). Historian Cyrus Mody contends that 'Nanoists often project a synthesis [of scientific and technological endeavour] far back into the past and the future' (Mody, 2004). This is, for example, achieved by:

> *Saying that nanoscience has been gathering steam (perhaps unnoticed) for a very long time in the guise of research in fields such as chemistry and materials science, or that nanotechnology has long been present in practices such as glass-making and blacksmithing where craft knowledge produces striking nanoscale effects.*

Similarly, the editor of Technology and Society journal The New Atlantis asserts that "we've been unwitting nanotechnologists for *centuries*" (Keiper, 2003, my emphasis), citing similar examples. This non-presentism extends to narratives of nature and nanotechnology:

> *Moreover, they [the nanotechnologists] say, nature (or "biology") has been doing nanotechnology for billions of years; every virus, bacterium, and cell is a nanomachineof enormous complexity... The progress of science, they say, means that it will inevitably be possible for us to understand and mimic nature's nanomachines; once we have done so, our own nanomachines will develop in a way determined by biology, chemistry, and engineering design; and as they develop, our inventions cannot help but to revolutionize our world just as nature's nanobots did. (Mody, 2004)*

The second key aspect of this non-presentism also appears to be a focus on the past, as 'the science of the nanoscale is acquiring its own histories' (Toumey, 2004) by reinterpreting past scientific and engineering developments.[10] For example, the discovery in 1991 of a molecular shape known as the "carbon nanotube" is today widely viewed as a pivotal moment in nanotechnology's history. At the time, however, 'this work was not called nanotechnology, but simply chemistry' (UNESCO, 2006). As nanotechnology is currently comprised of a loose "community of communities", with each group having its own history, nanotechnologists can pick and choose to create histories and new narratives.

Drawing on earlier sections and a study of nano-imaginaries (Kearnes, Macnaghten, & Wilsdon, 2006) core narratives can be distilled. Each framing it differ-

ently, is integrative, and aligns well with the different "types" of nanotechnology identified by Wood et al. (2008). They are:

- *'Understanding and utilising the properties of matter at the nanoscale'* (i.e. an *incremental* nanotechnology narrative): This framing highlights new collaborations focussed on understanding and exploiting the nanoscale. In this narrative we move from "accidental" nanotechnologists (e.g. Indian craftsmen who made the famous Damascus blades, artists from earlier periods such as Renaissance artists) to, in the present and future, conscious nanotechnologists. Key figures from physics (e.g. studied quantum effects) and chemistry who have been providing insights into the nanoscale for centuries, become celebrated nanotechnology pioneers;
- *'An extension of the miniaturisation imperative'* (i.e. an *evolutionary* narrative): This framing is rooted in recent developments in microelectronics and data storage and the general direction of modern technological innovation – 'smaller, cleaner, cheaper, faster, smarter' (Fowler, 2002). Nanotechnologies have been used to create tiny features on computer chips over the past two decades (Royal Society & Royal Academy of Engineers, 2004). Linked with this, transcending "Moore's Law" is seen as an economic and technological imperative and strategic race is on to secure a place in the nanotechnology-enabled future quickly evolving from the high-technology-present. Nanotechnology is the next, inevitable step (e.g. nano-electronics);
- *'The "clean and green" linchpin for solving societal problems'* (combining *incremental* and *evolutionary* nanotechnology narratives): This narrative frames nanotechnology as an 'instrument of sustainability' (Colvin & Weisner, 2005) and embraces other key narratives of nature and nanotechnology (Wickson, 2008). New concepts of "green nanotechnology" are advocated, which integrate nanotechnology with green chemistry and green engineering, with key applications forecast for clean energy and water purification (Schmidt, 2007a & 2007b). The "strategic science" trend is accelerated by the search for solutions to the critical problems currently facing humanity;
- *'Control over the structure of matter and transformative human mastery, through "technologies converging at the nano-scale"'* (i.e. a *radical* nanotechnology narrative): This narrative connects with the long-running quest to gain mastery-over-nature, which is reframed as positive and necessary. The present and future is seen as a trajectory of increasing control – and ability to "manipulate matter" at all scales – through the inevitable convergence of nanotechnology with biotechnology, IT and cognitive science (which the US and Europe are competing to define, see Fuller, 2009). This will, thus, create an "enabling platform" for human mastery and innovation. Linked with this the goal of *'improving human performance'* – augmenting and enhancing human qualities and abilities via technology – is advocated (which trans-humanists argue there is a history of and should be embraced).[11]

As can be seen above, narratives of nanotechnology draw on different pasts, interpretations of the present and anticipated futures (it is worth also noting that these are reframed in a similar fashion by biotechnology advocates[12]). Critical narratives of nan-

otechnology, as articulated by activists, are typically a reaction to the radical framing. For example, prominent critics of the nano dream, ETC Group, responded to the 'strategy to merge the sciences based on the unity of nature and material unity at the nanoscale' and desire for 'godlike mastery over all knowledge, matter, mind and life' (ETC Group, 2003).[13] The "nano dreams" of some are the "nano nightmares" of others. In futures literature such nano-visions have also been the cause for concern (Bowman & Hodge, 2006; Dunkley, 2004; Slaughter, 1999).

Furthermore, nanotechnology is 'saturated in multiple temporalities' (Selin, 2006a). Selin argues that time is built differently into such narratives and the characterisation of technology. She presents the following four types, which can be considered deeper beliefs:

- *Trajectories or paths*: This relates to a deterministic characterisation of travelling along a set path. Linked with this is the notion of "path dependency" – the structuring influence of the past on the present and the future;
- *Discontinuous and disruptive*: viewing technology as disruptive and non-linear – potential for breaks from past and present, allowing for interruption;
- *Uncertain and indeterminate*: Characterising nanotechnology as 'out of control' and inherently uncertain. Selin states that akin to this idea 'is the notion of nanotechnology development as an active, emergent and continually ongoing process'; and
- *Immediacy*: Characterises now as the "right time" for nanotechnology, a sense of urgency, imminent; it is grounded in the present. For example, the right time for nanotechnology investment, not wanting to be 'left behind'.

The above beliefs are held by various actors in the nanotechnology debates and reflected in different core narratives (e.g. seeing technology as travelling on a set trajectory is expressed by the *'extension of the miniaturisation imperative'* narrative). Some narratives are intended to mobilise, others expressed seek to define nanotechnology as a new science (Kearnes et al., 2006). All are part of the increasing contestation of nano-futures, which has contributed to the creation of new anticipatory strategies and practices, and are summarised in Appendix 1.

Nano-futures: The Shaping of Emerging Technoscience

> S*ocial, cultural, moral, political and economic visions of promise, threat and governance have shaped and are shaping – in uneven and complicated ways – the research trajectories that will determine the eventual form of nanotechnologies (Kearnes & Macnaughten, 2005, p.279).*

In the theoretical background it was noted that the *Sociology of Expectations* is primarily a move from 'looking into' to 'looking at' the future. It focuses 'the analytical gaze towards the phenomenon of future orientation itself' (Brown, Rappert, & Webster, 2000, p.4) and considers how 'futures occupy a contested terrain'. Many government, scientists, entrepreneurs and investors are promoting the nano-vision, seeking to build support and investment. Many pressures are also contributing to greater hype in science. Other actors, such as critical civil society organisations, articulate counter-claims about its potential. They view the inherent nature of current and poten-

tial nanotechnologies as disruptive (echoing the rhetoric of many nano-advocates), highlight risks and express different images of the future forecasting negative consequences.[14] Overall, they advocate precaution (see Joint civil society statement, 2007), and greater public participation in technology assessment and development. Different actors are trying to convince us that the nano-future will bring about particular outcomes – nano dreams or nightmares.

In this way, nanotechnology exemplifies the *political economy* of expectations (see Brown, 2003). "Hyper-expectations", fed by nano-hype, are fuelling counter-concerns. As *Nature* consulting editor Philip Ball has described, in 2003 nanoscientists started to be viewed as mad scientists, the 'new Victor Frankensteins, the modern Prometheuses, the contemporary Fausts, dabbling with dangerous forces they cannot control' (Ball, 2003). Here in Australia a number of public interest and environmental organisations have called for an immediate moratorium, fearing the potential impacts of the future 'reconstruction of the world at the atomic or molecular level' (a radical nanotechnology narrative) and also arguing current nanotechnologies (incremental) potentially carry unacceptable risks for human and environmental health. Some critics also fear it is being developed as a technological panacea prolonging a "business-as-usual" path. Other emerging technologies have encountered similar opposition. In particular, genetically-modified crops proponents have struggled with widespread opposition. New attempts to control the future through new technologies will inevitably create new problems of risk (as earlier noted by Giddens); the question is how to effectively manage these risks.

If concerns continue to grow, nano-futures could quickly become more uncertain and rhetoric far less deterministic. Consequently, government policy could become less supportive, investment dry up, additional precautionary risk assessments required, restrictive regulations then introduced, and so on and so forth. Public acceptability of products incorporating nanotechnologies could decline.[15] Similar co-evolutionary interactions between science and society have recently been evident in biotechnology (particularly GM foods), another area of emerging science fuelled by implicit utopian imaginaries (Kearnes, Grove-White, Macnaghten, Willsdon, & Wynne, 2006). Indeed, nanotechnology's novelty, complexity and publicity makes it fundamentally uncertain and "post-normal science" (Barben, Fisher, Selin, & Guston, 2007; Funtowicz & Ravetz, 1993). Barben et al. elaborate:

> *Not only is it unclear which scientific and technological potentials out of the many that theoretically exist might come to pass, but the shape and desirability of eventual sociotechnical outcomes may in part depend on the work of the new interactions and approaches [of the stakeholders, organisations and publics involved]. Indeed, nanotechnology can also be thought of as a metaphor for even more inchoate potential futures of other new technologies, the history of technological emergence, and the role of technoscience in destabilizing social systems – for better and for ill (pp.979-80).*

In this context new *anticipatory* strategies and practices are being developed alongside these rapidly emerging technologies. Since around 2000 new forms of public and stakeholder engagement and governance have been embraced. These include

"upstream engagement" (Wilsdon & Willis, 2004), via public participation processes very early in the innovation process in which they deliberate with scientists various potential technological developments (often considering different future scenarios crafted or vetted by nanoscientists)[16], a more proactive approach to societal issues through more detailed mapping of ethical, legal and social implications (commonly referred to as "ELSI" research), and new conceptualisations of "anticipatory governance" models (Barben et al., 2007). Barben et al. argue that 'the futuristic discourse of nanotechnologies, as well as their fundamental technical and social uncertainties, requires the cultivation of a societal capacity for foresight' through a combination of formal methodologies and 'more generalised abilities to bridge the cognitive gap between present and future' (echoing Slaughter, 1999). It has also been argued that, with respect to nanotechnology, the debate needs to move from discussing the pace nanotechnology should advance, and how this can be enabled, to a more open discussion of whether it *should* be developed and to what social purposes it could be directed (see Wilsdon, & Willis, 2004; Wintle, Burgman, & Fidler, 2007). Nanotechnology has since 2003 has increasingly been the focus of these experiments (Barben et al., 2007; Bowman, & Hodge, 2007; Gavelin, Wilson, & Doubleday, 2007; Stilgoe, 2007), intensifying the relationship between science, technology and society. Indeed, anticipatory governance is the framing concept of the largest social science nanotechnology initiative in the US (Fuller, 2008).

The hope of policy-makers is that likely societal concerns can be predicted (e.g. anticipating the reception to nano-based products) and mitigated, through such future-oriented activities, in order to smooth the commercialisation process. Other actors seek a more genuine "opening up" of science (Funtowicz, & Ravetz, 1993; Ravetz, 2000 & 2004; Stirling, 2007 & 2008). British sociologist Steve Fuller (2009) argues that some of the new engagement strategies are actually aimed at "priming" the future – that is they, in effect, serve to *acclimatise* publics to 'whatever nano-driven changes might be on the horizon'. Publics start to become 'accustomed to thinking in terms of nano-futures'. However, Fuller also contends that it could ultimately have a double impact on emerging nano-futures:

> *The anticipatory acceptance of nanotechnology may lead, on the one hand, to an anti-science backlash if sufficient benefits are not forthcoming or, on the other, to a willingness to interpret all manner of marginal nano-driven improvements as indicative of greater things to come. (2009, p.25)*

We don't know how this will play out. What is clear is that the terrain of "nano-futures" is increasingly contested and new practices used to create, know and govern possible, potential and preferred futures are becoming central to the shaping of technoscience. The direction of innovation, and its social and environmental outcomes, is being debated along with the means available to "steer" it. One means is perhaps the images of the future, the imaginaries, which implicitly inform technoscience. What these new practices and articulated promises perhaps best do is make these more transparent and debated.

Certainly, a growing "meme" in Science and Technology Studies is *reflexiveness*, which is defined as 'a process by which the broadened community of participants concerned about the direction and impacts of scientific advance and technological innova-

tion gain a fuller understanding of the social context in which they operate' (Sarawitz & Woodhouse, 2003). This quality would be nurtured by greater futures-responsiveness (Slaughter, 1996).

Conclusions and Observations: Nano and Futures

This paper began with an outline of how two radically opposing long-term visions of a 'nano-enabled' future, "nano-optimism" and "nano-pessimism" (Arnall & Parr, 2005), appear set for heightened profile and conflict. In explicating and describing this, the paper also outlined the promises, narratives and temporalities mobilised in the recent intensification of expectations about nanotechnology and the political economy of "nano-futures". The discussion around nanotechnology was shown to epitomise contemporary processes 'making the future present' (Munshi, Bartlett, Kurian, & Lakhtakia, 2007) through nano-hype and hopes, new engagement and governance practices, and other emerging anticipatory strategies.

Although this paper focused on the exploring and understanding *nano-optimism* it also noted the increasing tension between nano dreams and nightmares as nanotechnologies become more controversial. Here in Australia, critical observers from Griffith University contend that 'it appears that the government has been swept off its feet by the promises of these new technologies' (Lyons, 2009) amid increasing civil society activism. Given the increasing future-orientation, what roles should the futures field play in helping to navigate possible nano-futures and tackle "structural irresponsibility"? Some possibilities are suggested by this paper, such as: identifying and assisting new mechanisms for *responsible forethought* which appear to be emerging (i.e. the increasing use of anticipatory activities in the governing of emerging science), inform the debates by communicating credible scenarios of what might be or become nanotechnology potentials and under which circumstances (to go beyond nano-hype), and practitioners considering their own expectations and how they could influence these debates (greater reflexive practice). Additionally, futures researchers and practitioners can take note of four key findings:

- Expectations have been found to play important performative roles in technological change (see the Sociology of Expectations and prospective techno-science). This is new evidence of the influence of images of the future and how they condition the present (Polak, 1961; Slaughter & Bussey, 2006, p.66);
- In considering the future trajectory and impact of emerging technologies (nano, bio and other technologies) it is necessary to critically consider increasing hype and related actor strategies and theories – e.g. the articulation of "promises" and the 'promise-requirement' cycles that emerge (van Lente, 1993; van Lente, & Rip, 1998). Deterministic rhetoric in nanotechnology – articulated by both nano-advocates and nano-critics – is a stark contrast to its emergent status, fuzzy boundaries and unsettled make-up. It should also be noted that the label "emerging technologies" is 'effectively a hidden form of technological determinism' (Johnson & Wetmore, 2009, p.441);
- New understandings of how technology and society work in step, shaped and being shaped by one another are emerging in STS and sociology. These can

inform futures work such as technology foresight, future scenario creation, etc.; and

- A useful analytical distinction can be made between 'looking into' and 'looking at' the future (Brown et al., 2000) – between attempts to forecast futures and considering attempts made to define the future and create direction or other phenomena of future-orientation. The later grasps the *politics* of the future, analyses contestation.

Ultimately, what we should primarily see in the emergence of "nanotechnology" is an important and fascinating attempt to define the future. As such, engagement with it must focus on this and (re)imagining of 'what is at stake – politically, culturally and socially – in the incredibleness of nanotechnology' (Kearnes, & Macnaughten, 2005) to enable greater reflexiveness.

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Notes

1. It is also worth noting that other many claims have been made on the being 'the next industrial revolution', including by biotechnology advocates, as well as more fundamental sustainability shifts from the current industrial age such as a move to a cyclic industrial system that mimics nature (Senge & Carstedt, 2001) and/or ecologically intelligent design principles and practices (see video titled 'The Next Industrial Revolution': http://thenextindustrialrevolution.org/).
2. See Adam's research project 'In Pursuit of the Future' for more information: http://www.cardiff.ac.uk/socsi/futures/.
3. http://query.nytimes.com/gst/fullpage.html?res=9C0CE3D9133AF936A35757C0A966958260&scp=2.
4. This version of nanotechnology – molecular manufacturing – is championed by the Foresight Nanotech Institute, which was founded by Drexler in 1986.
5. See: http://www.nano.gov/html/facts/whatIsNano.html.
6. The report states that funding for nanotechnology in 2006 totalled $11.8 billion, up approximately 13% from 2005 and that Europe outspent the United States. Venture capital spending on nanotechnology reached $699 million in 2006, up 10% from 2005. See: http://www.luxresearchinc.com/tnr.php.
7. It should be noted that this study differentiated between nanoscience and nanotechnology. Nanoscience was defined as 'the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale', and nanotechnology as 'the design, characterisation, production and application of structures, devices, and systems by controlling shape and size at the nanometre'.

8. Walsh elaborates: 'Most nanotechnologies will need to be incorporated into a larger system or product or may require end user behavioural changes in order to be implemented'.
9. See: http://powerofsmall.org.
10. See for example http://www.discovernano.northwestern.edu/whatis/History/#. The provides a history of nanotechnology timeline going back to 30BC.
11. Transhumanism is "an international, intellectual and cultural movement supporting the use of science and technology to enhance human mental and physical abilities and aptitudes, and overcome what it regards as undesirable and unnecessary aspects of the human condition, such as disability, suffering, disease, aging and death" (http://en.wikipedia.org/wiki/Transhumanism). Indeed, the website of the World Transhumanist Association website asserts that "both present technologies, such as genetic engineering, information technology, and pharmaceuticals, as well as anticipated future capabilities, such as nanotechnology, machine intelligence, uploading, and space colonization, are all part of the transhumanist ambit" http://transhumanism.org/index.php/WTA/about/.
12. Genetically modified (GM) food advocates trace the history of genetic engineering back to prehistoric times and, in essence, position the new science of genetic engineering as simply a new set of techniques for doing what we have always done, only better. One timeline, for example, jumps from prehistoric times to the end of the 19th century where 'foods are manipulated through the use of yeast and fermentation' and 'some naturalists and farmers begin to recognize "hybrids", plants produced through natural breeding between related varieties of plants', to 1900 where 'European plant scientists begin using Gregor Mendel's genetic theory to manipulate and improve plant species' (a variety is crossed with a related plant to produce desired characteristics), and then jump to 1953 when the three-dimensional double helix structure of DNA is discovered. See for example: American Public Media, 'History of genetic engineering', part of *The Global Politics of Food* section, accessed at: http://americanradioworks.publicradio.org/features/gmos_ india/history.html. Another history notes that 'animal and plant breeders have found ways to alter and change genes to their advantage for thousands of years' before outlining modern genetics. See: ThinkQuest, 'Human's playground: genetic engineering', Oracle Education Foundation, accessed at: http://library.thinkquest.org/04apr/00774/en/txt/history.html.
13. They explain this foreseen scientific convergence in the following way: 'convergence happens when Nanotech merges with Biotechnology (enabling the control of life through the manipulation of Genes) and with Information Technology (enabling the control of knowledge through the manipulation of Bits) and with Cognitive Neuroscience (enabling the control of the mind through the manipulation of Neurons). Controlling Bits, Atoms, Neurons and Genes adds up to a little 'BANG' theory enabling a *godlike mastery* over all knowledge, matter, mind and life. [Emphasis added]
14. For example, also see the publications of the Friends of the Earth Nanotechnology Project: http://nano.foe.org.au/, viewed on 28/10/2009 (in particular see Miller et al., 2006; Miller & Senjen, 2008; Miller, 2008a, 2008b, 2009).
15. A possible weak signal of this is the recent controversy over nanoparticles in sunscreens in Australia.

16. For example see the NanoFutures project, which presents six possible scenarios, run by the Centre for Nanotechnology and Society at Arizona State University: http://cns.asu.edu/nanofutures/.

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Appendix 1

Summary of key nanotechnology narratives

Overall conceptualisation	Framing	Narrative	Core view of nano / nano-futures	Example nano-technologies (past / current / proposed)
Incremental advance	*Nano as 'new understandings, and utilisation, of the properties of matter at the nanoscale'*	We're going from being "accidental" to "conscious" nanotechnologists, thanks to new scientific equipment and understandings. Overall, 'nanotechnology' is "nothing new" and, thus, should not be considered risky. Key figures from physics and chemistry, who have provided insights into the nanoscale for centuries, become celebrated pioneers.	• ***Reframing* of present and past** science/research • A positive continuation of "rebranded" traditional scientific research (e.g. in chemistry, physics, etc)	• The product of further advancements familiar areas such as materials science, colloid science, etc, such as materials that have superior properties as a result of enhanced nanoscale structures • Further bulk production of nanoparticles (e.g. zinc oxide nanoparticles used in sunscreens), use in consumer products
	Nano as 'an extension of the miniaturisation imperative'	'Nanotechnology' is rooted in the general direction of technological innovation (e.g. microelectronics) and is, thus, a natural extension of these developments A "strategic race" is now on to secure a place in the nano-enabled future – 'nanotechnology' is (essentially) inevitable and necessary for national economic competitiveness etc.	• ***Linear trajectory*** ('from micro to nano'): evolves from recent past and present • **Inevitable development** guided by imperatives in the 'here and now'	• Scaling down of existing technologies to the nanoscale (e.g. in computer chips) • Additional advances in information technologies (e.g. nano-electronics, distributed computation) and medical technologies (e.g. molecular drug delivery, new diagnostic devices, etc)
	Nano as 'an emerging "clean and green" linchpin for solving societal problems'	Nanoscience and nanotechnologies provide an expanded "toolkit" to help create solutions to current and emerging critical problems. 'Nanotechnology' (as well as other emerging technologies) enables future sustainable applications and solutions and leads the way to a more sustainable global future.	• ***Vision* of nanoscience and technological capabilities harnessed to solve social / environmental problems** • Growth of 'strategic science' and technical capacity	• New 'green nanotechnologies' in energy generation and storage (e.g. advanced photovoltaic such as polymer based, 'integrated solar' application such as addition of dye-sensitised solar cell to bricks, etc), water, environmental remediation, and other preventative technologies (e.g. use of nano-sensors)
	Nano as being focussed on enabling us to 'control our material universe' and achieve 'human mastery'	*Critic narrative*: 'Nanotechnology' is the latest aspiration for "godlike mastery" and will soon introduce the most powerful set of tools to date. Emerging technologies primarily serve private interests and introduce novel kinds of hazards and new orders of risk.	• ***Uncertain*, indeterminate** – nano is 'out of control' • Connected to other emerging technologies (i.e. a broader technological trajectory)	• N/A • Note: critics tend to focus on potential military applications and surveillance technologies and to anticipate a broader concerning/emerging paradigm (rather than a 'technology')
Represents a radical discontinuity from existing science and technology		*Advocate narrative*: 'Nanotechnology' will provide an enabling platform for mastery and a new wave of technological innovation; potential for novel capabilities and qualities emerging from 'technologies converging at the nanoscale' (i.e. nano, biotechnology, information technology, cognitive science)	• ***Disruptive and non-linear*** • **Discontinuous**: potential for dramatic breaks e.g. change amounting to 'the next industrial revolution'	• Long-term visions of a nano-enabled future hydrogen economy • Various proposals for "molecular manufacturing" – such as Drexlerian, bionanotechnologies, etc – for bottom-up fabrication of materials