Beyond GE – Next Generation Technologies:

Promises, Panaceas, or Problems in the Making?

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✔ Nanotechnology Briefing Paper

✔ Synthetic Biology Briefing Paper

✔ Geoengineering Briefing Paper

*** The purpose of the following briefing papers is to introduce three unfamiliar and complex emerging technologies: nanotechnology, synthetic biology, and geoengineering.*

These papers are not intended to be scientific publications; rather they are informal summaries of various issues arising from each technology, including the health, environmental, ethical and larger societal concerns rarely included in mainstream media coverage.

Should you have any questions about particular assertions or the source of certain information, please feel free to ask a presenter at the briefing.

Nanotechnology Briefing Paper

Nanotechnology 101

Nanotechnology is a powerful new platform technology for taking apart and reconstructing nature at the atomic and molecular level. A "nanometer" (nm) equals one billionth of a meter – for reference, a DNA molecule is about 2.5 nm wide. Engineered or manufactured nanoparticles are more than merely tiny; they have the capacity to exhibit different fundamental physical, biological, and chemical properties than their larger-scale counterparts. Such properties can include a difference in color, greater strength, better conductivity and elasticity, and increased reactivity and toxicity. These different characteristics and their associated risks cannot be predicted from the behavior of the same material in bulk form; scientists are just beginning to understand the toxicity of nanomaterials.

It is these novel properties that have spurred R&D across a wide range of industry sectors, which are spending billions to modify existing materials at the nanoscale and to research new nanomaterials, devices, and systems. Some say nanotech's ability to radically change our manufacturing, agricultural, economic, and social structures will bring about the next Industrial Revolution.

Applications

The only publicly available inventory (http://www.nanotechproject.org/inventories/consumer) shows over 1,000 products containing nanomaterials currently on the US market, with at least three new products introduced every week. $147 billion worth of nano products was produced in 2007. By 2015, the market is expected to grow to $3.1 trillion worldwide.

Nano products currently available include personal care and anti-microbial products (the largest sectors), clothing, sporting goods, children's toys, pet products, dietary supplements, food packaging, kitchenware, bedding, consumer electronics and appliances, cleaning agents, fuel additives, automotive parts, and medical devices.

Because there are no labeling requirements, known nano products likely represent only a small fraction of the actual number commercially available.

The current commercialization of nanotech is limited to the so-called first or passive phase of nanomaterials. Future predictions include nano structures that perform specific functions or react to certain catalysts, as well as self-replicating nanobot assembly machines. Additionally, since biological processes, chemical reactions, and computer/ electronics manufacturing and processing all take place at the nanoscale, the possibilities for converging diverse technologies – including biotechnology/ synthetic biology, cognitive sciences, informatics, and robotics – have increased dramatically.

Investments

From 2000-2009, global government investment in nanotech was $40 billion. Major investors include the US, EU, Japan, and South Korea – with China, India, and Russia beginning to close the gap. However, risk research is woefully underfunded, comprising only 4-5% of the annual budgets in the US and EU. In 2008, global corporate R&D spending reached $6.6 billion, passing government spending for the first time.

Risks

The same features that make nanomaterials unique also create unique risks to human health and the environment. Due to their size, nanomaterials are more easily taken up by the human body, entering via inhalation, ingestion, and possibly the skin. They can cross biological membranes (like the blood-brain barrier), cell walls, tissues, and organs more readily than larger particles and are small enough to evade the body's defenses. Studies have shown that some nanoparticles can enter the nuclei of cells, and can cause DNA mutation, structural damage to mitochondria, and cell death.

Manufactured nanomaterials represent a new, unprecedented class of industrial pollution. Very little is known about nanomaterials in the environment, particularly over their lifetime; we lack adequate field measuring, monitoring, and control methodologies. Nanomaterials may be able to persist, bioaccumulate, reach places larger particles cannot, and act as a vehicle for other toxins (with a large and active surface for absorbing other contaminants). Their durability and how they will react with various substances is entirely unknown.

Health and Environment Concerns

- Carbon nanotubes – utilized for their lightweight strength in electronics and sporting goods – can exhibit asbestos-like behavior and cause the development of mesothelioma.
- Carbon fullerenes (also called buckyballs) – used in face and anti-aging creams – have had adverse impacts on aquatic species and been toxic to human liver cells at low levels of exposure.
- Nano titanium dioxide and nano zinc oxide – commonly used in cosmetics and to make sunscreens transparent – can produce free radicals, damage DNA, and cause cell toxicity, especially when exposed to UV light.
- Nanosilver – inserted in hundreds of consumer products for enhanced germ-killing properties – is shown by an increasing body of evidence to be harmful to human health and the environment.

Broader Societal Concerns

- Knowledge dearth: Polls show that 80% of the American public is completely unaware of or knows very little about nanotech.
- Global South impacts: New nanomaterials could potentially upend the economies of traditionally commodity-dependent developing countries – the world's poorest nations. For example, rubber tappers in Thailand and cotton farmers across Africa could see demand for their products plummet if new nanomaterials are developed to replace conventional commodities.
- Patenting the nano periodic table: With nanotech, the reach of exclusive monopoly extends to the fundamental building blocks of all of life. There is currently a gold rush on the patenting of nanomaterials and processes, with 5,408 existing US patent documents and 3,443 pending applications.

Oversight

No US law is specifically designed to regulate nanotech, and global oversight has languished far behind commercialization. Voluntary programs in both the US and EU have failed to incentivize industry to share what risk data they have. Any modest progress made has been a direct result of demands from civil society. In spring 2009, California and Canada both introduced mandatory risk reporting requirements for the manufacture of some nanomaterials. In the US, although a number of laws/agencies have some applicability to/jurisdiction over nanomaterials, no proactive efforts have been made to utilize them. The EPA and FDA are only considering mandatory regulation of nanomaterials because of legal actions by public interest organizations. The Occupational Health and Safety Administration is now looking into nanoparticle exposure standards for workers – there are currently none. Other inroads include reforming the Toxic Substances Control Act (the general chemical law) to address nanomaterials, and securing more environmental, health, and safety research funding from the National Nanotechnology Initiative (funding legislation that is currently in the process of reauthorization).

In the EU, the precautionary general chemical law, REACH, will cover nanomaterials, although it is still unclear how, as nano-specific adjustments have yet to be undertaken. However, in April 2009, the European Parliament adopted a resolution urging the European Commission to treat nanomaterials as new substances (unlike in the US) and to complete a review of all relevant legislation within two years. Cosmetic manufacturers in the EU will soon be required to label some nanomaterials, and the Commission is also finalizing a directive on the use of nanomaterials in food.

Additional Resources

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Synthetic Biology Briefing Paper

Synthetic Biology 101

"Synthetic biology" describes efforts to design, create, and commercialize new biological organisms. This differs from traditional genetic engineering: adding a few genes from another species to an existing organism to alter one aspect of its physiology or behavior. Synthetic biology does include a type of extreme genetic engineering: more profoundly redesigning the genetic pathways of bacteria and yeast in many phases in order to produce specific functions. It also consists of a top-down approach: using a DNA synthesizing machine (found on eBay for about four hundred dollars) to replicate an entire bacteria or yeast genome and trying to get it to "boot up" – to live and reproduce. Other synthetic biologists are actually *writing* genetic code – sometimes in new combinations that do not exist in the natural world – by using published gene luke said sequence information to patch together inexpensive DNA strands (the building blocks of life) ordered from an online DNA "foundry." Synthetic biology also encompasses bottom-up techniques to build new life forms from scratch, which are not even necessarily dependent on DNA. If successful, these experiments could produce radically different life forms.

Applications

Top-down synthetic biologists test out their synthesized genetic material in living cells, often with the goal of creating designer organisms that have various industrial functions. Two of the most touted uses of synthetic organisms are for combating diseases and creating third-generation biofuels. Febit, a German biotech company, is developing a human cancer biochip that can be used to screen for the presence of genes associated with common types of cancer in a sample of DNA. California-based Amyris Biotechnologies has received major funding from the Gates Foundation to develop a synthetic biology-engineered version of artemisin, an anti-malaria drug. As for fuels, Amyris and dozens of other companies are using synthetic biology to engineer microbes that will transform sugar (or any other cellulosic source) into a petroleum-like hydrocarbon fuel to replace currently used alcohol-based ethanol. Whether synthetic biology proves to be sound science and products function as promised remains unknown – saying nothing of the possibility that pursuing these seemingly benign applications might create unforeseen and catastrophic side effects.

Synthetic biology can also be put to other, perhaps more nefarious, uses. In 2002, US researchers reported that they had built the poliovirus from scratch, using gene sequence information available on the Internet and DNA strands from a mail-order company. The researchers then infected lab mice with the poliovirus; some mice were paralyzed, others died.

Investments

While the global market for synthetic biology products was estimated to be a paltry $234 million in 2008, major investments are coming fast and furious with the founding of the first synthetic biology trade association. ExxonMobil has announced that it will invest over $600 million in a new photosynthetic algae biofuels program in partnership with synthetic biologist J. Craig Venter. BP has already made an investment in Venter's company to sequence the genomes of naturally occurring, oil-metabolizing microbes that live in oil, natural gas, coal and shale, with the goal of designing new organisms that may be able to produce fuel. One of the highest-profile (and most controversial) synthetic biology investments is BP's $500 million grant to UC Berkeley establishing the Joint Energy Biosciences Institute, which is also subsidized by $50 million from the California state government. A portion of the research that results from the Institute will be withheld as BP's proprietary information.

Risks/Societal Concerns

The most obvious and widely acknowledged risk of synthetic biology is that it could produce bio-weapons. The security implications of organisms that can be created with made-to-order genes has the CIA worried enough that it helped fund the development of security features for Febit's products and sales. In addition to the intentional misuse of organisms created through synthetic biology, there is the risk of their accidental release. It is likely that synthetic organisms will not function predictably and may not be able to be contained or controlled, potentially polluting the environment and reproducing, spreading rapidly through ecosystems.

Proponents see synthetic biology as a clean solution to the daunting problems of climate change, energy, health, and water resources. However, such techno-fixes might exacerbate problems or create entirely new and unforeseen consequences. For example, in the process of making agrofuels, synthetic biology will create a thirst for plant-based sugars, leading to a plant and land grab and furthering the destruction of the world's biodiversity. (Ironically, some scientists argue that synthetic biology can contribute to the *preservation* of biodiversity – what people may make extinct in the environment, they can recreate in the laboratory). Far from halting climate chaos, agrofuels are already believed to have accelerated the crisis, made millions hungry, and displaced small farmers and indigenous peoples.

Very few in the public interest community are aware of how rapidly this technology is developing and how many bioengineering students and amateur scientists are learning its techniques. In particular, the annual International Genetically Engineered Machine (iGEM) competition encourages such interest by having undergraduate students compete to build synthetic biology systems and operate them in living cells. This year's contest will even allow teams not affiliated with academic institutions – the so-called "do-it-yourself bio-hackers" building designer organisms in their own kitchens and garages.

Oversight

There is currently no synthetic biology-specific legislation or regulation. In this gap, profit can trump environmental and social justice, further the privatization of science, and enable broad monopoly claims on engineered and synthetic organisms.

Similar to nanotech, the revision of the Toxic Substance Control Act in the US may afford public interest groups a chance to advocate for oversight and insist that the environmental and ethical challenges of synthetic biology are fully explored. In addition, the National Institutes of Health Recombinant DNA Advisory Committee has proposed revisions to research guidelines, which would make the assessment of some synthetic biology products' safety and efficacy matters of public record. Other than synthetic biology symposiums held by groups like the Organization for Economic Cooperation and Development, the UK's Royal Society, and the US National Academies, very little government attention has been paid to this rapidly developing technology.

Additional Resources

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Geoengineering Briefing Paper

Geoengineering 101

Geoengineering is the intentional, large-scale manipulation of the earth's environment. It includes many technologies attempting to, for example, manage solar radiation, sequester greenhouse gases in the soils or the ocean, or modify the weather. Long considered marginal by environmental and scientific communities searching for solutions to climate change, geo-engineering is rapidly moving into the mainstream, receiving serious consideration from senior officials in government, politicians, academic circles, and think tanks, as well as a heightened media profile and growing public awareness. The surge in interest is explained by the failure of governments to reduce fossil fuel consumption and effectively respond to global warming. For the most part, geo-engineering technologies are still at R&D stages, but there is a major push for public funding and real-world experimentation.

Applications

These examples are not exhaustive but cover the major technologies at play:

- Burying carbon in geological formations such as depleted petroleum reserves, coal beds, or deep in the seabed, essentially forming CO_2 lakes.
- Fertilizing the ocean with iron or nitrogen to stimulate the growth of phytoplankton with the goal of promoting carbon sequestration deep at sea.
- Genetically engineering algae to theoretically increase its CO_2 carrying capacity and then releasing it into the world's oceans.
- Modifying weather patterns by cloud seeding and suppressing or redirecting hurricanes.
- Pumping aerosol sulfates in the stratosphere to block sunlight and thereby lower the earth's thermostat.
- Installing space mirrors made of superfine aluminum mesh between the earth and the sun to reflect sunlight and moderate the earth's temperature.
- Spraying seawater into the air through unmanned ships to make clouds whiter, thereby reflecting more of the sun's rays.
- Engineering climate-ready crops to increase plant albedo (making leaves shinier and therefore more reflective) and drought, heat, or saline tolerance.

Investments

Investment in geo-engineering has thus far mostly been the purview of individual entrepreneurs and small start-up companies hoping to profit from the carbon market (the highest-profile commitment to date is philanthro-capitalist Sir Richard Branson's offer – known as the Virgin Earth Challenge – to pay $25 million to anyone who can develop a commercial technology capable of removing significant amounts of greenhouse gases from the atmosphere). Governments have not yet invested in geo-engineering directly; however, in the past year, scientific bodies that influence government policy such as the UK Royal Society and the US National Academies have signaled that they will recommend their respective governments allocate funds for geo-engineering research. Already in the UK, advisory councils have allocated £5 million for geo-engineering related activities to occur in late 2009.

Ocean Fertilization Case Study: The Planktos Story

Planktos Inc. was a US start-up company that intended to sow the oceans with iron in order to create plankton blooms that would theoretically sequester CO_2 (and allow Planktos to sell commercial carbon offsets). In March 2007, Planktos announced plans to set sail from Florida to dump tens of thousands of pounds of tiny iron particles over 10,000 square kilometers of international waters near the Galapagos Islands, a location chosen, among other reasons, because no government permit or oversight would be required. In efforts to stop Planktos, civil society groups filed a formal request with the US EPA to investigate Planktos' activities and regulate them under the US Ocean Dumping Act. In addition, public interest organizations asked the Securities Exchange Commission to investigate Planktos' misleading statements to potential investors regarding the legality and purported environmental benefits of their actions. Hit with negative publicity, Planktos announced in February 2008 it was indefinitely postponing its plans because of a "highly effective disinformation campaign waged by anti-offset crusaders."[1] In April 2008, Planktos announced bankruptcy, sold its vessel, and dismissed all employees; it "decided to abandon any future ocean fertilization efforts" due to "serious difficulty" raising capital as a result of "widespread opposition."[2]

In May 2008, at the UN Convention on Biological Diversity (CBD), 191 countries agreed to a ground-breaking *de facto* moratorium on commercial ocean fertilization. Nonetheless, in early 2009, the LOHAFEX expedition was given a green light by the German government in violation of the agreement, and began to dump six tons of iron sulphate over 300 square kilometers in the Scotia Sea, east of Argentina. It is one of the largest ocean fertilization experiments to date. Various other *in situ* experiments are also expected to proceed.

Risks/Broader Social Concerns

The principal risk, already palpable, is that geo-engineering may offer governments quick techno-fixes for mitigating the effects of climate change, rather than the more difficult decision to substantially reduce emissions. It is also quite feasible for carbon-offsetting firms to set up unregulated, unsupervised, and dangerous geo-engineering projects in order to sell carbon credits to unsuspecting individuals, corporations, and even governments. Perhaps more frighteningly, geo-engineering techniques could intentionally or inadvertently become weapons of mass destruction, creating droughts or famines in specific regions to destroy or disable an enemy.

Many members of the scientific and technical communities are concerned that the full effects and long-term consequences of various geo-engineering schemes are not well understood. Proposed systems may be ineffective, unpredictable, or unstable as a result of external events, potentially leading to profound and unforeseeable disruptions to the climate system and the environment. Sunlight blocking schemes have the potential to release additional greenhouse gases into the atmosphere, damage the ozone layer, diminish biodiversity, make solar power less effective, and allow ocean acidification to proceed unhindered. Ocean fertilization initiatives could increase production of nitrous oxide and methane, create possibly toxic plankton blooms, and have unforeseen impacts on ocean ecosystems. Some schemes may simply be unreliable due to mechanical failure. The Inter-Governmental Panel on Climate Change (IPCC), the leading international scientific authority, has not devoted much attention to geo-engineering, dismissing it as “largely speculative and unproven, and with the risk of unknown side-effects.”[3]

Oversight

An international discussion about these technologies and their impacts is urgent. The lack of global oversight and multilateral governance raises huge political and economic issues over who decides what techniques get deployed and under what conditions. Defining appropriate means of regulating these planet-altering schemes will be a central debate in global governance in the coming decade. It will be critical that civil society and Southern governments are equipped to participate in the debate.

The regulation of ocean fertilization has been discussed at the London Convention (which regulates marine dumping) and will be a key issue at the UN Framework Convention on Climate Change meetings in December 2009 in Copenhagen and at scientific meetings of the CBD in 2010. It is also likely that various countries will hold congressional or parliamentary hearings on geo-engineering in the near future.

The 1978 Environmental Modification Convention, which prohibits using weather intervention as a weapon, could have relevance for “peaceful” geo-engineering efforts to combat climate change because, in practice, any unilateral weather modification will likely threaten neighboring countries and put the entire international community at risk.

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