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New Nukes

> Coal is the killer. Of all the fossil fuels, coal is the one that could make this planet uninhabitable.
>
> —Fred Pearce, *New Scientist*

> With climate change, those who know the most are the most frightened. With nuclear power, those who know the most are the least frightened.
>
> —Variously attributed

For the definitive word on how much to worry about climate change, environmentalists in America have taken to relying on James Hansen, NASA's authoritative and outspoken climatologist. When Hansen declared in 2007 that we must not settle for leveling off carbon dioxide in the atmosphere at 450 parts per million (ppm) but must take the level *down* from the current 387 ppm to 350 ppm or lower, the new environmentalist slogan became "350!"

Environmentalists take no notice of Hansen's views on nuclear, however. As President Obama was taking office, Hansen wrote him an open letter suggesting new policy to deal with the climate crisis. "Coal plants are factories of death," he wrote. "Coal is responsible for as much atmospheric carbon dioxide as the other fossil fuels combined." Hansen proposed what America needed: a carbon tax "across all fossil fuels at their source"; the phasing out of all coal-fired plants; and "urgent R&D on 4th-generation nuclear power, with international cooperation." He warned: "The danger is that the minority of vehement anti-nuclear 'environmentalists' could cause development of advanced safe nuclear power to be slowed such that utilities are forced to continue coal-burning in order to keep the lights on. That is a prescription for disaster." He repeated the point at the end of the letter: "One of the greatest dangers the world faces is the possibility that a vocal minority of antinuclear activists could prevent phase-out of coal emissions."

Environmentalists have much less to fear in reality from the current nuclear power industry than they think, and much more to gain from new and planned reactor designs than they realize. Hansen is right: Nukes are Green; new nukes even more so. Here's how.

• Nuclear power inspires in most environmentalists one particularly deep aversion. They recoil from the idea of passing on to endless future generations the care of the deadly poison of nuclear waste. That was my view as well until one day in 2002. It was a visit to Yucca Mountain, of all things, that began to change my mind about nuclear power. I'll report the occasion in some detail because it's a look inside a "here-be-dragons" blank area on most people's mental map of the nuclear world, and you'll watch two people reverse their opinion about nuclear and an organization change its mind about itself.

The Yucca Mountain Repository for "spent nuclear fuel and high-level radioactive waste" one hundred miles northwest of Las Vegas, Nevada, has been lodged in America's political throat ever since the project was initiated in 1978. That had nothing to do with why the board of The Long Now Foundation made a site visit in 2002. We just wanted to see what a hole in a Nevada mountain looked like.

Long Now's maypole project (around which everything else dances) is a monumental ten-thousand-year clock, to be installed inside a mountain in eastern Nevada as an icon to, as we say, "help make long-term thinking automatic and common instead of difficult and rare." What kind of spaces work best inside a mountain, we wondered, especially inside a desert mountain? We thought that Yucca might give us some hints, and indeed it did—long, straight, cylindrical tunnels are boring; a twenty-five-foot ceiling is boring; but anything below ten feet is cozy, and anything above thirty-five feet is thrilling.

Our main lesson from Yucca, though, threatened Long Now's very core. Something was pathological about Yucca Mountain, and the sickness was embedded in its long-term thinking, its ten-thousand-year time frame. Among those on the bus were Danny Hillis, designer of the clock, and Peter Schwartz, cofounder of Global Business Network. I wrote in my trip report that at the entrance to the Repository,

> a training video informed us that it was important not to trip on anything, and showed how to use a belt-mounted emergency breathing apparatus. Danny Hillis remarked that it is the device which, in event of a mine fire, OSHA demands to find on your body. Outside the tunnel entrance were not one but two brand new ambulances, contextually shrieking "SAFETY, SAFETY, SAFETY!!"
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> After a briefing in a pleasant underground "alcove" we rode a noisy train a mile and a half into the mountain—laser straight in a 25-foot diameter tunnel. The overall loop tunnel is 5 miles long. The eventual storage "drifts" have yet to be excavated, except for a few test drifts. We got off the train to visit one of the tests, where a vastly expensive experiment is under way to see how heating and cooling affects the rock and water flow around the drift—four years heating it up as if it had radioactive waste in it, four years cooling it down, modeling the first 1,000 years of waste storage.
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> That evening we debriefed the Yucca Mountain experience over dinner. We were universally appalled that the government had poured $8 to $16 BILLION ("depending on how you count") into that hole in the ground. Most of the money had gone into gargantuan tests meant to reassure the public that the stored waste would be "safe" for 10,000 years. It was a grotesque expenditure, based on 1950s ideas, a deeply political set of gestures meant to reassure critics who are largely uninterested in science and distrustful no matter what.
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> Peter Schwartz bet that if the waste goes in the mountain

(there's a 50 percent chance that it will), in 50 to 100 years we will be taking it back out as a valuable energy resource.

> I proposed that it was the 10,000-year time frame that made people crazy, which calls into question the whole premise of Long Now. We asked ourselves: If Long Now had been asked to handle the nuclear waste problem, what would we have done? Danny said, "I would have built the same hole in the ground, for only a couple hundred million, and told everyone that we just wanted to put the waste there for a hundred years while we thought about what to do with it eventually."
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> We realized that Yucca Mountain is a classic example of the folly of long-term planning—the illusion that we know now how to do the right thing for the next ten millennia. What Long Now pushes is almost the opposite: long-term thinking—where you set in motion a framing of events so that a process is made intensely adaptive, preserving and indeed increasing options as time goes by.

The more I thought about the standard environmentalist stance on nuclear waste, which I had espoused for years, the nuttier it seemed to me. The customary rant goes: "You have to guarantee that all the radioactivity in the waste will be totally contained for ten thousand years (no, a hundred thousand years; no, a million years), and if you can't guarantee that, you can't have nuclear power." Why? "Because any amount of radioactivity hurts humans and other life forms. It might get in the ground water."

What humans? The assumption seems to be that future humans will be exactly as we are today, with our present concerns and present technology. How about, say, two hundred years from now? If we and our technology prosper, humanity by then will be unimaginably capable compared to now, with far more interesting things to worry about than some easily detected and treated stray radioactivity somewhere in the landscape. If we crash back to the stone age, odd doses of radioactivity will be the least of our problems. Extrapolate to two thousand years, ten thousand years. The problem doesn't get worse over time, it vanishes over time.

The Yucca trip set in motion another board member's conversion from anti- to pro-nuclear. Peter Schwartz, an energy expert who served for a long time on the board of Amory Lovins's Rocky Mountain Institute, eventually became highly vocal on behalf of a nuclear revival. He and Lovins had friendship-threatening arguments on the subject.

• A year after the Yucca trip, Global Business Network was invited to run a scenario workshop for Canada's Nuclear Waste Management Organization, which was conducting a series of meetings to explore what Canada should do with the waste from its twenty-two CANDU nuclear reactors. One option was to heave it down a deep hole in the ancient, stable bedrock of the Laurentian Shield and forget about it. Another was to leave it where it is now in dry cask storage at the reactor sites. Another was to develop a Yucca-like site for retrievable underground storage. At the workshop, I told my Yucca Mountain story. Also participating in the workshop were several Indians (the tribes are called First Nations in Canada) who proposed taking the "seven generations" approach to future responsibility long credited to the Iroquois League. Using the standard number for a generation—25 years—that would mean a 175-year time frame for thinking about the waste.

After eighty meetings across Canada, the nation's nuclear waste policy emerged. It is based, says a report from the organization, on the principle of "Respect for Future Generations: we should not prejudge the needs and capabilities of the future. Rather than acting in a paternalistic way, we should leave the choice of what to do with the used fuel for them to determine." Accordingly, Canada has an "adaptive phased management" plan, where the spent fuel remains in wet and dry storage at the reactor sites while a "near term" (1 to 175 years) centralized shallow underground facility is built, designed for easy retrieval; that will be followed by a deep geological repository for permanent storage. Future Canadians have options at every step. No mention is made of 10,000 years. The report does note that "during the 175-year period, the overall radioactivity of used fuel drops to one hundred thousandth of the level when it was removed from the reactors." Nuclear waste has the interesting property that it loses toxicity over time, unlike many forms of chemical waste, such as mercury.

Two things about nuclear had changed for me, I gradually realized. Waste disposal no longer looked like a cosmic-level problem, and carbon-free energy from nuclear looked like a major solution in light of growing worries about climate change. My opinion on nuclear had flipped from anti to pro. The question I ask myself now is, What took me so long? I could have looked into the realities of nuclear power many years earlier, if I weren't so lazy.

Gwyneth Cravens, a novelist and former *New Yorker* editor, did what I should have done. In 1980 she was among the activists who shut down the $6 billion Shoreham Nuclear Power Plant in Long Island before it ever opened, which helped frighten the American nuclear industry to a standstill. In the 1990s, she started hearing the other side from a friend in the industry, a nuclear-safety scientist at Sandia National Laboratories in Albuquerque named Rip Anderson. Sensing a story, she traveled with Anderson as her guide through the U.S. nuclear power industry and came up with a masterly account of the journey, *Power to Save the World: The Truth About Nuclear Energy*, published in 2007.

I asked her what really changed her mind about nuclear. "Two things," she said. "Baseload and footprint."

" 'Baseload,' " she explains in the book, "refers to the minimum amount of proven, consistent, around-the-clock, rain-or-shine power that utilities must supply to meet the demands of their millions of customers." Baseload is the foundation of grid power. So far it comes from only three sources: fossil fuels, hydro, and nuclear. Two thirds of the world's electricity is made by burning fossil fuels, mostly coal. The Green, noncarbon one third is split evenly between hydroelectric dams and nuclear reactors at about 16 percent each. (In the United States, 71 percent of our electricity is from coal and gas, 6.5 percent from hydro, about 20 percent from nuclear.)

Cities require grid power, and that means baseload. The world's growing cities and the billions of people climbing the "energy ladder" out of poverty will demand a lot more baseload by midcentury. If climate is the major Green threat, and cities are a major Green boon, then nuclear power looks doubly Green.

Wind and solar, desirable as they are, aren't part of baseload because they are intermittent—productive only when the wind blows or the sun shines. If some form of massive energy storage is devised, then they can participate in baseload; without it, they remain supplemental, usually to gas-fired plants. (Space-based solar, however, could feed directly into baseload, microwaving the juice from orbit down to surface rectennas. Sunlight in space has three times the intensity of the pallid stuff on Earth, and it's always on, so solar panels in space have three times the sun exposure of solar panels on roofs. That adds up to a ninefold advantage. Expensive commute, though. Japan is planning a 1-gigawatt space solar facility nevertheless and a California utility claims it will have a 200-megawatt solar farm in orbit by 2016.)

- As for footprint, Gwyneth Cravens points out that "A nuclear plant producing 1,000 megawatts takes up a third of a square mile. A wind farm would have to cover over 200 square miles to obtain the same result, and a solar array over 50 square miles." That's just the landscape footprint. (By the way, 1,000 megawatts equals 1 gigawatt—a billion watts; I'll use that measure most of the time here.)

More interesting to me is the hazard comparison between coal waste and nuclear waste. Nuclear waste is minuscule in size—one Coke can's worth per person-lifetime of electricity if it was all nuclear, Rip Anderson likes to point out. Coal waste is massive—68 tons of solid stuff and 77 tons of carbon dioxide per person-lifetime of strictly coal electricity. The nuclear waste goes into dry cask storage, where it is kept in a small area, locally controlled and monitored. You always know exactly what it's doing. A 1-gigawatt nuclear plant converts 20 tons of fuel a year into 20 tons of waste, which is so dense it fills just two dry-storage casks, each one a cylinder 18 feet high, 10 feet in diameter.

By contrast, a 1-gigawatt coal plant burns 3 million tons of fuel a year and produces 7 million tons of CO_2, all of which immediately goes into everyone's atmosphere, where no one can control it, and no one knows what it's really up to. That's not counting the fly ash and flue gases from coal—the world's largest source of released radioactivity, full of heavy metals, including lead, arsenic, and most of the neurotoxic mercury that has so suffused the food chain that pregnant women are advised not to eat wild fish and shellfish. The air pollution from coal burning is estimated to cause 30,000 deaths a year from lung disease in the United States, and 350,000 a year in China.

As for comparing full-life-cycle, everything-counted greenhouse gas emissions, a study published in 2000 by the International Atomic Energy Agency shows total lifetime emissions per kilowatt-hour from nuclear about even with those of wind and hydro, about half of solar, a sixth of "clean" coal (if it ever comes), a tenth of natural gas, and one twenty-seventh of coal as it is burned today.

• Baseload. Footprint. Add portfolio—the idea that climate change is so serious a matter, we have to do *everything* simultaneously to head it off as much as we can. The first definitive portfolio statement came from engineer Robert Socolow and ecologist Stephen Pacala in 2004. Their paper in *Science*, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," introduced the idea that a set of "stabilization wedges," made up of already proven technologies and practices, could reduce greenhouse gas emissions to a tolerable level, but only if all the wedges are pursued extremely aggressively at the same time, starting yesterday.

The paper proposed seven wedges to level off emissions: energy efficiency, renewables, clean coal, forests and soils (stop deforestation and agricultural tilling), fuel switch (coal to gas, oil to heat pump, etc.), and nuclear. Tripling the world's current nuclear capacity to 700 gigawatts a year over fifty years would reduce carbon emissions by 1 gigaton a year at the end of the period, for a total of 25 gigatons over the fifty years. (In 2008 the world's carbon emissions were over 7 gigatons a year and rising fast. To convert Socolow's carbon emissions to carbon dioxide emissions—the more common measure—multiply by 3.67; thus the 7 gigatons of carbon equals 25.7 gigatons of carbon dioxide.) There's nothing heroic or unusual about that rate of adding nuclear capacity. The Socolow/Pacala paper noted, "The global pace of nuclear power plant construction from 1975 to 1990 would yield a wedge, if it continued for 50 years."

Al Gore's climate movie, *An Inconvenient Truth*, featured Socolow's diagram with only six wedges, leaving out nuclear.

• Of all the wedges, energy efficiency and conservation come first, last, and always, as far as I'm concerned. You get the most result with the least cost at the greatest speed. As Amory Lovins has been proving eloquently for decades, saving energy doesn't cost money; it makes money, and it can be carried out at every level, from individual behavior to global programs. Those who argued that conservation would do economic harm have been thoroughly refuted by events. Europeans and Californians use half the energy per person of most Americans, and they are doing fine. In the 1970s, the Jerry Brown administration in California set in motion an array of programs that kept energy use dead level for the next three decades while the state's per capita income grew by 80 percent, and while the other states' energy use went up by 50 percent. California's greenhouse gas emissions per capita are less than half of what the other states put out.

How did California do that? A physicist named Arthur Rosenfeld at Lawrence Berkeley National Laboratory was inspired by the OPEC oil embargo of 1973 to shift his career to energy efficiency. Through his advocacy, California pursued "technology forcing" (specific mandates on efficiency in refrigerators and cars); new regulations on heat efficiency in buildings; tax credits for solar panels; and a decoupling of profits from sales in energy companies, so corporations like Pacific Gas & Electric were suddenly motivated to reward energy conservation in their customers and *not* motivated to build new power plants. My gang was in the thick of that. While I served on the governor's personal staff, one Whole Earth friend (Huey Johnson) was secretary of resources, another (astronaut Rusty Schweickart) chaired the Energy Commission, two (Sim Van der Ryn and Peter Calthorpe) were running the State Architect's office, and still another (Wilson Clark) ran the Office of Appropriate Technology .

(Jerry Brown is still at it. Elected attorney general of California in 2006, he immediately focused the office on climate change, with several creative initiatives. One will require that new projects in the state prepare a *climate* impact report as part of their environmental impact report. Another recognizes that the worst polluters of air and atmosphere are the world's totally unregulated ships burning the vilest of fuels, called bunker. Brown set up a coalition of West Coast attorneys general, who will insist that the Clean Air Act applies to all shipping within the two-hundred-mile limit, so the ships will have to shift to cleaner fuel systems, such as diesel-electric, and scrub what comes out of their stacks if they want to do business on the West Coast.)

Efficiency improvement has already accomplished a lot. From 1975 to 2004, the world decreased its "energy intensity" (the amount of energy consumed per dollar of GDP) by 32 percent (44 percent in the United States). There is a great deal more where that came from. We have barely begun to wring the last wasteful joule out of our buildings, vehicles, infrastructure, cities, farms, power lines, ships, armies—the whole apparatus of civilization.

But energy efficiency, crucial as it is, can't replace all the coal-fired plants that have to be shut down, and it can't generate power for the burgeoning energy demand of the growing economies in China, India, Africa, and Latin America. That takes us back to baseload and the choice between coal and nuclear.

● A fourth consideration, along with baseload, footprint, and portfolio, is the role of government. In recent years, environmentalists have largely given up on governments, preferring to work with global and local NGOs, with businesses, and among the grassroots. But infrastructure is one of the things we hire governments to handle, especially energy infrastructure, which requires no end of legislation, bonds, rights of way, regulations, subsidies, research, and public-private contracts with detailed oversight. Energy policy is a matter of such scale, scope, speed, *and* patient follow-through that only a government can embrace it all. You can't get decent grid power without decent government power.

These arguments, plus others I'll come to, have persuaded a surprising number of prominent environmentalists to become pronuclear, some enthusiastically, some grudgingly; some noisily, some quietly. Is

there any pattern in who they are and why they espouse nuclear? I think there is.

Start with Jim Lovelock, Gaia's prophet. Gaia theory itself is almost a Green religion, and Lovelock's 1957 invention of the electron capture detector led first to the pesticide measurements behind Rachel Carson's revolutionary *Silent Spring* (1962), then to the detection of environmental PCBs, then to the discovery of atmospheric chlorofluorocarbons and their role in ozone depletion. Lovelock has been pronuclear all his life, ever since his medical research with radioactive isotopes back in the 1940s. He promoted nuclear to my reluctant ears when I first met him in 1985. In a much quoted op-ed in England's *Independent* in 2004, he wrote:

> By all means, let us use the small input from renewables sensibly, but only one immediately available source does not cause global warming and that is nuclear energy. . . . Opposition to nuclear energy is based on irrational fear fed by Hollywood-style fiction, the Green lobbies and the media. These fears are unjustified, and nuclear energy from its start in 1952 has proved to be the safest of all energy sources. . . . I am a Green and I entreat my friends in the movement to drop their wrong-headed objection to nuclear energy. Even if they were right about its dangers, and they are not, its worldwide use as our main source of energy would pose an insignificant threat compared with the dangers of intolerable and lethal heat waves and sea levels rising to drown every coastal city of the world. We have no time to experiment with visionary energy sources; civilisation is in imminent danger and has to use nuclear—the one safe, available, energy source—now or suffer the pain soon to be inflicted by our outraged planet.

Pronuclear public opinion in England went from below 5 percent to over 40 percent. In a reversal of previous policy, the government is planning ten new reactors to replace and add to the nineteen reactors that currently provide 20 percent of England's electricity.

Jesse Ausubel, director of the Program for the Human Environment at Rockefeller University, convened a pioneering conference on climate change back in 1979. He originated the idea of *decarbonization*, noting the two-hundred-year trend of humans using fuels with ever fewer carbon atoms—wood to coal to oil to gas, down to zero carbon with hydrogen and nuclear. In 2007 he published a paper in the *International Journal of Nuclear Governance, Economy and Ecology* in which he declared, "Nuclear energy is green. Renewables are not green." His argument was based on footprint analysis. "As a Green," he wrote, "I care intensely about land-sparing, about leaving land for Nature. . . . Considered in watts per square meter, nuclear has astronomical advantages over its competitors." The solar energy equivalent of a 1-gigawatt nuclear reactor, he projected—with his own variation on Saul Griffith's and Gwyneth Cravens's calculations—would require 150 square kilometers (58 square miles); the wind power equivalent, 770 square kilometers (298 square miles); the corn biofuel equivalent, 2,500 square kilometers (965 square miles).

Patrick Moore, a Canadian who got his PhD in ecology, was a cofounder of Greenpeace in 1971 and became its president in 1977. He left in 1986, declaring that the organization and the environmental movement had become antiscience. Still a strong proponent of forestation, he is best known as a Green spokesman for nuclear power, with a paid role these days as cochair of the Clean and Safe Energy Coalition, founded by the Nuclear Energy Institute, a U.S. lobbying organization.

• The late Anglican Bishop Hugh Montefiore had been a trustee of UK Friends of the Earth for twenty years when he became convinced by climate dangers that as an environmentalist he had to support nuclear power. Told that he could not stay on as a Friends of the Earth trustee if he did that, he resigned, and wrote in a 2004 article,

> The future of the planet is more important than membership of Friends of the Earth. . . . The real reason why the Government has not taken up the nuclear option is because it lacks public acceptance, due to scare stories in the media and the stonewalling opposition of powerful environmental organisations.

> Most, if not all, of the objections do not stand up to objective assessment.

Tim Flannery is a world-renowned Australian biologist and conservationist who wrote what is considered one of the best books on climate, *The Weather Makers* (2006). In a 2006 column for a Melbourne newspaper, he posited that

> Over the next two decades, Australians could use nuclear power to replace all our coal-fired power plants. We would then have a power infrastructure like that of France, and in doing so we would have done something great for the world, for whatever risks go with a domestic nuclear power industry are local, while greenhouse gas pollution is global in its impact.

The next year he amended his view to support nuclear in places like China, Europe, and the United States that don't have Australia's renewable energy resources. Australia should keep selling its abundant uranium to those markets, he declared, but should not build its own nuclear plants.

John Holdren, President Obama's science adviser, is an energy and environment heavyweight. He has been an expert on nuclear weapons proliferation, a professor of environmental policy at Harvard, a director of Woods Hole Research Center, and long a coauthor with Paul Ehrlich of ecopolicy texts. His stature gave him cochairmanship of the National Commission on Energy Policy, and he wrote the commission's authoritative 2004 report, *Ending the Energy Stalemate*. It recommended, among other things, that Congress expand support for developing a new generation of nuclear reactors, and it pushed for centralized "interim" storage sites for spent fuel—a detour around the Yucca Mountain roadblock. Holdren told a *New York Times* reporter, "I'm often asked, 'Can you solve the climate problem without nuclear energy?' And I say, 'Yes, you can solve it without nuclear energy.' But it will be easier to solve it with nuclear energy."

Jared Diamond, biologist, conservationist, and author of *Collapse* (2004), had read Holdren's report closely, so when he was asked by an audience member at a San Francisco talk if he "agreed with Stewart Brand in supporting the revival of nuclear," he surprised the audience and me by saying yes: "To deal with our energy problems we need everything available to us, including nuclear power."

James Howard Kunstler, fervent opponent of suburbs, wrote a book in 2004 titled *The Long Emergency*. I'm persuaded by neither his expectation of how peak oil plays out nor his views on the fragility of big cities, but many environmentalists are, and they should note that he ends his "Beyond Oil" chapter with the words, "Nuclear power may be all that stands between what we identify as civilization and its alternative."

There is a category of prominent environmentalist that I predict will increase in coming years—the reluctant tolerators. When they express support of nuclear, they are careful to use sentences too complex to be quote-worthy. Al Gore is one such; he told a Congressional hearing what he usually avoids saying in public, that he is not opposed to nuclear power and expects it will grow somewhat. My old teacher Paul Ehrlich says that climate issues have made him more supportive of nuclear. Bill McKibben, author of *The End of Nature*, penned a friendly review of Gwyneth Cravens's *Power to Save the World* in the environmentalist publication *OnEarth*. "Environmentalists need to understand that times and circumstances change," he wrote, "and they need to rethink priorities. It's not enough for greens to say that nuclear power is risky and comes with consequences; everything comes with consequences." McKibben said he goes along with the IPCC proposal that nuclear "should provide 18 percent of the planet's electricity, up from 16 percent at the moment."

Looking at these Green nuclear proponents—twelve, if you include me—what is the pattern? All but one are obsessed with climate (Patrick Moore is not), and all but four are scientists (Montefiore, Kunstler, Gore, and McKibben are not). With everyone I've encountered who is really immersed in climate issues, the common view of nuclear is "the lesser of two evils" and "take nothing off the table." As for scientists, Gwyneth Cravens reported in her book that they invariably poll high in support of nuclear, ranging from 89 percent among scientists in general up to 95 percent for energy scientists and 100 percent for nuclear and radiation scientists. *(Those who know the most are the least frightened.)*

- And there is a generational element. For a fine piece of journalism about the nuclear debate within the environmental movement, Jason Mark, editor of *Earth Island Journal*, did his research online. As he reported in his 2007 article, "The Fission Division,"

> The anti-nuclear consensus among environmental policy professionals . . . does not extend to the grassroots. A review of some of the most popular green news and opinion Web sites reveals a lively discussion about the merits of expanding nuclear power generation. For example, when Grist.org asked readers, "In the light of the mounting threat of climate change, does nuclear power deserve another look?" 54 percent of respondents voted "Yes." A poll on Treehugger.com showed 59 percent of readers conditionally in favor of atomic energy.
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> Whenever the issue comes up in green forums, an energetic back-and-forth ensues. During one online discussion, a visitor to a blog hosted by Earthjustice Legal Defense wrote: "I have been an ardent foe of nuclear power generation for over three decades. . . . However, in the last two years I have reversed my position, and now support the building of a new generation of nuclear plants in the USA. The reason is that global warming is such a huge and imminent issue, that I think we must accept the lesser evil of nuclear power generation." When the subject came up on the Web site WorldChanging.com, readers were split roughly 50-50.

A generation gap has emerged. For younger Greens, cold-war nuclear fears are ancient history, and Chernobyl is not part of their personal experience. The threat of climate change is what dominates their world, along with accelerating technology, with which they are comfortable. From the perspective of the young, nuclear is just another technology, to be judged on how well it works, not on antiquated obsessions of their elders.

In 2009 the Director of Greenpeace UK from 2001 to 2007, Stephen Tindale, told the *Independent* he was now supporting nuclear, and he wasn't alone:

> My change of mind wasn't sudden, but gradual over the past four years. But the key moment when I thought that we needed to be extremely serious was when it was reported that the permafrost in Siberia was melting massively, giving up methane, which is a very serious problem for the world.
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> It was kind of like a religious conversion. Being anti-nuclear was an essential part of being an environmentalist for a long time but now that I'm talking to a number of environmentalists about this, it's actually quite widespread—this view that nuclear power is not ideal but it's better than climate change

Older environmentalists talk about nuclear power exclusively in terms of what they see as the four great problems that condemn the technology—safety, cost, waste storage, and proliferation. Those four have no form of positive, only degrees of badness, and they are treated as absolutes. If a reactor accident is possible, then nuclear power is impossible; if the capital costs are high, then nuclear power is impossible, and so on. Absolutes are potent. Once something is seen as a capitalized Absolute Evil, it functions as a premise; everything has to exist in relation to your opposition to it.

By contrast, the four considerations I began with—baseload, footprint, portfolio, and government-scale—are logics rather than problems. They are relative rather than absolute, which means they invite thinking in terms of trade-offs and risk balancing. And they are open to the positive, treating nuclear as one potential tool to help head off climate change and end poverty worldwide.

Holding all eight logics and problems in mind simultaneously nets out, for me, to a strong argument for expanding nuclear power. From that perspective, I see the four problems of safety, cost, waste handling, and weapons potential differently than I used to. I've learned to disbelieve much of what I've been told by my fellow environmentalists, and I now think of the four problems the way an engineer does, as *design* problems. Define them, frame them in a way that is solvable, solve the damn things, and once you've got a solution, act on it.

Reactor safety is a problem already solved. In 2008 the world had 443 civilian nuclear reactors boiling up 16 percent of all electricity and keeping a yearly 3 gigatons of carbon dioxide that would have been generated by coal plants out of the atmosphere. Year after year, the industry has had no significant accidents, having learned hard lessons from the three that got away—England's Windscale fire in 1957, the Three Mile Island meltdown in 1979, and the Chernobyl steam explosion in 1986.

"Because a single new accident could destroy the entire nuclear industry worldwide," Tim Flannery argues, "lots of work has gone into minimizing the risk of accidents. As a result, new nuclear technology is relatively safe." Bill McKibben makes a different point: "Nuclear power is a potential safety threat, if something goes wrong. Coal-fired power is guaranteed destruction, filling the atmosphere with planet-heating carbon when it operates the way it's supposed to."

McKibben's pragmatism suggests we reassess our fears in light of real risks closely examined, and that begins with noticing how fear works. An article in *Psychology Today,* "Ten Ways We Get the Odds Wrong," lists some of the elements that play out in nuclear dread:

> We fear spectacular, unlikely events. . . .
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> We underestimate threats that creep up on us. . . .
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> Risk arguments cannot be divorced from values. . . .
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> We love sunlight but fear nuclear power. . . . The word radiation stirs thoughts of nuclear power, X-rays, and danger, so we shudder at the thought of erecting nuclear power plants in our neighborhoods. But every day we're bathed in radiation that has killed many more people than nuclear reactors: sunlight. It's hard for us to grasp the danger because sunlight feels so familiar and natural.
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> We should fear fear itself. Though the odds of dying in a terror

attack like 9/11 or contracting Ebola are infinitesimal, the effects of chronic stress caused by constant fear are significant.

- Particularly germane to nuclear is "Risk arguments cannot be divorced from values." Because Hiroshima and the cold war threw everything atomic into the Absolute Evil category, our feelings about nuclear energy are tainted by our revulsion about nuclear weapons. Thus the chemical release of the Bhopal incident in 1984 is treated as far less consequential than the radiation release from Chernobyl, even though over six thousand died from Bhopal versus fifty-six from Chernobyl (forty-seven workers, nine children). Through fear of radiation and expected birth defects, the World Health Organization reported, couples in the Chernobyl area had thousands of abortions. But no human birth defects have been found to result from Chernobyl—nor, by the way, from Hiroshima. As for disease, the low-dose-radiation expert John Gofman declared that "the number of fatal cancers to come over the years and decades ahead as a direct result of this accident will not be lower than 500,000." In fact it was less than 1 percent of that figure.

"It is roughly estimated that the total number of deaths from cancers caused by Chernobyl may reach 4,000 among the 600,000 people having received the greatest exposures." So says the Chernobyl Forum's report, which was exhaustively researched by seven UN agencies and published in 2006. Its findings are summarized online at the ever-illuminating GreenFacts.org site. About 100,000 of the 600,000 most exposed would die of cancer in any case, if Chernobyl had never happened. For every 100 of the normal cancer victims, four may die earlier because of Chernobyl radiation. Statistically it is a nonevent—epidemiology can't detect it.

The real damage to people in the region, according to the Chernobyl Forum report, is from poverty and mental stress. "The most significant public health impact of Chernobyl has been on mental health," says Luisa Vinton, who headed the forum, in the video *Living with Chernobyl* (2007). "The conclusion we've come to is that fear of radiation is a far more important health threat than radiation itself." The report asserts that what the region around Chernobyl now needs more than anything else is economic stimulus.

- The report also mentions that "the Exclusion Zone has paradoxically become a unique sanctuary for biodiversity." In a fascinating book, *Wormwood Forest: A Natural History of Chernobyl* (2005), Mary Mycio observes that

> It is one of the disaster's paradoxes, but the zone's evacuation put an end to industrialization, deforestation, cultivation, and other human intrusions, making it one of Ukraine's environmentally cleanest regions—except for the radioactivity. But animals don't have dosimeters. . . . The Rhode Island–sized territory has become a fascinating and at times beautiful wilderness teeming with beavers and wolves, deer and lynx, as well as rare birds such as black storks and azure tits.

The rare white-tailed eagle now thrives in the area, and Europe's only remaining native megafauna, the long-endangered European bison and Przewalski's horse, have been introduced successfully. In 1994 two biologists from Texas Tech, Ronald Chesser and Robert Baker, began fifteen years of research on radiation effects in the animals in the Exclusion Zone. In the famously radioactive Red Forest (where all the pines had been killed by fallout, though the birches survived), they started with wild mice.

> We were surprised to find that although each mouse registered unprecedented levels of radiation in its bones and muscles, all the animals seemed physically normal, and many of the females were carrying normal-looking embryos. This was true for pretty much every creature we examined—highly radioactive, but physically normal. It was the first of many revelations.

They did find elevated levels of genetic mutations in voles and reported their results in a 1996 cover story in *Nature*. Right after it was published, they got an automated sequencer, and instead of refining their findings, it completely refuted them—nothing genetically significant was going on in the voles. With anguish, they retracted the *Nature* paper. Robert Baker concludes on his home page that as far as the Chernobyl animals are concerned, "the elimination of human activities such as farming, ranching, hunting and logging are the greatest benefit, and it can be said that the world's worst nuclear power plant disaster is not as destructive to wildlife populations as are normal human activities. Even where the levels of radiation are highest, wildlife abounds."

That is an interesting statement: "The world's worst nuclear power plant disaster is not as destructive to wildlife populations as are normal human activities."

I predict there will be a Chernobyl National Park. It has the perfect ingredients. It is a major historic site. When 330,000 people moved out and wildlife moved in, it became one of Europe's finest natural preserves. The UN Development Programme has called for ecotourism development there. With the exception of a few well-known (and fading) hot spots, radioactivity has dropped to normal background levels. Already reforested, the ghost town of Pripyat, which once housed 50,000, is a poignant reminder of the cost of design folly—the Chernobyl reactors had no containment structures. The site of the reactor itself is a grim monument which, once the final protective shield is in place, may last as long and as evocatively as Stonehenge.

• Several inappropriate Absolute Evils distract rational discussion about nuclear safety. One is cancer. Jim Lovelock, whose degree and early career were in medicine, wrote in 2004, "We must stop fretting over the minute statistical risks of cancer from chemicals or radiation. Nearly one third of us will die of cancer anyway, mainly because we breathe air laden with that all-pervasive carcinogen, oxygen." Cancer researcher and entrepreneur William Haseltine explains another inevitability: "Cancer is a disease of aging. It's going to be hard to prevent cancers, because they are so intrinsically tied to the aging process itself." The surest way to prevent cancer is the traditional method: Die younger of something else.

Radiation acquired its Evil reputation mainly as a legacy of the atomic bomb. Our horror at Hiroshima is transferred, like referred pain, to the only thing we can directly influence, which is nuclear power. For a sense of the legacy effect, compare other dangerous infrastructure-scale energy forms. Gasoline is intensely explosive, killing thousands routinely in auto accidents and elsewhere. Natural gas blows up houses, flows through vulnerable pipelines, and travels around in bomblike ships. Grid electricity is lethal all the way to your light fixture, electrocuting any who touch it carelessly, and setting no end of fires. The great Green hope, hydrogen, has reactivity that weakens pipes, volatility that makes it the most leak-prone of gases, and an ignition point so low that a cellphone can ignite it; and it burns with an invisible flame. Another fond hope, vast quantities of carbon dioxide to be captured at coal-fired plants and piped to underground sequestration, introduces yet another dangerous gas to the energy inventory. In 1986 a dense cloud of CO_2 belched out of Lake Nyos in Cameroon, flowed downhill at 20 miles an hour, and suffocated 1,700 villagers and 3,500 livestock up to 15 miles away. Known all too well to miners as "choke damp," carbon dioxide kills instantly in any concentration greater than 15 percent.

Radiation from nuclear energy has killed not a single American, but of all these energy by-products it is the only one we dread. Nuclear radiation as used in medicine for diagnosis and treatment has saved countless lives, while exposing all the patients to levels of radiation that are many times what is illegal in the nuclear power industry.

• An abiding issue that should not abide much longer concerns the accumulated effects of low-dose radiation. In the 1970s I ran occasional screeds on the subject from Helen Caldicott and the late John Goffman in *CoEvolution Quarterly*, until I read about an experiment comparing the health of lab rats exposed to mild radiation with rats not so exposed. Instead of getting sick, the dosed rats did *better* than the control rats; radiation was good for them. I published no more on the subject.

Decades later, in 2007, I asked Jim Lovelock for his views on low-dose radiation. "The jury is still out, is my answer," he said. "There are two schools. One school says low dosage is good for you. It's called *hormesis*. There's growing evidence for that; it looks quite interesting. The other one says that low dosages are more dangerous. The evidence that impresses me is this: In some parts of the world, in India and Iran, the natural background radiation is huge. The life expectancy of people in those places is the same as anywhere else. There's no evidence of anything nasty going on."

Because background radiation everywhere is considerable, the only way to prove or disprove the standard "linear no-threshold" model, which insists that *all* levels of radiation are harmful to some degree, is to run experiments in a place with no background radiation whatever. That is exactly the plan with a proposed ultra-low-level radiation biology laboratory in the WIPP (Waste Isolation Pilot Plant) nuclear repository deep in a New Mexico salt formation.

Background radiation levels in the salt chambers a half mile down are a tenth of surface levels, and shielding can reduce the radiation to near zero. Comparative experiments with cells, tissue cultures, and transgenic mice highly susceptible to cancer should determine once and for all which of the three theories of low-dose radiation is right. Is it the no-threshold theory? Or, if there is a threshold beneath which radiation damage is negligible, what is the threshold? Or, if the hormesis theory of biopositive effects from low-dose radiation turns out to be correct, what is the most advantageous dose level, and what are the mechanisms of benefit—DNA repair, scavenging of toxic agents, removal of damaged or cancerous cells, or something else? (The hormesis expert T. D. Luckey reportedly finds about 6,000 millirems a year to be the optimum dose level for health.)

At stake are hundreds of billions of dollars. If the standard no-threshold theory is wrong, as most scientists suspect it is, then the U.S. government has been overspending by orders of magnitude on nuclear cleanup, and it will overspend surreally on heading off trace contamination from projects such as the Yucca Mountain repository. The Environmental Protection Agency relies on the no-threshold model to require that nuclear sites do whatever it takes to expose the nearby public to no more than 15 millirems of radiation a year. That is half a mammogram (30 mrem), a fifth of the *range* of normal

U.S. background radiation (from 284 mrem in Connecticut to 364 mrem in Colorado), a sixty-sixth of a CT scan (1,000 mrem; 62 million are done every year in the United States), and an eightieth of one year of smoking a pack and a half of cigarettes a day (1,300 mrem; there are 45 million smokers in the United States). People in Ramsar, Iran, live with a background radiation of 13,000 millirems a year with no apparent health consequences. Astronauts are allowed 25,000 millirems per shuttle mission.

It appears to me that the main public safety issue around nuclear power is what Luisa Vinton and the United Nations agencies found at Chernobyl: "Fear of radiation is a far more important health threat than radiation itself." The lesson of Chernobyl is double: one, be careful; two, be careful what you fear.

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That nuclear's high capital cost is the leading complaint from everybody opposing it is due to the prodigious efforts of one man. Amory Lovins, founder and head of Rocky Mountain Institute, has been slicing and dicing the arcana of nuclear-power finance for three decades, to formidable effect.

Lovins is an old friend and colleague. In *CoEvolution Quarterly*, I purveyed his perspective on energy efficiency and praised his books. One time at a Hackers' Conference, I saw him blow away that hard-to-dazzle audience with his discourse on how conventional cars spend most of their energy getting out of their own way, how the nested nuances of his Hypercar design could deliver spectacular energy efficiencies, and how those savings in aggregate would transform the world energy economy. In his writings and talks, Lovins has a pungency of phrasing that rivals the silver-tongued economist John Maynard Keynes. "If," he says offhandedly in an interview, "you build an efficient, diverse, dispersed, renewable electricity system, major failures—whether by accident or malice—become impossible by design rather than inevitable by design."

The Lovins brief against nuclear (or what one opponent calls his "obsessive ongoing vendetta against nuclear") makes the following case. Private capital is the most objective judge and proof of which energy forms are best, and in that arena, nuclear always loses and micropower always wins, and that's why micropower is soaring throughout the world while nuclear is stalled. By micropower Lovins means efficiency, cogeneration (also known as CHP—combined heat and power), small hydro, and renewables such as wind, solar, biomass, and geothermal. "The cheapest, most reliable power is typically produced at or near customers." To Lovins, government intervention to assist nuclear because of climate fears is actually counterproductive because it tilts investment away from the micropower alternatives, which are faster and cheaper to deploy and more effective against climate change. "In no new nuclear project around the world is there a penny of private capital at risk."

In 1986 a TV interviewer asked Lovins about the future of nuclear power. "There isn't one," he replied. "No more will be built. The only question is whether the plants already operating will continue to operate during their lifetime, or whether they'll be shut down prematurely." At a debate in 2007 he declared, "Nuclear is dying of an incurable attack of market forces despite what the industry wants you to believe."

● In 2007, as Lovins was speaking, the following was taking place. Around the world, thirty-one reactors were under construction. In the United States, the Nuclear Regulatory Commission was bracing for an expected seventeen new nuclear plant applications (they were still on track in 2009), while Canada was preparing for new reactors in Alberta and New Brunswick (that one is to sell part of its power to Maine, which shut down its only nuclear plant in 1997). In Europe one nation after another was reversing course on nuclear. Green Finland started construction on a huge, 1.6-gigawatt plant, then added another. Green Germany quietly decided to keep its seventeen reactors working rather than shut them down as previously announced. Green Sweden did the same with its ten reactors while expanding their capacity. Green Belgium decided likewise with its seven reactors. Italy had shut down its four reactors in 1987, after Chernobyl, and soon became Europe's largest energy importer, mostly from nuclear France; in 2007 it began a program to build four new reactors. Gordon Brown's Labor government in England made the decision to upgrade all

of its nineteen reactors and build new ones. Ireland, Norway, and Poland were planning their first reactors. France, already getting 80 percent of its electricity from nuclear, began building new reactors and expanding its comprehensive nuclear operations to serve a global market through its $7 billion public corporation, AREVA. Russia set off on the same path, planning to double its number of reactors, currently thirty-one, and sell to an international market with its new $8-billion state-owned holding company, Atomenergoprom.

In the developing world, Russia's interested potential customers include "Vietnam, Malaysia, Egypt, Namibia, Morocco, South Africa, Algeria, Brazil, Chile and Argentina," according to the *New York Times*. The article added that "Western investors, including such heavyweights as Citigroup, are seeking ways to bet on the Russian nuclear power industry." Now building nukes for the first time are Albania, Belarus, Turkey, Iran, the United Arab Emirates (two 1.6 gigawatt reactors under way), Burma, Thailand, Vietnam, and Bangladesh; considering doing so are Syria, Israel, Jordan, Saudi Arabia, Bahrain, Kuwait, Oman, Qatar, Algeria, Ghana, Nigeria, Kazakhstan, Indonesia, and the Philippines; and expanding on the nukes they already have are Ukraine, Hungary, Bulgaria, Armenia, Argentina, Mexico, Brazil, South Africa, Pakistan, South Korea, and Taiwan. (You can keep track of the count at Wikipedia's entry, "Nuclear energy policy.")

India, with seventeen reactors now providing 3 gigawatts of power, plans to expand the capacity tenfold to 30 gigawatts.

After ordering two reactors from Westinghouse, China signed a $12 billion deal with AREVA—said to be the largest in the history of the industry—and is aiming to grow its nuclear capacity to 70 gigawatts by 2020. It has eleven reactors working, five under construction, thirty planned, and eighty-six proposed.

Japan, the largest user of nuclear power after the United States and France, with fifty-five reactors in operation, is planning eleven new reactors by 2017. The government wants to transform its electricity mix from 30 percent nuclear now to 60 percent nuclear by 2050.

In early 2009, in *Ambio* magazine, Amory Lovins declared: "Nuclear power is continuing its decades-long collapse in the global marketplace because it's grossly uncompetitive, unneeded, and obsolete."

How can someone so smart be so wrong about a subject he knows so well? It turns out that his arguments against the economics of nuclear power work only within the narrow commercial boundaries he defines, which increasingly no longer apply, and he focuses mainly on the United States. His reasoning has no traction in relatively dirigiste economies like France, Japan, and most developing countries, especially China and India; if those governments want nukes, they build nukes. More important, the loom of climate change has altered everybody's perspective on costs and risks.

• The problem is not that nuclear is expensive. The problem is that coal is cheap.

"Nuclear is dying of an incurable attack of market forces," said Lovins. It was market forces that gave us coal's dominance—40 percent of the world's electricity comes from coal (and 20 percent from gas, 16 percent from nuclear, 16 percent from hydro, 6 percent from oil, 2 percent from renewables). If only market forces rule, coal will continue to beat everything else, and the world's goose is cooked.

That realization motivates governments even in strongly capitalist societies like the United States and Britain. By government fiat, coal will be made expensive—through carbon taxes, cap-and-trade markets, requirements for CCS (carbon capture and sequestration), and mandates. In the competition to provide baseload power, as the cost of coal-fired electricity goes up, nuclear will take the lead as the most cost-effective alternative. (The economics of wind, hydro, cogeneration, solar, and geothermal also gain in relation to a properly crippled coal.) The fate of gas-fired plants, including cogeneration, will depend on the local price of natural gas, which in most places is rising precipitously. And no nation that has been dependent on Russia for natural gas wants to remain so, because it gets used as a political weapon.

The sticker shock for nuclear comes right at the start. Like the other major Green power sources—hydroelectric dams and large wind farms—nuclear plants require massive up-front capitalization; but once the facility is built, operating costs are low compared to fuel-intensive coal and gas plants, accounting for only one quarter to one third of the plant's lifetime expense.

Wind is serious infrastructure, and growing fast—94 gigawatts capacity worldwide in 2007 (nuclear was 365 gigawatts; coal, 1,393 gigawatts). Expanding wind power always means expanding long distance power lines. In Denmark and Germany, which led the European wind revolution, new construction has tapered off due to rising costs and scarcity of appropriate sites. Some are offended by the sight of massive wind farms churning away (Jim Lovelock and Robert Kennedy Jr. come to mind), but personally I find them thrilling. Unfortunately, wind power remains limited by intermittency to about 20 percent capacity (so that 94 gigawatts is four-fifths illusory), while nuclear plants run at over 90 percent capacity these days; and there still is no proven storage technology that would make wind a baseload provider. (Potential massive energy storage techniques that are being explored include flywheels, hot liquid, compressed air, and better batteries or distributed batteries in everybody's plug-in hybrid car.)

Many bird-loving environmentalists fight wind farms because of the harm to birds. My favorite Green publication, *High Country News*, ran the following list without comment: "Annual bird kill in the US: wind turbines, 28,500; buildings, 550 million; power lines, 130 million; cats, 100 million; cars, 80 million; pesticides, 67 million."

• Solar so far is a bit player in electricity generation—10 gigawatts of capacity total in the world in 2007, but with solar's 14 percent capacity factor, that's only 1.4 gigawatts operational, less than one large nuclear reactor. I fondly remember the 1970s solar boom, which ended the moment Ronald Reagan became president and canceled Jimmy Carter's solar tax credits. I had the delicious opportunity to interview Ted Turner in front of the 2007 Solar Power Conference, which had twice the attendance of the previous year, 12,500 people. Among them were only a few of the old solar guard such as John Schaeffer, whose solar mail-order catalog, *Real Goods*, has freed thousands from the grid since 1978. Schaeffer and I were surrounded by suits, most of them apparently avid to save the world *and* become rich from a technology they expected to be heavily subsidized any day. That's why they wanted to hear from rich, Green, Ted Turner. Turner went cheerfully off topic to inveigh against the Iraq War, noting that the enemy motivated their troops by promising them forty virgins when they die. "If we had incentives like that for solar power," Turner cracked, "we'd have it made." (I couldn't resist asking Turner about nuclear; he said, "I would rather have a nuclear plant than a coal-burning plant.")

Boundless ingenuity and capital are being focused on solar, with new materials and new configurations—nano-this and concentrated that; someday, maybe, energy-producing solar paint. The most efficient so far is concentrated solar thermal, in which focused mirrors heat a fluid to run turbines, and some of the heat can be stored in steam accumulators when the sun goes behind a cloud or sets for the night. With enough breakthroughs, sustained over decades, solar could and should become a leading source of electricity. Hasten that day! Meanwhile, the finance-management firm AllianceBernstein opines that "the solar industry has benefited recently from spectacular policy-driven growth. . . . We think that the speculative interest is becoming bubble-like, particularly given that industry fundamentals depend on government subsidies and political support."

My wife, Ryan, and I use plenty of solar with no need for incentives. We've had solar panels trickling maintenance-free power into the battery bank on our tugboat for twenty-six years. The electric fence that keeps cattle out of the oak savannah we're restoring runs on solar, and so does the automatic gate in the fence. Best of all is the solar water heater for our lap pool. We get an 80°F pool for seven months of the year with no use of propane, and the panels work in reverse on hot days, radiating excess heat to the night sky. Solar works well at the individual level; wind does not. Wind works well at the infrastructure level; solar, so far, does not.

• A standard objection to nuclear, following Amory Lovins's lead, is that it is grossly oversubsidized: It could never compete in a fair market, it steals subsidies that solar should get, etc. A 2007 study compared U.S. government energy incentives over the past fifty years for oil, coal, gas, hydro, nuclear, wind, solar, and geothermal, with particular focus on the period from 1994 to 2003. The incentives tallied included direct subsidies, research, tax relief, regulation, government services, and market intervention. Among the conclusions were these:

> The general perception that the oil industry has been the major beneficiary of Federal subsidies is correct, with this source receiving nearly half of all subsidy support. . . . The perception that renewable energy has been short-changed at the expense of other energy sources is not correct. . . . Coal and nuclear technologies have been underfunded, while solar technologies such as photovoltaics, solar thermal, and wind have been well funded.

(Details, with illuminating graphs, may be found in Roger H. Bezdek and Robert M. Wendling, "A Half Century of United States Federal Government Energy Incentives: Value, Distribution, and Policy Implications," *International Journal of Global Energy Issues*, vol. 27 [2007], no. 1.) The study leaves out the copious subsidies at the state level for renewable energy.

"Clean coal" is supposed to be a low-carbon alternative to nuclear for baseload power once we have carbon capture and sequestration (CCS). As of 2009, there was not a single demonstration plant using CCS, though China is working on one. Even industry proponents of CCS don't expect the first commercial application before 2030 or broad use before 2050. The volume of CO_2 that has to be dealt with is overwhelming. A 1-gigawatt coal-fired plant burns eighty rail cars of coal a day, each car carrying 100 tons of coal. The resulting CO_2 weighs 2.4 times as much as the coal, so that plant will produce over 19,000 tons of carbon dioxide a day—7 million tons a year. It has to be separated, compressed to a liquid, piped to a suitable location, pumped down half a mile, and sealed off permanently. Good luck with that in the developing world. A Swede named Anders Hansson did the math on the billions of tons of carbon dioxide that would have to be buried to make a difference and concluded, "Carbon dioxide would be the world's largest transported good." *Washington Post* cartoonist Tom Toles has it right: The best carbon sequestration technique is to leave the coal in the ground.

You may have heard this one: "It's no good building new reactors because we're running out of uranium." In fact we're not, and it wouldn't matter if we did. Known uranium deposits cover a hundred years of current-level use. The rising price of uranium is driving new exploration, with finds turning up all over the world. The price rise also makes reprocessing of spent fuel more attractive, and that leverages existing uranium manyfold. The leading substitute for uranium, thorium, is three times as abundant, and it can't melt down, it's useless for weapons, and it generates little waste. Meanwhile, new reactors are increasingly efficient, and breeder models create more fuel than they use. I'll come back to the new designs in a minute.

● We Greens are not economists. When someone needs fiscal advice, they don't usually hire an environmentalist, because they know we don't really know about money and we don't really care about money. Our agenda is to protect the natural environment, not taxpayers or ratepayers. We're perfectly happy requiring such impediments as environmental impact reports, which add horrendous costs and delays to projects, and our arguments for protecting one endangered species or another do not include cost analysis. How much is a condor worth? Don't even ask.

Occasionally we'll invent useful economic instruments like debt-for-nature swaps, and many of our organizations are well run financially, but money issues are customarily employed by Greens strictly as a weapon. "If you want to kill a power project," advises one activist in *Orion* magazine, "focus on economics." I recall the futurist Herman Kahn talking about the fight over the Trans-Alaska Pipeline in the 1970s: "The Greens began by complaining about the design of the pipeline, and they were right, it did have flaws. But once those were fixed, the Greens put all their effort into forcing delays and extravagances that raised the cost of the system. Their final argument was that the pipeline should not be built because it was too expensive. That's like a kid murdering his parents and then asking for mercy from the court because he's an orphan."

Amory Lovins does have economic expertise. He deploys cost analysis brilliantly in the service of energy efficiency and conservation. His Rocky Mountain Institute well earns its $9 million a year helping corporate clients and the military make their energy practices both frugal for themselves and good for the environment. But when Lovins aims his well-honed techniques at nuclear power, I think his private-sector bias gets in the way. He has said, "I admire those who try to reform public policy, but

I don't spend much time doing that myself. In a tripolar world of business, civil society, and government, why would you want to focus on the least effective of that triad?"

With global warming, the game has changed. Market forces cannot limit greenhouse gases. Governments have to take the lead. What they deem the atmosphere requires will be the prime driver of the economics of energy.

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A common refrain against nuclear goes, "Solving the problem of waste storage is so difficult, not a single geological repository for nuclear waste is operating anywhere in the world."

But there is one in the United States, in operation burying radioactive stuff since 1999. WIPP, the Waste Isolation Pilot Plant in New Mexico, got through its safety reviews thanks largely to Rip Anderson, the scientist at Sandia Labs who guided Gwyneth Cravens through the nuclear world for her book. For political reasons, WIPP was assigned only waste (some low-level, some high-level) from U.S. military activities, while the high-level waste from the civilian energy program was supposed to go to Yucca Mountain in Nevada. Having studied every kind of repository in detail, Anderson declares:

> From a technical point of view, the best place on dry land to store all nuclear waste—wherever it comes from—is at WIPP. We've proven that every way you can think of. We have traceability and transparency. Geologically and hydrologically, it's the safest. There's room for it, and more panels can be mined out of the salt bed whenever we want. It's only politics and bureaucracy that stand in the way.

WIPP is a salt formation, and Yucca Mountain is a dry desert ridge in a huge military reservation, but that's not why one is now working and the other isn't. New Mexico is familiar with nuclear technology, through long experience with Los Alamos and Sandia, where nuclear weapons were designed and built. Nevada is where the bombs were tested. Nevadans miss no opportunity to get in a fight with the federal government, which owns 86 percent of the state's land. Nuclear waste in Nevada? "No, God damn it! Take your garbage somewhere else!" Antinuclear environmentalists restate that sentiment in terms of dangers of transport, insufficient testing on groundwater flow, effects of heat on rock, impossibility of defining what will happen over 10,000 years, etc.

Jim Lovelock is baffled by the fuss:

> Consider the Yucca Mountain nuclear-waste depository in Nevada: It cost a fortune to construct, and we need it about as much as we need a facility for imprisoning dangerous extraterrestrials. We must stop living in a sci-fi world. In the real world, high-level nuclear waste from 40 years of energy production in the U.K. and France is stored as chunks of glass packed in stainless steel containers and buried a few meters underground. Sandy [Lovelock] and I stood on all the French high-level nuclear waste at La Hague in Normandy. The radiation level on my own monitor was only 0.25 microsieverts an hour, which is about 20 times less than you'd find in any long-distance passenger plane.

In Finland, construction is going ahead on a deep geological repository for high-level wastes at Eurajoki, where the project found a welcome because the local population had become comfortable with nuclear power: It has been generated in their neighborhood for thirty years. The repository should open for business in 2020. Meanwhile, Finland's neighbor Russia wants to become a nuclear fuel handler for the world—mining, processing, shipping, and reprocessing fuel, and then storing the waste.

The method of dealing with nuclear waste in the United States that emerged, de facto, in the absence of a national repository is proving so practical that a new solution is based on it. U.S. reactor operators now put their spent fuel in pools to cool off for a few years, then pack it in dry cask storage out behind the parking lot. So it is for all 121 reactor sites in thirty-nine states. Since the casks are designed for transport (there's a thrilling video made at Sandia of trains, planes, and trucks ramming the casks without release of spent fuel), the idea now being legislated—with support of the

Obama administration—is to cart them to a few well-guarded "interim" sites where they can be parked for decades while the nation decides whether it wants to recycle the material or bury it. Thus the United States would adopt Canada's "adaptive phased management" solution. To my eye, the emerging rule is: Plan short and option long; take the actions in the near term that preserve the most choices for the long term.

That approach was taken with funding for waste storage. American purchasers of nuclear-generated electricity have been paying for eventual storage facilities for years. Some $28 billion has accumulated. What's in short supply now is political decisiveness.

• I used to be certain that reprocessing spent fuel is the right thing to do. The once-through "waste" we bury has 95 percent of its energy still in it. If all the existing spent fuel in the United States were reprocessed, our whole nuclear fleet could run for seven years on nothing else. The eventual volume of unreusable waste after reprocessing is a fraction of the usual waste—some say a fourth, others a tenth—and the radioactive material does not remain dangerous for nearly as long. Because weapons-capable plutonium is generated in the current forms of reprocessing, Presidents Gerald Ford and Jimmy Carter shut down the U.S. operation in the hope that the rest of the world would follow suit. It didn't work. Routine in France, Russia, England, Germany, and Japan, reprocessing is being considered in many nations with ambitious nuclear-energy programs. These days, the United States itself is undertaking to build reprocessing plants in Idaho, New Mexico, and South Carolina.

An article in the engineering magazine *IEEE Spectrum* on France's exemplary reprocessing operation is what gives me some second thoughts. The facility at La Hague reprocesses 1,700 tons of spent fuel a year, with an impeccable safety record. But even in France, with its primary reliance on nuclear for electricity, the enormous cost of reprocessing makes it economic only if the price of uranium is very high, or if the nation is developing fast breeder reactors. While the eventual waste from reprocessed fuel is relatively short-lived, it is much "hotter" and trickier to handle than the once-through spent fuel.

And then there's the weapons issue. That's the one that keeps Al Gore hesitant about nuclear. He has said:

> For eight years in the White House, every weapons-proliferation problem we dealt with was connected to a civilian reactor program. And if we ever got to the point where we wanted to use nuclear reactors to back out of a lot of coal—which is the real issue: coal—then we'd have to put them in so many places, we'd run that proliferation risk right off the reasonability scale. And we'd run short of uranium, unless they went to a breeder cycle or something like it, which would increase the risk of weapons-grade material being available.

Current reprocessing techniques produce plutonium and enriched uranium, which are potential bomb materials. There are political and technical workarounds, though.

- First, it should be said that nuclear energy has done more to eliminate existing nuclear weapons from the world than any other activity. Megatons to Megawatts (I guess they decided against Megadeaths to Megawatts) is the name of a joint U.S.–Russia program to convert warheads into fuel. It began in 1994, and currently 10 percent of the electricity Americans use comes from Russian missiles and bombs. The goal is to convert twenty thousand nuclear warheads into fuel by 2013; that's enough energy to run the whole U.S. nuclear fleet for two years. Two processes are involved. One "downblends" weapons-grade highly enriched (95 percent) uranium to low-enriched (5 percent) uranium for reactor use. The other converts plutonium into a "mixed oxide" (MOX) that also works as a fuel. In the next few years, the United States will supplement Russian efforts by commencing to forge our own nuclear swords into plowshares in Tennessee and at a new facility in South Carolina. This whole astonishing program has occurred with scant media attention and zero public hoopla. (Freeman Dyson tells me that's good: "Important moves toward disarmament always go better when they are not reported in the media. Historic examples are

Nixon's getting rid of U.S. biological weapons and George Bush Senior getting rid of most of the U.S. tactical nukes. Both these big disarmament moves were done quietly so that they did not become political issues.")

No other weapons system creates so much civilian value when dismantled. The sundry calls from around the world and across the political spectrum to eventually eliminate *everybody's* nuclear weapons inventory and apparatus can draw on this strong additional incentive.

There is logic for and against the argument that expanding nuclear energy expands the possibility of nuclear weapons proliferation. The observation that "more nuclear means more nuclear, period" has bracing clarity. A worldwide nuclear energy renaissance involves massive expansion of nuclear skills, nuclear equipment, and nuclear materials—a whole nuclear economy. Nuclear weapons programs should have no problem quietly expanding in the shadow of all that, right?

Among the critiques of this energy-to-weapons sequence, perhaps the strongest argument is that it hasn't occurred that way in history. Israel, India, South Africa, and North Korea secretly developed their weapons capability from research reactors, not from an energy program. Of the thirty-one nations currently using nuclear power, only seven have nuclear weapons (the United States, Russia, England, France, China, India, and Pakistan), and in each case the weapons program came first. North Korea and Israel have weapons but no nuclear power (though both have energy projects under way).

What I hear from people in the intelligence world is that antiproliferation efforts are going surprisingly well, mainly because international cooperation is inclusive and intense. It doesn't matter if a particular American administration is in bad odor; every nation has its own strong motivation to have no nuclear weapons capability in non-state-actor hands. The full argument against the nuclear terrorism threat is worth hearing from John Robb, who runs the blog *Global Guerillas* and wrote *Brave New War* (2007):

> Though most of the worry over WMDs [weapons of mass destruction] has focused on nuclear weapons, those aren't the real long-term problem. Not only is the vast manufacturing capability of a nation-state required to produce the basic nuclear materials, but those materials are difficult to manipulate, transport, and turn into

weapons. Nor is it easy to assemble a nuke from parts bought on the black market; if it were, nation-states like Iran, which have far more resources at their disposal than terrorist groups do, would be doing just that instead of resorting to internal production.

It's also unlikely that a state would give terrorists a nuclear weapon. Sovereignty and national prestige are tightly connected to the production of nukes. Sharing them with terrorists would grant immense power to a group outside the state's control—the equivalent of giving Osama bin Laden the keys to the presidential palace. If that isn't deterrent enough, the likelihood of retaliation is, since states, unlike terrorist groups, have targets that can be destroyed. The result of a nuclear explosion in Moscow or New York would very probably be the annihilation of the country that manufactured the bomb, once its identity was determined—as it surely would be, since no plot of that size can remain secret for long.

Even in the very unlikely case that a nuclear weapon did end up in terrorist hands, it would be a single horrible incident, rather than an ongoing threat. The same is true of dirty bombs, which disperse radioactive material through conventional explosives. No, the real long-term danger from small groups is the use of biotechnology to build weapons of mass destruction. In contrast with nuclear technology, biotech's knowledge and tools are already widely dispersed—and their power is increasing exponentially.

(I'll get to Robb's final point on biotech in a later chapter. I should add that his view of Iran is that, whatever its ambitions for nuclear weapons, it does actually need nuclear energy, and that gives the world bargaining leverage on exactly how Iran proceeds with nuclear technology.)

• The many minds over many decades that have focused on preventing further nuclear proliferation have converged in the last few years on a single, all-encompassing strategy—an international fuel bank. Rid the world of the creation of weapons-grade plutonium and uranium and of hidden pockets of those materials by closely managing the world market in nuclear fuels and spent fuels so that unsupervised enrichment and reprocessing cannot occur. There is no explosive capability in nuclear fuel or spent fuel by themselves: They're far too dilute. Many nations would welcome the outsourcing of their fuel reprocessing, because it is so expensive and tricky, and it would be a great relief for them to have their nuclear waste go away to be treated as someone else's resource or service instead of lingering as a politically fraught local storage problem. The nation would basically rent nuclear fuel from a trusted international facility that comes around like the milkman to drop off milk and pick up empty bottles.

That is the idea behind GNEP—the Global Nuclear Energy Partnership—which could wind up being the one lasting accomplishment of the George W. Bush administration. Put forward in 2006, GNEP was blasted by antinuclear organizations and criticized by the National Academy of Sciences; but the partnership was quickly joined by eighteen nations, including France, Japan, Canada, and Britain, and it got support from the head of the International Atomic Energy Agency, crucial for program oversight. Part of the GNEP scheme is to develop new proliferation-resistant reprocessing techniques and new reactor designs such as the sodium-cooled fast reactor, which breeds its own fuel, reducing traffic in nuclear fuel as well as reducing spent-fuel mass and longevity. Whether or not the GNEP prevails, it is just the most ambitious of several multinational fuel-cycle initiatives being proposed and funded. One or a combination of them is likely to be operative by the 2010s. President Obama announced his support of a nuclear fuel bank program before a global audience in Prague in early 2009.

• One reason the French were able to build a fleet of fifty-six reactors providing nearly all of the nation's electricity in just twenty years was an efficient licensing process that took four years instead of the twelve years that became standard in the United States. As a result, France has the cleanest air in Europe, the lowest electrical bills, and a $4 billion export business selling energy to all its neighbors, including Green Germany and nuclear Britain (2 gigawatts flows west under the English Channel). France shut down its last coal-fired plant in 2004. It emits 70 percent less carbon dioxide per capita than the United States.

Lessons learned. The U.S. Nuclear Regulatory Commission has adopted the French approach, with design standardization and a licensing process based on the model that emerged in Taiwan, Japan, and South Korea. Reactor manufacturers can get their designs *pre*approved. One next-generation reactor, from Westinghouse, has already been approved, and two others, from AREVA and GE, are in process. Many reactor-site approvals already exist, left over from the 1970s boom. Once a utility decides to build, it applies for a single combined construction and operating license, and the NRC has three years to grant or deny the license. Get the data, hear the critiques (including those from environmentalists), make adjustments, *decide*, and move on. With standardized designs and standardized parts, construction of large new plants should be completed in four years.

This is the kind of mobilization that is needed to deal with climate change. It should be applied to every activity affecting greenhouse gases, including renewable-energy technologies, transportation, agricultural practices, and city design.

Seeking that kind of acceleration, in 2005 Congress passed the Energy Policy Act with incentives for wind, solar, geothermal, biofuels, wave and tidal power, clean coal, efficiency and conservation . . . and nuclear. As the *Economist* summarized it, the act

> offers four different types of subsidies for new reactors. First, it grants up to $2 billion in insurance against regulatory delays and lawsuits to the first six reactors to receive licences and start construction. Second, it extends an older law limiting a utility's liability to $10 billion in the event of a nuclear accident. Third, it provides a tax credit of 1.8 cents per kilowatt hour for the first 6,000 megawatts generated by new plants. Fourth, and most importantly, it offers guarantees for an indeterminate amount of loans to fund new nuclear reactors and other types of power plant using "innovative" technology.

The act includes funds for research on what are called generation IV reactors. (The reactors currently operating in the United States are generation II,

and the ones now being constructed are referred to as generation III-plus—with better built-in safety and efficiency.) Generation IV designs, which are not expected to be commercial before the 2030s, aim for maximum all-around sustainability through lower construction and operating costs, superhigh fuel efficiency, greatly reduced waste with shorter-term radioactivity, and high temperatures capable of generating hydrogen or desalinating water. The goal is to solve permanently every one of the four major problems with current reactors—safety, cost, waste, and proliferation. A consortium of ten nations and the European Union is carrying out the research.

James Hansen suggests that the development of generation IV reactors could be sped up by applying some of the $28 billion already collected from the nuclear industry for waste storage: "This fund should be used to develop fast reactors that consume nuclear waste, and thorium reactors to prevent the creation of new long-lived nuclear waste." The reactors he's referring to are the integral fast reactor, which, he says, "can burn existing nuclear waste and surplus weapons-grade uranium and plutonium, making electrical power in the process," and the liquid-fluoride thorium reactor. Full-scale working reactors, Hansen proposes, could be developed first in China, India, or South Korea, where the need is greatest, with American or European technical support. Deployed in the United States, the waste-burning reactors would make Yucca Mountain irrelevant.

Freeman Dyson comments: "Next-generation reactors could make a big difference. I like especially Lowell Wood's scheme for building a thorium breeder that runs for fifty years without refueling. It is buried deep underground, and after the thorium is burned, it stays in the ground and is never touched." Details on the design may be found in a 2008 paper in *Progress in Nuclear Energy*. The five authors conclude with the reactor's advantages: "No more mining, no more enrichment operations, zero spent-fuel handling, no reprocessing or waste storage facilities, and the reactor vessel is the (robust) burial cask."

• The new nukes with the greatest potential appeal for environmentalists are microreactors. They speak directly to Amory Lovins's call for distributed micropower ("The cheapest, most reliable power is typically produced at or near customers"). They have the advantage of capital costs and construction times a fraction of what is required for the standard gigawatt-plus big nuclear plants, and the development time for new designs also is drastically shorter.

Right now Russia is building 35-megawatt reactors that float on barges, for use starting in 2010 along the nation's newly navigable Arctic coast, and Russia's developing-world clientele is expected to buy some for remote coastal villages. In Japan, Toshiba has invented a 10-to-50-megawatt "nuclear battery" the company calls 4S—for "super safe, small, and simple"—expected to be ready around 2015. Not to be outdone in the acronym department, the Lawrence Livermore Lab in California has a 20-megawatt reactor design it calls SSTAR—"small, sealed, transportable autonomous reactor." The idea with these small units is that they can be trucked in and planted in the ground, and no fuel goes in, no waste comes out—they're simply replaced decades later.

A company in New Mexico called Hyperion is building 25-megawatt reactors using a uranium hydride–based design from the Los Alamos National Laboratory; the company claims it has a hundred firm orders at $25 million per reactor. A company in Oregon, NuScale, has a 40-megawatt light-water reactor design it says can be in operation by 2015. Then there's the pebble-bed modular reactor being developed in South Africa. Meltdown-proof, it also can operate underground, at a scale of 100 megawatts.

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To my mind, the Green path forward begins with environmentalists realizing that nuclear power will grow no matter what we do. Our customary opposition would make it grow badly—slowly, expensively, unsystemically, and with dangerously poor overall coordination. But if we encourage it in the right way, nuclear energy growing well would mean that it minimizes humanity's carbon-loading of the atmosphere; that it collaborates well with other carbon-free or superefficient energy forms; that it helps generate other Green services such as desalination or hydrogen; that its uranium and thorium make minimum lasting mess on their way from the ground and back to it; that it helps eliminate nuclear weapons; that it securely

energizes cities and thereby helps reduce world poverty; and, if something better comes along, that it gracefully gives way to its replacement.

Glow-in-the-dark Greens might push especially hard for first-rate microreactors and help them to find customers. We might insist that the next version of the Kyoto Protocol does not repeat the disgrace of denying carbon credits for nuclear power. We might lobby for open-sourcing the various reactor designs, for public debugging and trust. We might encourage investigating nuclear propulsion on commercial ships, the current source of 4 percent of greenhouse gas emissions—double the amount generated by airplane traffic. And as we promote plug-in cars, we might note that they reduce carbon emissions only if their electricity comes from Green sources such as nuclear, wind, hydro, and solar.

If hydrogen becomes a practical fuel, we might support high-temperature generation IV reactors that specialize for hydrogen. The same machines could drive desalination, the most energy-intensive source of water and also the least naturally disruptive way to provide water for our increasingly coastal populations. Because coal is now understood to be the long-term systemic horror we once thought nuclear was, we should closely monitor the real-world effectiveness of coal disincentives and make sure they work. To encourage public confidence and familiarity with nuclear, we can follow Sweden's and France's example by opening all reactors to public tours. (A third of all Swedes have toured a nuclear plant, which helps to explain why 80 percent of the population supports their continued use.)

For our fellow environmentalists still queasy about nuclear, we might quote Al Gore's mentor Roger Revelle, who sponsored the atmospheric carbon dioxide studies that first exposed the inconvenient truth about climate change. Revelle regarded nuclear as "much more benign" than other energy sources. He said, "What we ought to do is imitate the French and Japanese. They haven't got any phobias about it." We can even invoke the Sierra Club, which pushed for nuclear power in the late 1960s and early 1970s as preferable to hydroelectric dams. They were right.

• The atmosphere responds to the aggregate of all human activities. What the United States does about nuclear is not the main event.

The squatters' rights organization in South Africa, Abahlali baseMjondolo, has declared: "Electricity is not a luxury. It is a basic right. It is essential for children to do their homework; for safe cooking and heating; for people to charge phones, to be able to participate in the national debate through electronic communication (TV discussion programmes, email, etc); for lighting to keep women safe and, most of all, to stop the fires that terrorise us."

About half of India has no grid electricity. What power there is comes from diesel fuel trucked around to local generators. A *New York Times* article told of the fate of one village:

> Chakai Haat once had power at least a few hours each day, and it changed the rhythm of life. Petty thefts dropped because the village was lighted up. The government installed wells to irrigate the fields. Rice mills opened, offering jobs.
>
> The boon did not last long. Strong rains knocked down the power lines. The rice mills closed. Darkness swathed the village once more.

Five out of six people live in the developing world—about 5.7 billion in 2010. One way or another, the world's poor will get grid electricity. Where that electricity comes from will determine what happens with the climate.

Live-linked footnotes for this chapter, along with updates, additions, and illustrations, may be found online at **www.sbnotes.com**.

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Green Genes

> A truly extraordinary variety of alternatives to the chemical control of insects is available. Some are already in use and have achieved brilliant success. Others are in the stage of laboratory testing. Still others are little more than ideas in the minds of imaginative scientists, waiting for the opportunity to put them to the test. All have this in common: they are biological solutions, based on understanding of the living organisms they seek to control, and of the whole fabric of life to which these organisms belong. Specialists representing various areas of the vast field of biology are contributing—entomologists, pathologists, geneticists, physiologists, biochemists, ecologists—all pouring their knowledge and their creative inspirations into the formation of a new science of biotic controls.
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> —Rachel Carson, *Silent Spring*, 1962

I daresay the environmental movement has done more harm with its opposition to genetic engineering than with any other thing we've been wrong about. We've starved people, hindered science, hurt the natural environment, and denied our own practitioners a crucial tool. In defense of a bizarre idea of what is "natural," we reject the very thing Rachel Carson encouraged us to pursue—the new science of biotic controls. We make ourselves look as conspicuously irrational as those who espouse "intelligent design" or ban stem-cell research, and we teach that irrationality to the public and to decision makers.

We also repel the scientists whose help we most need to develop a