Nanotechnology to Confront Our Real Risks:

From Conscience and Energy Security to Global Artificial Photosynthesis

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We may be missing the bigger picture when thinking about the risks of nanotechnology. Nanotechnology can be applied to overcome risks to energy security, particularly through artificial photosynthesis.

Nanotechnology Risk

When the public considers risk in relation to nanotechnology, their minds are likely to turn to some at-best partial understanding of toxicological risks associated with nanoparticles in products such as sunscreens. Radio, print, internet and TV media previously have provided them with examples of experts contending with government-supported (if not funded) regulators discussing the relative risks of nanoparticle forms of zinc oxide and titanium dioxide to make sunscreens more cosmetically appealing against the risk of various forms of skin cancer.

They might also be aware that those carbon nanotubes that make strong, lightweight building materials, tennis racquets, golf clubs, pavers or bike frames also risk causing asbestosis-like lung cancer when inhaled (on the basis of animal models). They might be aware of the risks to the food chain of bacteria-destroying nanosilver inserted in clothes and washing machines to reduce odour and biofilm.

There are, however, much more important risks (see box, p.40) that humanity and its environment are now facing that nanotechnology seems destined to address, if only our scientists and policy-makers would take the risk of seeing it in that context.

Energy Security and the Risks of Old Photosynthesis Fuels

Energy as a precondition to all commodities is central to our concept of geopolitical risk. In fact, energy security can be regarded as a global public good – like air, water, and freedom from torture and political corruption.

Risk here is often discussed in terms of resource estimates and reserves (such as oil supplies), reserve-to-production ratios, the share of zero-carbon fuels involved in energy production, dependence on imports, and political risk rating. Other ways of conceptualising energy security risks involve assessing the production per capita of old photosynthesis fuels (coal, crude oil and natural gas), nuclear fission, hydroelectricity, photovoltaics, wind and other renewable sources, plus imports less exports, corrected for net changes in energy stocks and remaining years of production. The degree of national and community self-sufficiency and diversification are also relevant to assessing energy security risk.

Australia's carbon emissions place us in the top 20 polluting countries. Our annual carbon pollution resembles that of countries such as Spain, France, Italy, South Korea and the United Kingdom. This reflects our availability of cheap and abundant coal, because electricity generation is our largest source of carbon pollution.

Energy supply risk also takes into account affordability risks such as stability of electricity prices over five years, the percentage of urban and rural populations with high quality connections to the grid, and actual prices paid by final consumers for ordinary gasoline inclusive of taxes and subsidies.

Another relevant area of risk is technology development and efficiency taking into account research intensity (current R&D expenditure), grid efficiency and the resilience of reserves and stockpiles.

The risk to environmental sustainability must take into account forest cover, water availability and annual emissions of carbon dioxide, sulfur dioxide, mercury pollution from coal-fired electricity consumption divided by total national population.

Related risks to good governance and regulation can be assessed through indices such as the mean score for energy corporations in terms of accountability, transparency, lack of corruption and contribution to public goods.

Australia was long regarded as having an enviable energy security position with little governmental recognition of the necessity to move away from fossil fuel dependency to achieve both energy security and mitigate climate change. Australia's role in the Asia Pacific Pact on Clean Development and Climate (AP6) has largely involved investigating clean coal technology, carbon dioxide sequestration and LNG/natural gas opportunities across the Asia-Pacific.

The Energy Charter Treaty signed in Lisbon in December 1994 protects foreign investments (national treatment or most-favoured nation treatment) and ensures non-discriminatory conditions for trade in energy materials,

NANOTECHNOLOGY RISK IN DIFFERENT DISCIPLINES

How to handle risk from new technologies would make a good screening issue for potential university academics. Candidates might be asked to imagine that they've written the exam essay question "What is risk?" or more specifically "What is risk in relation to nanotechnology?" The appointment committee would then probe what the candidate would expect from their undergraduate and postgraduate students. One appropriate initial answer, of course, might be: "That depends on the course I'm teaching".

A course related to public health or medical epidemiology may require a discussion of the precautionary principle (the capacity of regulators to prevent a product being marketed, even though the scientific evidence raises serious, but not conclusive, adverse environmental or public health concerns). Discussion could take place about how the principle arose in European environment protection legislation. It could then describe how the US Food and Drug Administration used this principle to keep the drug thalidomide out of that country and so prevented in that population the birth defects that arose when mothers in other nations used it. The answer could then evaluate in what circumstances genetically modified food and nanotechnology (particularly nanotechnology used in medicines, sunscreens, foods and building materials) should similarly be kept away from the public, despite the other advantages that might arise. The risks of mesothelioma from inhaling nanoparticles that (like those of certain forms of asbestos) are relatively long and biopersistent could be discussed, particularly in relation to workers who use electric saws to cut nanoparticle-impregnated pavers or other building materials.

Maybe the student is studying philosophy and the question seeks an argument about how conscience, virtue or faith (or perhaps all three) advance along with our use of new technologies. Our use of technology in life, some students might suggest, seems organised by political, corporate, religious and cultural structures (or perhaps even more intricate patterns of symmetry) to present us with risky choices that gradually determine our values and character.

Perhaps the relevant course is psychology or business management, and the exam question invites the student to explore the motivations for humans to invest in and manage a profitable supranational nanotechnology company despite being aware of the potential public health and environmental risks associated with its products and the way in which it products and energy-related equipment based on World Trade Organization rules. It ensures reliable cross-border energy transit flows through pipelines, grids and other means of transportation. It allows resolution of disputes between investors and host countries.

Into this mix now comes the 2011 Australian Clean Energy legislation. This involves 18 separate pieces of legislation designed to implement a carbon pricing mechanism, but creating a set of risks for carbon polluters who wish to continue with business as usual. Eligible emissions units are issued with assistance provided for emissions-intensive, trade-exposed activities and coal-fired electricity generators.

From 1 July 2012 the carbon price set by this legislation will be $23 per tonne, rising at 2.5% per annum in real terms. After 1 July 2015 there will be a transition to a fully flexible market price under the emissions trading scheme. Transport fuels – liquid petroleum fuels, liquid petroleum gas, liquefied natural gas and compressed natural gas – are excluded from the scheme.

Between 2015 and 2018 the carbon price ceiling will be set at $20 above the expected international price, to rise by 5% each year. The carbon price floor will be $15, rising annually by 4%.

The legislation creates incentives for the creation of new renewable energy initiatives with low carbon pollution. A new $10 billion commercially oriented Clean Energy Finance Corporation, for instance, will invest in renewable energy, low pollution and energy efficiency technologies. A new Australian renewable energy agency will administer $3.2 billion in government support for research and development, demonstration and commercialisation of renewable energy.

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An energy security council will provide the government with advice on systemic risks to

seeks to manipulate the structures of the democratic process to enhance its control and profits (for example by influencing trade negotiations, lobbying, or political party campaign contributions).

The area of study might be international relations or climate change and the examiner could justifiably expect the student to discuss issues such as the relationship between nanotechnology and risks to geopolitical stability. A good answer might investigate the role of nanotechnology in relation to the risks to food, water and energy security as the human population rises towards 10 billion and its energy use increases from 450 exajoules (EJ) per year to well over 500 EJ/year. This answer could take into account the risk of catastrophic weather events associated with human-induced global warming, loss of biodiversity, threats of war and terrorist acts.

Perhaps the course is tort law and the student is required to discuss the idea of reasonably foreseeable risk as the basis of legal liability for non-contractual civil wrongs associated with the risky use of nanotechnology. This answer could explore whether existing therapeutic goods, chemical or veterinary and agricultural regulation is adequate in relation to nanoparticles. Should products containing nanoparticles require a separate set of safety data or can they rely on the less expensive and hard to acquire alternative of relying on data from the macroscale versions from which they were derived?

International trade law can cause risk to the development of new technologies (such as nanotechnologies) for the public good. One example is the World Trade Organisation's (WTO) General Agreement on Tariffs and Trade, which facilitates foreign corporate ownership, for example, of electricity, communications and health services sectors. Another is the WTO Trade Related Intellectual Property Rights agreement, which has increased intellectual monopoly privileges such as patents owned by such corporations for the primary benefit of shareholders. Bilateral trade agreements (such as the AUSFTA) likewise create risks for science-based analysis of the cost-effectiveness of new medicines under the Pharmaceutical Benefits Scheme. Investor–state dispute settlement provisions create the risk of foreign manufacturers of new technologies seeking substantial compensation when public health legislation diminishes their investments.

energy security from financial impairment of power stations including from the introduction of carbon pricing.

A climate change authority will advise on pollution caps, progress towards meeting targets, and undertake reviews of the mechanism.

A clean energy regulator will administer the carbon pricing mechanism.

The new legislation will create risks for companies that decided not to invest in continuous technological improvements that shift to the world to a renewable-based electricity supply, including a hydrogen-powered economy. Indeed, the ultimate risk to energy security may be answered by the creation of off-grid energy solutions.

Indeed, if we consider the present critical risks to humanity and our environment from first principles it seems that what is most needed is something that provides cheap, easily accessible energy, assists food and water security and removes carbon dioxide from the atmosphere. Sounds easy?

Surprisingly, there is just such an application of nanotechnology. It is called artificial photosynthesis, although it might just as readily be termed applied or advanced photosynthesis.

Risk of Embracing Global Artificial Photosynthesis

So why is enhancing photosynthesis so central to overcoming the risks we now face? First, photosynthesis has been and remains crucial to the existence of life on this planet. In the Zebra River region of Namibia, for example, one can find fields of stone-age hand tools alongside much more ancient stromatolites. Stromatolites were the fossil remnants of cyanobacteria that were among the first photosynthetic organisms. They began creating oxygen on Earth 2.5 billion years ago. Photosynthesis is not only the source of our oxygen, but also by absorbing carbon dioxide it provides the basic substrates for our food and basic fuels, including oil (from decayed cyanobacteria in shallow oceans), coal and natural gas (from decomposed old forests).

Photosynthesis can be viewed as the planet breathing, although in a reverse way to us, taking in carbon dioxide and releasing oxygen. But it can also be considered as the planet's nervous system – generating a basic voltage that powers the world's life. This is because photosynthesis takes light energy from the Sun and stores it in chemical bonds.

In its present nanotechnologically unenhanced form, photosynthesis globally traps 4000 EJ/year solar energy as biomass. This compares with a global human energy use of 500 EJ/year. The ratio of potentially usable solar energy to this amount is about 9000 to 1. An exajoule (EJ) is a measure of global energy supply and consumption (1 EJ = 1×10^{18} J).

In the 1800s, most people believed that only birds would ever fly, so they took risks to achieve that ideal, attaching large artificial wings and jumping off cliffs. Likewise, most people today still believe that only plants or certain bacteria can "do" photosynthesis, so they take risks genetically engineering them.

Yet why should our policy-makers not now embrace the idea that the best way of overcoming our energy security risk may involve redesigning our building and infrastructure to incorporate the global use of wholly nanotechnology-based artificial photosynthesis – providing a cheap source of hydrogen fuel, oxygen, carbon dioxide absorption and soil nutrients?

Numerous key components of the photosynthetic process can be improved by nanotechnology. Photosynthetic organisms absorb photons from various regions of the solar spectrum into chlorophyll molecules, and plants do the same (but using different biological cell structures).

A crucial component of this process is the use of the oxygen-evolving complex in a protein known as photosystem II to split water into hydrogen and oxygen. At the core of this process is a manganese–calcium cluster. This structure was recently characterised in a paper in *Nature* by Professor Kamiya and others at Osaka University to the level of 1.9 angstroms, showing that the cluster had a "distorted chair" shape. Some of its components remain controversial, but such fundamental characterisation of the natural photosynthetic structure makes the scientific and commercial risks of attempting a wholly nanotechnologically based water-splitting structure much more feasible.

The electrons produced by sunlight-driven water splitting thereafter are captured in chemical bonds by photosystem I to produce molecules such as NADPH (nature's form of hydrogen). This can be combined with carbon dioxide to make food in the form of three-carbon sugars, then sucrose and starch via the complex enzyme RuBisCO.

Large research teams in many nations, including the United States, Japan, the UK and Australia, are already accepting the risks of using nanotechnology to actively redesign photosynthetic components such as light capture antennae, artificial reaction centre proteins, organic polymers and inorganic catalysts. A major aim of their work is to achieve low-cost, localised, off-the-grid use of sunlight to split water and achieve hydrogen for fuel cells or compression and hyper-cooling to form a liquid fuel that when burnt produces fresh water. Nanotechnology is capable of providing more efficient, "fully flexible" and wholly artificial (non-life-based) photosynthetic systems that could be incorporated in engineered structures.

Governance Risks and Global Artificial Photosynthesis

However, the major artificial photosynthesis teams aren't working in close collaboration with each other, or with researchers in closely related areas like photovoltaics, quantum coherence methods to enhance electron transfer, and storage of hydrogen fuel.

A major risk is that without the creation of some global governance structure to assist these teams to collaborate more efficiently, the benefits of artificial photosynthesis may arrive too late to prevent major geopolitical disruption in the transition to a sustainable world powered by renewable energy and a steady-state economy. One idea is that the work will proceed faster if a large global project (like the Human Genome Project) could be established to foster collaboration among artificial researchers across the world.

The first international conference dedicated to creating a Global Artificial Photosynthesis (GAP) project was held in Australia at Lord Howe Island in August. As well as having endorsement from the UNESCO Natural Science Sector, it was an official event of the UNESCO 2011 International Year of Chemistry. Speakers included national and international experts in various aspects of artificial photosynthesis, such as photovoltaics, hydrogen fuel cells, quantum coherence in electron transfer, and international governance systems.

Presentations at the conference discussed refinements in their understanding of the construction of the photosynthetic oxygen evolving centre. They confirmed that a major focus of such research now was to develop water-splitting catalysts that stay active for extended periods of time or can be easily regenerated and made from readily available and inexpensive materials. Amongst the many inorganic catalysts that were being tested to allow sunlight to split water into hydrogen for fuel cells more robustly than biomimetic materials, the prime candidates appeared to be nickel, cobalt oxide, ferritin and manganese.

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Presenters set out how nanostructured materials such as semiconductor nanowires, or plasmonic resonances on nanoparticles, could allow an artificial photosynthesis device to absorb photons from a much wider region of the solar spectrum. Similarly, thin film dye-sensitive solar cells of semiconductor nanoparticles or carbon nanotubes could allow multiple stacking of solar cells to exploit the solar spectrum more profitably.

Governance experts spoke of techniques by which patents over artificial photosynthesis could be controlled so they stimulated rather than stifled innovation. They debated subsidy methods for artificial photosynthesis technologies, how they would assist energy security issues, the impact of parity between the cost of photovoltaic electricity and that purchased from the electricity grid, and how photovoltaics can produce continuous power by pumping water above 450 metres and then allowing it to fall and turn turbines.

There was much optimism to facilitate collaborations for how nanotechnology-based artificial photosynthesis systems may involve large coastal plants splitting seawater. They could use sunlight captured in desert areas to produce carbon-neutral hydrogen-based fuels. When burned, such hydrogen fuels would also provide fresh water for the city more efficiently than current desalination plants.

Global artificial photosynthesis could replace globalisation as a model of economic growth. Economies might restructure to emphasise smaller locally powered units, minimising the energy used in gathering raw materials and low-cost labour to make and transport goods for use in other countries. A world powered by artificial photosynthesis will be much closer to being ecologically sustainable.

Conclusion

Modern lines of scientific enquiry and technology have made some old philosophical, political and disciplinary classifications of risk redundant. People are increasingly willing to take risks to promote a vision of a better world not dominated by corporate greed.

Among the solutions is nanotechnology-based artificial photosynthesis. This could be an energy game-changer, if, for instance, it was able to engineer into every human structure the capacity of that structure to use sunlight to break water as a source for hydrogen fuel, or absorb carbon dioxide to make fertiliser for the surrounding soil. In other words, such buildings would become trees.

Such a society would not need an ideology to transform it towards the ideal societal virtues of environmental sustainability, justice and equity, because technology would necessarily promote such a transition by empowering local communities to control their own futures.

Immanuel Kant's *Critique of Pure Reason* introduced the idea that there can be understandings about reality that are true but do not correlate with common sense, a notion that influenced Einstein and promoted many modern physicists to take intellectual risks to achieve breakthroughs in understanding. Policy-makers must take risks to focus new technologies such as nanotechnology on the chief public health and environmental problems of our times. The more people exercise self-restraint and discipline themselves to what they are meant to do to overcome these risks for our collective good, the more humanity will be entitled to have an optimistic view about its future. Much of that optimism, it has been argued, should be linked to the possibilities of artificial photosynthesis.

NANOTECHNOLOGY HOLDS PROMISE FOR SAFER BREAST IMPLANTS

A review published in *WIRE's Nanomedicine and Nanobiotechnology* explores how nanotechnology may be used to develop safer breast implants as an alternative to silicone rubber, minimising health complications.

Around 75% of post-mastectomy patients elect some form of breast reconstruction. The only material option available to women undergoing breast reconstruction and augmentation is based on silicone rubber. While no medical device is 100% safe and effective, there is an extraordinarily high rate of complications reportedly attributed to silicone breast implants (20–30%; no other medical device has such a high failure rate), including increased incidence of systemic diseases, various forms of cancer and psychological disease.

Lead review author Judit E. Puskas of the University of Akron, Ohio, and researchers surveyed the literature on breast implants from the perspective of material science to determine how nanotechnology may enable the future development of safer breast implants.

By reducing the size of the components in nanostructured materials, unprecedented properties can be achieved. The authors are currently developing an alternative nanostructured material to silicone rubber that will minimise complications. The new material will also be able to deliver cancer drugs locally to improve the efficacy of treatment and minimise side-effects of chemotherapy.

"If successful, our material could be used for implants with drug delivery capabilities," Puskas notes. "We are hoping that this review will contribute to a better understanding of the controversial issues and motivate material scientists and medical doctors to work together to develop alternatives based on new nanotechnology for the women who opt for a device made of synthetic materials."

Source: Wiley-Blackwell