

Promises, Panaceas, or Problems in the Making?

A Closer Look At Emerging Technologies

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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. Whether engineered, manufactured or naturally occurring, nanoparticles are more than merely tiny; they can exhibit different fundamental physical, biological, and chemical properties from 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, and scientists are just beginning to explore the toxicity of nanomaterials.

The novel properties of nanoscale materials have spurred R&D across a wide range of government and industry sectors, which are spending billions to modify existing materials at the nanoscale and to research new nanomaterials, devices, and systems. Many experts believe that nanotech’s abilities to radically change our manufacturing, agricultural, economic, and social structures will bring about the next Industrial Revolution.

State of the Nano Market

At the close of 2009, the only publicly available inventory of products containing nanomaterials currently on the US market (compiled by the Project on Emerging Nanotechnologies), included more than 1,000 products, with at least three new products introduced every week (<http://www.nanotechproject.org/inventories/consumer>). Because there are no labeling requirements, known nano-containing products likely represent only a small fraction of the actual number commercially available.

According to analysts, the current worldwide market for nano products falls somewhere between \$12 billion and \$224 billion. (The large discrepancy in estimates is due partially to different methodologies for determining the value

of a nano product, for example the value of the nano component vs. the value of the final product).

Currently available nano products 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 and dispersants (including unregistered products proposed for use in the BP oil spill clean-up efforts), fuel additives, automotive parts, and medical devices.

There are well over 2,000 nanotech companies undertaking research and/or manufacture. No one knows how many workers across the globe are involved –

State of the Nano Market (cont.)

estimates range from 35,000 to 63,000 – but the number is predicted to reach somewhere between 2 and 10 million worldwide within 5 years. As with market figures, employment assessments are difficult due to lack of government oversight of nanotech R&D and commercial activity, and the absence of a standard definition for nano.

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 and synthetic biology, cognitive sciences, informatics, and robotics – have increased dramatically.

Investments

In 2009, governments added approximately \$10 billion to the almost \$40 billion they'd invested in nanoscience and nanotechnologies over the last decade. The largest spenders in nanotech historically – the US, EU and Japan – are now seeing China, South Korea, India, and Russia beginning to close the gap. Risk research is woefully underfunded everywhere, comprising only 4-5% of annual nano-related research budgets in the US and EU. Meanwhile, total global corporate R&D spending on nanotech has surpassed that of governments since 2008.

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 (including the placenta and 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.

Selected Health and Environment Concerns

- Carbon nanotubes – utilized for their lightweight strength in electronics and sporting goods, and envisioned for a wide range of applications including food packaging, drug delivery and bioremediation – can exhibit asbestos-like behavior and cause the development of mesothelioma.
- Carbon fullerenes (also called buckyballs) – used in face and anti-aging creams – have been found to have adverse impacts on aquatic species and to damage 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.

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 nano-

Broader Societal Concerns

- Knowledge dearth: Recent polling shows that 66% 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 that replace these (or other) commodities.
- Patenting the nano periodic table: With nanotech, the reach of exclusive monopoly extends to the fundamental building blocks of all of life. By some accounts, more than 12,000 nanotech patents have been granted over the last three decades (1976-2006) by the U.S. Patent & Trademark Office, the European Patent Office and the Japan Patent Office. As of March 2010, nearly 6,000 patents for nano have been awarded by the USPTO, and another 5,184 applications are waiting to be examined.

Oversight (cont.)

materials, 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

Center for Disease Control and Prevention, National Institute for Occupational Safety and Health: "Approaches to Safe Nanotechnology – Managing the Health and Safety Concerns Associated with Engineered Nanomaterials," March 2009.

<http://www.cdc.gov/niosh/docs/2009-125/pdfs/2009-125.pdf>

Environmental Health Perspectives: "Barrier Capacity of Human Placenta for Nanosized Materials," Wick P, Malek A, Manser P, Meili D, Maeder-Althaus X, Diener L, et al. 2010.

<http://ehp03.niehs.nih.gov/article/info:doi/10.1289/ehp.0901200>

Environmental Health Perspectives: "Reviewing the Environmental and Human Health Knowledge Base of Carbon Nanotubes," Helland A, Wick P, Koehler A, Schmid K, and So C, 2007. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1940104/>

European Parliament: "MEPs call for ban on food from cloned animals, demand a moratorium on foods using nanotechnology." July 2010.

http://www.europarl.europa.eu/news/public/focus_page/008-76988-176-06-26-901-20100625FCS76850-25-06-2010-2010/default_p001c009_en.htm

Lloyds of London, "Nanotechnology: Recent Developments, Risks, and Opportunities." 2007

http://www.lloyds.com/NR/rdonlyres/B9C7371E-83D4-49DD-8268-5D6C800FBDDF/0/ER_Nanotechnology_Report.pdf#search='nanotechnology

NanoAction, "Principles for the Oversight of Nanotechnologies and Nanomaterials." 2007.

<http://nanoaction.org/nanoaction/doc/nano-02-18-08.pdf>

United States Government Accountability Office: "Nanotechnology: Nanomaterials Are Widely Used in Commerce, but EPA Faces Challenges in Regulating Risks" May 2010.

<http://www.gao.gov/products/GAO-10-549>

Synthetic Biology Briefing Paper

Synthetic Biology 101

“Synthetic biology” describes new extreme genetic engineering techniques that design, create, and commercialize new organisms from scratch using engineering principles. Synthetic biology differs from the creation of Genetically Modified Organisms (GMOs), where existing strands of naturally occurring DNA are experimentally cut and pasted between organisms (for example, putting genes from bacteria into corn). Synthetic biologists create entirely new artificial DNA strands on a machine called a DNA synthesizer (available on eBay for about four hundred dollars). They then engineer these strands together as coded components to make new “genetic programs” (like computer programs) intended to instruct a microbe, plant or animal or whatever they are part of to behave in a particular way. At this stage, most synthetic biology is focused on “reprogramming” existing bacteria, yeast and algae to make new chemicals, biofuels and medicines. Some synthetic biologists are going beyond creating synthetic DNA and are trying to manufacture all of the parts of a living cell from “scratch” (i.e. from basic chemical components). Others are designing new artificial forms of DNA that would produce radically different and novel life forms.

Applications

Synthetic biologists test out their synthesized genetic “programs” in living cells, often with the goal of creating designer organisms that have various industrial functions. In this way microbes can be hijacked to behave like tiny factories, pumping out valuable products including:

Biofuels: Currently most investment in synthetic biology involves re-engineering microbes to ferment plant material into next generation biofuels, either to help break down cellulosic wood and grasses into sugars or to alter algae to produce higher quantities of oil for fuel.

Biomaterials and bioplastics: Just as synthetic microbes can turn plants into fuel, they can also be engineered to ferment plants into plastics and bio-based chemicals. For example, DuPont commercially produces the bioplastic Sorona from vats of synthetic yeast.

Medicine: 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 derived from a plant. Others are developing engineered viruses to fight cancer or create new vaccines.

Crop plants: Synthetic biology company Verenum (now owned by BP) has worked with biotech company Syngenta to develop corn plants whose stalks break down more readily into starch for biofuels.

Computers: DNA can be synthesized to solve math problems and encode information; bacteria are being designed that behave as logic gates on biological chips; and viruses are being engineered to grow simple circuits.

Applications (cont.)

Geoengineering: Synthetic biology is being applied to plants and algae to increase uptake of carbon dioxide from the atmosphere and to improve nitrogen fixation in an attempt to manage the effects of global climate change.

Bioweapons: Back in 2002, US researchers reported that they had built a working poliovirus from scratch, using gene sequence information available on the Internet and DNA strands from a mail-order company.

DIY Biotech: So-called “do-it-yourself bio-hackers” build designer organisms in their own kitchens and garages. An annual student competition, the International Genetically Engineered Machine (iGEM) competition encourages undergraduate and high school students to build the “coolest” synthetic organisms they can imagine – from bacteria that can flash and take photographs, to biological sensors and fuels.

Case Study: Craig and Synthia

Perhaps the highest-profile synthetic biologist is the controversial inventor/industrialist Craig Venter, who previously led the decoding (and privatization) of the human genome. In June 2010, scientists from his company, Synthetic Genomics Inc., announced they had succeeded in building a synthetic genome (i.e. a full set of DNA) for the bacteria *Mycoplasma capricolum*, then coaxed another cell to “boot it up,” bringing the synthetic genome to life. While media claims that Venter has “created life from scratch” were somewhat overplayed, the new synthetic bacteria – dubbed Synthia by the press and critics – is a significant step forward in synthetic biology. Venter claims that by using the same techniques used to build Synthia, he can now create millions of new species per day to be screened for industrial uses – vastly increasing the rate of development and power of genetic engineering as a field. He also has applied for far-reaching patents on Synthia in order to license the technology as a molecular operating system on which synthetic biologists can more easily run their genetic programs.

Investments

While the global market for synthetic biology products was estimated at only \$234 million in 2008, billions of dollars of investments are now being made in the field with the founding of two synthetic biology trade associations; major interest from the biotech, energy and chemical industries; and the involvement of venture capital leaders such as Khosla Ventures and Kleiner Perkins. 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, Life Technologies Inc. and Novartis also have high-profile investments in Venter’s company Synthetic Genomics Inc. Other major investors in the field include Shell, Total, Chevron, Cargill, DuPont, Virgin and

Goodyear. 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 resulting from the Institute’s work will be withheld as BP’s proprietary information.

Risks/Societal Concerns

Proponents see synthetic biology as a clean solution to the daunting problems of climate change, energy, health, and water resources, among others. Unfortunately, such techno-fixes are at least as likely to exacerbate rather than ease existing problems, and may also create entirely new and unforeseen consequences such as:

Risks/Societal Concerns (cont.)

Biowarfare and Bioterror: The most widely acknowledged risk of synthetic biology is that it could produce bioweapons. It is now possible to inexpensively create and modify deadly killers such as smallpox and the 1918 flu virus (which was previously extinct).

Environmental Risk and Bioerror: In addition to intentional misuse of organisms created through synthetic biology, there is the risk of their accidental release, escape or malfunction. No matter how they get out, once they are, synthetic organisms are likely to be difficult to contain or control, and have the potential to reproduce and spread throughout ecosystems, irreversibly polluting and/or changing the environment.

Bioeconomy and Justice: By enabling all sorts of plant matter to be transformed into biofuels and bioplastics, synthetic biology will create a thirst for plant-based sugars, leading to ever more powerful plant and land grabs that further the destruction of the world's biodiversity and push vulnerable communities off their lands. Unfortunately this consequence of what many hope will be a new, green engine for economic growth is little considered or discussed. Perhaps 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.

Bad Metaphors: Synthetic biologists treat living systems as though they were mere computer systems, as predictable and programmable as the electronic equipment on which so many of us rely so heavily. But cellular life may not function that neatly – these engineered organisms should be expected to evolve, change and “malfunction” in very unexpected ways.

Oversight

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

While governments have been slow to attempt to regulate the field, the past year has seen an upswing in interest in synthetic biology research and industrialization. Following the announcement of Synthia, President Obama ordered his Bioethics Commission to undertake a study into the ethics, oversight and regulation of synthetic biology and report back by the end of 2010. The National Institutes of Health Recombinant DNA Advisory Committee has proposed revisions to research guidelines, which would make assessments of some synthetic biology product safety and efficacy information accessible to the public. And as with nanotech, the revision of the US Toxic Substances Control Act now underway could afford public interest groups an opportunity to advocate for oversight and fuller exploration of environmental and ethical challenges of synthetic biology. Internationally, the announcement of Synthia motivated several member countries of the UN Convention on Biological Diversity (CBD) to propose that an international *de facto* moratorium be enacted to prevent the release of synthetic organisms into the environment. That moratorium will be considered at the next CBD meeting scheduled for October 2010 in Nagoya, Japan.

Additional Resources

Jon Mooallem, "Do-It-Yourself Genetic Engineering," February 10, 2010. New York Times Sunday Magazine. <http://www.nytimes.com/2010/02/14/magazine/14Biology-t.html>

The Presidential Commission for the Study of Bioethical Issues
<http://www.bioethics.gov/background/>

Denise Caruso, "Synthetic Biology: An Overview and Recommendations for Anticipating and Addressing Emerging Risks." 12 November 2008.
<http://www.scienceprogress.org/2008/11/synthetic-biology>

The Long Now Foundation, "Drew Endy and Jim Thomas Debate Synthetic Biology." 17 November 2008.
http://fora.tv/2008/11/17/Drew_Endy_and_Jim_Thomas_Debate_Synthetic_Biology

ETC Group, "Extreme Genetic Engineering - An Introduction to Synthetic Biology." January 2007. http://www.etcgroup.org/en/materials/publications.html?pub_id=602

Rathenau Institute, "Constructing life: the world of synthetic biology." November 2007.
<http://www.rathenauinstituut.com/showpage.asp?steID=2&item=2644>

Synbiosafe Project, "Interviews on Synthetic Biology." June 2007 – July 2008.
<http://www.synbiosafe.eu/index.php?page=expert-interviews>

Woodrow Wilson International Center for Scholars, Synthetic Biology Project:
<http://www.synbioproject.org>

Geoengineering Briefing Paper

Geoengineering 101

Geoengineering is the intentional, large-scale manipulation of the earth's environment. It encompasses multiple technologies in attempts to, for example, manage solar radiation, sequester greenhouse gases in the soils or the oceans, and/or modify the weather. Long considered marginal by environmental and scientific communities searching for solutions to climate change, geoengineering has moved rapidly into the mainstream, and now receives serious consideration from senior officials in government, politicians, academic circles and think tanks, as well as heightened media and public attention. This surge in interest is both explained and driven by the failure of governments to reduce fossil fuel consumption and effectively respond to global warming. For the most part, geoengineering technologies are still at R&D stages, but there is a growing push for public funding and real-world experimentation. This has led a coalition of international civil society groups to call for a ban on geoengineering experimentation.

Applications

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

- Burning hundreds of millions of hectares of biomass and burying the resulting "biochar" in the soil in order to sequester CO₂.
- Fertilizing the ocean with iron or nitrogen to stimulate the growth of phytoplankton, with the goal of promoting carbon sequestration deep at sea.
- Attempts to genetically engineer algae to increase its CO₂ carrying capacity, and then release them in large amounts into the world's oceans.
- Modifying weather patterns by cloud seeding, and suppressing or redirecting hurricanes and other storms.
- Pumping aerosol sulfates into 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 geoengineering has thus far mostly been the purview of individual entrepreneurs and small start-up companies hoping to profit from the carbon market.

Philanthro-capitalist Sir Richard Branson's offer – known as the Virgin Earth Challenge – to pay \$25 million to the inventor of a commercial technology that would remove significant amounts of greenhouse gases from the atmosphere has never been awarded. Bill Gates also attracted attention early this year when his personal \$4.5 million investment in geoengineering endeavors came to light. Already in the UK, advisory councils have allocated £5 million for geoengineering-related activities. In the US so far there has been only *ad hoc* funding through the National Science Foundation, Department of Energy, NASA and USDA, but a significant research program is expected to be announced in 2010, following hearings in the House Committee on Science and Technology, held jointly with its UK counterpart.

Risks/Broader Social Concerns

The principal risk, already palpable, is that geoengineering may offer governments quick

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

Ocean Fertilization Case Study: The Planktos Story

Planktos Inc. was a US start-up company that intended to sow the oceans with iron nanoparticles in order to create plankton blooms that would theoretically sequester CO₂ (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, 191 countries agreed to a groundbreaking *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.

Risks/Broader Social Concerns (cont.)

Many members of the scientific and technical communities are concerned that the full effects and long-term consequences of various geoengineering 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 cause massive disturbances in rainfall in tropical latitudes, damage the ozone layer, diminish biodiversity, make solar power less effective, and allow ocean acidification and sea level rises to proceed unhindered. Ocean fertilization initiatives could increase production of nitrous oxide and methane, create toxic plankton blooms, and have unforeseen impacts on ocean ecosystems, human health and livelihoods. Some schemes may be simply unreliable due to mechanical failure.

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.

So far, the main multilateral venues for debate over geoengineering have been the Convention on Biological Diversity (CBD), and the London Convention and Protocol on Marine Dumping. Both have focused primarily on restricting ocean fertilization. The CBD Conference of Parties scheduled for October 2010 in Japan will debate draft language calling for a moratorium on geoengineering activities, requiring national delegates to take a stand on this issue. The Inter-Governmental Panel on Climate Change (IPCC), the leading international scientific authority, has thus far largely avoided the issue, dismissing it as "largely speculative and unproven, and with the risk of unknown side-effects".³ However the next IPCC report is expected to devote considerable attention to geoengineering, forcing it, and the UN Framework Convention on Climate Change, to grapple with these issues in the near future. Other multilateral venues that could become relevant include the UN Convention on the Law of the Sea and UN treaty bodies that address economic, social and cultural rights. In stark contrast, some scientists and institutions involved are strongly advocating for different forms of self-regulation and "bottom-up" processes, and explicitly arguing against UN treaty involvement.

¹ "Planktos Indefinitely Postpones Ocean Iron Fertilization Project." 3 February 2008. http://www.redorbit.com/news/science/1253657/planktos_indefinitely_postpones_ocean_iron_fertilization_project/index.html

² "Planktos Announces Resignation and Release of CEO and Employees." 31 March 2008. <http://carbonsequestration.blogspot.com/2008/04/planktos-announces-resignation-and.html>

³ "Summary for Policymakers. In: Climate Change 2007: Mitigation." May 2007. pg 15, point 17. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-spm.pdf>

Additional Resources

James Fleming, *Fixing the Sky: The Checkered History of Weather and Climate Control*. Columbia University Press, 2010.

Claire L. Parkinson, *Coming Climate Crisis: Considering the Past, Beware of the Big Fix*. Rowman and Littlefield, 2010.

Eli Kintisch, *Hack the Planet: Science's Best Hope - or Worst Nightmare - for Averting Climate Catastrophe*. Wiley 2010.

Alan Robock, "20 reasons why geoengineering may be a bad idea." 23 April 2008.
<http://climate.envsci.rutgers.edu/pdf/20Reasons.pdf>; updated in Robock, Alan, Allison B. Marquardt, Ben Kravitz, and Georgiy Stenchikov, 2009: "The benefits, risks, and costs of stratospheric geoengineering."
<http://climate.envsci.rutgers.edu/pdf/2009GL039209.pdf>

Alex Steffen, "Geoengineering and The New Climate Denialism." April 2009.
<http://www.worldchanging.com/archives/009784.html>

ETC Group, *Retooling the Planet: Climate Chaos in a Geoengineering Age*, Swedish Society for Nature Conservation, 2009.

UK Royal Society, "Geoengineering the Climate: Science, Governance and Uncertainty." September 2009. <http://royalsociety.org/geoengineeringclimate>