CHAPTER 3

NUCLEAR POWER: CLIMATE FIX OR FOLLY?

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Nuclear power, we are told, is a vibrant industry that is dramatically reviving because it is proven, necessary, competitive, reliable, safe, secure, widely used, increasingly popular, and carbon-free—a perfect replacement for carbon-spewing coal power. New nuclear plants thus sound vital for climate protection, energy security, and powering a vibrant global economy.

There is a catch though, the private capital market is not investing in new nuclear plants, and without financing, capitalist utilities are not buying. The few purchases, nearly all in Asia, are all made by central planners with a draw on the public purse. In the United States even the new government subsidies of 2005, which approach or exceed the total cost of new nuclear plants, failed to entice Wall Street to put a penny of its own capital at risk during what were, until autumn 2008, the most buoyant markets and the most nuclear-favorable political and energy-price conditions in history—conditions that have largely reversed since then.

This semi-technical chapter, summarizing a detailed and documented technical paper,[1] compares the cost, climate protection potential, reliability, financial risk, market success, deployment speed, and energy contribution of new nuclear power with those of its low- or no-carbon competitors. It explains why soaring taxpayer subsidies have not attracted investors. Instead, capitalists favor climate-protecting competitors with lower cost, shorter construction time, and less financial risk. The nuclear industry claims it has no serious rivals, let alone those competitors—which, however, already outproduce nuclear power worldwide and are growing enormously faster.

Most remarkably, comparing the abilities of all options to protect the earth's climate and enhance energy security reveals why nuclear power *could never deliver* these promised benefits even if it *could* find free-market buyers—while its carbon-free rivals, which won more than $90 billion of private investment in 2007 alone,[2] do offer highly effective climate and security solutions, much sooner and with higher confidence.

UNCOMPETITIVE COSTS

The Economist observed in 2001 that "Nuclear power, once claimed to be too cheap to meter, is now too costly to matter—cheap to run but very expensive to build."[3] Since then, it has become even more costly to build, and in a few years, as old fuel contracts expire, it is expected to become more expensive to run.[4] Its total cost now markedly exceeds that of coal- and gas-fired power plants, let alone the cheaper decentralized competitors described below.

Worldwide construction costs have risen far faster for nuclear than for non-nuclear plants. This is not, as commonly supposed, due primarily to higher metal and cement prices: repricing the main materials in a 1970s U.S. plant (an adequate approximation) to March 2008 commodity prices yields a *total* Bill of

Materials cost only ~1 percent of today's overnight capital cost. Rather, the real capital-cost escalation is due largely to the severe atrophy of the global infrastructure for making, building, managing, and operating reactors. This forces U.S. buyers to pay in weakened dollars, since most components must now be imported. It also makes worldwide buyers pay a stiff premium for serious shortages and bottlenecks in engineering, procurement, fabrication, and construction: some key components have only one source worldwide. The depth of the decline is revealed by the industry's flagship Finnish project, led by France's top builder, which after 3 years of construction, is at least 3 years behind schedule and 50 percent over budget. An identical second unit, gratuitously bought in 2008 by the 85 percent-state-owned Électricité de France to support the 91 percent-state-owned vendor Areva (orderless 1991–2005), was bid ~25 percent higher than the Finnish plant and without its fixed-price guarantee, and suffered prompt construction shutdowns for poor quality.

The rapid escalation of U.S. nuclear capital costs can be seen by comparing the two evidence-based studies[5] with each other and with later industry data (all including financing costs, except for the two "overnight" costs, but with diverse financing models—see Table 3-1). As the Director of Strategy and Research for the World Nuclear Association candidly put it, "[I]t is completely impossible to produce definitive estimates for new nuclear costs at this time. . . ."[6]

Date	Source	Capital Cost (2007 $/net el. W)	Levelized Busbar Cost, 2007 $/MWh
7/03	MIT	2.3	77–91
6/07	Keystone	3.6–4.0	83–111
5/07	S&P	~4	
8/07	AEP	~4	
10/07	Moody's	5–6	
11/07	Harding	4.3–4.6	~180
3/08	FPL filing	~4.2–6.1 [3.1–4.5 overnight]	
3/08	Constellation	[3.5–4.5 overnight]	
5/08	Moody's	~7.5	150
6/08	Lazard	5.6–7.4	96–123
11/08	Duke Power	[4.8 overnight]	

Table 3-1. Escalating U.S. Nuclear Construction Cost Estimates (Including Interest and Real Escalation Unless [Overnight]), 2003–08 (2009–10 Continue the Trend).[7]

By 2007, as Figure 3-1 shows, nuclear power was the costliest option among all main competitors, whether using MIT's authoritative but now low 2003 cost assessment, the Keystone Center's mid-2007 update (top of nuclear plant bar), or later and even higher industry estimates (Moody's arrow).[8] For plants ordered in 2009, formal studies have not yet caught up with the latest data, but it appears that their new electricity would probably cost (at your meter, not at the power plant) around 10–13¢/kWh for coal rather than the 9¢ shown, about 9–13¢/kWh for combined-cycle gas rather than the nearly 10¢ shown, but around 15–21¢/kWh for new nuclear rather than the 11–15¢ shown.[9] However, nuclear's decentralized competitors have suffered far less, or even negative, cost escalation, for example, the average price of electricity sold by new U.S. windfarms *fell* slightly in 2007.[10] The 4.0¢/kWh average windpower price for projects installed in 1999–2007 seems to be more representative of a stable forward market, and corresponds to ~7.4¢/kWh delivered and firmed—just one-half to one-third of new nuclear power costs on a fully comparable basis.

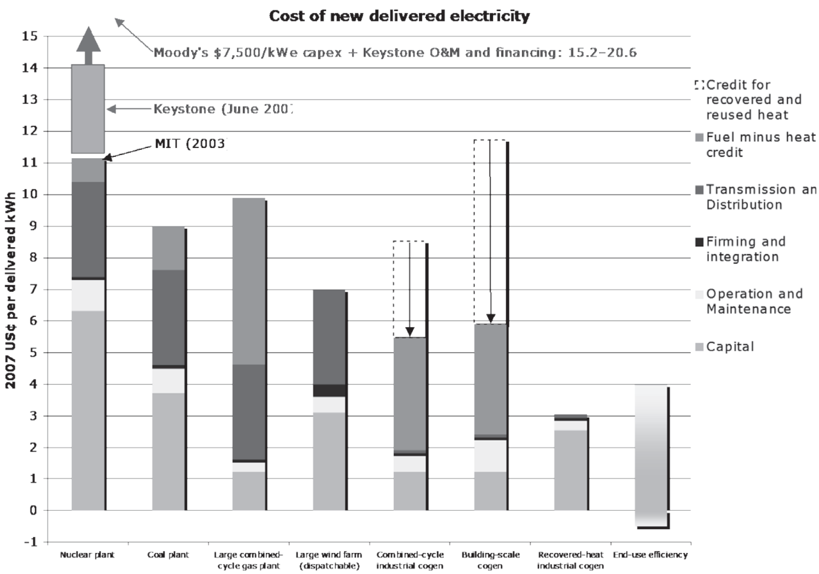

Figure 3-1. An Apples-to-Apples Comparison of the Cost of Making and Delivering a New Firm kWh of Electrical Services in the United States Based on Empirical ~2007 Market Costs and Prices.

Noncentral Station Competitors.

Cogeneration and efficiency are "distributed resources," usually located near where energy is used. Therefore, they do not incur the capital costs and energy losses of the electric grid, which links large power plants and remote wind farms to customers.[11] Wind farms, like solar cells, also require "firming" to steady their variable output, and all types of generators require some backup for when they inevitably break.[12] Figure 3-1 reflects these costs.

Making electricity from fuel creates large amounts of by-product heat that is normally wasted. Combined-cycle industrial cogeneration and building-scale cogeneration recover most of that heat and use it to displace the need for separate boilers to heat the industrial process or the building, thus creating the economic "credit" shown in Figure 3-1. Cogenerating electricity and some useful heat from currently discarded industrial heat is even cheaper because no additional fuel is needed, so no additional carbon is released—only what the factory was already emitting.[13]

End-use efficiency, by far the cheapest option, wrings more (and often better) services from each kilowatt-hour by using smarter technologies—substituting brains for dollars and carbon. That is mainly how California has held per-capita electricity use flat for the past 30 years, saving ~$100 billion of investment to supply electricity, while per-capita real income rose 79 percent (1975–2005). Its new houses, for example, now use one-fourth the energy they used to. Yet California is further accelerating all its efficiency efforts because there is so much still to save. McKinsey & Company has found that efficiency can profitably offset 85 percent of the normally projected growth in U.S. electricity consumption to 2030.[14] Just using all U.S. electricity as productively as the top 10 states now do (in terms of gross state product per kWh consumed, roughly adjusted for economic mix and climate) would save about 1,200 TWh/y—~62 percent of the output of U.S. coal-fired plants.[15]

Saving electricity costs far less than producing and delivering it, even from *existing* plants. California investor-owned utility efficiency programs cost an average of 1.2¢/kWh in 2004, and 83 Pacific Northwest utility programs cost 1.3¢/kWh.[16] The national average is about 2¢, but hundreds of utility programs (mainly for businesses, where most of the cheap savings are) cost less than 1¢.[17]

A major power engineering firm helped investment firm Lazard compare observed U.S. prices, finding that efficiency and many renewables cost less than a new central plants (see Figure 3-2). Lazard's recent comparison shows most centralized options beating all new central stations; this chart omits cogeneration, overstates wind costs, and understates nuclear costs. [18]

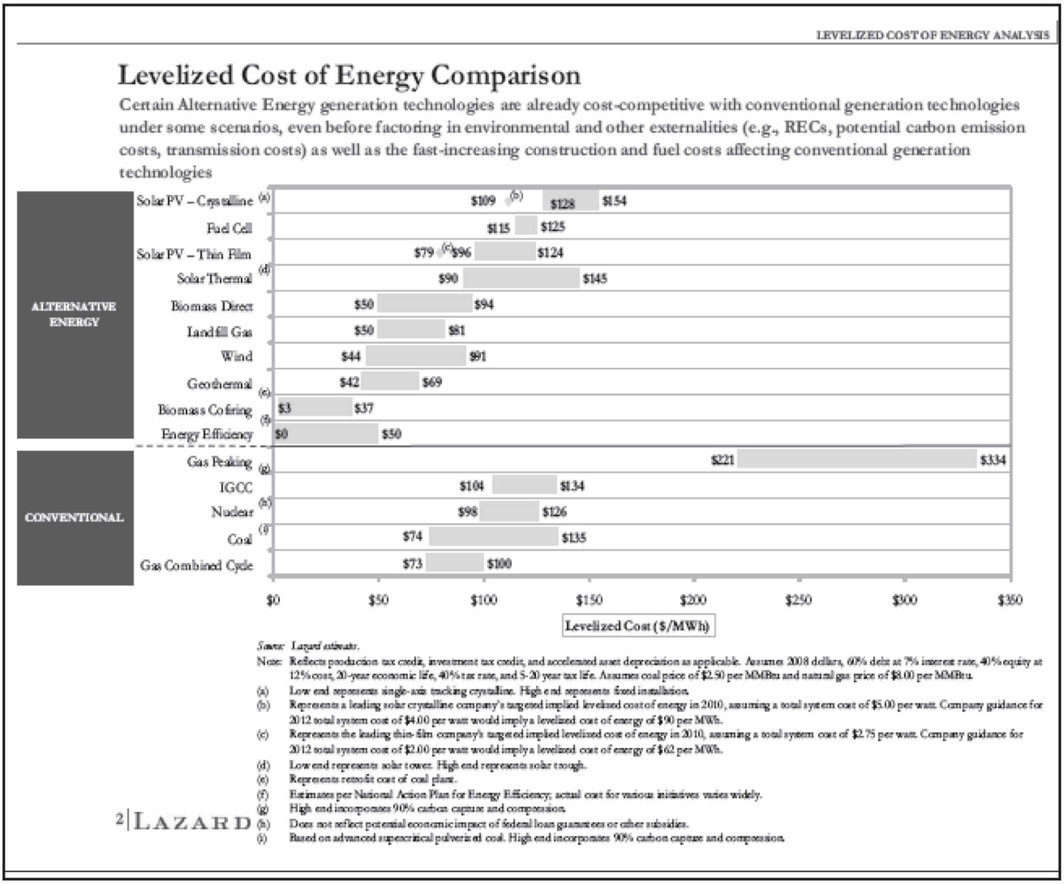

Figure 3-2. Lazard's Levelized Cost of Energy Comparison.

WHY THESE COMPARISONS UNDERSTATE THE LACK OF COMPETITIVENESS OF NUCLEAR POWER

These conventional results and assessments greatly understate the size and profitability of today's electric efficiency potential. In 1990, the utilities think-tank EPRI and RMI, in a joint article, assessed the potential to be as ~40–60 percent and ~75 percent, respectively, at average 2007-$ costs of about 3 and 1¢/kWh.[19] Now both those estimates look conservative, for two reasons:

1. As EPRI suggests, efficiency technologies have improved faster than they have been applied, so the potential savings keep getting bigger and cheaper.[20]

2. As RMI's work with many leading firms has demonstrated, integrative design can often achieve radical energy savings at *lower* cost than small or no savings.[21] That is, efficiency can often *reduce* total investment in new buildings and factories, and even in some retrofits that are coordinated with routine renovations.[22]

Wind, cogeneration, and end-use efficiency already provide electrical services more cheaply than central thermal power plants, whether nuclear or fossil-fueled. *This cost gap will only widen*, since central thermal power plants are largely mature and getting costlier, while their competitors continue to improve rapidly. Indeed, a good case can be made that photovoltaics (PVs) can *already* beat new thermal power plants. For example, if you start in 2010 to build a new 500-MW coal-fired power plant in New Jersey, plus an adjacent photovoltaic (PV) power plant, before the coal plant comes online in 2018, the solar plant will produce a slightly larger amount of annual electricity at lower levelized cost, but with 1.5x more onpeak output, and the PV manufacturing capacity used to build your plant can then add 750 more MW *each year*.[23] Of course, the high costs of conventional fossil-fueled plants would go even higher if their large carbon emissions had to be captured—but this coal/solar comparison assumes a carbon price of *zero*.

The foregoing cost comparison is conservative for four important *additional* reasons:

1. End-use efficiency often has side-benefits worth 1–2 orders of magnitude (factors of 10) more than the saved energy.[24]

2. End-use efficiency and distributed generators have 207 "distributed benefits" that typically increase their economic value by an order of magnitude.[25] The *only* distributed benefit counted above is reusing waste heat in cogeneration.

3. Integrating variable renewables with each other typically saves over half their capacity for a given reliability;[26] indeed, diversified variable renewables, forecasted and integrated, typically need *less* backup investment than big thermal plants for a given reliability.

4. Integrating strong efficiency with renewables typically makes both of them cheaper and more effective.[27]

The uncompetitiveness of new nuclear power is clear without these four conservatisms, and is overwhelming with them. As we will see, the marketplace concurs—and that is good news for the global climate.

UNCOMPETITIVE CO_2 DISPLACEMENT

Nuclear plant operations emit no carbon directly and rather little indirectly.[28] Nuclear power is therefore touted as the key replacement for coal-fired power plants. But this seemingly straightforward substitution could be done instead by using *non*-nuclear technologies that are cheaper and faster, so they yield more climate solution per dollar and per year.

As Figure 3-3 shows, various options emit widely differing quantities of CO_2 per delivered kilowatt-hour:[29] Coal is by far the most carbon-intensive source of electricity, so displacing it is the yardstick of carbon displacement's effectiveness. A kilowatt-hour of nuclear power does displace nearly all the 0.9-plus kilograms of CO_2 emitted by producing a kilowatt-hour from coal. But so does a kilowatt-hour from wind, a kilowatt-hour from recovered-heat industrial cogeneration, or a kilowatt-hour saved by end-use efficiency, and all three of these carbon-free resources cost far less than nuclear power per kilowatt-hour, so they save far more carbon per dollar.

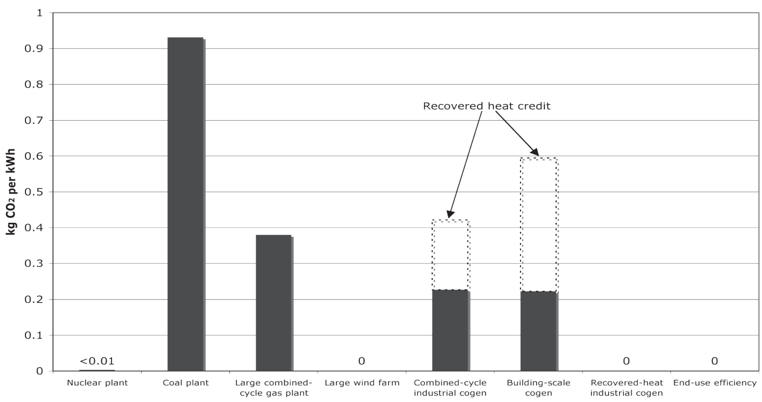

Figure 3-3. Operating CO_2 Emitted Per Delivered kWh.

Combined-cycle industrial cogeneration and building-scale cogeneration typically burn natural gas, which does emit carbon (though half as much as coal), so they displace somewhat less net carbon than nuclear power can, around 0.7 kilograms of CO_2 per kilowatt-hour.[30] Even though cogeneration displaces less carbon than nuclear does per kilowatt-hour, it displaces more carbon than nuclear does *per dollar spent on delivered electricity*, because it costs far less. With a net delivered cost per kilowatt-hour approximately half of that of nuclear (using the most conservative comparison from Figure 3-1), cogeneration delivers twice as many kilowatt-hours per dollar, and therefore displaces around 1.4 kilograms of CO_2 for the same cost as displacing 0.9 kilograms of CO_2 with nuclear power.

Figure 3-4 compares the cost-effectiveness of different electricity options in reducing CO_2 emissions, counting both their cost-effectiveness (kilowatt-hours per dollar), and any carbon emissions. New nuclear power is so costly that shifting a dollar of spending from nuclear to efficiency protects the climate severalfold more than shifting a dollar of spending from coal to nuclear. Indeed, under plausible assumptions, spending a dollar on new nuclear power *instead of* on efficient use of electricity has a worse effect on climate than spending that dollar on new coal power! How much net carbon emissions from coal-fired power plants can be displaced by buying a dollar's worth of new electrical services using different technologies? Note that the carbon savings from realistic efficiency investments are far above the upper-right corner of the chart.

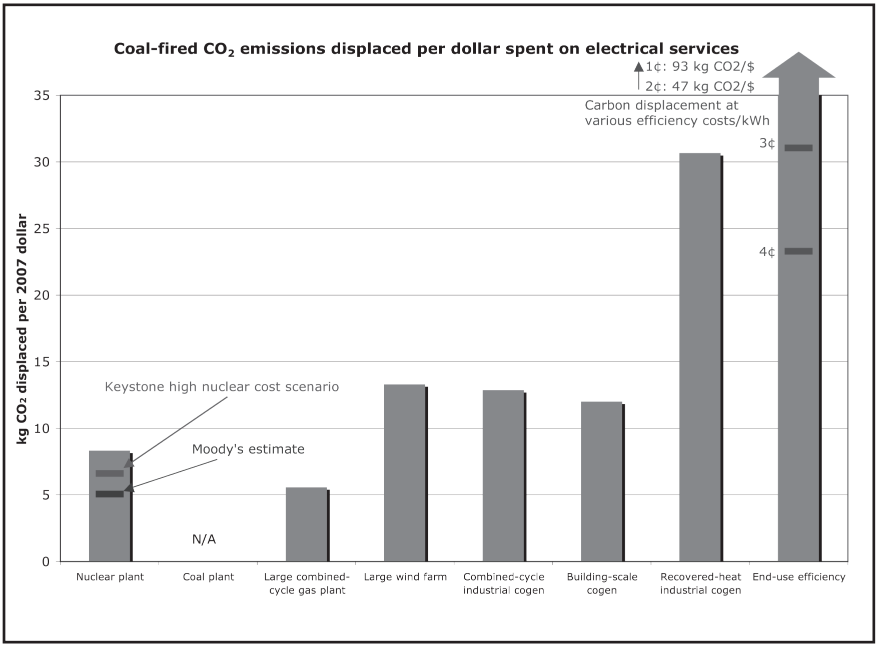

Figure 3-4. Coal-Fired CO_2 Emissions Displaced per Dollar Spent on Electrical Services.

If we are serious about addressing climate change, we must invest resources wisely to expand and accelerate climate protection. Since nuclear power is costly and slow to build, buying more of it rather than its cheaper and swifter rivals will instead reduce and retard climate protection.

QUESTIONABLE RELIABILITY

All sources of electricity sometimes fail, differing only in how predictably, why, how often, how much, and for how long. Even the most reliable giant power plants are intermittent, they fail unexpectedly in billion-watt chunks, often for long periods. Of all

132 U.S. nuclear plants built (52 percent of the 253 originally ordered), 21 percent were permanently and prematurely closed due to reliability or cost problems, while another 27 percent have completely failed for a year or more at least once. The surviving U.S. nuclear plants produce ~90 percent of their full-time full-load potential, but even they are not fully dependable. Even reliably operating nuclear plants must shut down, on average, for 39 days every 17 months for refueling and maintenance, and unexpected failures do occur too. To cope with such intermittence by both nuclear and centralized fossil-fueled power plants, which typically fail about 8 percent of the time, utilities must install a roughly 15 percent "reserve margin" of extra capacity, some of which must be continuously fueled, spinning ready for instant use. Heavily nuclear-dependent regions are particularly at risk because drought, earthquake, a serious safety problem, or a terrorist incident could close many plants simultaneously.

Nuclear plants have an additional disadvantage, for safety, they must instantly shut down in a power failure, but for nuclear-physics reasons, they cannot be quickly restarted. During the August 2003 Northeast blackout, nine perfectly operating U.S. nuclear units had to shut down. After 12 days of a painfully slow restart process, their average capacity loss had exceeded 50 percent. For the first 3 days, just when they were most needed, their output was 3 percent below normal.

The big transmission lines that highly concentrated nuclear plants require are also vulnerable to lightning, ice storms, rifle bullets, cyber-attacks, and other interruptions.[31] The bigger our power plants and power lines get, the more frequent and widespread regional blackouts will become. Because 98–99 percent of power failures start in the grid, it is more reliable to bypass the grid by shifting to efficiently used, diverse, dispersed resources sited at or near the customer.

Additionally, a portfolio of many smaller units is unlikely to fail all at once because its diversity and dispersion make it more reliable even if its individual units are not.[32] The same logic applies to the two renewable electricity sources—windpower and photovoltaics—whose output varies with weather or daytime. Of course, the sun does not always shine on a given solar panel, nor does the wind always spin a given turbine. Yet, if properly firmed, both windpower, whose global potential is 35 times that of the world's electricity use,[33] and solar energy, all of which that strikes the earth's surface every ~70 minutes is equivalent to that used by humankind each year, can deliver reliable power without significant cost for backup or storage.[34] These variable renewable resources become *collectively* reliable when diversified in type and location and when integrated with three types of resources: steady renewables (geothermal, small hydro, biomass, etc.); existing fueled plants; and customer demand response. Such integration uses weather forecasting to predict the output of variable renewable resources, just as utilities now forecast demand patterns and hydropower output. In general, keeping power supplies reliable despite large wind and solar fractions may well require *less* backup or storage capacity than utilities *have already bought* to manage intermittence from big thermal stations. The renewable energy myth of unreliability has been debunked both by theory and by practical experience.[35]

LARGE SUBSIDIES TO OFFSET HIGH FINANCIAL RISK

The latest U.S. nuclear plant proposed to be built is estimated to cost $12–24 billion (for 2.2–3.0 billion watts), much more than the industry's claims for new construction, and off the chart as shown in Figure 3-1. The utility's owner, a large holding company active in 27 states, has annual revenues of only $15 billion. Even before the current financial crisis, such high and highly uncertain capital costs made financing prohibitively expensive for free-market nuclear plants in the half of the United States that has restructured its electricity system. These high costs also make it prone to politically sensitive rate shock in the rest of the United States. For example, a new nuclear kilowatt-hour costing, say, 18 cents "levelized" over decades implies that the utility must collect ~30 cents to fund its first year of operation.

Lacking investors, nuclear promoters have turned back to taxpayers, who already bear most nuclear accident risks, have no meaningful say in licensing, and for decades have subsidized existing nuclear plants by ~1–8¢/kWh. In 2005, desperate for orders, the politically potent nuclear industry got those U.S. subsidies raised to ~5–9¢/kWh for new plants, or ~60–90 percent of their entire projected power cost, including new taxpayer-funded insurance against legal or regulatory delays. Wall Street still demurred. In 2007, the industry won relaxed government rules that made its 100 percent loan guarantees (for 80 percent debt financing) even more valuable. One utility's data indicated a cost of about $13 billion for a single new plant, which is almost equal to its entire capital cost. However, rising costs made the $4 billion of the new 2005 loan guarantees scarcely sufficient for a single reactor, so Congress raised taxpayer guarantees to $18.5 billion. Congress will soon be asked for another $30+ billion in loan guarantees, or even for a blank check (as both Houses separately approved in 2010). Meanwhile, the nonpartisan Congressional Budget Office has concluded that defaults are likely.

Wall Street is ever more skeptical that nuclear power is as robustly competitive as claimed. Starting with Warren Buffet, who recently abandoned a nuclear project because "it does not make economic sense," the smart money is heading for the exits.[36] The Nuclear Energy Institute is therefore trying to damp down the rosy expectations it created. It now says U.S. nuclear orders will come not in a tidal wave but in two little ripples—a mere 5–8 units coming online in 2015–16, then more if those are on time and within budget. Even that sounds dubious, as many senior energy-industry figures privately agree. In today's capital market, governments can have at most about as many nuclear plants as they can force taxpayers to buy. Indeed, the big financial houses that lobbied to be the vehicles of those gigantic federal loan guarantees are now largely gone; a new administration with many other priorities may be less supportive of such largesse; and the "significant" equity investment required to qualify for the loan guarantees seems even less likely to come from the same investors who declined to put their own capital at risk at the height of the capital bubble. The financial crisis has virtually eliminated private investment in big, slow, risky projects, while not materially decreasing investment in the small, fast, granular ones that were already walloping central plants in the global marketplace.

THE MICROPOWER REVOLUTION

While nuclear power struggles in vain to attract private capital, investors have switched—and the financial crisis has accelerated their shift[37]—to cheaper, faster, less risky alternatives that *The Economist* calls "micropower"—distributed turbines and generators in factories or buildings (usually cogenerating useful heat), and all renewable sources of electricity *except* big hydro dams (those over 10 megawatts).[38] These alternatives surpassed the global capacity of nuclear power in 2002 and its electric output in 2006. Nuclear power now accounts for about 2 percent of worldwide electric capacity additions, *vs*. 28 percent for micropower (2004–07 average) and probably a good deal more in 2007–08.[39]

Despite subsidies that are generally smaller than those for nuclear power and many barriers to fair market entry and competition,[40] negawatts (electricity saved by using it more efficiently or timely) and micropower have lately turned in a stunning global market performance. Figure 3-5 shows how micropower's actual and industry-projected electricity production is running away from that of nuclear power, not even counting the roughly comparable additional growth in negawatts, nor any fossil-fueled generators under 1 megawatt.[41] Global electricity produced, or projected by industry to be produced, by decentralized low- or no-carbon resources—cogeneration ("CHP"), mostly gas-fired, and distributed renewables (those other than big hydroelectric dams). Micropower obtained over $100 billion of new private capital in 2007—roughly an eighth of the total global energy investment.

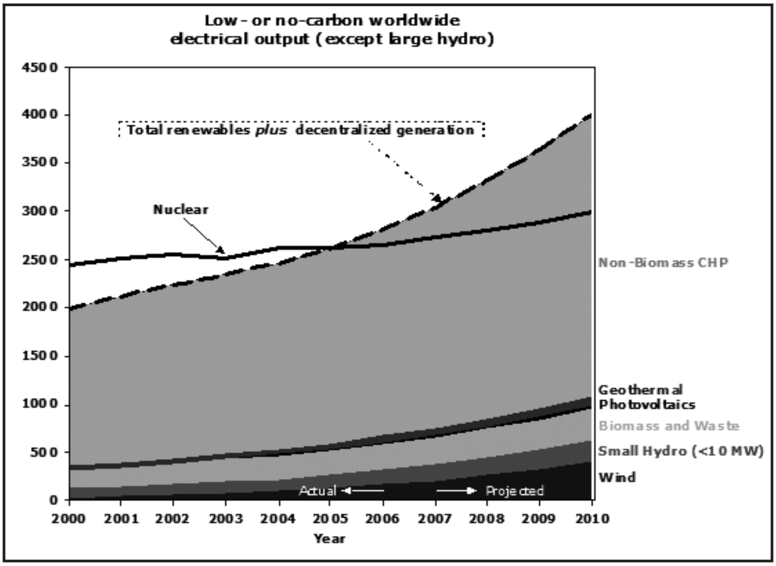

Figure 3-5. Low- or No-Carbon Worldwide Electrical Output (Except Large Hydro).

The nuclear industry nonetheless claims its only serious competitors are big coal and gas plants. But the marketplace has already abandoned that outmoded battleground for two others: central thermal plants vs. micropower, and megawatts vs. negawatts. For example, the United States added more windpower capacity in 2007 than it added coal-fired capacity in the past 5 years combined. By beating *all* central thermal plants, micropower and negawatts together provide about half the world's new electrical services. Micropower alone now provides a sixth of the world's electricity, and from a sixth to more than half of all electricity in 12 industrial countries, though the United States lags with ~6 percent.

In this broader competitive landscape, high carbon prices or taxes cannot save nuclear power from its fate.

If nuclear did compete only with coal, then far-above-market carbon prices might save it; but coal is not the competitor to beat. Higher carbon prices will advantage all other zero-carbon resources—renewables, recovered-heat cogeneration, and negawatts—as much as nuclear, and will partly advantage fossil-fueled but low-carbon cogeneration as well. The nuclear industry does not understand this because it does not consider these competitors important or legitimate.

SMALL IS FAST, LOW-RISK, AND HIGH-RISK IN TOTAL POTENTIAL

Small, quickly built units are faster to deploy for a given total effect than a few big, slowly built units. Widely accessible choices that sell like cellphones and PCs can add up to more and sooner than ponderous plants that get built like cathedrals. Small units are much easier to match to the many small pieces of electrical demand. Even a multi-megawatt wind turbine can be built so quickly that the United States will probably have a hundred billion watts of them (matching its nuclear capacity) installed before it builds its first one billion watts of new nuclear capacity, if any. As noted earlier, this speed reduces financial risk and thus makes decentralized, short-lead-time projects more financeable, especially in hard times.

Despite their small individual size, and partly because of it, micropower generators and electrical savings are already adding up to huge totals. Indeed, over decades, negawatts and micropower can shoulder the entire burden of powering the economy. The Electric Power Research Institute (EPRI), the utility think-tank, has calculated the U.S. negawatt potential (cheaper than just running an existing nuclear plant and delivering its output) to be two to three times the 19 percent share of nuclear power in the U.S. electricity market; RMI's more detailed analysis found even more. Cogeneration in factories can make as much U.S. electricity as nuclear does,[42] plus more in buildings, which use 69 percent of U.S. electricity. Windpower at acceptable U.S. sites can cost-effectively produce several times the nation's total electricity use,[43] and other renewables can make even more energy without significant land-use, variability, or other constraints. Thus, just cogeneration, windpower, and efficient use—all profitable today—can displace nuclear's current U.S. output by ~6–14 times over. This ratio becomes arbitrarily large when photovoltaics are included.

Nuclear power, with its decade-long project cycles, difficult siting, and (above all) unattractiveness to private capital, simply cannot compete. In 2006, for example, it added less global capacity than photovoltaics did, or a tenth as much as windpower added, or 30–41 times less than that added by micropower. Renewables other than big hydro dams won $56 billion of private risk capital; nuclear, as usual, got zero. China's distributed renewable capacity reached seven times its nuclear capacity and grew seven times faster. In 2007, China, Spain, and the United States each added more windpower capacity than the world added nuclear capacity. The nuclear industry trumpets its growth, yet micropower is already bigger and is growing 18 times faster.[44]

SECURITY RISKS

President Bush rightly identified the spread of nuclear weapons as the gravest threat to America. Yet that proliferation is largely driven and greatly facilitated by the flow of materials, equipment, skills, and knowledge, all wrapped in the innocent-looking civilian disguise of nuclear power. (Reprocessing nuclear fuel, which President Bush tried to revive, greatly complicates waste management, increases cost, and boosts proliferation.) Yet by acknowledging the market failure of nuclear power and moving on to more secure, least-cost, energy options for global development would unmask and penalize proliferators by making bomb ingredients harder to get. This would make proliferation far more difficult, and easier to detect by focusing scarce intelligence resources on needles and not on haystacks.[45] The new administration has an extraordinary opportunity to turn the world away from its rush toward a "nuclear-armed crowd" by setting a good example in domestic energy policy and by helping all developing countries with the nonviolent, cheaper, faster energy alternatives that are already winning in the global market.[46]

Nuclear power has other unique challenges too, such as long-lived radioactive wastes, potential for catastrophic accidents, and vulnerability to terrorist attacks. But in a market economy, the technology could not proceed even if it lacked those issues, so we need not consider them here.

CONCLUSION

So why do otherwise well-informed people still consider nuclear power a key element of a sound climate strategy? Not because that belief can withstand analytic scrutiny. Rather, it seems, because of a superficially attractive story, an immensely powerful and effective lobby, a new generation who forgot or never knew why nuclear power failed previously (almost nothing has changed), sympathetic leaders of nearly all main governments, deeply rooted habits and rules that favor giant power plants over distributed solutions and enlarged supply over efficient use, the market winners' absence from many official databases (which often count only big plants owned by utilities), and lazy reporting by an unduly credulous press.

Is it not time we forget about nuclear power? Informed capitalists have. Politicians and pundits should, too. After more than half a century of devoted effort and a half-trillion dollars of public subsidies, nuclear power still cannot make its way in the market. If we accept that unequivocal verdict, we can at last get on with the best buys first; proven and ample ways to save more carbon per dollar, faster, more surely, more securely, and with wider consensus. As we have seen before, the biggest key to a sound climate and a good security strategy is to take market economics seriously.

ENDNOTES - CHAPTER 3

1. A. B. Lovins and I. Sheikh, "The Nuclear Illusion," *Ambio*, forthcoming, 2011, RMI Publ. #E08-01, preprinted at *www.rmi.org/images/PDFs/Energy/E08-01_AmbioNuclIllusion.pdf*, to be updated in 2010–11 for publication.

2. Justin Winter for Michael Liebreich (New Energy Capital, London, UK), personal communication, December 1, 2008, updating that firm's earlier figure of $71b for distributed renewable sources of electricity. The $90b is bottom-up, transaction-by-transaction and excludes M&A activity and other double-counting. Reliable estimates of investment in no-carbon (recovered-waste-heat) or relatively low-carbon (fossil-fueled) cogeneration are not available, but total global cogeneration investment in 2007 was probably on the order of $20b or more.

3. "A renaissance that may not come: this week, the Bush administration revealed an energy policy that strongly supports nuclear power," *The Economist*, Vol. 359, Issue 8222, May 19, 2001, pp. 24–26.

4. Due to prolonged mismanagement of the uranium and enrichment sectors: *Nuclear Power Joint Fact-Finding*, Keystone Center, June 2007, available from *www.keystone.org/spp/documents/FinalReport_NJFF6_12_2007(1).pdf,* estimated new fuel contracts will rise from the canonical ~0.5¢/kWh to ~1.2–1.7¢ for open or ~2.1–3.5¢ for closed fuel cycles.

5. *Ibid*.; "A renaissance that may not come."

6. Steve Kidd, "Escalating costs of new build: what does it mean?" *Nuclear Engineering International*, August 22, 2008, available from *www.neimagazine.com/storyprint.asp?sc=2050690*.

7. MIT, *The Future of Nuclear Power*, 2003, available from *web.mit.edu/nuclearpower/*. This is very conservatively used as the basis for all comparisons in this chapter, but we also show some later variants.

8. All monetary values in this article are in 2007 U.S. dollars. All values are approximate and representative of the respective U.S. technologies in 2007 except as noted. Capital and fuel costs are levelized over the lifespan of the capital investment. Analytic details are in Endnote 1, and for the underlying 2005 analysis, in A. B. Lovins, "Nuclear Power: Economics and Climate-Protection Potential," RMI Publ. #E05-14, January 6, 2006, available from *www.rmi.org/images/PDFs/Energy/E05-14_NukePwrEcon.pdf,* summarized in A. B. Lovins, "Mighty Mice," *Nuclear Engineering International*, December 2005, pp. 44-48, available from *www.rmi.org/images/PDFs/Energy/E05-15_MightyMice.pdf*.

9. Based, as in Figure 3-1, on the June 2007 Keystone findings adjusted to Moody's May 2008 capital cost, on the assumption that a somewhat stronger dollar might partly offset escalation. Anecdotal reports suggest that real capital cost escalation remains rapid in Europe and Asia, depending on exchange rates: for example, eight recent Asian plants look to end up costing ~$4/W, consistent with mid-2007 U.S. cost estimates.

10. From 4.8 in 2006 to 4.5¢/kWh, 0.9¢ higher than shown in Figure 3-1. U.S. wind turbines became 9 percent costlier during 2006–07, and may rise another ~10 percent in 2008, largely because rapid growth bottlenecked some key component supplies, but capacity factors improved, too: e.g., the average kW of Heartland wind projects installed in 2006 produced 35 percent more electricity than one installed in 1998–99, due mainly to better-designed turbines, higher hub heights, and better siting. All windpower data in this chapter are from R. Wiser and M. Bolinger, "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007," U.S. Department of Energy (DOE)/EERE, LBL-43025, May 2008, available from *www1.eere.energy.gov/windandhydro/pdfs/43025.pdf*. All windpower prices are net of some minor Renewable Energy Credit trading and of the U.S. Production Tax Credit whose levelized value is 1.0¢/kWh, far smaller than subsidies to central thermal power plants. See D. Koplow, "Energy Subsidy Links Pages," Washington DC: Earthtrack, 2005, available from *earthtrack.net/earthtrack/index.asp?page_id=177&catid=66*.

11. Distributed generators may rely on the power grid for emergency backup power, but such backup capacity, being rarely used, does not require a marginal expansion of grid capacity, as does the construction of new centralized power plants. Indeed, in ordinary operation, diversified distributed generators *free up* grid capacity for other users.

12. "Firming" is a term referring to the provision of a back-up capability to ensure continuous supply.

13. A similar credit for displaced boiler fuel can even enable this technology to produce electricity at negative net cost. The graph conservatively omits such credit (which is very site-specific) and shows a typical positive selling price. The cogeneration results shown are based on actual projects considered representative by a leading developer.

14. McKinsey & Company, "Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?," National Academies Summit on America's Energy Future, Washington DC, March 14, 2008, slide 7.

15. N. Mims, M. Bell, and S. Doig, "Assessing the Electric Productivity Gap and the U.S. Efficiency Opportunity," Snowmass, CO: Rocky Mountain Institute, January 2009, available from *www.rmi.org/rmi/Library/2009-08_AssessingElectricProductivitiyGap*.

16. C. Rogers, M. Messenger, and S. Bender, "Funding and Energy Savings from Investor-Owned Utility Energy Efficiency Programs in California for Program Years 2000 Through 2004," California Energy Commission, August 2005, available from *www.energy.ca.gov/2005publications/CEC-400-2005-042/CEC-400-2005-042-REV.pdf*; Tom Eckman, 1 May 2008 Northwest Power Planning Council memo "Conservation Savings—Status Report for 2005–07," available from *www.nwcouncil.org/news/2008/05/3.pdf*. For total societal cost, add ~30–80% depending on the sector.

17. For example, S. Nadel, *Lessons Learned*, NYSERDA 90-8, ACEEE, 1990. These 1980s results remain valid today because most U.S. utilities have invested so little in efficiency that their opportunities are more like those of the 58 firms whose 237 programs through 1988 yielded median program costs of 0.3¢/kWh for industrial savings, 0.9¢ for motor rebates, 1.2¢ for loans, and 1.4¢ for new construction rebates.

18. "Levelized Cost of Energy Analysis, v. 2.0," Lazard, June 2008, available from *www.narucmeetings.org/Presentations/2008%20EMP%20Levelized%20Cost%20of%20Energy%20-%20Master%20June%202008%20(2).pdf*.

19. A. Fickett, C. Gellings, and A. B. Lovins, "Efficient Use of Electricity," *Scientific Amererican*, Vol. 263, No. 3, 1990, pp. 64–74. The difference, analyzed by E. Hirst in ORNL/CON-312 (2001), was nearly all methodological, not substantive, A. B. and L. H. Lovins, "Least-Cost Climatic Stabilization," *Annual Review of Energy and the Environment*, Vol. 16, 1991, No. 433–531, pp. 8-11, available from *www.rmi.org/images/PDFs/Energy/E9133_LstCostClimateStabli.pdf*, for example, EPRI excluded but RMI included saved maintenance cost as a credit against efficiency's capital cost, so their respective average costs of commercial lighting retrofits (~1986 $) were +1.2 and –1.4¢/kWh; EPRI examined potential savings only to 2000 (including 9–15% expected to occur spontaneously), while RMI counted the full long-term retrofit potential;

and EPRI assumed drivepower savings 3x smaller and 5x costlier than EPRI adopted elsewhere in the same *Scientific American* article. RMI's assessment summarized a 6-volume 1986–92 analysis of ~1,000 technologies' measured cost and performance.

20. RMI estimated that during 1984–89, U.S. efficiency potential roughly doubled while its real cost fell by threefold. Since 1990, mass production (often in Asia), cheaper electronics, competition, and better technology, according to James K. Rogers PE, cut the real cost of electronic T8 ballasts by >90 percent to 2003 (while lumens per watt rose 30 percent), turned direct/indirect luminaires from a premium to the cheapest option, and cut the real cost of industrial variable-speed drives by ~83–97 percent (some vendors of midsize motors now give them away). Compact fluorescent lamps became 85–94 percent cheaper during 1983–2003; window air-conditioners got 69 percent cheaper since 1993 while becoming 13 percent more efficient; and low-emissivity window coatings became ~84 percent cheaper in just 5 years.

21. Integrative design produces these expanding (not diminishing) returns to efficiency investments: A. B. Lovins, "Energy End-Use Efficiency," Rocky Mountain Institute, 2005, available from *www.rmi.org/images/PDFs/Energy/E95-28_SuperEffBldgFrontier.pdf*, further elucidated in the senior author's five public lectures, "Advanced Energy Efficiency," delivered at Stanford's School of Engineering in March 2007 and available from *www.rmi.org/stanford*. RMI's recent redesigns of over $30 billion worth of industrial projects consistently found ~30–60 percent energy savings on retrofit, typically paying back in 2–3 years, and ~40–90 percent savings in new projects, nearly always with *lower* capital cost.

22. For example, an RMI design for retrofitting a 200,000-ft^2, curtainwall office building when it needed reglazing anyhow could save three-fourths of its energy at slightly *lower* cost than the normal 20-year renovation that saves nothing: A. B. Lovins, "The Super-Efficient Passive Building Frontier," *ASHRAE Journal*, June 1995, pp. 79–81, available from, *www.rmi.org/images/PDFs/Energy/E95-28_SuperEffBldgFrontier.pdf*.

23. This is simply because PVs can ride down the cost curve (they'll clearly continue to get 18 percent cheaper for each dou-

bling of cumulative global production volume, which is nearly doubling every year), they produce the most output on summer afternoons when most utility loads peak, and they can start producing energy and revenue in year one, reducing their financial risk. Many technological and institutional breakthroughs are in view that could well make the costs of PVs drop even faster than their historic cost curve. Thomas Dinwoodie, SunPower Corporation Systems (Founder and CTO), "Price Cross-Over of Photovoltaics vs. Traditional Generation," Richmond, CA: SunPower Corporation Systems, 2008.

24. For example, ~6–16 percent higher labor productivity in efficient buildings, higher throughput and quality in efficient factories, better clinical outcomes in efficient hospitals, fresher food in efficient refrigerators, better visibility with efficient lighting, etc. Just counting such side-benefits can, for example, double the efficiency gains in a U.S. steel mill at the same cost.

25. The biggest of these come from financial economics, for example, small fast modular projects have lower financial risk than big slow lumpy projects, and renewables hedge against fuel-price volatility risk. These 207 phenomena are explained and documented in an *Economist* book of the year: A. B. Lovins, E. K. Datta, T. Feiler, K. R. Rábago, J. N. Swisher, A. Lehmann, and K. Wicker, *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size*, Snowmass, CO: Rocky Mountain Institute, 2002, available from *www.smallisprofitable.org*.

26. For windpower in the three power pools that span the central United States from Canada to Texas: J. Traube, L. Hansen, B. Palmintier, and J. Levine, "Spatial and Temporal Interactions of Wind and Solar in the Next Generation Utility," *Windpower 2008*, June 3, 2008, available from *www.rmi.org/rmi/Library/2008-20_WindSolarNGU*.

27. For example, an integrated retrofit of efficiency, demand response, and 1.18 MW of PVs at the Santa Rita Jail in Alameda County, CA, easily met a 10 percent/year IRR hurdle rate—the $9-million project achieved a present-valued 25-year benefit of $15 million and hence would have made money even without its $4-million state subsidies—because on the hot afternoons when the PVs produced the most power, the efficient jail used little,

leaving a bigger surplus to resell to the grid at the best price. Or my own household can run on ~120 average W (a tenth the U.S. norm), obtainable from 3 m^2 of PVs—a system cheaper than connecting to wires 30 meters away. If built today, my household would need only ~40 average W, from 1 m^2 of PVs—a system cheaper than connecting to wires already on the side of the house. Both these comparisons assume free electricity; the point is that superefficient end-use can make the breakeven distance to the grid, beyond which it is cheaper to go solar than to connect, drop to about zero.

28. We ignore here the modest and broadly comparable amounts of energy needed to build any kind of electric generator, as well as possible long-run energy use for nuclear decommissioning and waste management or for extracting uranium from low-grade sources and restoring mined land afterwards. B. K. Sovacool, "Valuing the greenhouse gas emissions from nuclear power: A critical survey," *Energy Policy*, Vol. 36, August 2008, pp. 2490–2953, surveyed these issues. He screened 103 published studies of nuclear power energy inputs and indirect carbon emissions; excluded the 84 studies that were older than 10 years, not in English, or not transparent; and found that the other 19 derived gCO_2e/busbar kWh figures ranging from 1.4 to 288 with a mean of 66, which is roughly one-seventh the carbon intensity of combined-cycle gas but twice that of photovoltaics or seven times that of modern onshore windpower. This comparison, or its less favorable dynamic equivalent described by A. B. Lovins and J. Price, *Non-Nuclear Futures*, Part II, Cambridge MA: Ballinger, 1975, however, is scarcely relevant, since the unarguable *economic opportunity cost* shown in this section is far more important and clear-cut.

29. Conservatively, assuming industry claims that nuclear power indirectly emits about one-seventh as much carbon as the mean of the 19 studies analyzed by Sovocool's literature review (Endnote 28), and similarly omitting the probably even smaller carbon footprint of renewables, recovered-heat cogeneration, and efficiency.

30. Since its recovered heat displaces boiler fuel, cogeneration displaces more carbon emissions per kilowatt-hour than a large gas-fired power plant does.

31. A. B. and L. H. Lovins, report to DoD republished as *Brittle Power: Energy Strategy for National Security*, Andover, MA: Brick House, 1981, posted with summaries #S83-08 and #S84-23, available from *www.rmi.org/sitepages/pid114.php*; Defense Science Board, *More Fight, Less Fuel*, February 13, 2008, available from *www.acq.osd.mil/dsb/reports/2008-02-ESTF.pdf*.

32. These arguments are elaborated and documented in Lovins *et al*., *Small Is Profitable*.

33. C. L. Archer and M. Z. Jacobson, "Evaluation of global windpower," available from *www.stanford.edu/group/efmh/winds/global_winds.html*, calculated at 80 m hub height. A later National Renewable Energy Laboratory study, published February 19, 2010, found three times the originally assessed profitable U.S. wind potential, totaling 10 TW or 37 PWh/y on available categories of land. Available from *www.windpoweringamerica.gov/filter_detail.asp?itemid=2542*.

34. Wiser and Bolinger, p. 27, document 11 recent U.S. utility studies showing that even variable-renewable penetrations up to 31 percent generally cost <0.5¢/kWh to "firm" to central-plant reliability standards. The two studies that found costs up to 0.8¢ didn't assume the sub-hourly market-clearing that most grid operators now use.

35. The nuclear industry's claim that because a modern economy needs highly reliable electricity, and therefore it also needs "24/7" power *stations* of billion-watt scale is absurd. *No* power source is 100 percent reliable; that is why utilities must use redundancy and elaborate operating techniques to ensure reliable supply despite unpredictable failures, which are especially damaging when the failed units are large. The same proven techniques apply similarly, but more easily, to large numbers of diverse renewables whose variable elements can be readily forecast. Without exception, more than 200 international and 11 U.S. studies have found this (see Lovins and Sheikh, pp. 22–27). Wind-rich regions of Germany, Spain, and Denmark have already proven it by meeting 20–39 percent of all annual electrical needs (and at times over 100 percent of regional needs) with variable renewables, without encountering instability nor significant integration costs.

36. Scott DiSavino, "MidAmerican drops Idaho nuclear project due to cost," *Reuters*, January 29, 2008, available from *www.reuters.com/article/idUSN2957446620080129*.

37. New Energy Finance found only a 4 percent drop in 3Q08 renewables financing, and recent data suggest a robust, even growing, solar sector despite grave financial distress and accelerating decline in the central-station business.

38. A term originated by *The Economist*'s then-energy correspondent Vijay Vaitheeswaran and publicized in his book, *Power to the People: How the Coming Energy Revolution Will Transform an Industry, Change Our Lives, and Maybe Even Save the Planet*, New York: Farrar, Straus and Giroux, 2005.

39. A thorough database of industry and official data sources is posted and available from *www.rmi.org/sitepages/pid256.php#E05-04*. Similar renewable energy data are available from *www.ren21.net*.

40. A policy agenda for removing many of these obstacles is in the last section of Lovins *et al*., *Small Is Profitable*.

41. Data for decentralized gas turbines and diesel generators exclude generators of less than 1 megawatt capacity.

42. O. Bailey and E. Worrell, "Clean Energy Technologies: A Preliminary Inventory of the Potential for Electricity Generation," LBNL-57451, Berkeley, CA: Lawrence Berkeley National Laboratory, April 2005, available from *repositories.cdlib.org/lbnl/LBNL-57451/*.

43. *20% Wind Energy by 2030*, Washington, DC: USDOE, Chap. 2, p. 2, available from *www.20percentwind.org/20p.aspx?page=Report*.

44. Lovins and Sheikh.

45. A. B. and L. H. Lovins and L. Ross, "Nuclear power and nuclear bombs," *Foreign Affairs*, Vol. 58, No. 5, Summer 1980, pp. 1137–1177, available from *www.foreignaffairs.org/19800601faessay8147/amory-b-lovins-l-hunter-lovins-leonard-*

ross/nuclear-power-and-nuclear-bombs.html or *www.rmi.org/images/other/Energy/E05-08_NukePwrEcon.pdf*; and also found in *Foreign Affairs*, Vol. 59, 1980, p. 172. Had that paper's market-driven strategy been adopted 30 years ago, the world would not be worrying about Iran and North Korea today.

46. This would satisfy the intent of the "nuclear bargain" in Article IV of the Non-Proliferation Treaty. See also C. A. Ford (Hudson Institute), "Nuclear Technology Rights and Benefits: Risk, Cost, and Beneficial Use under the NPT's Article IV," Conference on Comparing Electricity Costs, held at NPEC/Carnegie Corporation of New York, December 1, 2008.