Nanotechnology: saviour or curse in today's environment?

G.C. Holt

Collegium Basilea (Institute of Advanced Study), Basel, Switzerland

Background

Nanotechnology, however one might define it, is perceived by many as synonymous with the dawn of a new age of technology similar to that of the Industrial Revolution of the 17th century in terms of its effect upon society. Certainly it is an area receiving much interest and funding in the developed world. Ever since Feynman threw down the gauntlet to scientists following his advances in quantum electrodynamics, with the statement that there was plenty of room at the bottom, giant strides have been made in both the understanding and manufacturing of objects of micrometre and nanometre scale. Most obvious of these, perhaps, is in the electronics advances of the last four decades, which have given rise to personal computing and mobile telephones to the extent that the rate of progress is now encapsulated in Moore's law, which states that computing processing power and memory will double every 18 months. This is not really a law subject to rigorous scientific proof, but on average has proved to be true and shows no conspicuous signs of failure. Strictly speaking, the advances in electronics are only just entering the nanoscale; the latest generation of semiconductor silicon is 60 nm thick with 30 nm forecast within five years.

There is a problem defining the boundaries of nanotechnology. Some argue[1] that only objects less than 100 nm and composed of components of less than 100 nm in some dimension constitute the group of nanotechnologies or nanoscience. This implies that recent advances in medicine concerning living cell structure and function could be construed as not nanotechnology, since a typical (eukatyotic) cell size is many micrometres. Whatever one defines as being within nanotechnology though, it is obvious that in medicine significant advances have also been made, not least of which has been the mapping of human genes and the elucidation of the structure of most viruses. At the virus and gene scale, I think there is little doubt that research and development falls under the nanotechnology banner. Perhaps another issue is where Feynman started. Quantum physics and elementary particles live in the subnano world. Should technologies associated with this physics and their microscopes, the particle accelerators, be considered under the nanotechnology umbrella? Here is another grey area that

[1] R.W. Whatmore, "Nanotechnology—should we be worried?", *Nanotechnology Perceptions* **1** (2005).

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could set the bottom limit to a nanotechnology definition, but one must be wary of being too precise as quantum effects such as tunnelling appear at the scale of a few nanometres.

For the purpose of this discussion the exact boundaries of nanotechnology are not required, suffice it to say that all technologies seeking to investigate, measure or fabricate objects less than the few hundred nanometres will be considered. With the etymology established, I can now include all future developments in electronics such as quantum computing, top-down fabrication such as photolithography, bottom-up fabrication using proteins or viruses, genetic mapping and manipulation, neuroscience, and future energy sources that rely upon an understanding of molecular or sub-molecular physics and chemistry.

Many authors, Drexler,[2] Crichton,[3] and others have addressed the issues that might arise as a consequence of mankind's interest in nanotechnology. There are perceived to be both great benefits and potential pitfalls, which could seriously damage our society. Benefits are already manifest, new composite materials for dentistry, prosthetics and construction, high factor sun creams, self cleaning paint, microsensors for water and chemicals, electronics and medical diagnosis. Some of the pitfalls, such as genetic manipulation, information overload as a result of vast computing power, and safety concerns with respect to potentially toxic or carcinogenic nanoparticles able to enter human beings through inhalation or skin contact, are being actively debated.

More futuristically, both Drexler and Crichton have predicted aggressive nanomachines embodying all the fears concerning genetic engineering, with significant computing power and endowed with novel energy sources, which will result in the near destruction of the human race. I am more optimistic about our future survival given our history and evolvability, which has enabled us to survive a major ice age, world wars and countless more local natural disasters. It is perhaps the rate of progress that is more frightening and could lead to a future scenario where genocide was possible. Kurzweil[4] is an optimist and sees Moore's law being applicable to the whole of nanotechnology. Using a doubling of capability every two years, he extrapolates to a so-called singularity about the year 2050, when finite sized computers will be orders of magnitude more powerful than the human brain, neuroscience and computer programming will be capable of simulating the human brain, and design by bottom-up assembly of new materials and products will have solved much of the current energy crisis. With this level of capability at our fingertips, it is conceivable that we could run out of control and that the intelligent machines of science fiction could take over.

Discussion of a doomsday scenario is not the purpose here, human beings will no doubt continue to evolve and develop societal changes that cope and regulate even in such a complex and high-powered world.

I am more concerned with the immediate next few decades during which the most pressing problem facing the human race is our ever demanding and increasing requirement for energy, and its effect on the environment. There is no doubt that since the Industrial Revolution the output of carbon dioxide from fossil fuel burning released into the atmosphere has increased at an alarming rate.[5]

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[2] K.E. Drexler, "*Engines of Creation: the Coming Era of Nanotechnology*", Anchor Books (1986).
[3] M. Crichton, "*Prey*", Harper Collins (2002).
[4] R. Kurzweil, "*The Singularity is Near*", Viking 2005 (for details see *Nanotechnology Perceptions* **1** (2005) 173–175).
[5] http://www.eia.doe.gov/iea/carbon.html.

The equivalent of nearly 7 gigatons of carbon from carbon dioxide was pumped into the world's atmosphere in 2002 from fossil fuel burning, and this figure is rising at 2% a year. It is likely that the carbon dioxide in the atmosphere, through the greenhouse effect, is contributing significantly to global warming. The sea level is rising at a rate of 20 cm per hundred years, although here it should be said that the connexion to global warming appears to be more tenuous.

However one regards the long-term effects of global warming and sea level rise, it is irrefutable that mankind is now having a major effect on the ecosystem, at the very least because of the amount of carbon that is now being released annually into the atmosphere, which is on the scale of that released in major natural volcanic eruptions (Mt St Helens released 25 gigatons of particulates[6]). The long-term stability of the planet is under threat and carbon emissions must be checked. In some sense the ecosystem is self-regulating because eventually the liquid and solid fossil fuels, which contribute to 77% of the carbon dioxide emissions, will be exhausted given our current rate of energy consumption. Unfortunately this will probably not occur until we have irreversibly damaged the ecosystem. If we are to sustain the lifestyle and economic growth to which we have become accustomed, the future quest (and for science, the challenge) must therefore be for new energy sources with carbon dioxide as a minimal by-product. The question is, will the projected benefits of nanotechnology solve this problem?

The future

There are really two essential (and related) problems connected with energy and the environment: taken in isolation, one is to reduce carbon dioxide output, and the other is to find a cleaner greener energy source.

Nanotechnology is not required to solve the first problem in isolation. Petroleum makes up 50% of all fossil fuel usage,[7] with transport and travel consuming 50% of that, hence the simple answer is to convert to electric cars and lorries, and ban cheap air travel. This probably means much greater dependence on nuclear fission to produce the electricity, at least for the near term. That is easier said than done, but could the following description of a couple going on holiday in the future be a reality?

They had finally found the time and booked a holiday. The early morning taxi to the boat terminal at Southampton had in the end been an uneventful, if somewhat expensive journey. The train would have been much cheaper. The liner was huge, reminiscent of the two Cunard line Queens, Elizabeth and Mary. But the elegant lines and funnels had been replaced with stealth technology developed for speed and wave penetration. The ship was more like a huge wedge with a thousand portholes twinkling in the morning gloom. After a pleasant dinner and a night's rest it was time to unwind and contemplate their future holiday. A routine common to cruise ships would soon develop with eating, sleeping and drinking featuring significantly in the quotidium. The open Atlantic flashed by at 40 knots, but relative to the distant horizon it seemed that they were stationary. The sea was typical of the winter Atlantic with waves that were

[6] S.W. Kieffer, "Fluid dynamics of the May 18 blast at Mount St Helens." In: *The 1980 Eruptions of Mount St Helens, Washington (*Ed Peter W. Lipman and Donal R. Mullineaux*),* pp. 379–400. Washington, D.C.: U.S. Government Printing Office (1981).[1AQ] http://www.creationism.org/sthelens/USGS1250/USGS1250l379-400.htm.

[7] http://www.eia.doe.gov/iea/carbon.html.

obviously quite big judging by the white tops, but at this height above them they appeared like white lines drawn on flat water. Spray occasionally rushed past the viewing windows, and only at the rear of the ship, protected from the sea-laden wind, was it possible to inhale some fresh air. No constitutional deck promenades on this ship.

They had decided on Australia and some sailing in the Whitsunday Islands together with some scuba diving. Now it seemed that the best way to relax sitting down after breakfast was with his laptop. Deciding that it might as well be more than just the sun, sea, sleep and visits to the in-laws, he was looking for more active pursuits with the aid of the internet. His wife had joined a cosmetic demonstration class, so there was time for some positive action to give the holiday some structure. He thought it somewhat ironic that here he was on another ship booking a sailing boat to spend even more time at sea. The sailing boat booking was simple enough, a 36 foot sloop with ample room for four. However, the diving looked as though it was becoming difficult; the equipment was straightforward but the insurance had moved along somewhat since the last time he went diving. The personal accident cover was astronomical. Delving further he discovered there appeared to be two options; a huge premium with non-liability clauses removing almost all responsibility from the boat supplier, or the reduced lifetime premium, quite reasonable, but entailing a one-off medical examination and a complete brain scan. It had been some time since he had thought about the frontiers of science and it was obvious from the insurance form that it had not taken long for the entrepreneurs to realise that money could be made from the confluence of nanotechnology, safety and society's tendency to litigation.

The brain scan, although expensive, seemed painless enough. A full NMR scan was required after waiting an hour for a drink containing thousands of nano-mappers to pass from the stomach to the bloodstream and into the brain so that the synapse and neuron sites could be located. The nano-mappers apparently were about the size of a minute grain of sand and would taste of grit, a bit like a badly mixed porridge. Much was made in the description of how harmless these machines were. Having propelled themselves to the brain using the local positioning system, they used a chemical recognition sensor to mark the neuron site by generating a series of electron spin flips in a carbon fullerene memory that formed the processing centre of the mapper. The encoded positioning of the neuron was then to be detected by the magnetic resonance scanner and stored as a point on the brain map. Once a few million neuron and synapse positions had been captured, the mappers were instructed to exit via the intestines using their flagellae for propulsion. All very safe and environmentally acceptable according to the sales description, as the nano-mappers were made of natural enzyme fragments, carbon, silicon and a protein battery that would happily return to the environment without any ill effects being felt by the patients or the ecosystem. The duration of the scan was dependent on how much you paid—there is always a catch—the more neurons you wanted mapped and the higher the fidelity of the brain map, the more you paid. A full scan took five days, whereas the minimal scan was only one, but the difference in fidelity was staggering, ranging from nearly a few million neurons to nearly a hundred thousand million. The later, he dimly recalled, must correspond the entire brain.

By now he was becoming interested in the technology. The sales description was well-written and engrossing, catering for those with a real science interest as well as those with more money than sense, who just wanted cheap insurance for life. Each neuron was modelled as a *low-power slow 1980s technology processor with limited memory. The synapse map provided the interconnexion diagram so that the brain simulation could be constructed. Depending on fidelity and of course cost, this could take anything from a week to a month after the scan. In the latter case, a degree of interaction with the patient was required to ensure that memories had been captured correctly. In the case of the minimal scan, this was unnecessary as only motor functions and speech were modelled.*

By now the real sales promotion had begun. The somewhat morbid and rather jaunty tone of the English belied the rather sinister undercurrent that was the whole point of the sale. In the event that one suffered a brain embolism as a result of decompression, then almost full recovery was nearly guaranteed provided one had paid enough and that the brain was re-oxygenated in a fairly short space of time. Tables followed showing the likely scenarios for decompression sickness, the recovery time of the rescue teams and the potential brain damage. Obviously a completely dead brain was not recoverable but for an extra investment one could live on in perpetuity as a simulation in one of a number of companies' supercomputers. Your simulation, it was promised, would be run at least once a year to both stimulate and provide historical updates to your virtual brain. And, moreover, if relatives came to visit your interface with the real world (a facial hologram with speech synthesis), you would be run at each visit and thus you would enjoy even further stimulation at no extra charge.

The less fortunate financially, and those involved in the more probable accident with only minor brain damage affecting motor or speech functions, were promised that the simulation would enable those functions to be restored after suitable regeneration of the damaged brain using stem cells taken from the bone marrow during the initial scan, and retrieved from deep frozen storage. The rest of the description was a little hazy as to how much of the brain could be regenerated in this way if more damage was sustained, and therefore the true benefits of a full scan and simulation in terms of rebuilding one's brain was left in some doubt.

He needed time to take this in. He could see that having a simulation of oneself with the requisite stem cells to rebuild tissue destruction would mean that in theory one could not obtain legal damages against a supplier who might be deemed responsible for any brain damage, and that the possibility of an exorbitant settlement, which historically was not unusual in order to provide care and support for the afflicted person for the duration of his or her life expectation, was also unlikely. The benefits to all suppliers and designers with legal responsibility was obvious. It was not only dangerous sports but transport systems, household appliances, almost anything, any machine, which could go wrong and harm human beings. This was just the beginning. Could the end be in sight of instant litigation by fat opulent lawyers who preyed upon people's misfortunes? This clone of oneself, this personality simulation, how good would it be? Would it be sentient? and if so, when it was switched off, would it be murder?

Interesting thoughts, but he had a decision to make in order to go scuba diving. He wondered about surfing the net and shopping around to see if there was a more conventional and cheaper insurance policy, or was it like the environmental issue where the G10 governments had finally found a capitalist solution to the problem of carbon dioxide emissions? Had governments forced every company supplying personal accident insurance to charge outrageous premiums so that only the rich and business-funded would pay, while everyone else was forced by price to take the minimal brain scan option? His mind drifted as the liner *ploughed through the seas, the wedge shaped bow piercing the wave tops while stabilizers and shock-mounted decks reduced the buffeting to an acceptable three-dimensional swinging motion that was almost soporific. This very ship was a product of a global policy. Cheap air travel had disappeared over a decade ago. The G10 had formed a cartel of the major oil companies forcing the price of aviation fuel into the stratosphere. The collapse of the national airlines was justified by the use of the oil tax revenue to pay for a massive increase in public services. Only the super-rich flew now, while everyone else was forced to spend more time, advertised as quality time and a necessary contrast to the frenetic pace of working life, travelling by sea in nuclear-powered superliners.*

Realities

So what is likely in the next two or three decades? Well, there is nuclear fission, not a new technology, and probably not nanotechnology, but because it is not new and has been in operation for the last 40 years, it is now very safe, while the use of plutonium and reprocessing mean that stocks of uranium are unlikely to run out for many generations. So what is all the fuss about? Decommissioning is expensive but placing radioactive waste deep into the earth's mantle is little different from replacing the original uranium oxide whence it came. Certainly prodigious amounts of carbon dioxide-free electricity are produced. The success of the French nuclear fission programme and the UK loss of North Sea oil and gas will probably force the UK government to embark on a fission reactor-building programme, which will provide affordable electricity for the next few decades. Ship-borne nuclear power has been around for a similar time and there seems little justification for not pursuing it further. Given that the power available from a small reactor (40 MW electrical is not atypical) is sufficient for both high-speed sea travel (20 MW for a 40 kiloton ship at 40 knots) and potentially for other uses such as producing hydrogen from sea water, this would seem a worthy avenue to pursue. Using its 20 MW of spare power, our future liner could produce 170 tons of hydrogen on the 10 day journey from the UK to Australia.[8] A world fleet of 1000 such ships making 30 such voyages per year would generate 5 megatons of hydrogen, which converts to the energy equivalent of 13 megatons of aviation fuel.[9] This in turn corresponds to about 10% of the world usage of aviation fuel in 1999[10] (aviation fuel constitutes 8% of fossil fuel output). Such hydrogen, as the main component of rocket fuel and clean fuel cell feedstock, can then be utilized as the fuel for an expanding air and surface transport system. Whether the water vapour produced by burning hydrogen will also contribute to the greenhouse effect is a moot point. More significantly, it is likely that the experiences following the Hindenburg airship disaster of 1937 and the Apollo 13 mission, in which hydrogen fuel cells and oxygen were carried on board, will engender a huge safety debate. There is also a problem with a fleet of nuclear-powered ships, since to date these have only been owned by governments. Commercial ownership and—nowadays—the ever-present threat of terrorism may not be politically acceptable.

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8 http://www.hydrogen.asn.au/hydrogen-technical-calculations.htm.

9 W. Peschka, "The status of handling and storage techniques for liquid hydrogen in motor vehicles." *International Journal of Hydrogen Energy* **12** (1987) 753–764 .

10 http://www.iata.org/whatwedo/environment/climate_change.htm.

Notwithstanding the safety issues of close proximity to hydrogen fuel, which is so easily explosive in contact with the atmosphere, the numbers appear to make some sense. Already the US seems, on the face of it, committed to this path.[11]

Where does nanotechnology come in? you might be forgiven for asking. Other potential sources of energy have also been around for some time, for instance nuclear fusion and hydrocarbon-based fuel cells. Neither has really reached the point of safe and commercial application, although fuel cells based upon protein interactions show some promise. Nuclear fusion, which arguably is nanotechnology, although the apparatus so far employed has been on a rather larger scale, has been promised as the energy panacea for the last five decades with little prospect of its materializing in the next five.

Solving the energy problem will not be easy and at the present epoch it is difficult to see what the future might yield. One approach, more nanotechnology-driven, is that of bottom-up self-assembly to produce almost all our structures both large and small, which may require very significantly less energy than our current construction techniques. For instance, the world produced 1.9 million million tons of concrete in 2003,[12] so that if only one thousandth of these structures were bottom-up assembled from carbon recovered from fossil fuel, the carbon equivalent of all the carbon dioxide released into the atmosphere would be eliminated (this is without taking into account that concrete production itself is a major source of carbon dioxide (about 3% of fossil fuel output)).[13] Unfortunately, history tends to show that what is saved in one area is amply made up by an expansion in another. For instance, the ubiquitous use of computers has certainly rendered many repetitive jobs obsolete, but unemployment in many Western countries is at an all-time low because of the growth in jobs either directly related to the use of computers or because new jobs are now possible.

The transport problem is probably more tractable. A draconian transport policy based upon making fossil fuel-driven travel prohibitively expensive may not be possible because of the vested interests. Forcing most people to travel by sea in nuclear-powered liners might be quite attractive, but may not be practicable in the commercial world driven by time pressures. A recent NASA competition for a possible future propulsion system,[14] yielded, apart from stratospheric ramjets, which may be more environmentally friendly than conventional jets, a quantum-based hyperdrive concept quite capable of inclusion in the Star Trek television series. The drive employs a cyclotron so that the accelerated charged object acquires relativistic mass. In a six dimensional representation of general relativity and quantum electrodynamics it is possible for this mass to act as dark matter and repulse the force of gravity using a connexion through the extra 2 dimensions. Such an antigravity drive would both demonstrate that more than four dimensions are required to describe the universe and provide a more energetically acceptable means of climbing into the atmosphere. Unfortunately the energy required to generate the requisite magnetic field is still prodigious. Hence in many ways this is no better

[11] George Bush remarked in 2003, "Tonight I am proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-power automobiles." http://www.energy.gov/energysources/hydrogen.htm.
[12] ISO/TC74 2004.
[13] http://en.wikipedia.org/wiki/Fossil_fuel.
[14] Haiko Lietz, "Take a leap into hyperspace", New Scientist, 07 January 2006, p. 24.

than an antimatter drive, which has similar requirements for its production and subsequent containment with the added problem of the disastrous safety hazard should the containment fail.

What next?

It is difficult to see how nanotechnology can really save the planet. The probable benefits will be in medicine, and health, computing capability, design methods and more efficient use of existing energy sources. As for a new energy source, this is much more speculative so that perhaps the only hope is that after the "singularity"[4] that the human brain, together with its simulated brain, will uncover sufficient of the universe's mysteries to enable the commercial conversion of matter to energy. In the meantime, I am afraid that nanotechnology will not be the saviour, although the safety and moral issues will, I suspect, be resolved, so that neither will it be a curse. Our current environmental problems will only be solved by political will. The US government's view that somehow technology, whether nano or not, will resolve the carbon dioxide emission problem is both naïve and ill-founded in the light of the lessons of history, which show that capitalism will follow profit rather than logic.