Minimizing Global Catastrophic and Existential Risks from Emerging Technologies through International Law

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Abstract: Mankind is rapidly developing "emerging technologies" in the fields of bioengineering, nanotechnology, and artificial intelligence that have the potential to solve humanity's biggest problems, such as by curing all disease, extending human life, or mitigating massive environmental problems like climate change. However, if these emerging technologies are misused or have an unintended negative effect, the consequences could be enormous, potentially resulting in serious, global damage to humans (known as "global catastrophic harm") or severe, permanent damage to the Earth—including, possibly, human extinction (known as "existential harm"). The chances of a global catastrophic risk or existential risk actually materializing are relatively low, but mankind should be careful when a losing gamble means massive human death and irreversible harm to our planet. While international law has become an important source of global regulation for other global risks like climate change and biodiversity loss, emerging technologies do not fall neatly within existing international regimes, and thus any country is more or less free to develop these potentially dangerous technologies without practical safeguards that would curtail the risk of a catastrophic event. In light of these problems, this paper serves to discuss the risks associated with bioengineering, nanotechnology, and artificial intelligence; review the potential of existing international law to regulate these emerging technologies; and propose an international regulatory regime that would put the international world in charge of ensuring that low-probability, high-risk disasters never materialize.

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Table of Contents

I. INTRODUCTION

The world is currently undergoing a remarkable revolution in science and technology that will seemingly allow us to engineer synthetic life of any imaginable variety, build swarms of robots so small that they are invisible to the human eye, and, perhaps, create an intelligence far superior to the collective brainpower of every human. Much of this "emerging technology" either already exists in rudimentary form or may be developed in the coming decades,[1] including the three technologies covered by this paper: nanotechnology, bioengineering, and artificial intelligence (AI). While many scientists point to these developments as a panacea for disease, pollution, and even mortality,[2] these emerging technologies also risk massive human death and environmental harm.

Nanotechnology consists of "materials, devices, and systems" created at the scale of one to one hundred nanometers[3]—a nanometer being one billionth of a meter in size (10^{-9} m) or approximately one hundred-thousandth the width of a human hair[4]—including nano-sized machines ("nanorobots"). Bioengineering also operates on a tremendously small scale but uses concepts of engineering to build new biological systems or modify existing biological systems[5] by manipulating the very building blocks of life.[6] Finally, AI, meaning intelligent computers, is a pathway to "the Singularity," the concept that manmade greater-than-human intelligence could improve upon its own design, thus beginning an intelligence feedback mechanism or "explosion" that would culminate in a godlike intelligence with the potential to operate at one million times the speed of the human brain.[7]

These and other threats from emerging technologies may pose a "global catastrophic risk" (GCR), which is a risk that could cause serious global damage to human well-being, or an "existential risk" (ER), which is a risk that could cause human extinction or the severe and permanent reduction of the quality of human life on Earth.[8] Currently, the main risks from emerging technologies involve the accidental release or intentional misuse of bioengineered organisms, such as the airborne highly pathogenic avian influenza A (H5N1) virus, commonly known as "bird flu," that scientists genetically engineered in 2011. However, with emerging technologies developing at a rapid pace, experts predict that perils such as dangerous self-

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[1] *See infra* Section II.

[2] *See* Terry Grossman et al., *Reinventing Humanity: The Future of Human-Machine Intelligence*, THE FUTURIST (Feb. 03, 2006), *available at:* www.kurzweilai.net/reinventing-humanity-the-future-of-human-machine-intelligence.

[3] Ortwin Renn & Mihail Roco, *Nanotechnology and the Need for Risk Governance*, 8 J. NANOPARTICLE RES. 153 (2006), *available at:* http://www.springerlink.com/content/y80541n7740785gm/fulltext.pdf.

[4] *Nanotechnology White Paper*, NANOTECHNOLOGY WORKGROUP, ENVIRONMENTAL PROTECTION AGENCY'S SCIENCE POLICY COUNCIL (SPC) 5 (2007), *available at:* http://epa.gov/osa/pdfs/nanotech/epa-nanotechnology-whitepaper-0207.pdf.

[5] *The Issues*, ETC GROUP, http://www.etcgroup.org/en/materials/issues (last visited Feb. 14, 2012).

[6] *See* Natalie Angier, *Peering Over the Fortress That is the Mighty Cell*, N.Y. TIMES (May 31, 2010), *available at:* http://www.nytimes.com/2010/06/01/science/01angi.html?ref=jcraigventer.

[7] *Overview: What is the Singularity?*, SINGULARITY INSTITUTE FOR ARTIFICIAL INTELLIGENCE, http://singinst.org/overview/whatisthesingularity (last visited Jan. 31, 2012).

[8] NICK BOSTROM & MILAN M. ĆIRKOVIĆ, *Introduction, in* GLOBAL CATASTROPHIC RISKS 25 (Nick Bostrom & Milan M. Ćirković, eds., 2008).

replicating nanotechnology,[9] deadly synthetic viruses available to amateur scientists, and unpredictable superintelligent AI[10] may materialize in the coming few decades.

Society should take great care to prevent a GCR or ER ("GCR/ER") from materializing, yet GCRs/ERs arising out of nanotechnology, bioengineering, and AI are almost entirely unregulated at the international level.[11] One possible way to mitigate the chances of a GCR/ER ever materializing is for the international community to establish an international convention tailored to these emerging technologies based on the following three principles: first, that nanotechnology, bioengineering, and AI pose a GCR/ER; second, that existing international regulatory mechanisms either do not include emerging technologies within their scope or else insufficiently mitigate the risks arising from emerging technologies; and third, that a international convention based on the precautionary principle could reduce GCRs/ERs to an acceptable level.

This paper purports to establish the threats of emerging technologies, highlight regulatory gaps under international law, and recommend an international framework to address the associated risks. Specifically, Section II discusses the benefits and risks of emerging technologies, establishing that bioengineering poses a GCR/ER now while nanotechnology and AI pose a GCR/ER in the future. Section II also provides the background of attempts to enjoin the operation of the Large Hadron Collider (LHC) to highlight difficulties courts have in addressing low-probability scientific threats and the conflicts of interest scientists may have in self-regulation. Section III then analyzes GCRs/ERs from bioengineering under international law, concluding that no international convention sufficiently regulates the risks arising out of bioengineering. This section focuses on bioengineering because it is the only emerging technology that poses an immediate GCR/ER. Section IV stitches together the fundamentals of an international treaty that would regulate GCRs/ERs from emerging technologies through concepts such as the precautionary principle, decisionmaking from a body of experts, and public participation. Finally, Section V concludes that states should act quickly to create a flexible, legally binding treaty to regulate the emerging technologies that present a GCR/ER.

II. BACKGROUND ON EMERGING TECHNOLOGIES AND EXISTENTIAL RISKS

While many experts cite a forthcoming revolution in nanotechnology, bioengineering, and AI as a source of great potential benefit to mankind and the environment, these technologies also risk causing profound negative consequences if insufficiently regulated. This section discusses current and forthcoming emerging technologies to highlight the benefits of emerging technologies while also establishing that they pose a GCR/ER. This background will serve as a foundation for an international regulatory regime that seeks to curtail the risks of emerging technologies without stifling their beneficial uses. Additionally, this section presents a brief case study of the LHC, which demonstrates the challenges of seeking judicial review of a complex scientific technology that poses a remote but significant harm and the problems with permitting self-assessment of risks amongst scientists.

[9] *See Nanotechnology White Paper, supra* note 4, at 12.
[10] Eliezer Yudkowsky, *Artificial Intelligence as a Positive and Negative Factor in Global Risk, in* GLOBAL CATASTROPHIC RISKS 237 (Nick Bostrom & Milan M. Ćirković, eds., 2008).
[11] *See infra* Section III.

A. Global Catastrophic Risk and Existential Risk

A GCR is a risk that has the potential to cause "serious damage to human well-being" on the global scale.[12] While the threshold of "serious" damage is somewhat ambiguous, one expert sought to clarify the matter by asserting that an event killing 10,000 people would not qualify as a GCR, while one that killed 10,000,000 people would.[13] Furthermore, an event need not affect the entire Earth to have a "global" scale, but certainly must affect at least several parts of the world.[14]

GCRs may be categorized into natural, anthropogenic, and intermediate risks. An example of a natural GCR that has already materialized is the Spanish flu pandemic,[15] while possible future natural GCRs include extreme natural disasters, another ice age, or a meteor striking the Earth.[16] Examples of past anthropogenic GCRs are the first and second World Wars, while possible future anthropogenic GCRs include nuclear war, accidents involving experimental technology, or bioterrorism.[17] Finally, intermediate GCRs are those that involve "complex interactions between humanity and its environment," such as climate change.[18]

One specific type of GCR is an ER, which is a low-probability, high impact risk that could (1) make humans go extinct or (2) severely and permanently harm the future quality of life of humans. An existential risk requires, at minimum, a global scope, a terminal (i.e. fatal) intensity, and a permanent effect on the quality of human life that continues into future generations.[19] Several GCRs are also ERs, such as nuclear war, certain experimental technologies, and climate change. Likewise, the three risks that this paper focuses on—nanotechnology, bioengineering, and AI—are both GCRs and ERs.

Because ERs are irrevocable, great care must be taken as to never let one happen. Although the probability of an existential risk materializing is up to much debate, some experts have come up with rough estimates. For example, Martin Rees, a decorated scientist and former President of the Royal Society,[20] believes there to be a fifty percent chance of human extinction before the 22nd century, with much of the risk arising from some of the emerging technologies discussed in this paper.[21]

B. Global Catastrophic Risks and Existential Risks from Emerging Technologies

States should consider concluding an international treaty to regulate emerging technologies if they perceive these technologies to pose a GCR/ER. This section considers the current and future risks and benefits posed by three emerging technologies—bioengineering,

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[12] BOSTROM & ĆIRKOVIĆ, *supra* note 10, at 23.
[13] *Id.* at 24.
[14] *Id*.
[15] *Id*.
[16] *Id.* at 13-27.
[17] *Id*.
[18] For a discussion of intermediate ERs, *see* MILAN M. ĆIRKOVIĆ, ANDERS SANDBERG, & NICK BOSTROM, *Anthropic Shadow: Observation Selection Effects and Human Extinction Risks*, 30 RISK ANALYSIS 1495 (2010).
[19] BOSTROM & ĆIRKOVIĆ, *supra* note 10, at 04.
[20] The Royalty Society, of which the about 1,500 Fellows and Foreign Members includes about 80 Nobel Laureates, is Britain's Academy of Sciences and publisher of nine peer-reviewed journals. *See About Us*, THE ROYAL SOCIETY, *at:* http://royalsociety.org/about-us (last visited Jan. 29, 2012).
[21] Steve King, *Worst Possible Scenarios,* SPECTATOR (May 24, 2003), reviewing MARTIN REES, OUR FINAL CENTURY? (2003), available on Westlaw at 2003 WLNR 8390689.

nanotechnology, and AI. This section concludes that bioengineering is the only emerging technology that poses an immediate GCR/ER, while nanotechnology and AI pose a future GCR/ER.

1. Bioengineering

Simply defined, bioengineering is the "engineering of living organisms." [22] Bioengineering is commonly associated with genetically modified (GM) foods made from crops that scientists develop to have qualities like pest resistance or increased nutrition. However, bioengineering is rapidly expanding beyond agriculture into fields like medicine, disease control, and life-extension. The technology behind bioengineering has also developed quickly, with scientists now able to understand and manipulate life at the molecular level such that biology is viewed as a "machine" that can be tweaked, like in genetic engineering, or even built from the ground up, like in synthetic biology.[23]

While breakthroughs in bioengineering research could significantly benefit mankind and the environment, bioengineering research can also be misused to the detriment of humans, animals, and environmental health.[24] Such "dual use" research currently poses significant risks to humankind, but even greater risks in the future. Furthermore, both current and future bioengineering technologies pose the risk of an accident that has significant detrimental effects. In exploring these issues, this section demonstrates that bioengineering poses an immediate GCR/ER.

a. Current technology

Bioengineering is already widely used to modify existing organisms, and scientists are on the cusp of creating entirely synthetic organisms. For example, scientists controversially use bioengineering to "improve" natural biological products and activities, resulting in increased nutrient value, bigger yields, and insect and disease resistance[25] in various types of crops.[26] In 2011, 94 percent by acre of soybeans in the United States were genetically engineered, while 73 percent of all U.S. corn was genetically engineered to be insect resistant and 65 percent to be herbicide tolerant.[27]

Another controversial current bioengineering technology is genetically engineer viruses, highlighted by the 2011 genetic engineering of the H5N1 virus to become highly contagious amongst ferrets. Many scientists argue that creating the genetically engineered virus was necessary to develop a remedy in case the H5N1 virus mutates naturally, but skeptics argue that the modified H5N1 virus is dangerous because of risks that the virus will escape or that

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[22] YUAN-CHENG FUNG & SHU CHIEN, INTRODUCTION TO BIOENGINEERING (Yuan-cheng Fung ed., 2001).
[23] *See* MAX E. VALENTINUZZI, UNDERSTANDING THE HUMAN MACHINE: A PRIMER FOR BIOENGINEERING (2004).
[24] This is the definition of "dual use research of concern" as defined by the NSABB. *See* Dual Use Research of Concern, Boston University, *available at:* www.bu.edu/orc/durc (last visited Mar. 18, 2012).
[25] *Food, Genetically Modified*, WORLD HEALTH ORG., *at:* www.who.int/topics/food_genetically_modified/en/ (last visited Mar. 14, 2012).
[26] *Bioengineering for Pollution Prevention Through Development of Biobased Materials and Energy*, ENVTL. PROT. AGENCY 10, EPA doc. EPA/600/R-07/028, *available at:* http://epa.gov/ncer/publications/statesci/bioengineering.pdf.
[27] *Adoption of Genetically Engineered Crops in the U.S.*, U.S. DEPT. OF AGRIC., *at:* www.ers.usda.gov/Data/BiotechCrops/ (last visited Mar. 14, 2012).

malicious actors will engineer a similar virus.[28] Another example of recent advancements in bioengineering is a project spearheaded by biologist Craig Venter that transplanted a completely synthetic DNA sequence, or "genome," into an E. coli bacteria—scientists then also added DNA "watermarks" such as the names of researchers and famous quotes—which Craig Venter termed "the first self-replicating species we've had on the planet whose parent is a computer."[29]

Bioengineering has also become vastly cheaper and more accessible to the general public. For example, massive databases of DNA sequences are available online from the Department of Energy Joint Genome Institute (JGI) and the National Center for Biological Information's GenBank® database.[30] To materialize these DNA sequences, individuals can order custom genomes online for a few thousand dollars, which are "printed" from a DNA synthesis machine and shipped to them, opening the door for amateur biologists to engage in genetic engineering.[31] DNA synthesis machines can print DNA strands long enough for certain types of viruses, which untrained individuals can obtain within six weeks of purchase.[32] Even the synthesizing machines themselves can be purchased on the Internet on sites like eBay.[33]

Much like bioengineering costs, the necessary expertise to engage in bioengineering is also plummeting. For example, since 2003, teams of entrepreneurs, college students, and even high school students submitted synthetic biology creations to the International Genetically Engineered Machine (IGEM) competition, such as UC Berkeley's "BactoBlood" creation—a "cost-effective red blood cell substitute" developed by genetically engineering E. coli bacteria.[34]

b. Forthcoming technology

Perhaps the greatest forthcoming development in bioengineering is synthetic biology, which includes techniques to "construct new biological components, design those components and redesign existing biological systems."[35] This is in contrast to the traditional form of bioengineering that utilizes "recombinant DNA" techniques in which the DNA from one organism is stitched together with DNA from other organisms or synthetic DNA.[36] One method of synthetic biology involves "cataloguing" DNA sequences like "Lego bricks" and assembling

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[28] Michael Specter, *The Deadliest Virus*, THE NEW YORKER 32-33 (Mar. 12, 2012).

[29] Some skeptics do not consider this to be the first instance of truly synthetic life because the genomes were based on existing DNA. *See* Angier, *supra* note 6; Nicholas Wade, *Researchers Say They Created a 'Synthetic Cell'*, N.Y. TIMES (May 20, 2010), *available at:* www.nytimes.com/2010/05/21/science/21cell.html.

[30] ENVTL. PROT. AGENCY, *supra* note 26, at 10. The JGI database is accessible at http://www.jgi.doe.gov/sequencing/why/index.html, and GenBank® is accessible at http://www.ncbi.nlm.nih.gov/genbank/.

[31] NATIONAL SCIENCE ADVISORY BOARD FOR BIOSECURITY (NSABB), STRATEGIES TO EDUCATE AMATEUR BIOLOGISTS AND SCIENTISTS IN NON-LIFE SCIENCE DISCIPLINES ABOUT DUAL USE RESEARCH AND LIFE SCIENCES 4 (June 2011), *available at:* http://oba.od.nih.gov/biosecurity/pdf/FinalNSABBReport-AmateurBiologist-NonlifeScientists_June-2011.pdf.

[32] Michele S. Garfinkel & Robert M. Friedman, *Synthetic Biology and Synthetic Genomics*, *in* THE FUTURE OF INTERNATIONAL ENVIRONMENTAL LAW 272 -273(David Leary & Balakrishna Pisupati, eds., 2010).

[33] *Id.* at 278-279.

[34] *See About Us*, INTERNATIONAL GENETICALLY ENGINEERED MACHINE COMPETITION, http://igem.org/About.

[35] Garfinkel & Friedman, *supra* note 32, at 270.

[36] *Fact Sheet Describing Recombinant DNA and Elements Utilizing Recombinant DNA Such as Plasmids and Viral Vectors, and the Application of Recombinant DNA Techniques in Molecular Biology*, UNIV. OF N.H. OFFICE OF ENV'T HEALTH AND SAFETY 2 (2011), *available at:* www.unh.edu/research/sites/unh.edu.research/files/images/Recombinant-DNA.pdf.

them in unique ways (assembling *natural* molecules into an *unnatural* system, like combining the molecules from several types of bacteria to create a new bacteria with novel properties. Another method of synthetic biology involves using DNA synthesizers to create life "entirely from scratch … the biological equivalent of word processors" (using *unnatural* molecules to emulate a *natural* system, like creating the synthetic equivalent of a natural strand of influenza).[37] One way to "birth" synthetic DNA is to insert the DNA into a "biological shell"—an organism, often a bacteria, that had its own genes removed—that can run the synthetic DNA like a computer runs software.[38] And while the technology to create eukaryotic cells (i.e. "a cell with a nucleus, such as those found in animals, including human beings") is a long ways away, synthetic viruses and bacteria are just around the corner.[39]

c. Benefits of bioengineering

Bioengineering is already displaying its potential to remedy major human health and environmental problems. For example, bioengineering is responsible for several pharmaceuticals and vaccines, such as insulin and a vaccine for Hepatitis B, while "gene therapy" employs genetically engineered viruses to help treat cancer.[40] Environmental benefits resulting from the 15.4 million farmers who grew genetically modified crops in 2010 include increased yield of six to thirty percent per acre of land, pest-resistant crops that require fewer pesticides (resulting in 17.1% less pesticide use globally in 2010), lower water use for drought-resistant crops, decreased CO_2 emissions, and crops that do not require harmful tilling practices.[41]

Forthcoming benefits to human health could be a new wave of ultra-effective drugs (e.g. antimalarial and antibiotic drugs), bioengineered agents that kill cancer cells, and the ability to rapidly create vaccines in response to epidemics.[42] Bioengineering could also serve as a beacon of human diagnostics by analyzing "thousands of molecules simultaneously from a single sample."[43] Meanwhile, forthcoming benefits to the environment could be organisms that remedy harmful pollution and superior forms of biofuel, for example.[44] Bioengineering could also spur an environmental revolution in which industries reuse modified waste from biomass feedstock and farmers grow bioengineered crops on "marginally productive lands" (e.g. switchgrass).[45]

d. Risks from bioengineering

While bioengineering offers current and future benefits to humans and the environment, there are also significant yet uncertain risks that could devastate human life, societal stability,

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[37] *What is Synthetic Biology?,* SYNETHICBIOLOGY.ORG, *at:* http://syntheticbiology.org/FAQ.html (last visited Feb. 16, 2012). *See also* Garfinkel & Friedman, *supra* note 32, at 269.
[38] *Id.*
[39] Garfinkel & Friedman, *supra* note 32, at 271.
[40] SCIENCE AND TECHNOLOGY COMMITTEE OF THE PARLIAMENT OF GREAT BRITAIN, BIOENGINEERING: SEVENTH REPORT OF SESSION 55-56 (2009-2010).
[41] *GM Crops: Reaping the Benefits, but Not in Europe*, EUROPEAN ASSOC. FOR BIOINDUSTRIES 1-8 (2011), *available at:* www.europabio.org/sites/default/files/europabio_socioeconomics_may_2011.pdf.
[42] Risk and Response Assessment Project, *Synthetic Biology and Nanobiotechnology*, U.N. INTERREGIONAL CRIME AND JUSTICE RESEARCH INSTITUTE (UNICRI), *at:* http://lab.unicri.it/bio.html (*last visited* Feb. 13, 2012); Garfinkel & Friedman, *supra* note 32, at 274-277.
[43] Elizabeth A. Thomson, *Paper Predicts Bioengineering Future*, MIT NEWS (Feb. 14, 2001), *at:* web.mit.edu/newsoffice/2001/biomedical-0214.html
[44] UNICRI, *supra* note 42.
[45] ENVTL. PROT. AGENCY, *supra* note 26, at iv.

and the environment.[46] This paper focuses on three predominant GCR/ER risks arising from bioengineering: (1) the accidental release of harmful organisms (a "biosafety" issue), (2) the malicious release of harmful organisms ("bioterrorism"), and (3) the bioengineering of humans. The first two are current GCRs/ERs, while the third is a future GCR/ER.

i. Risk of an accident

An accidental release of a bioengineered microorganism during legitimate research poses a GCR/ER when such a microorganism has the potential to be highly deadly and has never been tested in an uncontrolled environment.[47] The threat of an accidental release of a harmful organism recently sparked an unprecedented scientific debate amongst policymakers, scientists, and the general public in reaction to the creation of an airborne strain of H5N1.[48] In September 2011, Ron Fouchier, a scientist from the Netherlands, announced that he had genetically engineered the H5N1 virus—his lab "mutated the hell out of H5N1," he professed—to become airborne, which was tested on ferrets; a laboratory at the University of Wisconsin-Madison similarly mutated the virus into a highly transmittable form.[49]

The "natural" H5N1 killed approximately 60 percent of those with reported infections (although the large amount of unreported cases means that this is an over estimate), but the total number of fatalities—three hundred and forty-six people—was relatively small because the virus is difficult to transmit from human to human. The larger risk comes from the possibility that a mutated virus would spread more easily amongst humans,[50] which could result in a devastating epidemic amongst the worst in history, if not the very worst.[51] To put this in context, about one in every fifteen Americans—20 million people—would die every year from a seasonal flu as virulent as a highly transmittable form of H5N1.[52]

Lax regulations and a rapidly growing number of laboratories exacerbate the dangers posed by bioengineered organisms. While lab biosafety[53] guidelines in the United States and Europe recommended that projects like reengineering the H5N1 virus be conducted in a BSL-4 facility (the highest security level), neither laboratory that reengineered the H5N1 virus met this non-binding standard.[54] Meanwhile, a 2007 Government Accountability Office (GAO) report

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[46] John Steinbruner et al., *Controlling Dangerous Pathogens: A Prototype Protective Oversight System*, CTR. FOR INT'L AND SECURITY STUDIES AT MD. 1 (2007), *available at:* www.cissm.umd.edu/papers/files/pathogens_project_monograph.pdf.

[47] *See* Garfinkel & Friedman, *supra* note 32, at 279.

[48] There are different types of "type A" influenza viruses in birds that are named according to the "two main proteins on the surface" of the virus, here H5 and N1. The H5N1 virus is just one type of bird flu. *See Key Facts About Avian Influenza (Bird Flu) and Highly Pathogenic Avian Influenza A (H5N1) Virus*, CTR. FOR DISEASES CONTROL AND PREVENTION (CDC), *at:* www.cdc.gov/flu/avian/gen-info/facts.htm (last visited Mar. 11, 2012).

[49] Specter, *supra* note 28, at 32-33.

[50] CDC*, supra* note 48.

[51] Robert Roos, *Live Debate Airs Major Divisions in H5N1 Research Battle*, CENTER FOR INFECTIOUS DISEASE RESEARCH AND POLICY (CIDRAP) NEWS (Feb. 3, 2012), *at:* www.cidrap.umn.edu/cidrap/content/influenza/avianflu/news/feb0312webinar-jw.html (see comments of Michael T. Osterholm of the National Science Advisory Board for Biosecurity).

[52] Specter, *supra* note 28, at 32.

[53] UNICRI, *supra* note 42.

[54] *Future Bird Flu Virus Work Should be Done in Most Secure Labs*, THE CANADIAN PRESS (Mar. 06, 2012), *at:* www.ctv.ca/CTVNews/Health/20120306/bird-flu-virus-labs-120306.

indicated that BSL-3 and BSL-4 labs are rapidly expanding in the United States. While there is significant public information about laboratories that receive federal funding or are registered with the Centers for Disease Control and Prevention (CDC) and the U.S. Department of Agriculture's (USD) Select Agent Program, much less is known about the "location, activities, and ownership" of labs that are *not* federally funded and *not* registered with the CDC or the USD Select Agent Program.[55] The same report also concluded that there is no single U.S. agency that is responsible for tracking and assessing the risks of labs engaging in bioengineering.[56]

While some claim that critics are overreacting to the genetically engineered H5N1 virus, there are a series of accidental releases of microbes from laboratories that demonstrate the risks of largely unregulated laboratory safety. In 1978, an employee died from an accidental smallpox release from a laboratory on the floor below her.[57] Many scientists believe that the global H1N1 ("swine flu") outbreak in the late 2000s originated from an accidental release from a Chinese laboratory.[58] Reports concluded that the accidental releases of Severe Acute Respiratory Syndrome (SARS) in Singapore, Taiwan, and China from BSL-3 and BSL-4 laboratories all resulted from a low standard of laboratory safety.[59] In the United States alone, a review by the Associated Press of more than 100 laboratory accidents and lost shipments between 2003 and 2007 show a pattern of poor oversight, reporting failures, and faulty procedures, specifically describing incidents at "44 labs in 24 states," including at high-security labs.[60] In 2007, an outbreak of Foot and Mouth Disease likely came from a laboratory that was the "only known location where the strain [was] held in the country"[61] because of a leaky pipe that had known problems.[62] This long history of faulty laboratory safety is why some experts, such as Rutgers University chemistry professor and bioweapons expert Richard H. Ebright, believe that the H5N1 virus will "inevitably escape, and within a decade," citing the hundreds of germs with potential use in bioweapons that have accidentally escaped from laboratories in the United States.[63] While the effects of such lapses in laboratory safety have not yet been felt aside from relatively small events such as the swine flu outbreak mentioned above, the increasing ability of less-sophisticated scientists to engineer more deadly organisms vastly increase the possibility that a lapse in biosafety will have detrimental effects.

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[55] GAO, High-Containment Biosafety Laboratories: Preliminary Observations on the Oversight of the Proliferation of BSL-3 and BSL-4 Laboratories in the United States, Statement of Keith Rhodes, Chief Technologist, Center for Technology and Engineering, Applied Research and Methods, GAO-08-108T (Oct. 4, 2007), *available at:* http://www.gao.gov/new.items/d08108t.pdf (emphasis added).

[56] *Id.*

[57] Specter, *supra* note 28, at 33.

[58] *Id.*

[59] Jennifer Gaudioso et al., *Biosecurity: Progress and Challenges*, 14 J. OF LABORATORY AUTOMATION 141, 143 (2009). *See also* Christian Enemark, *Preventing Accidental Disease Outbreaks: Biosafety in East Asia*, NAUTILUS INSTITUTE FOR SECURITY AND SUSTAINABILITY, AUSTRAL PEACE AND SECURITY NETWORK (ASPNET) (2006), *available at:* http://nautilus.org/apsnet/0631a-enemark-html.

[60] Larry Margasak, *Accidents on Rise as More US Labs Handle Lethal Germs*, THE ASSOC. PRESS (Oct. 03, 2007), *available at:* http://articles.boston.com/2007-10-03/news/29232771_1_biosafety-level-4-labs-accidents.

[61] United Nations Office for Disarmament Affairs, *Developing a Biological Incident Database*, UNODA OCCASIONAL PAPERS: NO. 15 12-13 (2009), *available at:* http://www.un.org/disarmament/HomePage/ODAPublications/OccasionalPapers/OP15-info.shtml.

[62] Gaudioso et al., *supra* note 59, at 143.

[63] Denise Grady & Donald McNeil Jr., *Debate Persists on Deadly Flu Made Airborne*, N.Y. TIMES (Dec. 26, 2011), *at:* http://www.nytimes.com/2011/12/27/science/debate-persists-on-deadly-flu-made-airborne.html.

An accidental or purposeful release of a bioengineered organism has potentially grave consequences. For example, researchers in Australia recently accidentally developed a mousepox virus with a one-hundred percent fatality rate when they had merely intended to sterilize the mice.[64] Scientists in the United States also created a "superbug" version of mousepox created to "evade vaccines," which they argue is important research to thwart terrorists, sparking a debate amongst scientists and policymakers about whether the benefits of such research is worth the associated risks.[65] If such a bioengineered organism escaped from a laboratory, the results would be unpredictable but potentially extremely deadly to humans and/or other animal species.

The widespread availability of bioengineering technology and information further increases the risks of error in a laboratory. Students and amateurs have a growing capability to create bioengineered organisms, as evidenced by the iGEM contests, which tests the bioengineering capabilities of students in high schools and colleges.[66] Because of the dangers posed by this dual use research, the U.S. National Science Advisory Board for Biosecurity (NSABB) has started outreach programs for amateur biologists, including untrained, curious young individuals who consider themselves "bioartists" rather than researchers.[67]

Defenders of genetically engineering viruses in a laboratory setting argue that such viruses could mutate outside of a laboratory anyway, and so understanding possible mutations in the laboratory is a defensive tool against the unknown.[68] As evidence, there have been previous examples of successful outcomes of bioengineering viruses, such as when Ralph Baric, using publicly available genome sequences, created a synthetic SARS virus contagious to bats that he claims can be tweaked to be a potential vaccine in the case of another SARS outbreak.[69] Furthermore, while environmentalists have long questioned the safety of GM foods on human health and the environment, GM foods have not been shown to be unsafe for human consumption[70] and so-called "super weeds" created from gene transfer from GM crops have not materialized.[71] However, just because a risk has not yet materialized does not mean that society should assume that a risk will not ever materialize, and a GCR/ER from bioengineering poses too much potential damage to rely on past events as an indicator of the future. Overall, this subsection demonstrates the risk of a bioengineered organism escaping from the lab with unknown but potentially catastrophic consequences, thus establishing a GCR/ER.

ii. Risk of bioterrorism

The threat of the malicious release of bioengineered organisms (i.e., bioterrorism) poses a GCR/ER.[72] Bioengineering enables a malicious actor to create an organism that is more deadly

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[64] *Researchers Make Vaccine-Evading Mousepox Virus, Igniting Scientific Debate*, THE ASSOC. PRESS (Oct. 31, 2003), *at:* www.usatoday.com/news/health/2003-10-31-antivaccine-monkeypox_x.htm.
[65] *Id.*
[66] Garfinkel & Friedman, *supra* note 32, at 279.
[67] NSABB, *supra* note 31, at 5.
[68] Steve Conner, *Research into Mutant Flu 'Must Go On,'* THE INDEPENDENT (Jan. 28, 2012), *at:* http://www.independent.co.uk/news/science/research-into-mutant-flu-must-go-on-6295929.html.
[69] Garfinkel & Friedman, *supra* note 32, at 275-276.
[70] *20 Questions on Genetically Modified Foods*, WORLD HEALTH ORG., *at:* http://www.who.int/foodsafety/publications/biotech/20questions/en/ (last visited Apr. 23, 2012).
[71] AFRICA ENVIRONMENT OUTLOOK 2: OUR ENVIRONMENT, OUR WEALTH, U.N. ENV'T PROGRAMME 312, available at: www.unep.org/dewa/africa/docs/en/aeo-2/chapters/aeo-2_ch09_GENETICALLY_MODIFIED_CROPS.pdf.
[72] *Id.* at 279.

to humans, animals, or plants than anything that exists in the natural world.[73] Experts say that the barriers for a terrorist to order a DNA sequence for a highly pathogenic virus online or acquire a DNA synthesis machine online are "surmountable."[74] Alternatively, bioterrorists could break into laboratories housing dangerous bioengineered organisms—like the H5N1 virus, for example—and release them. Meanwhile, third world countries with laxer standards and lower laboratory accountability are rapidly discovering and using bioengineering, which may give bioterrorists an easier pathway to obtain deadly bioengineered organisms.[75]

There have already been several occasions in which groups attempted to use or successfully used biological weapons. One unsophisticated example of bioterrorism occurred when an individual contaminated salads and dressing with salmonella in what apparently was an attempt to decide a local election.[76] Another example is a slew of attacks by Aum Shinrikyo, a Japanese cult, in the 1990s, the worst of which killed 12 people and injured over 5,000 from the release of sarin nerve gas in a subway in Tokyo in 1995.[77] While these particular acts of bioterrorism did not cause widespread death, deploying extremely deadly bioengineered organisms over a large area is real possibility: tests by the United States in 1964 demonstrated that a single aircraft can contaminate five thousand square kilometers of land with a deadly bacterial aerosol.[78]

The recent engineering of an airborne H5N1 virus demonstrates society's concern over risks of bioterrorism arising from bioengineering. Before scientists could publish their results of their bioengineered airborne H5N1 virus in the widely read journals *Nature* and *Science*, the NSABB determined that the danger of releasing the sensitive information outweighed the benefits to society, advising that the findings not be published in their entirety.[79] The main risk is that either a state or non-state actor could synthesize a "weaponized" version of the H5N1 virus to create a disastrous pandemic.[80] There is precedent of outside groups recreating advanced bioengineering experiments, such as when many scientists immediately synthesized hepatitis C replicons upon publication of the its genetic code.[81] However, the NSABB's recommendation was nonbinding, and there is nothing to stop other scientists from releasing similar data in the future. Furthermore, while the NSABB merely assert that the "blueprints" of the virus should not be printed, other biosecurity experts argue that the virus should never have been created in the first place because of risks that the viruses would escape or be stolen.[82]

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[73] Steinbruner et al., *supra* note 46, at 3.
[74] Garfinkel & Friedman, *supra* note 32, at 278-279.
[75] *See* RICHARD A. POSNER, CATASTROPHE: RISK AND RESPONSE 219 (2004).
[76] *Agroterrorism and Food Safety: Deliberate Contamination of Food*, FED'N OF AM. SCIENTISTS, *at:* www.fas.org/biosecurity/education/dualuse-agriculture/1.-agroterrorism-and-foodsafety/deliberate-contamination-foods.html (last visited Mar. 14, 2012).
[77] The cult had previously taken advantage of amateur biology by purchasing a machine from a company in Oregon that "simulates molecular experimentation without the need for [an] actual laboratory...." Barry Kellman, *Biological Terrorism: Legal Measures for Preventing Catastrophe*, 24 HARV. J.L. & PUB. POL'Y 417, 425 (2001).
[78] Julian Perry Robinson, *Bringing the CBW Conventions Closer Together, in The CBW Conventions Bulletin: News, Background and Comment on Chemical and Biological Weapons Issues*, 80 Q. J. OF THE HARV. SUSSEX PROG. ON CBW ARMAMENT AND ARMS LIMITATION 1 (2008), *available at:* http://www.admin.susx.ac.uk/Units/spru/hsp/documents/cbwcb80.pdf.
[79] THE CANADIAN PRESS, *supra* note 54.
[80] Conner, *supra* note 68.
[81] U.S. NATIONAL RESEARCH COUNCIL AND THE U.S. INSTITUTE OF MEDICINE, GLOBALIZATION, BIOSECURITY, AND THE FUTURE OF LIFE SCIENCES 23 (2006).
[82] Grady & McNeil Jr., *supra* note 63.

iii. Bioengineering of Humans

A final GCR/ER arising out of bioengineering, but which has not yet occurred, involves inheritable genetic alterations of humans. In one possible scenario, bioengineering would create a new species or subspecies of humans—sometimes called "transhumans"[83] or "posthumans"[84]—that presents a variety of risks. First is the risk of a eugenics movement that prejudices "normal" humans. Second, posthumans may have a competitive advantage that is detrimental to normal humans.[85] In another scenario, genetically engineered humans may perceive the normal humans as "inferior, even savages, and fit for slavery or slaughter."[86] Meanwhile, normal humans could attempt to preemptively suppress genetically engineered humans to protect themselves in the future, which could result in warfare amongst the different groups.[87] For these reasons, some argue that genetically engineered humans are "potential weapons of mass destruction" that could result in human genocide, and thus an international convention is necessary to address that risk.[88] On the other hand, there is also the possibility that genetically engineered humans would supplement humans and live harmoniously in society, but the possibility of a favorable outcome is not a sufficient reason to disregard potentially catastrophic risks.

Other scholars believe that genetically engineering humans pose an ethical quandary, and that "humans will lose the experiential or other basis that makes us human" if such a movement becomes widespread.[89] These scenarios may not be too far in the future, as current science has proven that "relatively simple gene alterations can significantly extend the lifespan of nematodes and mice," so perhaps there will be pressure from certain groups to expand these technologies to humans.[90] Furthermore, embryonic technology is heading towards the possibility of "designer babies," which would use genetic engineering to create "specific traits in pre-implanted embryos."[91] On the other hand, proponents of genetically engineering humans cite benefits such as increased life-expectancy, superior intelligence, and eradication of genetic defects, arguing

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[83] Transhumanism may be defined as "the intellectual and cultural movement that affirms the possibility and desirability of fundamentally improving the human condition through applied reason, especially by using technology to eliminate aging and greatly enhance human intellectual, physical, and psychological capacities." *See* ANDREW LUSTIG ET AL., ALTERING NATURE: VOL. 2 240 (2008).

[84] A posthuman is an individual "so significantly altered as to no longer represent the human species." CHARLES W. COLSON & NIGEL M. DE S. CAMERON, HUMAN DIGNITY IN THE BIOTECH CENTURY: A CHRISTIAN VISION FOR PUBLIC POLICY 85 (2004). This involves "redesigning the human condition, including such parameters as the inevitability of aging, limitations on human and artificial intellects, unchosen psychology, [and] suffering...." BERT GORDIJN & RUTH CHADWICK, MEDICAL ENHANCEMENT AND POSTHUMANITY 140 (2009). Posthumanism also frequently may involve enhancing humans through nanotechnology and cybernetics. For example, "individuals could have electronic brain implants to create human to computer interaction," which is a technology already in development. Lisa C. Ikemoto, *Race to Health: Racialized Discourses in A Transhuman World*, 9 DEPAUL J. HEALTH CARE L. 1101, 1112-1113 (2005), *citing* RAMEZ NAAM, MORE THAN HUMAN: EMBRACING THE PROMISE OF BIOLOGICAL ENHANCEMENT 181-187 (2005).

[85] George J. Annas et al., *Protecting the Endangered Human: Toward an International Treaty Prohibiting Cloning and Inheritable Alterations*, 28 AM. J. LAW MED. 151, 161-162 (2001).

[86] *Id.* at 162.

[87] *Id.*

[88] *Id.*

[89] Ikemoto, *supra* note 84, at 1102.

[90] *Id.* at 1112-1113.

[91] BILL MCKIBBEN, ENOUGH: STAYING HUMAN IN AN ENGINEERED AGE 47 (2002).

that just because we are born human does not mean that we are bound to remain that way.[92] Nonetheless, genetically engineered humans present a GCR/ER.

2. Nanotechnology

Nanotechnology involves manipulating materials or systems at the atomic, molecular, and supramolecular scales to create structures, devices, and systems with radical and novel properties.[93] Nanotechnology works on a scale of approximately 1-100 nanometers, with one nanometer being a billionth of a meter (10^{-9} m).[94] To put this in perspective, a red blood cell is 1,000 nanometers, a single DNA strand is 2 nanometers in diameter, and the width of a human hair is 100,000 nanometers.[95] While development of nanotechnology is nascent, nanotechnology research and development is massive, and many experts believe that nanotechnology will result in pervasive change in "all sectors and spheres of life," including "social, economic, ethical and ecological spheres."[96]

a. Current Technology

Researchers categorize nanotechnology into four generations. The first generation consists primarily of "nanomaterials" (or "passive nanostructures") and is already widely available in the global market. Nanomaterials includes nanoparticles, coatings, and nanostructured material[97] that are created by reducing "normal" materials to the nanoscale[98] and typically combining them with normal materials to improve their functionality,[99] making materials stronger, lighter, more flexible, or more conductive, amongst other desirable traits.[100] Nano-sized materials have fundamentally different properties from their normal-sized counterparts because the size of a particle affects that particle's properties; thus, for example, creating nanomaterials from gold creates a unique color, melting point, and chemical properties.[101] Already, over 800 products use nanomaterials,[102] accounting for $225 billion of

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[92] As Kevin Warwick, a posthumanism advocate, declared, "I was born human. But this was an accident of fate – a condition merely of time and place. I believe it's something that we have the power to change." COLSON & CAMERON, *supra* note 85, *citing* Kevin Warwick, *Cyborg 1.0*, WIRED 15 (2000). *See also* Ikemoto, *supra* note 84, at 1102.

[93] Renn & Roco, *supra* note 3, at 153.

[94] *Nanotechnology White Paper, supra* note 4, at 12.

[95] *Id.*

[96] *See* Renn & Roco, *supra* note 3, at 154.

[97] *Id.* at 153-156.

[98] Building nanomaterials from the "bottom up" is still being tested in laboratories; while scientists can successfully manipulate an individual atom, they have not achieved the ability to create construct technologies with "atomic precision," which is a central goal of nanotechnology scientists. *Frequently Asked Questions - Molecular Manufacturing*, FORESIGHT INSTITUTE, www.foresight.org/nano/whatismm.html

[99] J. CLARENCE DAVIES, OVERSIGHT OF NEXT GENERATION NANOTECHNOLOGY 11 (April 2009), *available at* www.nanotechproject.org/process/assets/files/7316/pen-18.pdf.

[100] Peter Kearns, *Nanomaterials: Getting the Measure*, OECD OBSERVER (2010), *available at:* http://www.oecdobserver.org/news/fullstory.php/aid/3291.

[101] *What's So Special About the Nanoscale*, NATIONAL NANOTECHNOLOGY INITIATIVE, http://www.nano.gov/you/nanotechnology-benefits (last visited April 21, 2012).

[102] *Nanotechnology and You: Benefits and Applications*, NATIONAL NANOTECHNOLOGY INITIATIVE, http://www.nano.gov/you/nanotechnology-benefits (last visited Feb. 04, 2012).

sales in 1999.[103] Such products include tennis rackets, sunscreen, stain-resistant pants, computer displays, paint, antimicrobial pillows, canola oil, non-stick pans, and various coatings and lubricants.[104] The construction industry foresees using nanomaterials to create stronger steel, bacteria-killing and fire-resistant materials, solar panels that generate more power, and energy-efficient lighting, which could increase the lifespan and lower the energy consumption of buildings.[105]

The second generation of nanotechnology, which currently only exists in laboratories, consists of "active nanostructure[s]"[106] that "change their behavior in response to changes in their environment," such as through "exposure to light" or the "presence of certain biological materials."[107] An example of the latter function is a nanodevice that targets the brain cells responsible for neuroinflammation to deliver pinpointed drugs as a potential treatment of cerebral palsy, as recently tested in rabbits.[108]

b. Forthcoming technology

The yet-unavailable third and fourth generations of nanotechnologies consist of complete nanosystems as opposed to mere nanotechnology components.[109] The third generation includes "three-dimensional nanosystems with heterogeneous nanocomponents" with "thousands of interacting components" that act like the parts to a sophisticated yet incredibly small machine.[110] And the fourth generation of nanotechnology consists of "heterogeneous molecular nanosystems" that operate "like a mammalian cell with hierarchical systems within systems," including technologies like molecular manufacturing and molecular nanorobotics (i.e. robots designed at the nanoscale).[111] This fourth generation of nanotechnology could spur widespread molecular manufacturing in which any designable product could be built with atomic precision, such as incredibly fast computers, nanorobots that perform a specific function, or complex machines.[112] Both third and fourth generation nanotechnology will focus on "bottom up" manufacturing rather than the "top down" approach, i.e. manufacturing nanotechnology on the molecular level rather than reducing existing materials to the nanoscale. The third and fourth

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[103] Cornelia Dean, *With Prevalence of Nanomaterials Rising, Panel Urges Review of Risks*, N.Y. TIMES (Jan. 25, 2012), *at:* http://www.nytimes.com/2012/01/26/science/nanomaterials-effects-on-health-and-environment-unclear-panel-says.html.

[104] *Nanotechnology White Paper, supra* note 4, at 11.

[105] *Nanomaterials Poised for Big Impact in Construction*, SCIENCE DAILY (Jul. 28, 2010), *at:* www.sciencedaily.com/releases/2010/07/100728121337.htm.

[106] *Frequently Asked Questions*, FORESIGHT INSTITUTE, *at:* www.foresight.org/nano/whatisnano.html (last visited March 02, 2012).

[107] J. CLARENCE DAVIES, *supra* note 99, at 11.

[108] *Nanotechnology-based Drug Treatment to Prevent Cerebral Palsy*, NANOWERK NEWS (Apr. 21. 2012), *at:* www.nanowerk.com/news/newsid=24972.php

[109] Mike Roco & Ortwin Renn, *Nanotechnology Risk Governance*, INT'L RISK GOVERNANCE COUNCIL (2006), *available at:* www.irgc.org/IMG/pdf/Chapter13_Nanotechnology__final.pdf.

[110] *Frequently Asked Questions*, FORESIGHT INSTITUTE, www.foresight.org/nano/whatisnano.html (last visited March 02, 2012); *What is Nanotechnology*, CENTER FOR RESPONSIBLE NANOTECHNOLOGY, *at:* www.crnano.org/whatis.htm (last visited March 14, 2012).

[111] *Frequently Asked Questions*, FORESIGHT INSTITUTE, *at:* www.foresight.org/nano/whatisnano.html (last visited March 02, 2012).

[112] *Powerful Products of Molecular Nanotechnology*, CENTER FOR RESPONSIBLE NANOTECHNOLOGY, www.crnano.org/products.htm (last visited Apr. 21, 2012).

generations of nanotechnology only exist in computer experiments and models,[113] but they are expected to be developed in the coming few decades.[114]

c. Benefits of nanotechnology

Nanotechnology is set to "have a significant impact on drug delivery, computing, communications, defense, space exploration, and energy," thus governments are spending significant amounts of money on nanotechnology research and development.[115] By testing different combinations and sizes of nanomaterials to fine-tune their desired effect,[116] materials can be lighter and stronger, resistant to bacteria, scratch proof, and hold superior charges.[117] Scientists have already created a variety of materials to benefit the environment: a paper towel for oil spills capable of absorbing 20 times its mass of oil by utilizing nanomaterials with enhanced absorption properties, thin and flexible solar panel films (perhaps one day even "paintable"), more efficient lithium-ion batteries, and superior windmill blades made of carbon nanotubes.[118] To benefit human health, 80 percent of cars already have nanomaterial filters to remove certain harmful particles from the air, and scientists are developing a filter that can remove viruses from water.[119] In the future, scientists predict that nanotechnology could also locate and deliver pinpointed treatment to cancer cells by creating "gold-coated nanoparticles" that target cancer cells and destroy then when heated by electromagnetic frequencies (as scientists tested at Rice University[120]), restore damaged cells to slow aging by molecularly engineering nanomedicines,[121] and increase solar efficiency by a factor of one hundred by developing materials with optimum light-absorption and energy conversion.[122]

d. Risks from nanotechnology

Currently, most apprehension over nanotechnology involves first generation nanomaterials, whose toxicity, potential to bioaccumulate, and health effects from exposure is generally unknown.[123] One concern is that nanoparticles are smaller in size than natural particles, and thus they may have an increased potential to permeate the lungs and blood vessels of humans and animals.[124] Another concern is that nanotechnology could have negative ecotoxilogical

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[113] *Id*.
[114] *See What is Nanotechnology*, CENTER FOR RESPONSIBLE NANOTECHNOLOGY, *at:* www.crnano.org/whatis.htm (last visited March 14, 2012).
[115] In the United States, for examples, the 21st Century Nanotechnology Research and Development Act allocated $3.7 billion over four years to nanotechnology research and development. Robert D. Pinson, *Is Nanotechnology Prohibited by the Biological and Chemical Weapons Conventions?*, 22 BERKELEY J. INT'L L. 279, 288 (2004).
[116] *What's So Special About Nanoscale*, NATIONAL NANOTECHNOLOGY INITIATIVE, http://www.nano.gov/you/nanotechnology-benefits (last visited April 21, 2012).
[117] *Benefits and Applications*, NATIONAL NANOTECHNOLOGY INITIATIVE, http://www.nano.gov/you/nanotechnology-benefits (last visited March 02, 2012).
[118] *Id.*
[119] *Id.*
[120] J. CLARENCE DAVIES, *supra* note 99, at 12.
[121] Theodoros Manfredi, *Nanotechnology in Medicine*, HEALTH GUIDANCE, www.healthguidance.org/entry/15895/1/Nanotechnology-in-Medicine.html (last visited May 01, 2012).
[122] Pinson, *supra* note 115*,* at 288.
[123] Renn & Roco, *supra* note 3, at 153-156 (2006)
[124] Kenneth Donaldson, *Engineered Nanoparticles: Understanding and Managing Potential Risks*, *in* NANOMATERIALS, SCIENCE FOR ENVIRONMENT POLICY (European Commission: 2009), *available at:* http://ec.europa.eu/environment/integration/research/newsalert/pdf/12si.pdf.

effects, for example by passing through the cell walls of fungi, algae, and bacteria; inhibiting photosynthesis and respiration in plants; or being unnaturally persistent in the environment.[125] Furthermore, preconceptions of the safety of the materials from which nanomaterials are derived do not accurately predict how their nanoparticle equivalent will act because nanomaterials can have unique toxicity, reactivity with other chemicals, persistence, and other qualities.[126] Overall, nanomaterials may pose a GCR because if nanomaterials become pervasive in consumer goods, building materials, and so forth, and they turn out to have a highly negative effect on health and the environment, then this may cause "serious damage to human well-being" on the global scale and thus constitute a GCR. However, they do not seem to pose an ER because toxic and harmful substances will not likely make humans go extinct or severely and permanently damage the future quality life of humans.

In the future, however, nanotechnology has immense ethical, health, and environmental implications, and several scenarios indicate the presence of both a GCR and an ER. For example, one risk is that nanotech "organisms," like an omnivorous bacteria constructed atom-by-atom, will out-compete their natural counterparts, causing unknown ecological effects.[127] Furthermore, because third and fourth generation nanotechnology will likely be designed to self-replicate in order to obtain meaningful amounts of particular nanotechnologies,[128] self-replicating nanotechnology (nanorobots, perhaps) could either mutate or be maliciously released such that they cause significant harm to humans and the environment. If such self-replication became uninhibited, a chain reaction of self-replication could significantly increase the potential damage to humans and the environment, or even engulf the entire Earth in a mass of self-replicating matter known as "grey goo."[129]

On the other hand, others argue that self-replication of nanotechnology is extremely unlikely to occur, and that the more imminent threat from nanotechnology arises from incredibly destructive weapons developed with nanotechnology.[130] Such nanotech weapons could be "more powerful than any known chemical, biological, or nuclear agent" and very difficult to detect.[131] For this reason, some commentators point out the possibility of a "nanotechnology arms race," which poses risks of state or non-state actors intentional using nanotech weapons or of accidents involving weapons development.[132] The international community's inability to eliminate the nuclear weapons programs of North Korea and possibly Iran highlights the complications of curtailing vastly powerful and destructive weapons once they are possessed by some states. Overall, future nanotechnology developments present several GCRs/ERs from both accidental and intentional uses.

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[125] Enrique Navarro, *Discovering How Nanoparticles Affect the Environment*, *in* NANOMATERIALS, SCIENCE FOR ENVIRONMENT POLICY (European Commission: 2009), *available at:* http://ec.europa.eu/environment/integration/research/newsalert/pdf/12si.pdf.

[126] Jose Lopez, *Bridging the Gaps: Science Fiction in Nanotechnology*, 10 INT'L J FOR PHILOSOPHY AND CHEMISTRY 129-152 (2004).

[127] Eric Drexler, ENGINES OF CREATION: THE COMING ERA OF NANOTECHNOLOGY (1986), available *at:* http://e-drexler.com/d/06/00/EOC/EOC_Chapter_11.html.

[128] *See Id.* at 304.

[129] DAVIES, *supra* note 99, at 18.

[130] Paul Rincon, *Nanotech Guru Turns Back on 'Goo'*, BBC (June 09, 2004)

[131] Pinson, *supra* note 115*,* at 281.

[132] *See Id.* at 288.

3. Artificial Intelligence

One common definition of AI is "the science of making machines do tasks that humans can do or try to do."[133] While much of society's association of AI arises from fictional film and literature—*2001: A Space Odyssey; I, Robot*; and the *Terminator* series all portray AI in a dangerous light—experts predict that many of the premises behind such science fiction will occur: computers with intelligence similar to or greater than humans, robotic warfare, vehicles operated by computers, and so forth. While AI may prove to benefit society immensely, many experts believe there is a risk of GCR/ER from highly sophisticated AI.

a. Current Technology

While AI is currently nowhere near the level that would pose a GCR/ER, several milestones show progress towards creating computers with immense AI. For example, a robot named Data does comedy routines in front of live audiences and is able to respond to the reaction of the crowd and adjust its comedy routine in real-time.[134] Neural "cochlear" implants—computer devices that translate sound and transmit it into the brain—provide hearing to individuals who are deaf.[135] Google developed a car that is automatically driven by computers, which has already logged 140,000 miles.[136] And supercomputers with AI defeated humans at games of great intellect and rational thinking: The IBM supercomputer Watson, which analyzes "200 million pages of information" in a mere three seconds, defeated several former champions on Jeopardy, and the IBM supercomputer Deep Blue defeated grandmaster Garry Kasparov at chess.[137]

Meanwhile, several educational institutes are already entirely dedicated to advancing AI. For example, the Singularity University, hosted by NASA and founded in part by Google, seeks to develop AI to "solve humanity's grand challenges,"[138] while the Singularity Institute for AI ("Singularity Institute"), established in part by former Pay Pal CEO Peter Thiel, teaches graduate students and executives about AI and engages in AI research and development.[139]

b. Forthcoming Technologies

Perhaps the most significant emerging AI technology arises out of the concept of "the Singularity," which is "the technological creation of smarter-than-human intelligence."[140] The basic premise of the Singularity is that if humans create a superhuman AI, then this superior mind could create a *more* superior mind, beginning a feedback loop that would cumulate in a

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[133] James F. Allen, *AI Growing Up: The Changes and Opportunities*, 19 AI MAGAZINE 13, 17 (1998).
[134] Todd Leopold, *Roboticist Sees Improvisation Through Machine's Eyes*, CABLE NEWS NETWORK (CNN) (Feb. 03, 2012), *at:* http://www.cnn.com/2012/02/03/living/creativity-improvisation-intelligence-heather-knight/index.html.
[135] Emily Singer, *Growing Neural Implants*, TECHNOLOGY REVIEW (July 16, 2008), *available at:* www.technologyreview.com/biomedicine/21087.
[136] Samuel Axon, *Google is Testing Cars that Drive Themselves*, CNN (Oct. 11, 2010), *at:* www.cnn.com/2010/TECH/innovation/10/11/google.testing.cars.mashable/index.html.
[137] Sam Gustin, *IBM's Watson Computer Heads to Wall Street for Post-Jeopardy Gig*, TIME (Mar. 7, 2012), *at:* http://business.time.com/2012/03/07/ibms-watson-supercomputer-heads-to-wall-street.
[138] Overview, SINGULARITY UNIVERSITY, *at:* http://singularityu.org/about/overview/ (last visited Feb. 5, 2012).
[139] Lev Grossman, *2045: The Year Man Becomes Immortal*, TIME MAGAZINE (Feb. 10, 2011), *at:* http://www.time.com/time/magazine/article/0,9171,2048299-2,00.html.
[140] *Overview: What is the Singularity?*, SINGULARITY INSTITUTE FOR ARTIFICIAL INTELLIGENCE, *at:* http://singinst.org/overview/whatisthesingularity (last visited Jan. 31, 2012).

near godlike intelligence.[141] Such "superintelligence" could feasibly think one million times faster than the human brain and even rewrite its own code to "recursively self-improve."[142] And humans themselves could be enhanced through "direct brain-computer interfaces" or "biological augmentation of the brain."[143]

Admittedly, superhuman AI seems a long way off: A recent study measuring the ability of the human brain to store, communicate, and compute information concluded that the processing power of the human brain is equivalent to the combined processing power of all general-use computers in the world in 2007.[144] However, some scientists predict an "intelligence explosion" in machines during the 21st century. Raymond Kurzweil, an MIT graduate with 19 honorary doctorates who was awarded the National Medal of Technology by Bill Clinton and who Bill Gates says is the best predictor of future AI he knows, forecasts that the Singularity will occur by 2045 at a level "about [one] billion times the sum of all the human intelligence that exists today" based on a model of exponential growth in technology.[145] Before then, predicts Kurzweil, humans will "reverse-engineer the human brain by the mid-2020s," and by the end of the 2020s, "computers will be capable of human-level intelligence."[146] On the other hand, others, like biologist Denis Bray, argue that the unique biochemical processes in the human body far supersede the programmable mind of a robot.[147]

c. Benefits of artificial intelligence

Current practical applications of AI include the unmanned navigation of cars; consumer protection, like discovering credit card fraud; educational advancement; medical technology; and data mining and analysis.[148] And in the future, superintelligent machines could benefit mankind by helping "eradicate diseases, avert long-term nuclear risks, and live richer more meaningful lives."[149] Ethicist Michael Ray LaCha argues that AI will be "morally perfect" and that humans

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[141] *Id.* I.J. Good, a British mathematician, cryptologist, and computer engineer, first came out up with the idea of an "intelligence explosion" in 1965. According to I.J. Good, "[s]ince the design of machines is one of these intellectual activities, an ultraintelligent machine could design even better machines; there would then unquestionably be an 'intelligence explosion,' and the intelligence of man would be left far behind. Thus the first ultraintelligent machine is the last invention that man need ever make." *Hear That? It's the Singularity Coming*, SENTIENT DEVELOPMENTS (June 29, 2011), *at:* www.sentientdevelopments.com/2011/06/hear-that-its-singularity-coming.html.

[142] *Overview: What is the Singularity?*, SINGULARITY INSTITUTE FOR ARTIFICIAL INTELLIGENCE, *at:* http://singinst.org/overview/whatisthesingularity (last visited Jan. 31, 2012).

[143] *Id*.

[144] Todd Leopold, *Roboticist Sees Improvisation Through Machine's Eyes*, CABLE NEWS NETWORK (CNN) (Feb. 03, 2012), *at:* http://www.cnn.com/2012/02/03/living/creativity-improvisation-intelligence-heather-knight/index.html.

[145] Kurzweil developed an exponential curve that predicts "change over time in the amount of computing power, measured in MIPS (millions of instructions per second), that you can buy for $1,000." Like the famous Moore's law, the figure doubled roughly every two years. Kurzweil ran the model backwards to the year 1900 and it still held true. Then he checked it against "the falling cost of sequencing DNA and of wireless data service and the rising numbers of Internet hosts and nanotechnology patents," which confirmed the exponential growth of his model. Grossman, *supra* note 139.

[146] *Id.*

[147] *Id.*

[148] David B. Leake, *Artificial Intelligence* (2002), *at:* www.cs.indiana.edu/~leake/papers/p-01-07/p-01-07.html (last visited Mar. 30, 2012); *see also* Matthew Stone & Haym Hirsh, *Artificial Intelligence: The Next Twenty-Five Years*, 26 AI MAGAZINE 85, 87 (2005).

[149] *Reducing Long-Term Catastrophic Risks from Artificial Intelligence*, THE SINGULARITY INSTITUTE, *at:* http://singinst.org/summary (last visited Mar. 10, 2012).

may rely on AI to make moral decisions.[150] An example of this would be relying on AI to decide whether going to war is likely to result in a net positive benefit to society. Meanwhile, many proponents of AI believe the Singularity to be of paramount importance in the future of the Earth—as significant as the "first self-replicating chemical that gave rise to life on Earth," according to some[151]—because such superintelligence would feasibly develop revolutionary technologies at a rapid pace, such as by discovering cures for all diseases or inventing new means to produce extraordinary amounts of food.[152] Others purport that AI could manage society without the "[c]onflicts of interest, flawed judgment, lack of information, or political considerations" that result in flawed human decisionmaking because AI could have a knowledge vastly superior to humans and could be programmed to act without human bias.[153]

d. Risks from artificial intelligence

AI poses a GCR/ER even if the chance of this risk materializing is enormously low. While some argue that humans need AI for their long-term survival,[154] others argue that superhuman AI presents the foremost challenge to the future existence of humans.[155] Assuming that humans develop highly intelligent AI, proponents of the technology argue that coding AI to be inherently friendly and possess moral values ("Friendly AI") mitigates any risks.[156] However, some individuals and corporations may derogate from Friendly AI principles, which would present the risk of creating a dangerous form of AI.[157] The difficulties of regulating vastly powerful technologies that could benefit society but also risks massive destruction is evident from current politics involving Iran's development of nuclear technologies, which Iran claims is for use as an energy source, but most of the international world believes is to develop weapons.[158] Furthermore, AI could suffer a "mechanical failure" in which AI does not work as designed and therefore presents unpredictable risks to mankind.[159] Finally, anticipating and controlling the outcome of highly intelligent AI is difficult,[160] especially if AI is "self-improving" and thus able to alter its own programming.[161]

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[150] WENDELL WALLACH & COLLIN ALLEN, MORAL MACHINES: TEACHING ROBOTS RIGHT FROM WRONG 194 (2009).
[151] *Overview: What is the Singularity?*, SINGULARITY INSTITUTE FOR ARTIFICIAL INTELLIGENCE, *at:* http://singinst.org/overview/whatisthesingularity (last visited Jan. 31, 2012).
[152] *Why Work Toward the Singularity*, THE SINGULARITY INSTITUTE, *at:* singinst.org/overview/whyworktowardthesingularity (last visited Apr. 21, 2012).
[153] *Benefits of the Singularity*, SINGULARITY ACTION GROUP, *at: home.mchsi.com/~deering9/benefits.html* (last visited Mar. 12, 2012).
[154] Michael Anissimov, *Interview with Robin Powell, Singularity Institute Advocate*, THE SINGULARITY INSTITUTE (Jan 12, 2012), *at:* singinst.org/blog/2012/01/12/interview-with-robin-powell-singularity-advocate.
[155] BOSTROM & ĆIRKOVIĆ, *supra* note 10, at 33.
[156] *Reducing Long-Term Catastrophic Risks from Artificial Intelligence*, THE SINGULARITY INSTITUTE, *at:* http://singinst.org/summary (last visited Mar. 10, 2012).
[157] WALLACH & ALLEN, *supra* note 150, at 194-195.
[158] *See Iran and Its Nuclear Program*, AMERICAN SECURITY PROJECT, *at:* americansecurityproject.org/issues/nuclear-security/iran-and-its-nuclear-program (last visited Apr. 21, 2012).
[159] Eliezer Yudkowsky*, Artificial Intelligence as a Positive and Negative Factor in Global Risk* (2006), *available at:* singinst.org/upload/artificial-intelligence-risk.pdf.
[160] Kaj Sotala, *From Mostly Harmless to Civilization-Threatening: Pathways to Dangerous Artificial General Intelligences*, SINGULARITY INSTITUTE FOR ARTIFICIAL INTELLIGENCE (2010), *at:* http://singinst.org/upload/mostly-harmless.pdf.
[161] *Id.*

One specific risk from AI is that highly-intelligent computers may be subject to errors, collapses, viruses, or other unforeseen developments that compromise their ability or intent to properly manage, for example, nuclear weapons, transportation, or other major elements of society.[162] A related risk is that a programming error could give AI the imperative to destroy mankind, or that AI's "benevolent" goals may be conflicting with the interests of humans.[163] If this occurs, AI may have the ability to wipe out humans if they are intellectually superior to humans.[164] Another risk is that AI would out-compete humans because of the pressures of evolution and self-preservation, which may compel AI to contest humans for scarce resources.[165] Finally, there is the risk that humans will undergo a calculated self-termination as humans opt to transcend our biological forms and be "transferred" to machines as "post-humans."[166] Overall, there is a clear GCR/ER from AI.

4. The Large Hadron Collider

The Large Hadron Collider (LHC) is a recent example of a failure of the legal system to properly consider what some scientists believed to be a GCR and an ER from a radical new technology. In September 2008, after fourteen years and, according to mid-range estimates, at least $8 billion dollars spent,[167] the European Organization for Nuclear Research[168] (CERN) began using the world's most powerful particle accelerator. The LHC accelerates protons or, more recently, lead ions, in opposite directions around a massive vacuumed track, about 27 kilometers (approximately 17 miles) in circumference and 50 to 175 meters underground, which the magnet-guided particles whip around at 99.99999 percent speed of light[169] (clocking in about 11,000 laps of 27 kilometers every second)[170] as they continuously smash together at up to 7 trillion electron volts[171] at four points of intersection—thereby creating exotic particles, evidently even the coveted Higgs boson—for hours at a time.[172] Most scientists throughout the world rejoiced at creating a particle accelerator seven times the energy of its nearest competitor, the Tevatron particle accelerator at the Fermi National Accelerator Academy in Illinois, and which has created "sub-atomic fireballs with temperatures of over ten trillion degrees [centrigrade], a

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[162] *See* JOHN LESLIE, THE END OF THE WORLD: THE SCIENCE AND ETHICS OF HUMAN EXTINCTION 95-103 (1998).
[163] Sotala, *supra* note 160.
[164] ROBERT H. SCHRAM, ILLUSAFACT: THE INEVITABLE ADVANCE OF OUR TECHNOLOGIES AND US 272-273 (2011).
[165] *Id.* at 273.
[166] *See* LESLIE, *supra* note 162, at 95-103.
[167] Others estimate just the "hardware" of the LHC as costing approximately $10 billion and the entire LHC program – including costs to "[operate] the experiment and [analyze] the data" – being "much greater." *See* Eric E. Johnson, *The Black Hole Case: The Injunction Against the End of the World*, 76 TENN. L. REV. 819, at 827 (2008-2009).
[168] "Organisation européenne pour la recherche nucléaire" in French.
[169] *See LHC Machine Outreach (Homepage)*, EUROPEAN ORG. FOR NUCLEAR RESEARCH (CERN), *AT:* http://lhc-machine-outreach.web.cern.ch/lhc-machine-outreach (last visited Feb. 04, 2012).
[170] *Id.*
[171] Judith Burns, *LHC to Shut Down for a Year to Address Design Faults*, BBC NEWS (Mar. 10, 2010), *at:* http://news.bbc.co.uk/2/hi/8556621.stm.
[172] Mike Lamont, *Explain it in 60 Seconds: The Large Hadron Collider*, SYMMETRY (Apr. 2005), *at:* http://www.symmetrymagazine.org/cms/?pid=1000095.

million times hotter than the [center] of the Sun"[173] that "[recreates] conditions … only a trillionth of a second after the Big Bang."[174]

Many scientists held their breath for the LHC to "reveal the origins of mass, shed light on dark matter, uncover hidden symmetries of the universe, and possibly find extra dimensions of space."[175] However, others feared that the accelerator could create a black hole to gobble up the Earth or "[convert] all the [Earth's] matter into a super-dense glob called a 'strangelet.'"[176] Scientists in the latter category attempted to seek court review of the LHC in a variety of international and domestic courts but to no success. In this regards, the following subsections highlight two problems with current international regulations of advanced technologies that may pose a GCR/ER: first, the difficulty of getting a court to consider a minority opinion in a highly complex scientific case, and second, the potential bias of scientists as risk assessors.

a. Difficultly in getting a court to consider the case

The LHC highlights the problems with traditional courts serving as risk assessors for a groundbreaking technology, i.e. one that has never been tested before.[177] While some scientists and other individuals sought injunctions from various national and international judicial bodies against operating the LHC—including a Swiss court,[178] the European Court of Human Rights (ECtHR),[179] the U.S. Ninth Circuit Court of Appeals,[180] the German Constitutional Court,[181] the International Security Court,[182] and the Administrative Court of Cologne[183]—all such attempts failed for a variety of reasons discussed below.

In the United States, Walter L. Wagner, a nuclear physicist, and Luis Sancho, founder of Citizens Against the Large Hadron Collider, failed in their bid to enjoin operation of the LHC in the case *Sancho v. U.S. Department of Energy*. The Ninth Circuit Court of Appeals, reviewing *de novo* the District Court of Hawaii's decision to deny standing for lack of subject matter jurisdiction,[184] ruled that, *inter alia*, Wagner does not have standing because he could not

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[173] Katia Moskvitch, *Large Hadron Collider (LHC) Generates a 'Mini-Big Bang'*, BBC NEWS (Nov. 8, 2010), *at:* http://www.bbc.co.uk/news/science-environment-11711228.
[174] Dennis Overbye, *Protons and Champagne Mix as New Particle Collider Is Revved Up*, N.Y. TIMES (Sept. 11, 2008).
[175] Samuel J. Adams, *"Honey I Blew Up the World!,"* 38 GA. J. INT'L & COMP. L. 131, 137 (2009), *citing Boston Physicists Celebrate First Beam for Large Hadron Collider*, J. TECH. & SCI. at 269 (Sept. 28, 2008).
[176] *Id.* at 133, *citing* Dennis Overbye, *Asking a Judge to Save the World, and Maybe a Whole Lot More*, N.Y. TIMES (Mar. 29, 2008), *at:* http://www.nytimes.com/2008/03/29/science/29collider.html.
[177] *Id.* at 134, *citing* Dennis Overbye, *The End is Nigh! A Big Stakes Suit to Save Us All*, INT'L HERALD TRIB. 2 (Mar. 31, 2008).
[178] Eben Harrell, *Collider Triggers End-of-World Fears*, TIME MAGAZINE (Sept. 04, 2008), *at:* www.time.com/time/health/article/0,8599,1838947,00.html.
[179] *Id.*
[180] *Sancho*, 392 F. App'x 610.
[181] Alan Gillis, *Interview: Professor Otto Rössler Takes On The LHC*, SCIENCE 2.0 (Aug. 12, 2008), *at:* www.science20.com/big_science_gambles/blog/interview_professor_otto_rössler_takes_lhc-31449.
[182] Otto E. Rössler, *Summary of My Scientific Results on the LHC-Induced Danger to the Planet*, LIFEBOAT FOUNDATION (Jan. 30, 2011), *at:* lifeboat.com/blog/2011/01/summary-of-my-scientific-results-on-the-lhc-induced-danger-to-the-planet.
[183] *Id.*
[184] The U.S. District Court of Hawaii dismissed the case for lack of subject matter jurisdiction or else on standing grounds.[184] The Court reasoned that the U.S. government's involvement with the LHC did not qualify as a "major

establish an injury in fact. According to the Court, Wagner's claim demonstrated, at most, "*potential* adverse consequences," which falls short of the standing requirement of a "*credible* threat of harm" because the risk of the obliteration of the Earth is too speculative.[185] However, advanced technologies that pose a GCR/ER are often highly improbable but result in catastrophic consequences if such risks materialize, thus GCRs/ERs are nearly impossible to challenge in the U.S. judicial system without consideration of the magnitude of their risks.

Operation of the LHC was also challenged in Europe. The German Constitutional Court rejected the claims of Gabriele Schröter—a biochemist who has published over 300 papers and who is known by some as the "father of Chaos theory"—because the Court believed that theories of mini-black holes or "strange matter" were unsubstantiated and theoretical, although the Court did recommend a conference on LHC safety issues.[186] Meanwhile, the ECtHR rejected German scientist Dr. Otto Rössler's attempt to enjoin the LHC without stating a reason for their decision.[187]

Notably, none of these courts had any expertise in science, so whether they could properly assess the associated risks is questionable. Although many judges have shown the ability to assess scientific principles, oftentimes a thorough understanding of a scientific topic requires cross-examination and other procedures in full-fledged court proceedings,[188] and thus dismissing a case before the testimony develops truly compromises the consideration that minority science receives. Furthermore, judges who receive scientific training are better able to weigh conflicting scientific evidence and judge methodological problems in scientific research presented to the court.[189]

Overall, these test cases demonstrate that the neither domestic nor international courts are equipped to handle disputes involving low-probability, high consequence advanced technologies. There seems to be no court that offers judicial relief for such situations, despite the fact that if a GCR/ER materializes, the lives of a huge amount of people are at stake.[190] While courts may rely upon the political process to mitigate such risks,[191] emerging technologies are becoming increasingly widespread and privatized, and the political process thus far has been insufficient to create sufficient safeguards from these risks.

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federal action" under § 4332(2)(c) of the National Environmental Policy Act (NEPA). *See Sancho v. U.S. Department of Energy,* 578 F.Supp.2d 1258 (D. Haw. 2008).

[185] *Sancho*, 392 F. App'x at 611.

[186] Gillis, *supra* note 181.

[187] Dr. Otto Rössler sought an emergency injunction from the European Court of Human Rights (ECtHR) for alleged violations of (1) the right to life under Article 2 of the European Convention on Human Rights (ECHR) and (2) the right to private and family life under Article 8 of the ECtHR. *See* LHC Critique, *Summary of the (Renewed) Complaint Against CERN and the LHC Experiments as Submitted to the European Court of Human Rights*, available at: lhc-concern.info/wp-content/uploads/2008/11/cern-lhc-kritik-statement-1-summary.pdf; *see also* Adams, *supra* note 175, at 152 (2009). The ECtHR rejected Dr. Dr. Otto Rössler's injunction requests via a "brief e-mail" that did not include any reasoning, and while the ECtHR stated that it will hear the case on the merits,[187] the author cannot find any information on such a pending case. *See* Harrell, *supra* note 179.

[188] Margaret Kovera et al., *The Effects of Peer Review and Evidence Quality on Judge Evaluations of Psychological Science: Are Judges Effective Gatekeepers?*, 85 J. OF APPLIED PSYCHOLOGY 574, 585 (2000).

[189] *See id.; see also* FEDERAL JUDICIAL CENTER, REFERENCE MANUAL ON SCIENTIFIC EVIDENCE 3-4 (2000).

[190] Adams, *supra* note 175, at 136.

[191] The U.S. District Court of Hawaii ruled that the political process, not NEPA, was the proper forum for handling the risks of the LHC. *Sancho,* 578 F.Supp.2d at1269.

b. Potential bias from CERN scientists as risk assessors

While scientists often reassure the public that GCRs/ERs from emerging technologies are nonexistent or negligible, some critics warn that scientists are unreliable risk assessors of their own work because financial incentives, career pressures,[192] and competition among competing groups of scientists taint their judgment.[193] Despite these inherent conflicts of interests, almost all of the LHC safety reports came from CERN scientists.[194] Two such CERN reports discussed various alleged risks of the LHC, but they did not weigh the probability of a GCR/ER against the value of operating the LHC.[195] While the reports concluded that operation of the LHC presented no danger,[196] at least *some* experts doubt this conclusion. For example, revered scientist Martin Rees quantified the risk of a global catastrophe arising from the LHC as being about one in 50 million,[197] whereas Toby Ord of Oxford University estimated the risk of a disaster as falling somewhere between one in 10,000 and 1,000,000.[198] While the differences in these estimates show the difficulty in estimating some GCRs/ERs, they obviously contradict the "no danger" conclusion of CERN and highlight the need for courts to consider unbiased scientific information in making decisions concerning low-probability GCRs/ERs.

While the operation of the LHC has not caused worldwide destruction, there have still been several accidents that, for some, put the reliability of CERN's assurances into doubt. The first incident occurred only nine days after the LHC began operating in 2008, when a "faulty electrical connection between two of the accelerator's magnets"[199] melted, causing one ton of helium to blast into the tunnel[200] and shutting down the LHC for 14 months.[201] The mistake in question was described by some as "basic" and should have been discovered during "four

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[192] For example, scientists may fear "reprisals and negative consequences" for challenging their superiors, or they may not want to squander large financial investments in scientific research. *See* Eric E. Johnson, *Culture and Inscrutable Science: An Analytical Method for Preliminary Injunctions in Extreme Cases,* PRAWFSBLAWG (Oct. 24, 2008), *at:* http://prawfsblawg.blogs.com/prawfsblawg/2008/10/culture-and-ins.html.

[193] One possible example of a technological arms race comes from the world's most powerful particle accelerator, the Large Hadron Collider. A scientist working on the project remarked that a temporary shutdown could enable a competing particle accelerator to beat them out to discovering the coveted Higgs boson. *See* Jonathan Leake, *Big Bang at the Atomic Lab After Scientists Get Their Maths Wrong*, SUNDAY TIMES (U.K.) (Apr. 8, 2008), *as cited by* Adams, *supra* note 175, at 136.

[194] *See e.g.* LHC SAFETY ASSESSMENT GROUP, REVIEW OF THE SAFETY OF LHC COLLISIONS (2008), *available at:* lsag.web.cern.ch/lsag/LSAG-Report.pdf (reaffirming a 2003 report that LHC presents no danger of "phenomena like a vacuum bubble," "stable and neutral black holes" and "strangelets"). Independent scientists eventually reviewed at least one such report at a later date. Richard Gray, *Legal Bid to Stop CERN Atom Smasher from 'Destroying the World,*" THE TELEGRAPH, *at:* http://www.telegraph.co.uk/news/worldnews/europe/2650665/Legal-bid-to-stop-CERN-atom-smasher-from-destroying-the-world.html.

[195] Dennis Overbye, *Gauging a Collider's Odds of Creating a Black Hole*, N.Y. TIMES (Apr. 15, 2008), *at:* http://www.nytimes.com/2008/04/15/science/15risk.html, *as cited by* Adams, *supra* note 175, at 134.

[196] Scientific Policy Committee, *SPC Report on LSAG Documents*, CERN (2009), *available at:* http://indico.cern.ch/getFile.py/access?contribId=20&resId=0&materialId=0&confId=35065.

[197] *Scientists: Nothing to Fear from Atom-Smasher*, THE ASSOCIATED PRESS (June 29, 2008), *at:* http://www.usatoday.com/tech/science/2008-06-28-atom-smasher_N.htm.

[198] Toby Ord et al., *Probing the Improbable: Methodological Challenges for Risks with Low Probabilities and High Stakes*, J. OF RISK RESEARCH 13(2) 191–205 (2010).

[199] Control Engineering Staff, *CERN Accident Findings Released*, CONTROL ENGINEERING (Dec. 01, 2008), *at:* http://www.controleng.com/search/search-single-display/cern-accident-findings-released/f9743ada37.html.

[200] Burns, *supra* note 172 (referring to the comments of Gerald Warner).

[201] *Id.*

engineering reviews."[202] This oversight caused some commentators to worry about mistakes in the mechanics or risk assessment of the LHC that could have more devastating results.[203]

Overall, this brief case study demonstrates that self-assessments of safety by scientists intimately involved with a project should be doubted. Therefore, an independent risk assessment should be a mandatory element of engaging in emerging technologies that pose a GCR/ER.

III. BIOENGINEERING AND INTERNATIONAL LAW

Despite the low probably but extremely high risk of global catastrophe posed by bioengineering, nanotechnology, and AI, international law has done very little to limit these risks. This section focuses solely on the emerging technology of bioengineering as a GCR/ER under international law because, unlike nanotechnology and AI, the current level of available bioengineering science already presents a GCR/ER. Furthermore, nanotechnology and AI are essentially unregulated at international law, whereas international law regulates some forms of bioengineering at least to some extent. After discussing several binding and non-binding international law instruments, this section demonstrates that there is no binding international regime that sufficiently addresses trade in bioengineered food, much less the GCRs/ERs arising out of risks posed by other forms of bioengineering, such as a potentially highly deadly bioengineered organism or a genetically engineered human.

A. Convention on Biological Diversity

The Convention on Biological Diversity (CBD) functions to conserve biological diversity, sustainably use the components of biodiversity, and share the benefits of genetic resources in a fair and equitable way.[204] Based on this objective, bioterrorism and genetically engineered humans do not fall neatly within objectives of the CBD. Nonetheless, a failure to mitigate GCRs/ERs arising from the accidental release of dangerous bioengineered organisms from a laboratory seems to fall within the biotechnology provisions of Article 8 of the CBD. Article 8 of the CBD states that each Party *shall* (meaning mandatory as opposed to discretionary), "as far as possible and appropriate,"

> (g) Establish or maintain means to regulate, manage or control the risks associated with the *use and release* of living modified organisms resulting from biotechnology which are likely to have adverse environmental impacts that could affect the conservation and sustainable use of biological diversity, taking also into account the risks to human health…[205]

First, Article 8(g) establishes an affirmative duty of parties to "regulate, manage or control" the use and release of living modified organisms (LMOs), and thus a failure to properly regulate the actions of private laboratories could breach this provision. Second, while the CBD does not define "LMOs," the Cartagena Protocol on Biosafety to the Convention on Biological

[202] Adams, *supra* note 175, at 137.
[203] *Id.*
[204] Convention on Biological Diversity, June 5, 1992, 1760 U.N.T.S. 79, 143; 31 I.L.M. 818 (1992), art. 1 [hereinafter CBD].
[205] *Id.* at art. 8(g) (emphasis added).

Diversity ("Cartagena Protocol") defines LMOs as "any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology".[206] Highly fatal bioengineered organisms possess a "novel combination of genetic material" obtained through biotechnology by the plain meaning of the language, thus they are LMOs. Third, while the act of bioengineering deadly organisms in a laboratory does not constitute a "release" of LMOs into the environment (to the contrary, such organisms are contained within a laboratory), bioengineered organisms in a laboratory do seem to qualify as a "use" of an LMO under Article 8(g). Although the term "use" is not defined in the CBD, bioengineering organisms in a laboratory clearly fall within the definition of "contained use" from the Cartagena Protocol ("any operation, undertaken within a facility … which involves LMOs that are controlled by specific measures that effectively limit their contact with, and their impact on, the external environment").[207] Because the broader term "use" in the CBD likely encapsulates the term "direct use" from the Cartagena Protocol, bioengineering organisms in a laboratory qualifies as a "use" within the meaning of the CBD.[208] Therefore, GCRs/ERs arising from bioengineering do seem to fall within Article 8(g) of the CBD.

While Article 8(g) seems to require parties to "regulate, manage, or control" highly fatal bioengineered organisms, the effectiveness of the CBD in mitigating GCRs/ERs arising out of bioengineering is severely limited because the provisions do not establish specific actions that Parties must take. For example, measures like laboratory safety requirements, training of individuals handling highly fatal bioengineered organisms, or laboratory monitoring requirements are all absent from the CBD. Although the Cartagena Protocol significantly elaborates on biosafety issues, the subsequent section concludes that they are too-trade focused and discretionary to provide meaningful protection.[209] Furthermore, even if the CBD did impose specific requirements upon Parties, the CBD does not include an enforcement mechanism, and thus enforcing the provisions upon unwilling Parties would prove difficult. In conclusion, while GCRs/ERs arising from bioengineering seem to fall within the CBD, the CBD is not an effective means of mitigating these risks.

B. Cartagena Protocol on Biosafety

The Cartagena Protocol expands upon the biosafety provisions of the CBD to regulate LMOs that may adversely affect biological diversity,[210] but the scope of the treaty is too trade-focused to sufficiently reduce the GCRs/ERs arising out of bioengineering. First, the scope of the Cartagena Protocol seems to include novel viruses and organisms developed in labs because Article 3 states that "living organisms" means "*any* biological entity" that can transfer or

[206] Cartagena Protocol on Biosafety to the Convention on Biological Diversity, art. 3(g), Jan. 29, 2000, 39 I.L.M. 1027 (2000) [hereinafter Cartagena Protocol]. Article 31(2)(b) of the Vienna Convention, which reflects customary international law, states that a treaty shall be interpreted in light of "any instrument which was made by one or more parties in connection with the conclusion of the treaty and accepted by the other parties as an instrument related to the treaty," which includes a protocol to the CBD—the Cartagena Protocol—that expands upon the CBD's biosafety provisions. Vienna Convention on the Law of Treaties, art. 31, May 23, 1969, 1155 U.N.T.S. 331 [hereinafter Vienna Convention].

[207] The Cartagena Protocol separately uses the term "direct use" in a context that applies to use "as food or feed, or for processing." *Id.* at art. 11. The broader term "use" in the CBD seems to encapsulate this meaning, as well.

[208] CBD, *supra* note 204, at art. 11.

[209] *See infra*, Section III(B).

[210] Cartagena Protocol, *supra* note 206, at art. 1.

replicate genetic material, even "sterile organisms, viruses and viroids."[211] However, Article 4 establishes that the Cartagena Protocol applies to the "*transboundary* development, handling, transport, use, transfer and release" of LMOs.[212] The term "transboundary" should be interpreted to modify each of the subsequent actions: development, handling, transport, use, transfer and release. The first listed action, "development," is not the only action that is transboundary in nature—handling and transport are inherently transboundary, for example—thus by extension Article 4 can reasonably be interpreted to apply solely to transboundary actions. Likewise, the "risk assessment" and "risk management" provisions of the Cartagena Protocol only apply to LMOs being exported or imported,[213] and the "handling" requirements of LMOs under Article 18 only apply to transboundary international movement.[214] Overall, the transboundary and trade-oriented scope of the Cartagena Protocol limits its applicability to GCRs/ERs arising from bioengineering because such actions generally take place within the territory of one state—such as the handling of a deadly bioengineered organism in a laboratory.

Even though some provisions of the Cartagena Protocol do seem to apply to the LMOs outside of the transboundary context, these provisions do not provide sufficient protections from GCRs/ERs arising out of bioengineering. For example, Article 17 applies to "unintentional transboundary movements" of LMOs, which would seem to include a bioengineered virus escaping from a laboratory while in the territory of one state. However, this article merely requires parties to "notify affected or potentially affected states" of unintentional transboundary movements of LMOs rather than requiring any preventative measures or risk assessments.[215] Notifying a party when a GCR/ER materializes will not likely prevent the global catastrophic or existential harm from occurring.

Likewise, the risk assessment and risk management requirements of the Cartagena Protocol are too discretionary to meaningfully mitigate low-probability GCRs/ERs arising out of bioengineering. The Cartagena Protocol requires Parties to undertake a risk assessment and implement risk management measures to "regulate, manage, and control risks … associated with the use, handling and transboundary movement of living modified organisms."[216] Specifically, the risk assessment stage requires Parties first to evaluate the likelihood, consequences, and the subsequent "overall risk" of adverse effects from the release of an LMO, and second to recommend "whether or not the risks are acceptable or manageable."[217] Based on the conclusions of the risk assessment, the risk management stage then requires Parties to, *inter alia*, take measures "to the extent necessary" to "prevent adverse effects" of LMOs on biological diversity and human health, and also to take "appropriate measures" to "prevent unintentional transboundary movements of [LMOs]."[218]

However, when applied to GCRs/ERs arising from deadly bioengineered organisms in a laboratory, the risk assessment and risk management provisions of the Cartagena Protocol fall short because decision makers in the risk management stage have broad discretion to decide

[211] *Id.* at art. 3.
[212] *Id.* at art. 4 (emphasis added).
[213] *Id.*at art. 15 and art. 16.
[214] *Id.* at art. 18.
[215] *Id*., at art. 17.
[216] *Id.* at arts. 16-17.
[217] *Id.* at Annex III(8).
[218] *Id.* at art. 16(2)-(3).

whether or not risks are acceptable. According to the Ad Hoc Technical Expert Group (AHTEG) on Risk Assessment and Risk Management under the Cartagena Protocol on Biosafety's Guidance on Risk Assessment of Living Modified Organisms, risk assessors are to provide *recommendations* as to whether or not risks arising from LMOs are "acceptable or manageable" based on their nation's own "protection goals," and final approval for the use of LMOs is entirely "up to the decision maker to decide,"[219] which the Guidance concedes is "typically decided at a political level and may vary from country to country."[220] The lack of standardized protection goals across all countries and the significant discretion allocated to decision makers in regulating LMOs results in inconsistent risk management policies. For example, Parties have shown significant differences of opinion in what risks are "acceptable" for GM crops, which are extremely popular and widely grown in the United States, Argentina, and Canada (these countries retain 98 percent by acreage of all GM crops in the world), but resisted by European countries and Japan because of food safety and environmental concerns.[221] On the one hand, the risk assessment and management process is valuable for Parties to consider the risks of LMOs and make policy decisions to mitigate those risks based on their domestic protection goals. However, when translated to GCRs/ERs from bioengineering, the single release of a dangerous bioengineered organism in any state could cause global catastrophic or existential harm in most or all other states. Therefore, sufficiently mitigating the risks of GCRs/ERs from bioengineering requires uniform measures, and so the failure of the Cartagena Protocol to proscribe clear requirements on how and to what extent Parties should mitigate GCRs/ERs arising from deadly bioengineered organisms compromises its effectiveness.

Even if the risk assessment and risk management provisions were more stringent in requiring Parties to minimize GCRs/ERs arising out of bioengineering, the Cartagena Protocol does not include any meaningful recourse against Parties that fail to meet their obligations. Parties attempted to address the lack of recourse under the Cartagena Protocol with the Nagoya - Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol on Biosafety ("Supplementary Protocol"), which creates a scheme of liability and redress for transboundary damage from LMOs, including damage from "unintentional transboundary movements" like the type that may arise from an accidental release of a bioengineered organism from a laboratory.[222] However, the Supplementary Protocol is insufficient to prevent GCRs/ERs from materializing because the provisions only provide *reactionary* redress for damage caused by an operator[223] after an LMO has already been released, whereas a GCR/ER should never be allowed to materialize.[224] Even though Article 5(5) prospectively regulates LMOs by requiring operators to engage in "appropriate response measures" if there is a "significant likelihood" that

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[219] *See* Guidance on Risk Assessment on Living Modified Organisms, Report of the Third Meeting of the Ad Hoc Technical Expert Group On Risk Assessment and Risk Management Under the Cartagena Protocol on Biosafety, at 18, U.N. Doc. UNEP/CBD/BS/AHTEG-RA&RM/3/4 (2011), *available at:* http://www.cbd.int/doc/meetings/bs/bsrarm-03/official/bsrarm-03-04-en.pdf.

[220] *Id.*

[221] M.K. SATEESH, BIOETHICS AND BIOSAFETY 205 (2008).

[222] *See* Nagoya-Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol on Biosafety, 15 October 2010, Annex to UN Doc. UNEP/CBD/BS/COP-MOP/5/17, at arts. 2-5, *available at:* http://bch.cbd.int/protocol/NKL_text.shtml.

[223] Article 2 defines operators as "any person in direct or indirect control" of an LMO of the living modified organism." *Id.* at art. 2(2)(c).

[224] *See Id.* at arts. 2-5.

the use of LMOs will result in "damage"[225] if "timely response measures are not taken," GCRs/ERs are low-probability and thus do not present a "significant likelihood" of materializing.[226] Note that the Supplementary Protocol has not entered into force because the Supplementary Protocol requires the accession of forty Parties to the Cartagena Protocol, but only the Czech Republic and Latvia have thus far acceded.[227]

Finally, another major limitation of both the CBD and the Cartagena Protocol is that the United States is not a party to either instrument.[228] Because the United States possesses some of the most sophisticated and potentially dangerous bioengineering technology, the absence of the United States from these instruments limits their effectiveness in reducing GCRs/ERs. Overall, the Cartagena Protocol does not seem to be an effective instrument to regulate GCRs/ERs from bioengineering.

C. Biological Weapons Convention

The Biological Weapons Convention is too focused on bioterrorism and neglectful of biosafety issues to sufficiently mitigate GCRs/ERs arising out of bioengineering. Under the Biological Weapons Convention (BWC), a state party cannot "develop, produce, stockpile or otherwise acquire or retain microbial or other biological agents [or] toxins … of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes...."[229] Legitimate scientific research, even research that poses a risk of accidentally releasing a highly deadly virus or publishing information that can be used for bioterrorism, usually has a "prophylactic, protective or other peaceful [purpose]" under article 1, which severely limits the BWC in regulating GCRs/ERs arising out of bioengineering. Bioengineered humans also clearly fall outside the scope of the BWC.

Similarly, while the BWC creates obligations that restrict transfer of biological weapons information or technologies, these obligations exempt peaceful purposes. Under Article III of the BWC, a state party cannot "transfer … directly or indirectly … assist, encourage, or induce any State, group of States or international organization to manufacture or otherwise acquire any of the agents, toxins, weapons, equipment or means of delivery specified in [Article I]."[230] Thus States have an affirmative duty to ensure that their bioengineering technologies are not transferred in violation of this provision. This article possibly applies to instances where States indirectly grant malevolent actors access to bioengineering techniques through publication of research and studies. However, Article X makes clear that the BWC exempts the "exchange of equipment, materials, and scientific and technological information" for biological agents when used to prevent disease or other peaceful purposes, while also exempting the "international

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[225] "Damage" is defined as "adverse effects on the conservation and sustainable use of biological diversity, also taking to account risks to human heath." *Id.* at art. 2(2)(b).
[226] *Id.* at Art. 5(5).
[227] *Parties to the Protocol and Signature and Ratification of the Supplementary Protocol*, CONVENTION ON BIOLOGICAL DIVERSITY, *at:* http://bch.cbd.int/protocol/parties/#tab=1 (last visited Apr. 17, 2012).
[228] List of Parties, CONVENTION ON BIOLOGICAL DIVERSITY, http://www.cbd.int/information/parties.shtml (last visited Mar. 19, 2012). The United States was nonetheless influential in negotiations for the Cartagena Protocol because they are a massive force in the world's agricultural market. Jonathan H. Adler, *The Cartagena Protocol and Biological Diversity: Biosafe or Bio-Sorry*?, 12 GEO. INT'L ENVTL. L. REV. 761, 763 (2000).
[229] Convention on the Prohibition of the Development, Production, and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction, art. 1, Apr. 10, 1972, 1015 U.N.T.S. 163 [hereinafter BWC].
[230] *Id.* at art. III.

exchange of [biological] agents and toxins and equipment" for peaceful purposes.[231] Thus Article III fails to address the GCRs/ERs arising out of dual use bioengineering research that is conducted for peaceful purposes but could result in an accidental release or be subject to unintended malicious use.

While the State Parties to the BWC have shown a growing concern for biosafety issues, such efforts are nonbinding and thus ineffective to protect against GCRs/ERs related to biosafety. In 2006, the Parties called upon State Parties to adopt "…legislative, administrative, judicial and other measures" to "ensure the safety and security of microbial or other biological agents or toxins in laboratories, facilities, and during transportation, *to prevent unauthorized access to and removal of such agents or toxins.*"[232] Five years later they called upon State Parties to "implement voluntary management standards on biosafety and biosecurity" and "encourage the promotion of a culture of responsibility amongst relevant national professionals and the voluntary development, adoption and promulgation of codes of conduct."[233] While these measures may put political pressure upon State Parties to increase both biosafety and biosecurity, they are nonbinding measures and thus ineffective to rely upon to mitigate GCRs/ERs arising out of bioengineering.

Even if the BWC included measures to address issues of biosafety and biosecurity, there is no formal compliance-monitoring body or verification mechanism to ensure proper enforcement.[234] While State Parties engaged in seven years of negotiations over a "BWC Protocol" that would establish an inspection regime as well as a variety of other measures intended to bolster, *inter alia*, the effectiveness, transparency, and implementation of the BWC, negotiations have stalled.[235] In particular, the Bush Administration stifled progress when it withdrew from negotiations in 2001 because of concerns over the BWC Protocol's ineffectiveness, harm to biodefense research, and increased costs to the biotechnology industry; the Obama Administration has continued to oppose the BWC Protocol.[236] Finally, another major limitation is that there are only 165 State Parties to the BWC, which "falls behind other multilateral arms control, disarmament and non-proliferation treaties." Thus bioengineering activities that present a GCR/ER could just be conducted within the territory of non-Parties.[237] Overall, while the BWC may reduce GCRs/ERs presented by biosecurity, the failure to sufficiently address issues like the accidental release of dangerous bioengineered organisms or human bioengineering, as well as practical limitations like the large number of states that are not Parties, limits its ability to mitigate GCRs/ERs from bioengineering.

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[231] *Id.* at art. X.

[232] Final Document, Sixth Review Conference of the State Parties to the BWC, at ¶ 11(c), BWC/CONF.VI/6 (2006) [hereinafter Sixth Review Conference Final Document] (emphasis added).

[233] Final Document, Seventh Review Conference of the States Parties to the BWC, at ¶ 13(b), BWC/CONF.VII/7 (2011).

[234] Martin Matishak, *BWC Review Conference Could Revive Verification Debate, Chairman Says*, GLOBAL SECURITY NEWSWIRE (July 08, 2011), *at:* http://www.nti.org/gsn/article/bwc-review-conference-could-revive-verification-debate-chairman-says.

[235] *Id.*

[236] The Obama Administration took the position that the proposed BWC Protocol is ineffective because states could easily operate under a false veil of legitimacy and rapidly-progressing biotechnology was becoming more difficult to monitor. Martin Matishak, *U.S. Announces New Strategy for Biological Weapons Convention*, GLOBAL SECURITY NEWSWIRE (Dec. 11, 2009), *at:* www.nti.org/gsn/article/us-announces-new-strategy-for-biological-weapons-convention.

[237] Sixth Review Conference Final Document, *supra* note 232, at 21.

D. Human Dignity Instruments

Inheritable human genetic alterations are subject to a variety of international soft law, legally binding regional instruments, and the occasional condemnation of IGOs, but no global convention regulates this GCR/ER.[238] The predominant binding instrument that regulates human genetic engineering is the Council of Europe's Convention on Human Rights and Biomedicine (CHRB). First, Article 13 of the CHRB states that "[a]n intervention seeking to modify the human genome may only be undertaken for preventive, diagnostic or therapeutic purposes and only if its aim is not to introduce any modification in the genome of any descendants."[239] The accompanying CHRB Explanatory Report clarifies that Article 13 strictly prohibits any inheritable genetic alterations of humans.[240] Notably, the Explanatory Report also acknowledges that permitting alteration of the human genome could endanger the entire human species, thus clearly recognizing the GCR/ER at issue.[241] However, while this convention may be effective at reducing the risk of GCR/ER arising from the genetic engineering of humans within certain European countries, only 29 out of 47 Council of Europe Member States are signatories and the rest of the world is left out, thus limiting the global effectiveness of the CHRB.[242]

Another possibility is that inheritable genetic alterations may constitute a human rights violation, but this seems unlikely under international law. Fukuyama argues that reengineering the "essence of humanity itself" and creating a new species could be a "crime against humanity," which would violate the Rome Statute of the International Criminal Court ("Rome Statute").[243] However, this argument does not seem to fall cleanly within the plain language of the Rome Statute.[244] The Rome Statute clearly establishes the scope of "crimes against humanity" as acts "…committed as part of a widespread or systematic *attack directed against* any civilian population, with knowledge of the attack…."[245] In turn, the word "attack" is defined as "course of conduct involving multiple commissions of acts," which most but not all states interpret to *not*

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[238] Examples include a 1997 press release from the WTO that condemned human cloning and called upon nations to prohibit human cloning (*see* WORLD HEALTH ORGANIZATION, WORLD HEALTH ASSEMBLY, 51ST SESSION, *Ethical, Scientific, and Social Implications of Cloning in Human Health*, WHA51.10, *available at:* http://www.who.int/ethics/en/WHA51_10.pdf); a legally-binding ban on human cloning from the Council of Europe (*see* Additional Protocol to the Convention for the Protection of Human Rights and Dignity of the Human Being with regard to the Application of Biology and Medicine, on the Prohibition of Cloning Human Beings, Apr. 5, 1997, CETS No. 168); and a U.N. declaration (*see* Universal Declaration on the Human Genome and Human Rights, U.N. Doc. A/RES/53/152 (1997)).

[239] Convention for the Protection of Human Rights and Dignity of the Human Being with regard to the Application of Biology and Medicine, art. 13, Apr. 5, 1997, CETS No. 168 [hereinafter CHRB].

[240] Explanatory Report, Convention for the Protection of Human Rights and Dignity of the Human Being with regard to the Application of Biology and Medicine: Convention on Human Rights and Biomedicine, at ¶ 91, *available at* conventions.coe.int/treaty/en/Reports/Html/164.htm [hereinafter CHRB Explanatory Report].

[241] *Id.* at ¶ 91.

[242] *Signatories to the CHRB*, COUNCIL OF EUROPE, *at:* http://conventions.coe.int/Treaty/Commun/ChercheSig.asp?NT=164&CM=8&DF=01/04/2012&CL=ENG (last visited Mar. 16, 2012).

[243] *See e.g.* FRANCIS FUKUYAMA, OUR POSTHUMAN FUTURE: CONSEQUENCES OF THE BIOTECHNOLOGY REVOLUTION (2002), *as cited by* Annas et al., *supra* note 85, at 153.

[244] The Vienna Convention states that treaties *shall* be interpreted "in accordance with the ordinary meaning … in their context" while considering the treaty's "object and purpose." Vienna Convention, *supra* note 206, at art. 31.

[245] Rome Statute of the International Criminal Court, art. 7, Rome Statute of the International Criminal Court, July 17, 1998, 2187 U.N.T.S. 90. [hereinafter Rome Statute] (emphasis added).

require actual use of force; thus a scientific bioengineering program could possibly qualify as an "attack."[246] However, the plain language of the Rome Statute excludes acts that are not attacks "directed against" a civilian population. Scientists who create genetically inheritable alterations in humans are not likely committing an attack "directed against" a population, but rather are attempting to improve the human body for the benefit of an individual or society. Any subsequent attack directed against humans, such as the possible suppression of humans by post-humans, is a mere consequence of inheritable genetic alterations. Therefore, inheritable genetic alterations do not likely violate the Rome Statute.

IV. RECOMMENDATIONS FOR AN EMERGING TECHNOLOGIES TREATY

While bioengineering that poses a GCR/ER is subject to several nonbinding international instruments, no internationally binding obligations sufficiently reduce the catastrophic risks arising out of bioengineering.[247] One possible solution is to expand several of these existing instruments and use them together in a piecemeal approach to regulate the various aspects of GCRs/ERs arising out of bioengineering. However, because the current regimes are inadequate and because the scope of emerging technologies that present a GCR/ER will likely increase as science continues to develop at a rapid pace, the better solution is for states to agree to a comprehensive treaty that can sufficiently mitigate the unique aspects of GCRs/ERs arising from all emerging technologies. Therefore, this paper proposes the framework of a model treaty that would mitigate GCRs/ERs arising out of emerging technologies with the following regulatory mechanisms: use of the precautionary principle, a body of experts, a review mechanism, public participation and access to information, binding reforms for scientists, laboratory safeguards, and oversight of scientific publications.

A. New International treaty

GCRs/ERs arising out of emerging technologies are unique in that a single event can result in widespread destruction, which is why the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) acknowledges that only a global convention is sufficient to curtail these ERs.[248] If a GCR/ER regulatory regime only regulates some states but not others, dangerous emerging technologies could instead be developed and utilized in the unregulated states. An example of this is when Richard Seed, an American physicist who wished to be the first person to clone a human, threatened to conduct his cloning in Mexico or Japan if the United States banned human cloning.[249] And if some states ban or regulate emerging technologies while others do not, this could threaten global security because "rogue states" would have a monopoly over dangerous emerging technologies.[250] Furthermore, without a truly global treaty, countries competing to quickly develop emerging technologies may engage in a race to arms that promotes speed over safeguards.[251] Finally, some states may believe that,

[246] MACHTELD BOOT, GENOCIDE, CRIMES AGAINST HUMANITY, WAR CRIMES: NULLUM CRIMEN SINE LEGE AND THE SUBJECT MATTER JURISDICTION OF THE INTERNATIONAL CRIMINAL COURT 478 (2002).
[247] POSNER, *supra* note 75, at 219.
[248] Annas et al., *supra* note 85, at 153.
[249] *Id.*
[250] Pinson, *supra* note 115, at 279-280 (referring specifically to nanotechnology).
[251] For example, AI experts cite the importance of "international cooperation around AI development" and to prevent an "AI 'arms race' that might be won by the competitor most willing to trade off safety measures for speed."

absent regulations binding upon all states, their emerging technology industries will be placed at a competitive disadvantage to unregulated countries. Thus all states should agree to an international treaty imposing evenhanded regulations.

An international treaty could potentially cover all emerging technologies that pose a GCR/ER, beginning with the three in this paper— nanotechnology, bioengineering, and AI. One significant reason that a GCR/ER international treaty should regulate nanotechnology, bioengineering, and AI is that these emerging technologies are predicted to overlap in many areas. Examples of potential convergences of nanotechnology, bioengineering, and AI are nano-sized components that interact with bioengineered organisms, like a bioengineered photosynthesis protein from a plant integrated with a nanotech film to capture sunlight and convert it into electricity;[252] a targeted-killing weapon that integrates a lethal genetically engineered organism with a nanoparticle that releases the organism upon detecting certain genetic traits in an individual's DNA;[253] a sophisticated form of AI that creates new technologies utilizing nanotechnology or bioengineering;[254] and the use of nanotechnology, bioengineering, and AI to either "enhance" humans (termed "posthumans") or to create a superintelligent machine with biological and nanotech properties.[255] An international treaty that covers all of these emerging technologies is best equipped to regulate their use as the boundaries blur between them. Furthermore, nanotechnology, bioengineering, and AI all have broad social and ethical implications, and so placing all of them under the auspices of one convention creates a central hub from which the public can determine what risks they are willing to take and what technologies should become pervasive in society. Finally, scientists are likely to uncover yet unknown GCRs/ERs from emerging technologies in the future, and so a GCR/ER treaty for emerging technologies should be flexible enough to incorporate other emerging technologies that could pose a GCR/ER in the future such that regulators can take relatively quick action on the international level rather than having to negotiate a new legal instrument.

States should consider concluding an international convention on GCRs/ERs from emerging technologies under the auspices of an existing international governmental organization (IGO). For example, concluding a treaty under the auspices of the United Nations is beneficial because linkages could be made with relevant U.N. subsidiary bodies, such as the U.N. Commission on the Science and Technology Development (CSTD),[256] and the United Nations has substantial financial resources and political clout. Another possibility to conclude a treaty under the auspices of the World Health Organization (WHO), which already works with issues like bioengineering and nanotechnology through non-binding initiatives and other means.[257] For

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Reducing Long-Term Catastrophic Risks from Artificial Intelligence, THE SINGULARITY INSTITUTE, *at:* http://singinst.org/summary (last visited Mar. 10, 2012).

[252] *Nanotechnology White Paper, supra* note 4, at 12.

[253] Émilio Mordini, *Converging Technologies*, CENTRE FOR SCIENCE, SOCIETY AND CITIZENSHIP, *at:* http://agora-2.org/colloque/gga.nsf/Conferences/Converging_technologies (last visited Apr. 21, 2012).

[254] Mark Avrum Gubrud, *Nanotechnology and International Security*, THE FORESIGHT INSTITUTE, *at:* www.foresight.org/Conferences/MNT05/Papers/Gubrud/

[255] J. CLARENCE DAVIES, *supra* note 99, at 19.

[256] The CSTD is a "gateway to information on science and technology" for the United Nations that the Economic and Social Council (ECOSOC) created in 1992 as a source of information and policy recommendations to other U.N. bodies. *See Homepage*, U.N. CONFERENCE ON TRADE AND DEVELOPMENT, *at:* http://www.unctad.info/en/Science-and-Technology-for-Development---StDev (last visited Apr. 21, 2012).

[257] *See e.g. WHO Biosafety and Laboratory Biosecurity Programme on Laboratory Biosafety and Biosecurity*, WORLD HEALTH ORG., *at:* http://www.who.int/ihr/biosafety/en/ (last visited Mar. 22, 2012). *See also*

example, the WHO Biosafety and Laboratory Biosafety programme (BLBP) organizes awareness-raising workshops, develops training materials for laboratory workers, and has created a nonbinding World Health Assembly resolution that "urges" Member States to take measures such as improving laboratory biosafety and increasing training for laboratory workers.[258] However, the WHO is traditionally not a forum under which treaties are concluded, with the 2003 Framework Convention on Tobacco Control being the only convention thus far concluded under the auspices of the WHO.[259] An alternative is to utilize the WHO's extensive resources on protecting human health by linking a treaty on GCRs/ERs from emerging technologies to the WHO or some other IGO through a protocol, a joint task force, or a collaborative agreement.[260]

One the other hand, rather than concluding a new international agreement, states could agree to amend existing international treaties to include increased safeguards over a wider range of activities, but existing treaties are not ideal for this purpose. As discussed above, neither the CBD, the Cartagena Protocol in Biosafety, the BWC, nor the various human dignity instruments sufficiently mitigate GCRs/ERs arising out of biotechnology.[261] While states could chose to amend legally binding instruments like the CBW and the Cartagena Protocol to include emerging technologies, states did not draft these treaties with GCRs/ERs for emerging technologies in mind, and thus they would have to be radically transformed in order to provide an effective international regime.[262] Therefore a new international treaty is the best way forward to regulate the emerging technologies contemplated in this paper.

B. Precautionary Principle

This section overviews the different applications of the precautionary principle and discusses how best to apply the precautionary principle to a treaty on GCRs/ERs from emerging technologies, concluding that specific strategies based on an affirmative application of the precautionary principle is ideal. While there are many renditions of the precautionary principle embodied in various international instruments,[263] the essence of the precautionary principle is that preventative or remedial measures can, should, or must be taken when there is scientific uncertainty that an unacceptable hazard may occur.[264] The precautionary principle is an essential element of an international treaty regulating GCRs/ERs from emerging technologies because society should not risk massive damage to human health and the environment from GCRs/ERs on a "trial and error" basis.

Nanotechnology, WORLD HEALTH ORG, *at:* www.who.int/foodsafety/biotech/nano/en/index.html (last visited Mar. 22, 2012).

[258] World Health Assembly Res. WHA58.3 (2005); *see also Biosafety and Laboratory Biosecurity*, WORLD HEALTH ORG., *at:* www.who.int/ihr/biosafety/key_activities/en/index.html (last visited Apr. 21, 2012). Note that none of these measures impose binding obligations on countries, and so they are less than ideal as a means to sufficiently mitigate GCRs/ERs arising from emerging technologies.

[259] *What is the Framework Convention on Tobacco Control?*, FRAMEWORK CONVENTION ALLIANCE, *at:* www.fctc.org/index.php?Itemid=5&id=8&option=com_content&view=article (last visited Apr. 21, 2012).

[260] *See* MARK A. SUTTON ET AL., THE EUROPEAN NITROGEN ASSESSMENT: SOURCES, EFFECTS AND POLICY PERSPECTIVE 557 (2011).

[261] *See e.g. supra*, Section III.

[262] *Id*.

[263] By one account, there are at least twenty different definitions of the precautionary principle. Cass R. Sunstein, *Irreversible and Catastrophic*, 91 CORNELL L. REV. 841, 848 (2006).

[264] *See* WORLD COMMISSION ON THE ETHICS OF SCIENTIFIC KNOWLEDGE AND TECHNOLOGY, THE PRECAUTIONARY PRINCIPLE 13-14 (2005), *available at:* http://unesdoc.unesco.org/images/0013/001395/139578e.pdf.

Many conventions apply the precautionary principle in a negative manner, like Article 3(3) of the U.N. Framework Convention on Climate Change (UNFCCC), which states that a "lack of full scientific certainty should not be used as a reason for postponing" precautionary measures to "anticipate, prevent, or minimize the causes of climate change and mitigate its adverse effect."[265] This provision does not actually require a state to take precautionary actions, but rather purports that scientific uncertainty is an inappropriate reason *not* to take precautionary actions. For example, while the Intergovernmental Panel on Climate Change (IPCC) concluded in its Fourth Assessment Report (AR4) that increases in global temperatures are "very likely" (i.e. above 90 percent likely) caused by anthropogenic greenhouse gas emissions,[266] UNFCCC Parties should not cite the lack of 100 percent scientific certainty as a basis for not reducing their greenhouse gas emissions. This is also an example of a nonbinding application of the precautionary principle because Article 3(3) merely states that UNFCCC parties "should" employ the precautionary principle in addressing climate change.[267]

Other conventions apply the precautionary principle as an exception to otherwise binding requirements. For example, Article 5.7 of the World Trade Organization's (WTO) Agreement on Sanitary, and Phytosanitary Measures (SPS Agreement) permits a WTO Member to adopt certain trade-restrictive sanitary and phytosanitary measures that are otherwise in violation of the liberalized trade provisions of the WTO when "relevant scientific evidence is insufficient" to assess particular risks to human, animal, or plant life or health.[268] The effect of this provision is that some WTO Members have more stringent sanitary and phytosanitary measures than others based on each WTO Member's chosen level of health standards.

Finally, some conventions reflect an affirmative application of the precautionary principle that recommends or requires precautionary measures in the face of scientific uncertainty. An example of this approach is embodied in Annex 4(a) of the Convention on the International Trade on Endangered Species (CITES), which states that Parties "shall, in the case of uncertainty … act in the best interest of the conservation of the species" when deciding whether to alter the protective status of a species or when gauging the effect of international trade on conserving a species.[269] In the case of CITES, application of the precautionary principle is hashed out through specific obligations, such as the requirement that a species listed under Appendix I (species that are "threatened with extinction") thereafter be listed under Appendix II (species that, *inter alia*, would be "threatened with extinction" unless trade in the species is strictly regulated) and monitored for a requisite time period before delisting that species

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[265] United Nations Framework Convention on Climate Change, art. 3(3), May 9, 1992, 31 I.L.M. 849 [hereinafter UNFCCC].

[266] *See* CLIMATE CHANGE 2007: SYNTHESIS REPORT. CONTRIBUTION OF WORKING GROUPS I, II AND III TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 27 (Rajendra K. Pachauri & Andy Reisinger, eds.). This rendition of the precautionary principle originated in the 1992 Rio Declaration on Environment and Development. *See* United Nations Rio Declaration on Environment and Development, Principle 15, June 13, 1992, 31 I.L.M. 874 [hereinafter Rio Declaration].

[267] UNFCCC, *supra* note 267, at art. 3(3).

[268] Agreement on the Application of Sanitary and Phytosanitary Measures, art. 5.7, Marrakesh Agreement Establishing the World Trade Organization, Annex 1A, THE LEGAL TEXTS: THE RESULTS OF THE URUGUAY ROUND OF MULTILATERAL TRADE NEGOTIATIONS (1999), 1867 U.N.T.S. 493 [hereinafter SPS Agreement].

[269] Convention on International Trade in Endangered Species of Fauna and Flora, Annex 4(A), Mar. 3, 1973, 993 U.N.T.S. 243 [hereinafter CITES].

entirely.[270] Furthermore, in contrast to the UNFCCC, CITES *requires* Parties to employ the precautionary principle as reflected in Annex 4.[271]

Negative, nonbinding, or exception-type applications of the precautionary principle are not ideal to effectively regulate GCRs/ERs arising from emerging technologies. First, the negative application of the precautionary principle would merely suggest or require that states *not* use scientific uncertainty about GCRs/ERs arising from emerging technologies as a reason for not taking action, but this does not impose an obligation upon states to affirmatively mitigate any risks, although applying the negative precautionary principle could be useful to eliminate "excuses" for noncompliance with other provisions of an emerging technologies GCR/ER treaty. Second, an exception-type application of the precautionary principle for GCRs/ERs from emerging technologies would be ineffective because this approach would result in different levels of protections from GCRs/ERs in different states, and an effective emerging technologies GCR/ER treaty should impose roughly uniform standards because a GCR/ER that materializes in any single state would have a global impact. On the other hand, this version of the precautionary principle may be useful if, for example, states negotiated exceptions to the WTO liberalized trade scheme as part of a treaty on GCRs/ERs arising from emerging technologies. Finally, a nonbinding application of the precautionary principle would limit the treaty's overall effectiveness because states are less likely to abide by its terms.

An affirmative and obligatory version of the precautionary principle would be most effective in regulating GCRs/ERs arising from emerging technologies. This approach could *require* states to take certain affirmative actions to regulate emerging technologies that pose an uncertain or undecided degree of GCR/ER. This is ideal because emerging technologies have the potential to result in global, permanent damage to the habitability of the Earth, and so requiring every state to implement precautionary measures is the prudent course of action, especially considering the rapid speed at which emerging technologies are developing. Furthermore, an affirmative and obligatory application of the precautionary principle is the best way to ensure that all states actually integrate precautionary mechanisms into their domestic law, because the level of requisite precaution can be determined and prescribed on the global level rather than having a patchwork of precautionary mechanisms from country-to-country that may or may not result in a sufficient level of protection on the global scale.

Although states would not likely be willing to impose widespread regulations upon entirely "speculative" risks, one way to implement the precautionary principle in an emerging technologies treaty is to trigger specific requirements when available data demonstrates a "reasonable grounds for concern" that a certain risk exceeds whatever level is deemed acceptable.[272] A body of experts representing widespread interests could determine when there is in fact a "reasonable ground of concern," and remedial measures would then be applied relatively consistently across all states. For example, a body of experts could determine that swarms of nanobots developed to search for oil in the ground (a technology that is currently

[270] *Id.* at Annex I, Annex 2(a), and Annex 4(B)(1).
[271] *See id.* at Annex 4(A).
[272] This is the basic justification for precautionary measures embodied in the European Union (EU) Communication on the Precautionary Principle. *See* Communication from the Commission on the Precautionary Principle, Commission on the European Communities, COM (2000) 1, *available at:* http://ec.europa.eu/dgs/health_consumer/library/pub/pub07_en.pdf.

being researched[273]) poses uncertain risks and that available information shows a "reasonable grounds for concern," which could trigger a requirement that states impose certain measures to regulate this technology or even prohibit it until there is further research of the risks. Subsequently, the treaty could require proponents of this technology to rebut the "reasonable grounds for concern" in order to continue the technology's development and/or application.

If the probability of a GCR/ER is inherently unascertainable even with extensive scientific research, as is often true with GCRs/ERs from emerging technologies,[274] one possible solution is for a body of experts to determine the necessary steps to prevent an "extremely bad worst case scenario" as a precautionary measure, regardless of likelihood and available information.[275] States would be required to take these steps if doing so requires modest costs that are not diverted from other crucial investments.[276] An example of this would be to require development of an approved failsafe mechanism in all superintelligent AI that has direct or indirect control over weapons systems. Another possibility is to ban or restrict emerging technologies that present an unquantifiable GCR/ER until scientific evidence proves that the risk, while still unknown, can effectively be reduced to a level that falls short of global catastrophic or existential harm. An example of this is to restrict scientists from synthesizing certain types of highly fatal bioengineered viruses until experts can prove the effectiveness of a vaccine that could prevent human death on the global scale if the virus is accidentally or purposefully released.

C. Composition and Function of a Body of Experts

A body of experts should have general regulatory authority over emerging technologies that pose a GCR/ER in all states that are parties the convention. One possible model is the Environmental Protection Agency (EPA), which, *inter alia*, promulgates and enforces regulations according to environmental statutes.[277] Likewise, the body of experts could apply the precautionary principle as previously discussed[278] and take regulatory steps necessary to reduce GCRs/ERs to an acceptable level. Depending on the general requirements created by a treaty on emerging technology GCRs/ERs, this body of experts could impose a variety of regulatory tools such as technical restrictions on products; permit requirements; total bans on certain emerging technologies; reporting requirement for certain industry sectors; laboratory safety rules; mandatory environmental, human health, and social impact statements for certain activities; and liability mechanisms to punish violators whether or not their activities cause any harm.

In terms of composition, the body of experts should consist of scientists, lawyers, government authorities, civil society representatives, and other experts chosen based on their area of expertise and equitable geographic representation. Specialists in nanotechnology,

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[273] Tom Fowler, *Super-Tiny Robots Someday May be Sent in Search of Oil*, THE HOUSTON CHRONICLE (May 18, 2009), *at:* www.chron.com/business/energy/article/Super-tiny-robots-someday-may-be-sent-in-search-1577303.php.
[274] RICHARD A. POSNER, *Public Policy Towards Catastrophe*, *in* GLOBAL CATASTROPHIC RISKS 151 (Nick Bostrom & Milan M. Ćirković, eds., 2008).
European Commission (2000), Communication from the Commission on the Precautionary Principle, (COM 2000/001), Brussels
[275] Sunstein, *supra* note 265, at 846.
[276] *Id.*
[277] *About EPA: Our Mission and What We Do*, ENVTL. PROT. AGENCY, *at:* http://www.epa.gov/aboutepa/whatwedo.html (last visited Apr. 22, 2012).
[278] *Supra* Section IV(A).

bioengineering, and AI are best equipped to handle complex fact patterns involving these technologies, especially as the science becomes more advanced, and so special qualifications in one or more of these fields should be mandatory.[279] Government authorities should have both a fluent understanding of various domestic legal systems as well as expertise in one or more emerging technologies. Meanwhile, civil society representation in the body of experts is essential both to inform other experts on what society considers to be an "acceptable" level of risk and to shape discussions about whether developing certain emerging technologies will have an undesirable impact on society. For example, the signatories to the Principles for Oversight of Nanotechnologies and Nanomaterials expressed concern that "[g]overnments and industry developers of nanotechnologies provide few meaningful opportunities for informed public participation in discussions and decisions about how, or even whether, to proceed with the 'nano'-ization of the world." And in terms of human bioengineering, Annas, et al. argues that altering the human species is an inherently democratic matter that should only be made a body that constitutes global representation.[280] Civil society representation will help ensure that global democracy influences global emerging technology regulations.

While a treaty on emerging technologies should grant the body of experts significant authority to manage GCRs/ERs on a day-to-day basis, states will want to retain decisionmaking powers for any changes to the treaty, and they may also wish to reserve the power to second guess the body of experts. If the body of experts finds it necessary to alter the treaty, whether to regulate a new technology under the convention or to modify the treaty provisions as applied to technologies already considered, the body of experts should be able to draft a resolution that becomes binding upon all parties if agreed to by a simple majority or two-thirds majority vote of all parties. This system could be modeled upon the Montreal Protocol to the Vienna Convention for the Protection of the Ozone Layer, under which Parties can reduce allowable production or consumption of "controlled substances" (ozone depleting substances) based on a two-thirds majority of present and voting parties.[281] Furthermore, if states wish to override a decision made by the body of experts, an emerging technologies treaty should require a majority or two-thirds majority of parties to vote in favor of doing so.

D. Review Mechanism

Domestic and international judicial systems currently lack sufficient review mechanisms for GCRs/ERs arising from emerging technologies. For example, in the United States, many federal courts use the *Daubert* standard to determine whether expert evidence is admissible in court. Under the *Daubert* standard, the judge decides whether expert evidence, which includes expert testimony, is admissible based on whether the evidence derives from "scientific knowledge."[282] In turn, "scientific knowledge" generally must be "testable."[283] Furthermore, judges must also consider whether expert evidence based on scientific knowledge receives

[279] For example, in terms of nanotechnology, a group of NGOs stated that "[a] precautionary approach requires mandatory, nano-specific oversight mechanisms to account for the unique characteristics of the materials," and this would best be achieved by those who are intimately involved in this field. INTERNATIONAL CENTER FOR TECHNOLOGY ASSESSMENT, PRINCIPLES FOR THE OVERSIGHT OF NANOTECHNOLOGIES AND NANOMATERIALS 1 (2008), *available at: www.foeeurope.org/activities/.../Principles_Oversight_Nano.pdf.*

[280] Annas et al., *supra* note 85, at 153.

[281] Montreal Protocol on Substances that Deplete the Ozone Layer, art. 2.9, Sept. 16, 1987, 1522 U.N.T.S. 3.

[282] *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 113 S. Ct. 2786, 2796 (1993).

[283] *Id.*

"general acceptance" from scientists.[284] However, GCRs/ERs are often extremely low-probability, and so "general acceptance" that they will materialize is typically absent. Furthermore, GCRs/ERs are almost never testable because they should never be allowed to materialize. Finally, as discussed above, judges may not have the scientific understanding to sufficiently gauge GCRs/ERs, particularly when a case is dismissed before advocates have the chance to develop their full arguments, and the expert advice they receive is often from scientists with a conflict of interest in the outcome of the case.[285]

To remedy these problems, an international treaty regulating GCRs/ERs from emerging technologies could either (1) require states to establish domestic "science courts" that are equipped to consider alleged GCRs/ERs arising from emerging technologies and which are required to factor in minority scientific opinions whether or not they are "testable,"[286] or (2) create an international court that enables citizens to submit disputes regarding GCRs/ERs from emerging technologies, much like the right of European citizens to submit disputes to the European Court of Human Rights. In either scenario, the judges should preferably be scientifically literate lawyers who are able to comprehend the science of emerging technologies and effectively question experts from the arena of emerging technology in question.[287] If an international court is established, such a court could take over the enforcement functions of the proposed body of experts by applying traditional judicial mechanisms such as penalties, injunctions, and other measures. Finally, for certain activities (as determined by the body of experts), the court should require the proponent of an emerging technology to establish the lack of an unacceptable risk in order to prevail.

E. Public Participation and Access to Information

A treaty on emerging technology GCRs/ERs should include provisions for significant public participation that is in addition to the civil society representation on the body of experts. Nanotechnology, bioengineering, and AI involve, *inter alia*, ethical, religious, philosophical, political, economic, and safety considerations, and thus a treaty on GCRs/ERs from emerging technologies should establish a forum in which the public can shape the debate about what kind of technologies mankind should develop. Such a forum could gauge global public concerns about health risks, social effects, morals, religious implications, and overall perception of emerging technologies to influence the body of experts, who should have a treaty-mandated duty to consider societal views in their decisions.[288] While the exact form that the public dialogue could take includes anything from a conference to a series of "town hall" style meetings, civil society organizations (CSOs) representing the public should be the ones to decide on the exact format through their participation in drafting the convention on GCRs/ERs from emerging technologies.

Furthermore, integrating the precautionary principle with a treaty on GCRs/ERs arising from emerging technologies inherently requires consideration of what hazards are "acceptable" or, as discussed above, what constitutes a "reasonable grounds for concern," which are

[284] *Id*.
[285] *See supra* Section II(B)(4)(a).
[286] One such example in the United States are the U.S. Court of Appeals for the Federal Circuit, a 3 judge panel that has "exclusive jurisdiction of appeals in patent-infringement and other patent cases." POSNER, *supra* note 75, at 210-211.
[287] *See id.* at 208.
[288] LYLE GLOWKA & LAWRENCE C. CHRISTY, LAW AND MODERN BIOTECHOLOGY 52 (2004).

benchmarks that should be heavily influenced by societal perspectives on emerging technologies and their risks. The treaty on emerging technologies should establish a subsidiary body responsible for organizing major public events and compiling data on societal perspectives to present to the body of experts and the state parties. The civil society representatives on the body of experts should strongly advocate for the positions compiled at such public events. Furthermore, before the body of experts makes major decisions that do not require urgent actions, there should first be a period of public comment, and the body of experts should be required to consider the public sentiment in their decisionmaking.[289]

Another specific way to empower the public to shape the international framework behind emerging technologies is to allow "observers" representing a wide variety of interests to participate both in the drafting of an emerging technologies treaty and in subsequent "conferences of the parties." The Conference of Parties to CITES (COP) is an example of a forum with significant public participation from CSOs. Under CITES, CSOs may become observers if they meet certain qualifications and one-third of CITES parties do not object.[290]

Finally, the public should also have broad access to information regarding emerging technologies. Such information could include, at minimum, annual reports on safety issues related to emerging technologies and annual summaries of current legal obligations arising out of treaty on emerging technology GCRs/ERs (including summaries of cases decided by the associated judicial body and measures imposed by the body of experts).[291] In order to gather sufficient and accurate data, an emerging technologies treaty should create specific and mandatory reporting requirements for both state parties and industries that research and develop emerging technologies. Furthermore, not only should this information merely be made publicly available, but a treaty on emerging technology GCRs/ERs should also mandate a communications body, perhaps overseen by the same subsidiary body responsible for organizing public events, that is responsible for disseminating information on emerging technologies to all sectors of society on a global level. Each state should also be required to grant "active" as opposed to "passive" access to information by actively distributing information on emerging technologies in a way that is most effective within their particular culture.[292]

F. Regulating Scientists

An international instrument on GCRs/ERs should regulate the conduct of scientists because the stakes of GCRs/ERs are too high to leave to a small group of self-interested individuals. While scientists often reassure the public that GCRs/ERs from emerging technologies are nonexistent or negligible, as discussed above, scientists who assess the risks of their own work may be intentionally or unintentionally influenced by pressures to make profits, achieve scientific breakthroughs, and outpace other groups of scientists.[293] For example, while CERN scientists found no significant risks from the LHC, other experts concluded that the LHC did pose at least some risks, and subsequent accidents with the LHC weakened the credibility of

[289] *See e.g.* Carl Brunch & Meg Filbey, *Emerging Global Norms of Public Involvement*, *in* THE NEW "PUBLIC": THE GLOBALIZATION OF PUBLIC PARTICIPATION 9 (Carl Bruch, ed., 2002).
[290] CITES, *supra* note 269, at art. XI.
[291] HODGE ET AL., INTERNATIONAL HANDBOOK ON REGULATING NANOTECHNOLOGIES 566 (2010).
[292] Brunch & Filbey, *supra* note 289, at 7-8.
[293] *See* supra Section II(4).

CERN scientists.[294] Yet CERN scientists were able to be their own risk assessors, and attempts of outside parties to impose meaningful oversight of the LHC were ineffective.[295] Although the LHC has not caused global catastrophic or existential harm, international law should ensure that scientists working with emerging technologies sufficiently consider and proactively minimize GCRs/ERs.

There are many possible ways for a treaty to regulate scientists without stifling scientific development. First, scientists should be required to undergo adequate training both to understand the nature of any GCRs/ERs arising from their particular field of work and to learn ways to mitigate these risks. For example, scientists working with genetically engineered viruses should be made aware of the risks posed by an accidental release, and they should undergo mandatory training to ensure that they follow strict protocols designed to prevent an accidental release. Second, scientists should be subject to a code of conduct that requires scientists to monitor their own ethical and professional conduct as well as the ethical and professional conduct of their peers and supervisors. One way to materialize this concept is to create ethical oversight organizations based on the model of state bar associations, which require membership of all practicing lawyers, punish ethical violations, and compel lawyers to report their peers or superiors if they violate certain ethical and professional rules.[296] In the context of a treaty on GCRs/ERs from emerging technologies, the body of experts or a subsidiary body thereof could decide what constitutes "ethical or professional" conduct, then domestic ethical oversight organizations could implement and refine these rules based on specific domestic needs. Finally, scientists should be equally regulated whether they are involved in government-funded projects or private projects. For example, while the NSABB provides recommendations on training and education for scientists in *federally* funded institutions, the growing number of private institutions conducting experimental research in emerging technologies clearly shows the need to regulate scientists working on projects funded with either federal or private money.[297]

G. Safeguarding Laboratories and Dangerous Emerging Technologies

Nanotechnology, AI, and bioengineering are all susceptible to misuse, and thus an international treaty on GCRs/ERs from emerging technologies should address the security of laboratories and other means of accessing these technologies. First, certain laboratories that participate in developing emerging technologies that pose GCRs/ERs should be required to register their facilities. For example, section 415 of the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 requires facilities that manufacture, possess, pack, or hold food bound for U.S. consumption to register with the U.S Food and Drug Administration (FDA), and such facilities must thereafter provide notice to the FDA about certain food shipments (article 307) and are also subject to record inspection by FDA agents (section 414).[298]

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[294] *Id*.
[295] *Id*.
[296] *See e.g.* Rule 8.3 of ABA's MODEL RULES OF PROF. CONDUCT (2011) ("A lawyer who knows that another lawyer has committed a violation of the Rules of Professional Conduct that raises a substantial question as to that lawyer's honesty, trustworthiness or fitness as a lawyer in other respects, shall inform the appropriate professional authority"); see also Rule 8.4(c) of ABA's MODEL RULES OF PROFESSIONAL CONDUCT (2011) ("It is a professional misconduct for a lawyer to engage in conduct involving dishonesty, fraud, deceit or misrepresentation").
[297] Committee on Assessing Fundamental Attitudes of Life Sciences as a Basis for Biosecurity Education, *A Survey of Attitudes and Actions on Dual Use Research in the Life Sciences*, NAT'L RESEARCH COUNCIL 2 (2009).
[298] Public Health Security and Bioterrorism Preparedness and Response Act of 2002, 42 U.S.C. § 201 (2002).

Similarly, facilities that engage in emerging technologies research that meets a certain threshold of danger (as determined by the aforementioned body of experts or a subsidiary body thereof) could be required to register their facilities at the international level, provide notice when they conduct or plan to conduct certain regulated activities, and make their records available for inspection by international authorities.

Second, a treaty on GCRs/ERs should impose mechanisms to monitor specific technologies that pose a GCR/ER if misused. For example, DNA synthesizers could be "licensed, tagged with electronic locators, and programmed to forbid the synthesis of dangerous DNA sequences," as recommended by Harvard biologist George Church, with the body of experts or a subsidiary body thereof determining what constitutes a "dangerous" DNA sequence based on annual or semi-annual reviews.[299] The body of experts or a subsidiary body thereof should determine which technologies pose a concern and then require registration of these technologies so they can be monitored and traced.

Third, laboratories conducting dual use research in emerging technologies should be required to meet a certain level of safety from accidental releases and theft. For example, laboratories with the most dangerous bioengineered pathogens should be *required* to be BSL-4 instead of being subject to non-binding recommendations on lab security.[300] Furthermore, some laboratories should be required to take certain measures to prevent theft or break-in by securing their physical compound and by installing advanced firewalls on their computer systems. Laboratories should also be required to undergo regular maintenance and inspection to ensure that they meet international regulations. In order to incentivize compliance, if facilities fail to meet safety regulations, they should be subject to substantial fines, and governments should be held financially liable for any significant damage that results from a failure to properly regulate their facilities. Finally, because the number of laboratories handling emerging technologies that pose GCRs/ERs is rapidly growing, states should be required to limit the total number of such laboratories to a number that can be effectively overseen by regulatory authorities.

H. Oversight Mechanism for Scientific Publications

Publicly disclosing scientific information that poses a GCR/ER opens the door for potential terrorists to obtain the information and then intentionally cause massive death to humans or damage to the environment, or else for amateur or under-qualified scientists to replicate such research without sufficient safeguards. This is why the NSABB recommended that findings on how to genetically engineer an airborne H5N1 virus should not be released into the public domain, specifically arguing that the risks outweighed the benefits to society.[301] However, the NSABB does not have the legal power to restrict scientific publications, and while so far the scientists behind the bioengineered H5N1 virus have not released their data, there is no guarantee that future scientists will comply with similar non-binding recommendations.

Likewise, scientists Ray Kurzweil and Bill Joy criticized the decision United States Department of Health and Human Services to release the full genome of the massively deadly 1918 influenza virus ("the Spanish flu"), because releasing such a virus could kill tens if not

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[299] Christopher F. Chyba, *Biotechnology and the Challenge to Arms Control*, ARMS CONTROL TODAY (Oct. 2006), *at:* http://www.armscontrol.org/act/2006_10/BioTechFeature.asp.
[300] Canada recently mandated that only BSL-4 laboratories are allowed to handle lab-made H5 viruses. *See* THE CANADIAN PRESS, *supra* note 54.
[301] *Id*.

hundreds of millions of people.[302] Kurzweil and Joy called for an "international agreement by scientific organizations" to oversee publication of scientific data that could result in acts of bioterrorism, equating the genetic code of deadly viruses to nuclear weapon designs.[303] States should expand this concept by creating an oversight mechanism for all sensitive materials from emerging technologies that pose a GCR/ER. For example, a subsidiary body of the body of experts could determine when the risk of releasing scientific information outweighs the potential benefits, and then take appropriate response measures. So as not to stifle scientific development, scientists whose research poses a GCR/ER should merely be required to redact certain sensitive information rather than being prohibited from releasing their data altogether.

IV. CONCLUSION

A series of fantastical scientific breakthroughs are leading towards or, in some instances, have already created technologies that question basic premises of life: that man cannot create life, that humans are the ultimate intelligent being, or that we are limited by the basic building blocks we find on Earth. While nanotechnology, bioengineering, and AI offer great benefits to society, they also have the potential to cause global catastrophic or even existential harm to humans. While bioengineering has caused a revolution in crop production, genetically engineered viruses have the potential to cause global devastation if accidentally or purposefully released. Nanotechnology has yielded materials that are stronger, lighter, yet nanomaterials also pose unknown human and animal health effects, and weapons developed from advanced nanotechnology could be far more destructive and concealable than nuclear bombs. And while AI could innovate every technology on the planet, a superintelligent machine could outcompete humans or be programmed to act maliciously.

While the chances of massive destruction from these technologies are not high, states should still act quickly to create a flexible, binding international treaty that limits GCRs/ERs arising from emerging technologies to a degree that society deems acceptable. As this paper demonstrates, emerging technologies do not fall squarely within current international law, and allowing a small group of self-interested scientists to regulate themselves is unacceptable when a single misstep could result in global catastrophic or existential harm. Instead, the international community, with the guidance of a body of experts representing a wide range of interests and strong considerations of the precautionary principle, should develop a binding framework to regulate emerging technologies at the international level. Furthermore, because emerging technologies will likely affect the entire world, society should help determine which risks they are willing to take and what moral, ethical, and other beliefs should influence an international regulatory regime. If the international community successfully concludes a treaty on GCRs/ERs from emerging technologies, then perhaps society can thrive in an age of technological innovation without suffering from the associated risks.

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[302] Ray Kurzweil & Bill Joy, *Recipe for Destruction*, N.Y. TIMES (Oct. 17, 2005), *at:* www.nytimes.com/2005/10/17/opinion/17kurzweiljoy.html.
[303] *Id.*