

# Nuclear Risk in Perspective: Making Fact-Based Energy Choices



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DECEMBER 2011

As champions of reason and science, U.S. progressives have a responsibility to avoid panicky overreactions and instead undertake a clear-eyed assessment of the actual risks of nuclear energy.

## Introduction

March 11, 2011 was a day of calamity the Japanese people will never forget. According to the National Police Agency of Japan<sup>1</sup> the Tōhoku earthquake and tsunami left 15,841 dead, 5,890 injured and 3,490 people missing (as of December, 2011). Mother Nature’s freakish, one-two punch also triggered the partial melt-downs of four reactors in the Fukushima Daaichi complex, one of the worst commercial nuclear power plant disasters in history.

The Fukushima incident has stoked nuclear dread around the world and led some to conclude that nuclear power is too risky. Perhaps the most dramatic shift in public attitudes has been in Germany, where a conservative-led government recently unveiled a plan to close down all the country’s nuclear power plants by 2022.

Americans, however, should not endorse this knee-jerk anti-nuclear policy. For the foreseeable future, nuclear power will remain a vital part of a balanced and realistic national energy portfolio. Moreover, as champions of reason and science, U.S. progressives have a responsibility to avoid panicky overreactions and instead undertake a clear-eyed assessment of the actual risks of nuclear energy.

Generating electricity—like getting out of bed in the morning, or any other human activity—carries inherent risks. That’s true regardless of the fuel used to generate power. Instead of carefully weighing and comparing such risks, however, some environmental activists have tried to pose a false choice between “clean” and presumably safe renewable fuels like wind, solar and geothermal energy, and “dirty” fossil fuels or allegedly “unsafe” nuclear power. This dichotomy has nothing to do with science.

No sensible person is against renewable energy. But it will probably be a long time—likely decades, not years—before such sources have a realistic prospect of providing the base load needs of our national economy, let alone meeting the growing requirements of the entire globe. The Obama administration takes a

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more realistic approach in including nuclear energy along with other non-carbon emitting sources in its “Clean Energy Standard.” To understand why this is the case, we first need to review a few of the often overlooked, but important subtleties of electrical power generation.

## How We Generate Power

Providing continuous power to U.S. businesses and homes entails three types of power generation: base load, peaking power, and intermittent. Base load power plants, such as nuclear, coal, geothermal, hydro, and sometimes natural gas (when the price is low enough) supply the minimum amount of energy power companies need to meet the demands of their customers. These power plants aim at producing energy at full capacity, for 24 hours a day, 365 days a year, usually at low cost, and are not designed to increase or decrease output to meet fluctuations in electricity demand. In contrast, peaking power plants, such as gas turbines, which mostly burn natural gas (although a few burn other fuels such as diesel oil, or jet fuel) can be turned on or off relatively quickly and easily to match power consumption changes at certain times of the day or season. Because they aren’t operated continuously, peaking plants are generally less efficient and more expensive to run.

The third type of power generation is relatively new to the electricity production world and comes from renewable but intermittent sources such as wind, solar (photovoltaic and thermal), wave, and tidal. Such generation typically must be operated in tandem with peaking power plants of equal capacity to fill the gaps when demand is high and the wind drops or the sun is obstructed by clouds. To provide continuous power from intermittent electrical power sources without peaking power plants would require the effective storage of electricity on an unprecedented scale. We are decades away the development of storage technologies (e.g., traditional batteries, pumped hydro storage, compressed air, molten salt, etc.) on a scale necessary to smooth out intermittent power fluctuations.

Another major constraint on intermittent energy sources is America’s aging electrical grid. Because transmitting electricity over large distances results in tremendous losses of power, you can’t simply take electricity from one place that has a surplus and ship it to a needy area. According to the U.S. Energy Information Administration,<sup>2</sup> transmission and distribution losses were rated at 6.5 percent in 2007.

Two upgrades to the grid would make integration with intermittent sources much more feasible. One is building a new infrastructure that combines high voltage super-conducting power lines coupled with liquid nitrogen pipelines, to transmit power with very little line resistance losses. Although the refrigeration required to keep these pipelines cold would use energy, this approach could cut losses from conventional lines in half.<sup>3</sup> Second, we need to build a smart grid to enhance energy efficiency. Using information technology, a smart grid would turn on home appliances (dishwashers, laundry machines, etc.) or activate industrial processes

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when electricity is most available and least expensive. At peak hours, it would turn off appliances to reduce demand and save consumers money. The U.S. Department of Energy<sup>4</sup> estimates that modernizing U.S. grids would save between \$46 and \$117 billion over the next 20 years. Yet with political pressures building to cut government spending, we may not see any serious public investment soon in upgrading the grid.

These are the realities. For now, and probably for the next half-century, we will not be able to generate power solely from intermittent sources without the use of base load and peaking power plants. For base load electricity generation, the realistic options are hydro, geothermal, oil, natural gas, nuclear, and coal. Hydro electricity generation, unfortunately, is a resource that has been almost completely tapped in the U.S. With new research on fish migration, it's more likely we will see dams torn down rather than built in the future. Geothermal is also a great resource, but there are simply not enough geothermal hot spots in the U.S. to make much more than a small dent in the base load demand. Oil-based electricity generation also is out of the question due to the high price of oil and the clear national interest in reducing our reliance on foreign oil. It is interesting to note, however, that even though electricity generated by oil power plants has fallen sharply over the past half-century, to about one percent of the total, that's still about the same percentage as all other non-hydroelectric renewable electricity generation combined. This leaves us with nuclear, coal, and natural gas for the bulk of our electricity generation. Using all three of these fuels entails risk. Discussions concerning these risks typically take one of two paths—health risks and financial risks. Let's examine each in turn.

## Health Risk

Obviously the first priority of any electrical power generation method should be to ensure the safety of humans working at it and living around it. It's time to confront myths and irrational fears and take a dispassionate look at the comparative health risks posed by nuclear, coal, and gas power plants that will provide our base load power.

Even the most determined nuclear power critics cannot attack the impeccable safety record of nuclear power reactors under normal operating conditions. But what about catastrophic failures, or meltdowns? Conveniently, the Tōhoku earthquake and tsunami gave us an in-depth look at what this risk to human life looks like. After being shaken by the most powerful earthquake to ever hit Japan, followed by a 50 foot tall tsunami, three reactors at the Fukushima nuclear power plant catastrophically failed. The death toll from this disaster, however, was zero.<sup>i</sup> Highly conservative estimations of the consequences of severe accidents at nuclear power plants in the 1970s predicted that a single nuclear power plant meltdown could kill hundreds of thousands from exposure to radioactive material.

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<sup>i</sup> However, two workers, tragically, did die from trauma in a reactor basement during the tsunami.

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These early risk calculations included several assumptions that, when combined, led to an unrealistic view of radiation risk. In a nutshell, here's how one would arrive at those numbers.

We know that high doses of radiation are harmful, and in extreme cases, can cause death. Less extreme (but still large) doses have also proven to increase the risk of certain types of cancer. Low doses are a different story. There is no scientific consensus on the risk from low doses of radiation. Because no one knows, the possible consequences of exposure to high doses are extrapolated down to zero-dose, zero-risk, just to be safe. Thus, it's assumed that exposure to any amount of radiation, however small, increases the risk of cancer. Bear in mind, there is no scientific proof of this; it is just the most conservative way to calculate risk, commonly referred to as the linear-no-threshold (LNT) hypothesis.

By the same logic, one could assume that a small dose of Ibuprofen is harmful because it's been shown to cause fatal liver damage when consumed in extremely large quantities. According to the LNT hypothesis, a low dose of Ibuprofen could slightly increase the risk of liver failure from extrapolating from the high-dose consequence. Given its widespread use, Ibuprofen could be shown to cause thousands of deaths per year. To back this claim up, we just need a large enough population—say, ten million people. A 0.01 percent increase turns into 1,000 extra cases of liver damage. Because liver failure is often fatal, one can conservatively assume that all of these people will immediately die from liver failure. This method of assessing risk leaves us with 1,000 deaths from small doses of the painkiller. Of course, if people were actually dying in such numbers, the pain killer would be banned from use.

Now let's talk real numbers. According to the Nuclear Energy Institute<sup>5</sup>, fewer than thirty workers at the Fukushima nuclear plant received significant whole-body doses of radiation. Of these, just two received whole-body doses of around 25 rem. The LNT hypothesis assumes a 0.04 percent cancer rate increase per rem.<sup>6</sup> Therefore, by this extremely conservative estimate, the two most heavily exposed workers increased their cancer risk by around 2%. That's unfortunate, but hardly tragic next to the staggering total of 24,000 people either dead or missing from the earthquake and tsunami.

Similar analysis is often cited to raise concerns about the long-term geologic disposal of nuclear waste. Such questions have led to the decision to terminate the Yucca Mountain project in Nevada. In that case, extremely low probability sequences of events are called upon to yield extremely low radiation exposures to the population of nearby residents one million years in the future. Admittedly it is very difficult to predict events that far into the future. However, considering the significant advances in the biological sciences over the past 50 years, it might be worth asking when our scientists will eliminate cancer from the human species? If the cancer puzzle is solved before small levels of radioactive materials are released into the environment, then the primary fear of geologic disposal of radioactive

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waste would be removed. However, making either prediction remains a difficult task and President Obama's Blue Ribbon Commission on America's Nuclear Future is scheduled to release its report in the coming months to help guide the country's discussion on the pathway forward on this so far largely intractable issue.

Coal power, which many erroneously view as safer than nuclear, has killed an average of 33 people in the U.S. every year for the past decade from mining accidents according to the Mine Safety and Health Administration.<sup>7</sup> The Upper Big Branch mine disaster in West Virginia on April 5, 2010 that killed 29 miners is a recent demonstration of the real risks associated with burning coal for electricity production. Coal mining around the world is even riskier. In China, coal is responsible for more than 4,500 deaths each year, according to the World Security Institute.<sup>8</sup> That's over 10 coal miner deaths per day for ten years.

Mining aside, the normal operation of coal power plants poses significant health risks. Coal-fired power plants release more toxic air pollutants than any other U.S. industrial pollution source, including mercury, arsenic, dioxin, hydrogen chloride, formaldehyde, and sulfur dioxide. The more than 400 coal-fired power plants across 46 states release 386,000 tons of hazardous air pollutants into the atmosphere each year<sup>9</sup>. According to the American Lung Association<sup>10</sup>, particle pollution from these power plants is estimated to kill approximately 13,000 people in the United States every year. Of course, these death-toll statistics should always be taken with a grain of salt because they are projections from mathematical models. Nonetheless, there is little doubt that pollution from coal-fired power plants causes asthma, chronic obstructive pulmonary disease, bronchitis and other lung diseases, heart attacks, strokes, lung (and other) cancers, birth defects and premature death. So while not everyone will be convinced that coal power kills exactly 13,000 people per year, there is a scientific consensus that the pollution is, in fact, deadly.

Ironically, combusting coal actually releases larger amounts of radioactivity than nuclear generation. Fly ash, which contains naturally occurring radioactive materials such as uranium, radium, and thorium, carries 100 times more radiation into the surrounding environment than a nuclear power plant producing the same amount of energy.<sup>11</sup> Oddly, coal-fired plants are not held to the same strict radiation release standards as nuclear plants. Although the radioactive material released from coal power plants is not nearly as likely to harm people's health as the other chemical byproducts discussed above, the accumulation of long-lived radionuclides over 200 years of burning coal in America could pose future ecological burdens, making some areas unlivable in the future based on today's public radiation protection standards.

Nor is natural gas less risky than nuclear power. According to the official Pipeline Safety Trust,<sup>12</sup> from 2002-2009 there were 2290 natural gas pipeline disasters, resulting in 65 deaths and 265 injuries, at an average of about 9 deaths per year.

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As examples of the dangers of natural gas production and delivery, on September 9, 2010 eight people died and 38 homes were destroyed by a natural gas explosion in San Bruno, Calif. and three workers were killed in two separate Texas gas pipeline explosions over a two-day period in June 2010. These disasters demonstrate the direct impacts on the lives of many people and continue today with a sad and shocking regularity.

## Financial Risk

The other main rap on nuclear power is that it's costly. The upfront costs of building new reactors are enormous. At the Vogtle site in Burke County, Georgia, Southern Nuclear is building two new, Advanced Plant 1000 (AP1000) reactors. These are the first U.S. plants to begin construction since 1979. They are also the first of the new Generation III+ reactor designs, which incorporate Passive Core Cooling Systems (PCCS). In contrast to the Generation II reactors at Fukushima, and every other reactor in the United States, if something were to go wrong in an AP1000, the plant would automatically achieve and maintain safe shutdown condition, giving the reactor operators 72 hours (3 days) until any intervention is necessary. These cutting-edge safety systems don't rely on the availability of electricity from the grid or diesel generators; instead, they utilize the natural forces of gravity, fluid circulation, and compressed gasses to keep the core and containment from overheating.<sup>13</sup>

The Municipal Electricity Authority of Georgia<sup>14</sup> estimates the cost of the two new AP1000 reactors at \$14 billion (including finance costs). It is important to acknowledge, however, that with each new reactor built, the cost should decrease as experience shows ways to streamline the process and cut costs. While some may view the initial upfront capital costs as too expensive, the cost for 60 years of clean electricity is actually quite competitive.

As a result, both Republican and Democratic administrations have pursued federal loan guarantees to reduce the financial risk<sup>ii</sup> to companies committed to building newer, safer nuclear plants. These guarantees are intended to help would-be builders raise private construction capital at no cost to the taxpayer.

A final financial risk of nuclear power is the cost of a large catastrophic disaster. The nuclear industry under the Price-Anderson Act<sup>15</sup> provides the most robust third party liability insurance in the world for any private industry. The way it works is that each plant has private commercial insurance to cover up to \$375 million in third party liability claims. If this initial amount is exceeded, the industry then has a secondary insurance pool paid for entirely by the utilities of \$121 million per reactor. This amounts to around \$12.6 billion (\$121M x 104 reactors) in combined secondary coverage. If the disaster costs more than this entire pool

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<sup>ii</sup> The nuclear utilities, however, still pay a credit subsidy fee in the DOE 1703 (nuclear) loan guarantee program, unlike the 1705 program for renewables only.

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in the absolute worst case, then the Congress would decide who pays for additional damages.

To put these numbers in perspective, the Three Mile Island accident cleanup cost a total of around \$1 billion over 14 years,<sup>16</sup> paid for by the utilities who shared ownership of the plant, General Public Utilities (GPU) and Metropolitan Edison. In addition, the accident resulted in third party liability claim payments of \$71 million to local residents and businesses to pick up the costs of evacuation and business interruption. The government was not financially liable, nor was the secondary pool used to cover the damage. In fact, the secondary pool has never once been used since its creation in 1957. The existence of the insurance pool, however, has served as motivation for industry cooperation and assistance to ensure all nuclear operators are focused on safety and operational excellence. For example, the Institute of Nuclear Power Operations (INPO), established and funded by the nuclear power industry, independently evaluates nuclear sites and shares both strengths and areas for improvement with other nuclear sites. In the wake of the BP oil spill, it was recommended to be used as role model for offshore oil drilling self-regulation by the BP Oil Spill Commission.<sup>17</sup>

Associated with financial risk is the possibility that a nuclear accident might make large areas of land unusable into the future. The 1986 Chernobyl accident in the Ukraine was easily the worst commercial nuclear disaster on record. To this day there is still a nearly eight square-mile “exclusion zone” around the old entombed reactor due to heightened levels of radiation. In contrast, Three Mile Island, the worst nuclear incident to occur in the United States, did no lasting damage to the surrounding land. Very little radiation was actually released during the disaster, and the old, partially melted reactor core was removed from the site. There are many people who walk right next to the extinct reactor every day; these are the site employees who work at the other still functioning reactor on the site.

The area around Fukushima will likely see a fate somewhere in between the poles of Chernobyl and Three Mile Island. As of this writing, the Japanese government has created a 12-mile radius (226 square miles) evacuation zone around the plant. Although it is still too early to tell what the ultimate exclusion zone around the site will be, judging by the radiation release in comparison to Chernobyl and Three Mile Island, the ultimate loss of land, if any, will likely be much smaller than Chernobyl.

Nuclear plants aren't the only ones susceptible to costly incidents. In 2008, at the Tennessee Valley Authority's Kingston coal-fired power plant, an ash dike ruptured and spilled over 1 billion gallons of coal fly ash slurry into the Emory and Clinch Rivers. Coal slurry consists of fly ash mixed with water, to minimize dust, and is commonly stored in large holding pools on site at coal power plants. The volume released was over 100 times larger than the 1989 Exxon Valdez oil spill and covered 300 acres of the surrounding land with a grey, toxic sludge, covering homes and disrupting the surrounding ecosystem for the foreseeable future.

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When finished, the cleanup is estimated to cost between \$675 million to \$1 billion<sup>18</sup> plus hundreds of millions more in property damage lawsuits.<sup>19</sup>

A recent Harvard University study<sup>20</sup> calculated the cost of coal throughout its entire life cycle. It found that coal costs around \$187.5 billion in public health expenses for treating cancer, lung disease, and respiratory sickness, as well as costs from deaths and injuries from mining and transportation. Mercury accounts for another \$29.3 billion, and costs from climate impacts, land use, energy consumption, and food prices are estimated at \$205 billion. The costs of cleanup from spills, impact on crops, property values, and tourism account for up to \$18 billion more. The final estimate is the American people pay in the range of \$500 billion per year for our dependence on coal. This doubles to triples the price of electricity per kWh. As with all the other calculations like this, these numbers should be taken with a grain of salt, as these are projections from mathematical models. However, this study at the very least, illustrates the substantial hidden costs of coal power.

Clean coal, mostly coal-fired power combined with carbon sequestration techniques, is often touted as the solution to the U.S. energy demand, but financial burdens still limit this application. Current estimates by the U.S. Department of Energy<sup>21</sup> of capturing CO<sub>2</sub> are expected to be around \$150 per ton of carbon, which would nearly double the cost of coal-fired electricity from 2.5 to 4 cents/kWh. Clean coal is also plagued by concerns over potentially high costs of social and environmental damage, and future regulations to ensure the perfect and perpetual removal of the CO<sub>2</sub> from the biosphere. Clean coal may become an important part of our energy infrastructure in the future, but industrial implementation of this technology remains decades away.

Natural gas, which so far has looked pretty good, has one historical disadvantage: price volatility. In the last 20 years, high crude oil prices, due in part to increased global turmoil, have strengthened the connection between the two commodities. High oil prices “allow” natural gas prices to rise unnaturally due to competitive fuel switching. One example of this was the energy crisis market manipulation of early 2001, which sent natural gas prices in the range of \$10 per MMBtu. Historically, however, gas volatility has been driven by natural events. Most notable were hurricanes Katrina and Rita, which sent gas prices in the \$12-\$14 per MMBtu range for months at a time and Hurricane Lili in 2002 at \$18/MMBtu.<sup>22</sup>

However, new developments in natural gas recovery from shale rock formations (so-called shale gas) may strongly reduce the price volatility for gas by providing a large, steady flow of gas at predictable and steady prices. If these developments pan out, this might enable gas to move into the base load electricity production regime, thus displacing coal and potentially reducing greenhouse gas emissions by up to 40 to 50%.

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## Real Risk vs. Risk as a Feeling

So far we have spoken of risk in terms of assessments based on logic, reasoning, and scientific deliberation. But this is not the way most people think about nuclear energy. Their perceptions are shaped by *risk as a feeling*<sup>23,24</sup>—an instinctive and intuitive reaction dominated by worry, fear, dread, and anxiety. These feelings often reflect a conflation of nuclear power and nuclear weapons, and the feelings of anxiety stoked by the Cold War arms race.<sup>25</sup>

One theory that many psychologists<sup>26,27</sup> agree may influence the public's feelings towards nuclear energy is the *affect heuristic*. It holds that if people feel favorably toward something, they are inclined to see its risks as low and its benefits as high. Conversely, if they feel unfavorably toward some activity, they see it as carrying high risks and low benefits. Affective responses occur rapidly and automatically in the human brain; notice how quickly you can sense the feelings associated with words such as “treasure” or “hate.” Given that the public is already perceived to have negative feeling towards nuclear power, the affective response complicates rational analysis.

## The Risk of Doing Nothing

Of course, there are also risks associated with inaction. Psychological studies over the past few decades have examined what happens when subjects are given the option to delay decision-making to obtain more information. For example, one study<sup>26</sup> gave decision makers the option, at various points in time, of evacuating a city threatened by a hurricane. Each time the decision to evacuate was delayed, the death toll increased if the city was hit. Evacuation too early also carried the risk of unnecessary financial and life loss if the hurricane did not hit city. This and other studies show decision makers categorically postpone action far past the optimal moment for decision. Such procrastination often has adverse consequences. A military commander, for example, can be completely certain of an enemy's intentions if he or she is willing to wait until all tactical options have become futile.

In the context of electricity generation, doing nothing means the continued utilization of fossil fuels for the majority of our electricity production. The common scientific consensus is that this course would lead inexorably to growing concentrations of carbon dioxide in the atmosphere. Global temperatures would rise, with all the attendant effects—melting polar ice caps, rising sea levels, droughts, extreme storms, ocean acidity increases, permanent displacement of large populations, and much more. It is also in this context that the abrupt post-Fukushima decisions by Germany and Switzerland to accelerate the shutdown of their nuclear power plants is puzzling. Both countries currently generate about thirty percent of their electricity using nuclear power. This is the third time Germany has tried to shut down their nuclear reactors, failing each time as the deadline approached when faced with the cost and environmental implication of alternative electricity generation. One is hard pressed to understand how they can realistically replace this large fraction of non-greenhouse gas emitting electricity with intermittent power sources, thus requiring a significant increase in burning coal or natural gas

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for electricity production. Thus, if they do follow through with it, the world should expect increasing future German and Swiss releases of greenhouse gas which may accelerate the effects of climate change.

In the last thirty years, some constituents of fossil-fuel wastes, including sulfur, carbon, and nitrogen oxides, volatile organic compounds (VOCs, e.g., methane, benzene, toluene, and xylene), and chlorofluorocarbons (CFCs) have been significantly reduced in order to lower the immediate impacts (such as acid rain) of these emissions. We are moving away from the heedless and unconstrained dumping of chemical wastes into the earth's atmosphere, but are we moving quickly enough to avert a global climate catastrophe? That too is a risk that must be weighed against the risks of expanding zero-carbon emitting nuclear power.

## Conclusion

It is not a hopeful sign that a significant part of the U.S. political spectrum is in denial about the science of global warming. Progressives have rightly criticized conservatives for their “know nothing” stance on climate change. But we can't just embrace science when it reinforces our views or preconceptions and ignore it when it doesn't. Progressives have an obligation to puncture the myths surrounding nuclear energy and fairly assess its risks in comparative perspective to other ways of generating electricity. We're confident that this will lead to the conclusion that nuclear energy should play an expanding role in meeting America's growing energy needs at least for the rest of this century, and probably beyond.

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## Endnotes

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- <sup>1</sup>National Police Agency of Japan, “Damage Situation and Police Countermeasures associated with 2011Tohoku district - off the Pacific Ocean Earthquake” (Emergency Disaster Countermeasures Headquarters, December 12, 2011), [http://www.npa.go.jp/archive/keibi/biki/index\\_e.htm](http://www.npa.go.jp/archive/keibi/biki/index_e.htm).
- <sup>2</sup> U.S. Energy Information Administration. “State Electric Profiles”, April 2011. [http://www.eia.gov/cneaf/electricity/st\\_profiles/e\\_profiles\\_sum.html](http://www.eia.gov/cneaf/electricity/st_profiles/e_profiles_sum.html).
- <sup>3</sup>Jacob Oestergaard et al., “Energy losses of superconducting power transmission cables in the grid,” *IEEE Transactions on Applied Superconductivity* 11, no. 1 (2001): 2375-2378.
- <sup>4</sup>L. D. Kannberg et al., *GridWise™: The Benefits of a Transformed Energy System* (Pacific Northwest National Lab: National Technical Information Service, September 2003).
- <sup>5</sup>Nuclear Energy Institute, “IAEA Study Team Recommends Regular Hazard Assessments”, June 1, 2011, <http://www.nei.org/newsandevents/information-on-the-japanese-earthquake-and-reactors-in-that-region/japan-earthquake-additional-nei-updates/japan-earthquake-nei-updates-for-wednesday-june-1/>.
- <sup>6</sup>National Research Council, *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2.*, Biological Effects of Ionizing Radiation BEIR VII (Washington D.C.: National Research Council of the National Academies, 2006).
- <sup>7</sup>Mine Safety and Health Administration, “MSHA Fact Sheets - Injury Trends in Mining”, June 3, 2011, <http://www.msha.gov/mshainfo/factsheets/mshafct2.htm>.
- <sup>8</sup>Tu Jianjun, “Coal Mining Safety: China’s Achilles’ Heel,” *China Security, World Security Institute* 3, no. 2 (2007): 36-53.
- <sup>9</sup>American Lung Association, “Toxic Air - The Case for Cleaning Up Coal-fired Power Plants”, March 2011.
- <sup>10</sup>Ibid.
- <sup>11</sup>J. P. McBride et al., “Radiological Impact of Airborne Effluents of Coal and Nuclear Plants,” *Science* 8 (December 1978): 1045-1050.
- <sup>12</sup>The Pipeline Safety Trust, “Natural Gas Transmission Pipeline Incidents 1986-2009”, 2010, <http://www.pstrust.org/>.
- <sup>13</sup> Westinghouse Website, “Westinghouse AP1000”, 2011, <http://ap1000.westinghousenuclear.com/index.html>.
- <sup>14</sup>World Nuclear News, “First piece of Vogtle financing”, March 2010, [http://www.world-nuclear-news.org/C\\_First\\_piece\\_of\\_Vogtle\\_financing\\_0103101.html](http://www.world-nuclear-news.org/C_First_piece_of_Vogtle_financing_0103101.html).
- <sup>15</sup>Nuclear Energy Institute, “Price-Anderson Act Provides Effective Liability Insurance at No Cost to the Public”, June 2010, <http://www.nei.org/resourcesandstats/documentlibrary/safetyandsecurity/factsheet/priceandersonact/>.
- <sup>16</sup>New York Times, “14-Year Cleanup at Three Mile Island Concludes”, 1993, <http://www.nytimes.com/1993/08/15/us/14-year-cleanup-at-three-mile-island-concludes.html>.
- <sup>17</sup> BP Oil Spill Commission, “Deep Water: The Gulf Oil Disaster and the Future of Offshore Drilling” (National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, 2011).
- <sup>18</sup>Dave Flessner, “TVA to ship spilled coal ash,” *Times Free Press*, June 6, 2009, <http://www.timesfreepress.com/news/2009/jun/06/tva-ship-spilled-coal-ash/>.

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- <sup>19</sup>Dave Flessner, “Lawsuit planned against TVA over Kingston coal ash spill,” *Times Free Press*, December 30, 2008.
- <sup>20</sup>Paul R. Epstein et al., “Full cost accounting for the life cycle of coal,” *N.Y. Acad. Sci Ecological Economics Reviews*, no. 1219 (2011): 73–98.
- <sup>21</sup>US Department of Energy, “Fossil Energy: Carbon Capture and Separation”, June 2011, <http://www.fossil.energy.gov/programs/sequestration/capture/>.
- <sup>22</sup>Ventyx Energy Advisors, “The Wonderful Curse of Natural Gas Price Volatility” (Ventyx, 2007).
- <sup>23</sup>George F. Loewenstein et al., “Risk as Feelings,” *Psychological Bulletin* 127, no. 2 (2001): 267-286.
- <sup>24</sup>E.K. Osei, G.E.A. Amoh, and C. Schandorf, “Risk Ranking by Perception,” *Health Physics* 72, no. 2 (1997): 195-203.
- <sup>25</sup>Vivianne H.M. Visschers et al., “How Does the General Public Evaluate Risk Information? The Impact of Associations with Other Risks,” *Risk Analysis* 27, no. 3 (2007): 715-727.
- <sup>26</sup>Paul Slovic et al., “Risk as Analysis and Risk as Feelings: Some Thoughts about Affect, Reason, Risk, and Rationality,” *Risk Analysis* 24, no. 2 (2004): 311-322.
- <sup>27</sup>Paul Slovic and Ellen Peters, “Risk Perception and Affect,” *Current Directions in Psychological Science* 15, no. 6 (2006): 322-325.
- <sup>28</sup>David R. Schwartz and William C. Howell, “Optimal Stopping Performance Under Graphic and Numeric CRT Formatting,” *Human Factors* 27, no. 4 (1985): 433-444.

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