"Global Sustainability: Timescales, Magnitudes, Paradigms, and Black Swans"

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We live in a time of great change, an increasingly global society, driven by the exponential growth of new knowledge and knitted together by rapidly evolving information and communication technologies. It is a time of challenge and contradiction, as an ever-increasing human population and invasive activities of humankind are now altering the fragile balance of our planet. The concerns are both multiplying in number and intensifying in severity: the destruction of forests, wetlands, and other natural habitats by human activities leading to the extinction of millions of biological species and the loss of biodiversity; the buildup of greenhouse gases such as carbon dioxide and their possible impact on global climates; the pollution of our air, water, and land. A global, knowledge-driven economy places a new premium on technological workforce skills as governments place increasing confidence in market forces to reflect public priorities despite the evidence that they have become increasingly unstable. Shifting geopolitical tensions are driven by the great disparity in wealth and power about the globe, manifested in the current threat to homeland security by terrorism. We are challenged to find new ways to provide for a human society that presently has outstripped the limits of global sustainability.

Yet, as the declaration of the Glion VII conference, drafted by Frank Rhodes, reassures us (Rhodes, 2009):

> "The daunting complexity of the challenges that confront us would be overwhelming if we were to depend only on existing knowledge, traditional resources, and conventional approaches. But universities have the capacity to remove that dependence by the innovations they create. Universities exist to liberate the unlimited creativity of the human species and to celebrate the

> unbounded resilience of the human spirit. In a world of foreboding problems and looming threats, it is the high privilege of universities to nurture that creativity, to rekindle that resilience, and so provide hope for all of Earth's peoples."

Today's challenges presented by global sustainability differ from those faced in earlier eras, and these will require major changes in educational, research, and service activities of our universities. This is the topic of this paper. Yet here, there are many things that puzzle me.

Some Puzzles

There is ample evidence that the world's climate is changing–and quite rapidly in fact, e.g., the shrinking of the Artic ice cap, the melting of glaciers around the world, shifting climates, and more intense storms. Furthermore, the fact that the only things that has changed in a massive way over the last thousand years are the doubling of carbon-dioxide concentrations in the atmosphere produced by the burning of fossil fuels and land-use practices. This strongly suggests this climate change is due to the activities of humankind. The increasing confidence on the part of the vast majority of the scientific community that the activities of humankind are changing the climate of the planet is illustrated by the most recent conclusion of the International Panel on Climate Change: "Warming of the climate system is unequivocal…Most of the observed increase in globally-averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" (IPCC, 2007). Yet, not only have we made rather feeble attempts to address this, but a substantial part of our population denies the reality of both climate change and human impact.

It is also puzzling that despite the growing evidence that our current energy infrastructure based largely on fossil fuels is no longer sustainable, whether because of limited reserves of oil and gas, the rising costs driven by the imbalance between supply and demand, or environmental impact, we continue on with business as usual–drilling more wells, fracturing more shale deposits for gas, building more coal-fired power plants, and producing more gasoline-guzzling automobiles. Of course, we do hear suggestions that perhaps renewables such as wind or solar power are the answer if only we would just invest in them–although another carbon-free technology, nuclear power, is rarely mentioned as an option.

The past several years has also clearly established the vulnerability of our financial markets, dependent as they are on poorly understood instruments such as derivatives and credit default swaps, guided by abstract theories developed by renegade theoretical physicists, driven by the insatiable greed of traders and gigantic banks, and linked tightly together through computers and networks into highly unstable, nonlinear, and poorly understood systems. Yet, despite the loss of many trillions of dollars and the livelihood of millions of people as these systems collapsed in 2008, pulling down our economies with them, we seem unwilling to take steps to regulate these dangerously unstable markets or discipline those who have made billions from speculative activities. Any engineer could warn that removing constraints (e.g., friction) from an intrinsically unstable system will lead to catastrophe!

Finally, I remain puzzled by how our society views the great tragedy this past year in Japan, hit by a massive tsunami triggered by one of the largest earthquakes in history. Although this natural disaster has destroyed cities and claimed tens of thousands of lives, we instead seem more concerned by the impact the tsunami caused to a 40-year old nuclear power plant, that while seriously damaged, has yet to have a measureable impact on public health, although it seems likely to have thrown seriously off course the global effort to expand nuclear power as the only currently viable major source of carbon-free electricity generation.

Of course, there are a lot of explanations to these puzzles. To be sure, people tend to believe what they want to believe. They tend to seek simple solutions to complex problems such as global climate change. So too, greed can be a very powerful destabilizing force, and the wrong incentives can stimulate taking excessive risks, whether in financial markets or the design of complex technology (e.g., BP's deepwater drilling). There are also problems in the way that experts describe these issues to the lay public (Bierbaum, 2011). Of course, it is not surprising that people do not believe what scientists try to tell them. Climate change can be both complicated and counterintuitive, for example, explaining why global warming could lead to major snowstorms. Furthermore, the scientific community can appear arrogant and cavalier at times (e.g., the "Climategate" scandal that led to cries of conspiracy and hoax). But to disregard Mother Nature is another matter.

We should have learned the dangers of benign neglect from a 20th century characterized by two world wars, the threat of nuclear holocaust, the impact of global pandemics (e.g., the influenza pandemic of 1918), the havoc caused by dictators and failed states, and the list goes on. The forces we face today are somewhat different, but no less threatening and challenging. Our current inability to generate sufficient concern and action to address the challenge of global sustainability may suggest that something more fundamental may be involved: the difficulty we have in comprehending the timescales, magnitudes, and paradigm shifts characterizing the challenges threatening global sustainability. There is one more characteristic that complicates this even further: the degree to which our world is being reshaped by “Black Swan” events (a term to be explained later).

Timescales

We usually think in terms of the timescales characterizing our own experiences. For example, businesses tend to function on timescales determined by quarterly earnings statements–little wonder here, since this is how Wall Street estimates the value of their stock. Public policy evolves on timescales of election cycles, in the U.S. typically two-year cycles corresponding to state and federal elections. (Of course, dictatorships tend to function on timescales determined by the lifetimes of their leaders, as vividly being demonstrated today in the Middle East and Africa.) We tend to think of natural phenomena, such as climate change or biological evolution operating on very long timescales, thousands or even millions of years. But all of this is changing, with serious implications for global sustainability.

As we have noted, evidence of global warming is now incontrovertible–increasing global surface and air temperatures, receding glaciers and polar ice caps, rising sea levels, and increasingly powerful weather disruptions–all confirm that unless the utilization of fossil fuels is sharply curtailed, humankind could be seriously threatened. There are several timescale issues here. In the near term (meaning decades), if the current rate of growth of fossil fuel combustion continues, atmospheric carbon dioxide concentrations that have been in the range of 200 to 300 ppm by volume for 400,000 years and have already increased to current levels of 390 ppm are projected to rise even further to 550 ppm by 2050 (Lewis, 2007). Although human adaptation could probably occur at this level, it would be in a radically different world in which biodiversity would be seriously threatened (e.g., the coral reefs would die), and the seas would rise by 1-2 meters, flooding much of the world’s lowlands. A world that continued to be primarily dependent upon fossil fuels could see carbon dioxide concentrations of 800 ppm by 2100, approaching the point at which even more serious events, such as the melting of the ice masses in Greenland or Antarctica could raise sea levels by several meters, or the methane in the Artic tundra could be released, triggering a possible runaway greenhouse process (think Venus).

Unfortunately, the lifetime of carbon dioxide in the atmosphere is very long. Even if current emissions could be eliminated, it would take thousands of years for concentrations to decay back to acceptable levels. Hence, we have only a few decades to address this problem before reaching the point of no return. As Nate Lewis of Caltech suggests, we are currently conducting the biggest experiment with Planet Earth that humankind has ever performed by tinkering with our climate, "We get to do this experiment exactly once. And there is no tomorrow, because in 20 years that experiment will be cast in stone. Within the next 20 years, we either solve this problem or the world will never be the same!" (Lewis, 2007)

However, the success of this "experiment" depends on facing up to a second challenge: Our current energy infrastructure, heavily dependent upon fossil fuels, is unsustainable, particularly within the context of global climate change, but also because of possible mismatch between supply and demand (particularly for oil that may already have reached a peak in production). Clearly, if nations are to meet their responsibilities for national security, economic prosperity, and environmental impact, the world must move rapidly and aggressively to address the need for a sustainable energy future. Yet, time is not on our side.

The energy industry and its markets are the world's most massive, most indispensable, most expensive, and most complex, in which major technological change occurs on a timescale measured in decades, not years (Smil, 2010). As Lewis points out, new energy sources, such as renewable energy technologies, are a "substitution" product that require first, fostering a marketplace where the technology can come to scale and compete (Lewis, 2007). Hence, even with strong government involvement in developing new energy technologies and intervention in the marketplace, it will take decades for sustainable technologies to have major impact. Yet, the clock continues to tick, carbon dioxide levels continue to rise, and the climate continues to change.

As yet another example of shifting timescales, we might consider the recent experiences of our financial markets, now not only coupled together electronically about the world, but with supercomputers instantaneously solving the complex equations developed by mathematicians and physicists ("quants") to determine key trading decisions, rather than the more deliberate decisions of analysts and brokers on the trading floor. Here the timescale issue involves new technologies driving such profound changes in our world such as information technology are characterized by an exponential pace of evolution in which characteristics such as computing speed, memory, and network transmission speeds for a given price increase by a factor of 100 to 1000 every decade. Scientists and engineers today believe that the exponential evolution of these technologies is not only likely to continue for the conceivable future, but, in fact, the pace may be accelerating

Magnitudes

In sharp contrast to the rapidly contracting timescales characterizing exponential technologies such as computers and networks, other activities critical for determining global sustainability are more constrained by their scale or magnitude. For example, producing energy, distributing it to society, and transforming it into useful functions requires a massive and expensive infrastructure. The scale of the necessary transformation of our energy infrastructure is immense. It is estimated that over $16 trillion in capital investments over the next two decades will be necessary just to expand energy supply to meet growing global energy demand driven by the energy needs of developing economies (compared to a global GDP of $44 trillion and a U.S. GDP of $14 trillion). Put another way, to track the projected growth in electricity demand, the world would need to bring online a new 1,000 MWe powerplant every day for the next 20 years! (Lewis, 2007) Moreover, the International Energy Agency estimates that to keep carbon dioxide emissions below 450 ppm (and global temperature increases below 2 degrees C) would require an investment of $12 trillion in low-carbon energy technologies and energy efficiency by 2030 (Smil, 2011).

0Yet, there is another important magnitude issue here. Unfortunately, most renewable energy sources such as wind, biofuels, and solar, are very dilute. MacKay demonstrates this by comparing the land mass requirements for each energy source by comparing power densities: windpower: 2.5 watts/m^2; biofuels: 1.5 watts/m^2 (in Brazil); solar: 6 watts/m^2 to meet the needs of the UK population, 1.5 watts/m^2, concluding that a renewable energy economy would take most of the UK land mass. He goes on to note that to meet the needs of Europe with solar energy would take a region of solar collectors about the size of Germany (MacKay, 2009).

A second example of just how magnitudes influence global sustainability is demographics. The United Nations has recently updated its projection of world population growth to 9.3 billion by 2050 and to over 10 billion by 2100 (United Nations, 2011). This raises the logical question: Can we sustain a population of such magnitude on Spaceship Earth? In fact, the basic premise of the free market system, which relies on steady growth in productivity and profits, based in part on similar growth in consumption and population, must be challenged by the very serious problems that will result from a ballooning global population, such as energy shortages, global climate change, and dwindling resources. The stark fact is that our planet simply cannot sustain a projected population of 10 billion with a lifestyle characterizing the United States and other developed nations with consumption-dominated economies.

To be sure, there are some signs of optimism here: a slowing population growth in much of the world (although not in Africa), the degree to which extreme poverty appears to be receding, both as a percentage of the population and in absolute numbers, and the rapid economic growth of developing economies in Asia and Latin America. During the past several decades, technological advances, such as the "green revolution" in agriculture, have lifted a substantial portion of the world's population from the ravages of extreme poverty. In fact, some nations once burdened by overpopulation and widespread poverty, such as India and China, now are viewed as economic leaders in the 21st century.

Yet today, there remain substantial and widening differences in the prosperity and quality of life of developed, developing, and underdeveloped regions; between the North and South Hemisphere; and within many nations (including the deplorable level of poverty tolerated in my own country, the richest on the planet). It is estimated that roughly one-sixth of the world's population, 1.5 billion people, still live in extreme poverty–defined by Jeffrey Sachs as "being so poor you could die tomorrow", mostly in sub-Saharan Africa, parts of South America, and much of central Asia. Sachs states this in even stronger terms, "More than 8 million people around the world die each year because they are too poor to stay alive. Malaria, tuberculosis, AIDS, diarrhea, respiratory inflections, and other diseases prey on bodies weakened by chronic hunger, claiming more than 20,000 lives each day" (Sachs, 2005).

Paradigm Shifts

Looking back over history, one can identify certain abrupt changes, discontinuities in the nature, the fabric, of our civilization. Clearly, we live in just such a time of very rapid and profound social transformation, a transition from a century in which the dominant human activities involved the exploitation of natural resources to manufacture and transport goods to one in which communication technology has become paramount, from economies based upon cars, planes, and trains to one dependent upon computers and networks. We are shifting from an emphasis on creating and transporting physical objects such as materials and energy to knowledge itself; from atoms to bits; from societies based upon the geopolitics of the nation-state to those based on diverse cultures and local traditions; and from a dependence on government policy to an increasing confidence in the marketplace to establish public priorities. A radically new system for creating wealth has evolved that depends upon the creation and application of new knowledge and hence, upon educated people and their ideas and institutions such as research universities, corporate R&D laboratories, and national research agencies where advanced education, research, innovation, and entrepreneurial energy are found (Drucker, 1995).

Whether through travel and communication, through the arts and culture, or through the internationalization of commerce, capital, and labor, or our interconnectedness through common environmental concerns, the globally community is becoming increasingly integrated. The liberalization of trade and investment policies, along with the revolution in information and communications technologies, has vastly increased the flow of capital, goods, and services, dramatically changing the world and our place in it (National Intelligence Council, 2005). Today, globalization determines not only regional prosperity but also national and homeland security. Our economies and our companies are international, spanning the globe and interdependent with other nations and other peoples.

It is also becoming increasingly clear that we are approaching an inflection point in the potential of information and communications technologies to radically transform knowledge work. When we think of digitally mediated human interactions, we generally think of the awkwardness of e-mail or televideo conferences or the instantaneous interaction with text messaging or video Skype. More recently, we have seen the power of social networking through software, such as Facebook and Twitter, to link together millions of people, not only building new communities but empowering social movements, such as the Arab Spring of 2011.

Beyond acknowledging the extraordinary and unrelenting pace of evolution of such technologies, it is equally important to recognize their disruptive nature. The impact on social institutions such as corporations, governments, and learning institutions is profound, rapid, and quite unpredictable. As Clayton Christensen explains in *The Innovators Dilemma*, while many of these new technologies are, at first, inadequate to displace today's technology in existing applications, they later explosively displace the application as they enable a new way of satisfying the underlying need (Christensen, 1997). If change is gradual, there will be time to adapt gracefully, but that is not the history of disruptive technologies.

Black Swans

During the past year, the world has been rocked by unanticipated events such as the failure of the BP Deepwater Horizon drilling platform in the Gulf of Mexico and the Fukushima Daiichi nuclear power plant accident resulting from a massive tsunami hitting the coast of Japan. It seems appropriate here to adopt the terminology of "black swan" introduced by Nassim Taleb to refer to an event that is "outside of regular expectations; carries an extreme impact; and makes us concoct explanations for its occurrence after the fact, making it explainable and predictable" (Taleb, 2007). The name arises from a 16th century conjecture that since all swans were presumed at that time to be white, and black swans were then presumed not to exist, if one were found it would disprove the impossibility of this presumption. (Actually, black swans did exist, but in Australia. Today they have also been imported into Europe.)

Taleb suggests that Black Swan events are increasing as our world becomes more complex and integrated, and today they may be more important than ordinary events in determining issues like global sustainability. "Black Swan logic makes what you don't know far more relevant that what you do know. Since Black Swans are unpredictable, we need to adjust to their existence (rather than naively trying to predict them). We need to consider the extremes, improbable or not, particularly if they carry an extraordinary cumulative effect. We need to invest more in prevention than in treatment." (Taleb, 2007)

The tsunami-driven accident at the Fukushima Daiichi nuclear plant in Japan was just such an event. Here the driving cause was a gigantic tsunami, over 35 m in height, created by a massive 9.0 quake that was several times the size of the maximum event deemed possible in the design of the Fukushima nuclear power plant. So what was the consequence? To be sure, there was catastrophic damage to the plant as it lost all electrical power and cooling for an extended period of time, allowing the fuel to overheat and partially melt and releasing radioactivity to the environment. Yet, the impact on public health has been minimal (at least to this point). As noted by *The Economist*, despite being hit by a natural disaster of biblical proportions causing immense damage to the plant, there was little damage to the environment beyond the plant's immediate vicinity or to public health (*Economist*, 2011).

In fact, the most serious impact is likely to be the erosion of public confidence in nuclear power, ironically a carbon-free technology that today provides 14% of the world's electricity with a 50-year safety record in which only one nuclear plant accident has occurred with a major consequence for public safety (Chernobyl). As observed by *The Economist*, "Fear and uncertainty spread faster and farther than any nuclear fallout" (*Economist*, 2011).

A second example is the failure of the BP Deepwater Horizon drilling platform in the Gulf of Mexico last year. Unlike Fukushima, the BP accident has caused many deaths and vast damage to the Gulf environment. And unlike the Japan incident, which was triggered by a natural disaster of biblical proportions, the BP Deepwater Horizon accident was clearly the result of human error–inadequate design, operation, and response. Yet, it was also a Black Swan event, thought to be impossible, of major consequence, yet clearly understandable and explainable in retrospect.

Clearly, such Black Swan events threaten global sustainability. The impact of major environmental events, such as the melting of the Arctic tundra and release of massive amounts of methane could trigger runaway global greenhouse instability. The rapid melting of the ice sheets in Greenland or the Antarctic could raise sea levels by several meters inundating coastal cities and populations. In fact, one can imagine Black Swan events that today seem of such remote possibility that they currently exist only in science fiction. Clearly, phenomena such as machine consciousness, contact by extraterrestrial intelligence, or cosmic extinction from a wandering asteroid are Black Swan "possibilities" for our civilization, but just as clearly they should neither dominate our attention nor our near-term actions. Indeed, the most effective way to prepare for such unanticipated events is to make certain that our descendants are equipped with education, wisdom, and foresight of the highest possible quality.

The Roles of Universities in Addressing the Challenges of Global Sustainability

In summary then, the forces driving change in our world–anthropogenic driven changes in our environment (climate change, declining biodiversity), changing demographics (aging populations, migration, increasing ethnic diversity), environmental impact (climate change, biodiversity), globalization (economic, geopolitical, cultural), and disruptive technologies (info-bio-nano technologies)–are likely to require very major changes in post-secondary education as a global knowledge economy demands a new level of knowledge, skills, and abilities on the part of our citizens. It will also require research universities capable of discovering new knowledge, to develop innovative applications of these discoveries, transfer them into society through entrepreneurial activities, and educate those capable of working at the frontiers of knowledge and the professions.

Yet, there are broader responsibilities beyond national interests–particularly for developed nations–in an ever more interconnected and interdependent world. Global challenges, such as crippling poverty, health pandemics, terrorism, and global climate change, require both commitment and leadership. So, what are the implications of these shifting timescales, magnitudes, paradigms, and emerging Black Swans characterizing a rapidly changing world for the future of the university? To be sure, the traditional roles of the university will continue to be important. But our educational programs must be characterized by both the depth and breadth to prepare our graduates for a world of constant and ever accelerating change. For example, an increasingly complex and rapidly changing world requires "T" graduates, capable of both depth in a particular discipline as well as intellectual breadth (Donofrio, 2009). Our research activities must evolve to develop the intellectual tools to address the challenges of a world increasingly threatened by humankind. And we must become more engaged with society beyond our campus to shape both public understanding and action. Whether motivated by the economic desire to create new markets or the more altruistic motives of human welfare, our universities have a responsibility to address global issues. Globalization requires thoughtful, interdependent and globally identified citizens. Educational institutions must think more concertedly about their role in promoting both individual and civic development.

But we must also recognize that a changing world demands a change in the university itself. Social computing will empower and extend learning communities beyond the constraints of space and time. Open knowledge and education resources will clearly expand enormously the knowledge resources available to our institutions. Immersive environments will enable the mastery of not only simply conventional academic knowledge, but as well tacit knowledge, enabling our students to learn not only how "to know" and "to do", but actually how "to be"– whether scholars, professionals, or leaders–but above all, contributing citizens of the emerging global community (Thomas, 2011).

But there is a possibility even beyond these. Imagine what might be possible if all of these elements merge, i.e., Internet-based access to all recorded and then digitized human knowledge, augmented by powerful search engines; open source software, open learning resources, and open learning institutions (open universities); new collaboratively developed tools (Wikipedia II, Web 3.0); immersive environments (World of Warcraft, Second Life); social networking (Facebook, Twitter); and ubiquitous information and communications technology (digital appliances such as smart phones and iPads). In the near future, it could be possible that anyone with even a modest Internet or cellular phone connection will have access to the cyberspace cloud containing all recorded knowledge of our civilization along with ubiquitous learning opportunities and social networking communities throughout the world.

Imagine still further the linking together of billions of people with limitless access to knowledge and learning tools enabled by a rapidly evolving scaffolding of cyberinfrastructure, which increases in power one-hundred to one thousand-fold every decade. This hive-like culture will not only challenge existing social institutions–corporations, universities, nation states–that have depended upon the constraints of space, time, laws, and monopoly but it will also enable the spontaneous emergence of new social structures as yet unimagined. Just think of the early denizens of the Internet such as Google, Wikipedia, Facebook, Twitter …and, unfortunately, Al Qaeda. In fact, we may be on the threshold of the emergence of a new form of civilization, as billions of world citizens interact together, unconstrained by today's monopolies on knowledge or learning opportunities.

Perhaps this, then, is the most compelling vision for the future of knowledge and learning organizations such as the university, no longer constrained by space, time, monopoly, or archaic laws, but rather responsive to the needs of a global, knowledge society and unleashed by technology to empower and serve all of humankind.

References

Bierbaum, Rosina. "Science, Policy, and Politics". Powerpoint Presentation, University of Michigan, 2011.

Christenson, Clayton. *The Innovator's Dilemma*. Cambridge, MA: Harvard Business School Press, 1997.

Donofrio, Nicholas. *Innovation that Matters*. Remarks at New York State Education Summit. Albany, NY, November 2, 2005.

Drucker, Peter. "Beyond the Information Revolution". *Atlantic Monthly*, 284:4, October, 1999.

The Economist. "When the Steam Clears", March 24, 2011; "In Place of Safety Nets", April 23, 2011.

Goodstein, David. *Out of Gas: The End of the Age of Oil.* New York: W.W. Norton, 2004.

IPCC, Intergovernmental Panel on Climate Change, "Climate Change 2007", Cambridge: Cambridge University Press, 2007.

Lewis, Nathan S. "Powering the Planet". *Engineering and Science*, No. 2, pp. 13-23, 2007.

MacKay, David. *Sustainable Energy – Without the Hot Air*. UIT Cambridge Ltd., 2009.

National Intelligence Council. *Mapping the Global Future, Project 2020*. Government Printing Office: Washington, DC, 2004.

Rhodes, Frank. Universities and the Innovative Spirit. The Second Glion Declaration, Geneva: Glion Colloquium, 2009.

Sachs, Jeffrey. *The End of Poverty: Economic Possibilities of Our Times*. New York, NY: Penguin Press, 2005.

Smil, Vaclav. "U.S. Energy Policy: The Need for Radical Departures". *Issues in Science and Technology*. National Academies, Washington, DC: National Academy Press, Summer 2009.

Smil, Vaclav. "Global Energy: The Latest Infatuations". *American Scientist*, Vol. 99, pp. 212-219, 2011.

Taleb, Nassim Nicholas. "The Black Swan: The Impact of the Highly Improbable". *New York Times*, April 22, 2007.

Taleb, Nassim Nicholas. *The Black Swan: The Impact of the Highly Improbable*, Second Edition. NewYork: Random House, 2010.

Thomas, Douglas and John Seely Brown. *A New Culture of Learning: Cultivating the Imagination for a World of Constant Change*. San Francisco: Thomas and Brown, 2011.

United Nations, *2010 Revision of the World Population Prospects*. Population Division. New York: United Nations, 2011.

Vest, Charles M., Chair. *Critical Choices: Science, Energy, and Security*. Advisory Committee to the Secretary of Energy. Washington, DC: U.S. Department of Energy, 2003.