The Next Wave of Nuclear Proliferation

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In recent years record oil prices, long-term concerns about fossil fuel supplies (particularly oil), and worries about the contributions of fossil fuels to the accumulation of greenhouse gases such as carbon and methane have helped revive interest in nuclear energy production.[1] Indeed, it has become commonplace to advocate renewed investment in nuclear energy production in the United States. There has been, however, little consideration as to what a global turn to nuclear energy on an enlarged scale would actually entail, let alone the security implications of such.

This article's concern, accordingly, is with what a globally expanded use of nuclear energy would mean for nuclear proliferation specifically (as opposed to the issues of nuclear waste disposal or the risk of catastrophic accident, which also merit serious consideration), and this topic as it centers on state actors (rather than nonstate actors such as terrorist groups). In doing so it will, first, examine what an enlarged use of nuclear energy would look like; second, what risks such a changed volume and distribution of nuclear energy production might entail; and third, what the options are for ameliorating those risks.

Expanding Nuclear Energy Use

A large-scale expansion of nuclear energy production would affect not only its sheer volume, but the distribution of such production around the world, an issue which has rarely drawn comment. These two matters are discussed below.

The Scale of Nuclear Energy Production, Present and Future

There are currently some 440 nuclear reactors operating worldwide, which as of 2006 produced 2,660 billion kilowatt-hours of electricity every year.[2] This comes to roughly 16 percent of global electricity consumption, and five percent of the world's total energy consumption.

Significant as this is, it leaves enormous room for growth not only given today's overall portfolio, but the economic expansion anticipated in the coming decades. The World Bank recently estimated world gross domestic product (GDP) would grow to $140 trillion by mid-century, a 160 percent rise.[3] Such a growth rate would significantly outpace any previous improvement in energy efficiency (the trend having been about ten percent a decade since 1970). Even assuming recently observed rates of progress hold, this will translate into an 80 percent increase in energy consumption.[4]

For nuclear energy to simply keep its position in the world's energy portfolio, production equivalent to 800 of today's reactors would be needed. The very reason, however, for much of the interest in nuclear energy is concern about the scarcity of fossil fuels, particularly oil, so it can be expected that nuclear energy will be called on to play a greater role than it has to date—at the very least, generating a larger share of the electricity the world uses. France currently gets 77 percent of its electricity through this medium. Were the entire world to follow a similar path, it would mean more than a quadrupling of output, with more than 2,000 reactors required to meet current needs, and between 3,000 and 4,000 reactors plausibly online by 2050. Were nuclear energy to become more important in areas where it has previously been marginalized, such as transportation—for instance, by powering fleets of electric vehicles or large-scale hydrogen fuel production—then the demand could rise even beyond current expectations, with one observer estimating that simply to compensate for an absence in fossil fuel production (rather than absolute decreases), some 5,000 to 6,000 reactors would be required by mid-century.[5]

Global Distribution of Nuclear Energy Production

It is rarely noted that the vast majority of the nuclear production facilities currently operating in the world are concentrated in a handful of in-

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dustrialized nations. Nearly half (218) are in just three countries—the United States (104), France (59), and Japan (55). Russia (which has 31 facilities), the United Kingdom (23), South Korea (20), Germany (18), Canada (17), and Ukraine (15), with another 124 reactors between them, account for another 28 percent of the total.

This puts three-fourths of the world's reactors, and 83 percent of its electricity production from nuclear energy, in nine countries with just 46 percent of the world's GDP, and 48 percent of its electrical production and consumption.[6] Another 47 reactors, and ten percent of capacity, are concentrated in just seven more countries—Sweden, Spain, Belgium, Taiwan, Switzerland, Czech Republic, and Slovakia, accounting for 16 nations controlling 93 percent of the world's nuclear-generated electricity.[7] By contrast there are no such plants in operation in the Middle East or Australasia as of this writing. On the entire African continent, there are only the two plants operating in South Africa, and there are just six in all of Latin America and the Caribbean, with two each in Mexico, Brazil, and Argentina.

It is inconceivable that anything like this distribution will continue in a world turning heavily to nuclear energy, a fact that has already laid the foundation for a broadening of production and use in East and South Asia.[8] We should also expect a large-scale, rapid establishment of nuclear energy production in areas where it has been virtually absent, for example, the Middle East, sub-Saharan Africa, and Latin America. To approximate France's current level of nuclear energy reliance, for instance, Iran alone would require roughly 18 operational reactors; Saudi Arabia, 20. More extensive substitution of nuclear energy for other sources of power, or future economic expansion (such as described above), will require a commensurate growth in the number of reactors.[9]

All of this may sound abstract, but moves in this direction are already well under way. Some 40 developing nations have expressed interest in starting nuclear energy programs, and many have moved beyond vague statements of intentions.[10] The United Arab Emirates, for instance, has already struck a deal for two reactors, the only one of 11 nations in this region (thus far) to have announced such plans.[11]

Assessing the Danger

As outlined above, a future in which the world as a whole turned to nuclear energy will mean not just an expansion of nuclear energy production, but substantial changes in production impacting mainland Asia, Africa, and Latin America. An assessment of the associated proliferation risk involved devolves basically into an examination of two dimensions, capabilities and intentions—what widened nuclear energy use will mean for the access of these states to nuclear weapons technology; and the impact that this new envi-

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ronment will have on a government's motivation to actually use that access to produce nuclear weaponry.

Technological Access

The increase in nuclear energy production described above will mean greater production, trading, and consumption of the fissile materials and other technologies that are part of the nuclear fuel cycle. The specifics differ according to reactor type, but every reactor uses uranium in the production of its fuel and produces plutonium in its waste, extractable in the fuel reprocessing procedure, and in such a manner that every type of reactor poses a measure of proliferation risk.[12] Gas-cooled and heavy-water reactors use natural uranium as fuel, but are ideal for producing weapons-grade plutonium. "Fast-neutron" reactors use fissile material (such as highly enriched uranium or plutonium) at the very start of their fuel cycle, and Fast Breeder Reactors in particular produce more fissile material than they consume.

Even Light Water Reactors (LWRs), which have been described as "proliferation-resistant" (two of which were provided to North Korea under the Agreed Framework), are no exception.[13] They use low-enriched uranium, which is not useful for making weapons, but which is produced in the same enrichment process used to manufacture weapons. Additionally, low-enriched uranium can be seen as halfway to weapons grade, since it can be more rapidly enriched to the needed level than stock natural uranium. At the same time, while these reactors produce relatively smaller quantities of lower quality plutonium than other types, it has been estimated that a 1,000-megawatt LWR can still generate enough "weapons-usable" plutonium for up to 50 bombs a year.[14]

The response on the part of those seeking to limit proliferation has, accordingly, been to encourage as many nuclear energy users as possible not to develop the entire fuel cycle; that is, to forgo building up their own fuel enrichment and reprocessing capabilities. Instead, it is proposed that they buy fuel and reprocessing services on the world market, as proposed in the Global Nuclear Energy Partnership of February 2006.

There are, however, widespread doubts about the initiative's likely cost and effectiveness, concerns articulated in a letter signed by a number of control organizations, including the Federation of American Scientists, the Union of Concerned Scientists, and the Arms Control Association.[15] Their objections, however, fail to include one important point—that states have been partly dissuaded from developing the full nuclear fuel cycle for economic reasons, a fact that may not remain operative in any massive expansion of nuclear energy use.

Simply put, it is cheaper for a small nuclear program to buy nuclear fuel on the world market than to build and operate the facilities required to enrich uranium domestically. This has resulted in only eight of some 30 nuclear energy producers actually engaging in enrichment on an industrial scale.[16] The same is true for fuel reprocessing facilities, especially given the relatively low cost of newly mined uranium. Accordingly, only a handful of states (Britain, France, Russia, Japan, and India) actually practice civil reprocessing.[17]

Any significant growth in nuclear energy production would change those economics. Many of today's "small" programs would become equal in size to those now considered large-scale, and for that reason their investments in enrichment and reprocessing less impractical. Additionally, with more programs large and small operational, there would be a larger, more lucrative market for fuel production and fuel recycling services; the latter would in all likelihood grow more attractive as enlarged uranium consumption tightens supplies and drives up prices. (Indeed, as the situation currently stands, many uranium exporters not regarded as likely proliferators—including Australia and Canada—are interested in enrichment technology because enriching their uranium before export would increase profitability.)[18] Certainly if uranium prices were to rise, there would be more interest in Fast Breeder Reactors, which one analyst suggests can extract more than 60 times as much energy per ton of mined ore as a "conventional" nuclear plant when operated in a closed circuit with thermal reactors and reprocessing facilities.[19]

In short, the economic incentives for states to refrain from developing the full nuclear fuel cycle will almost certainly weaken, while the particularly worrisome fast-neutron reactors will become more attractive. At the same time, the heightened dependence on nuclear energy, and the experience of energy scarcity, will continue to reinforce the search for "energy independence" and "energy security," contributing to the pressure that the nonproliferation regime is already experiencing, as the result of being a "ratifier" of unequal access to nuclear technology.[20] In any event, such changes enormously increase the already substantial burden of monitoring and securing the storage and movement of the supplies associated with nuclear power generation, not to mention the political costs of maintaining the regime.[21]

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Motivation

As outlined previously, any plausible combination of political arrangements and technological innovations is likely to have uneven results. Determined states are likely to find it easier to acquire the means for producing fissile material, which raises the other key dimension of the issue—the motivation for acquiring these weapons in the first place.

Long-established research strongly indicates that the motivation to build nuclear weapons is more of a factor than simply achieving the technological capacity.[22] Indeed, it is due to this excessive focus on capacity that earlier predictions about the speed and the extent of nuclear proliferation (which projected 25 to 50 nuclear-weapon states by the year 2000) proved wrong.[23] The relative ease with which the weapons might be built is proof of this; a program to develop a minimal capability from scratch could cost as little as $500 million, less than the price of a modern warship.[24]

In short, were capacity the only issue, there would be far more nuclear powers in the world, though of course access to the means cannot be ruled out as a factor in decisionmaking. When much of the infrastructure for developing a nuclear arsenal is already in place, as may be the case in several advanced countries, the decision to do so entails lower costs; and given the speed with which these programs can be initiated, the nations in question are also less susceptible to preventative action than countries starting from scratch.[25] A particular danger is that having such facilities in place provides them with the option of diverting material from the fuel cycle for covert weapon programs.[26]

The rationale driving the shift to nuclear energy in the first place (energy and climate stress) will increasingly translate into greater motivation on the part of some actors to pursue a nuclear capability. Broad economic disruption is nearly certain as the result of the tightening of oil supplies and the climate changes this scenario anticipates. Politically, this may translate into changes in the distribution of international power depending on individual states' ability to cope (as with wealthier nations, or ones with energy-efficient economies), or even profit from these conditions (for instance, oil exporters);

while the most vulnerable states may collapse, creating even greater problems for the international community (havens for crime, terrorism, or refugee flows).[27] Intensified conflict over territory and waters rich in energy and other resources will become increasingly likely.

Alliances, trading relationships, and other arrangements will be in flux, and when combined with the associated anxiety and vulnerability may exacerbate a desire on the part of certain states to minimize their vulnerability. A goal which nuclear weapons have long been viewed as a cheap way of achieving. The "nuclearization" of a single state can induce a chain reaction across a region. The nuclearization of China spurred India and in turn Pakistan to follow suit, and the Argentinean and Brazilian nuclear programs fed off one another. Today the possibility that a nuclear North Korea may lead South Korea or Japan to acquire nuclear weapons is often discussed.[28] In the Middle East there are signs that Saudi Arabia is reviewing its nuclear options, and a nuclear-armed Iran may encourage the Saudis and others in the region to continue down this path.[29]

With nuclear technology more widely available these actions can be taken much more rapidly and at less cost. Those pursuing this course of action will find it a simple matter to amass large stockpiles of nuclear weapons. It is also worth noting that even were the development of actual nuclear weapons to remain a rarity, "virtual arsenals" could be more common, leaving the nuclear weapons status of a longer list of countries uncertain, in many cases deliberately so, with a detrimental impact on the security environment.[30]

Possible Responses

It would be a mistake to focus excessively on any one track for ameliorating the risk of proliferation. When all is said and done, the current monitoring mechanisms will remain, and so will the maintenance of a stable security environment. Individual cases will require tailored solutions. Nonetheless, the spread of nuclear energy production means a significantly enlarged number of countries will have access to the full nuclear fuel cycle. There are then two primary ways to ameliorate the associated threats. One is to seek methods of nuclear energy production that are inherently proliferation-proof, as may be the case with "Generation IV" nuclear reactors. The other is to reduce the need for nuclear energy production, by making overall energy consumption more efficient, and by increasing production from alternative, nonfossil fuel sources.

New Reactor Designs

Some experts argue that the next-generation (Generation IV) reactor designs will reduce the proliferation risks associated with nuclear energy production. Advocates of next-generation fast-neutron reactors argue that they could provide more efficient energy production. This would enable them to recover up to 99 percent of the energy from their fuel, allowing them to use smaller quantities and a greater variety of fuel types, including natural uranium and possibly even depleted uranium.[31] They would also generate less waste (perhaps only one percent), containing only trace amounts of the transuranics needed for weapons manufacture, than other reactors of similar capacity.[32] This would permit "pyroprocessing," a different, possibly cheaper, approach to reprocessing fuel that is less suitable for weapons manufacture.[33] Finally, these different procedures will permit onsite fuel fabrication, fuel recycling, and waste processing, something current reactor fuel cycles do not allow, reducing the transportation and security problems.

While appearing to be a panacea for many of nuclear power's problems, these designs will not be commercially viable until at least 2030. Additionally, despite their obvious advantages, pressuring states to adopt reactors of any given type raises many of the same political issues as the schemes associated with restricting a potential proliferator's access to nuclear fuel—especially given the fact that established nuclear powers, based on their intention of retaining their current nuclear arsenals, are almost certain to continue operating their existing reactors.

Improved Energy Efficiency

As previously noted, a trend toward more efficient energy use has been evident in recent decades. Running at roughly ten percent a decade, this move to greater energy efficiency is inadequate to compensate for the increases in economic growth. It has, however, been a factor in reducing the rate of energy consumption.

There are some real reasons for concern that this trend will not be sustainable. In fact, it may be that the law of diminishing returns has already set in. Relatively efficient energy nations, for example Italy and Japan, have since the 1980s seen the rate of improvement in their energy efficiency stagnate.[34] It is the less-efficient states such as the United States and Britain that have witnessed the most significant gains, enabling Britain to catch up to the more efficient nations.[35]

The gains of even the most inefficient of the advanced countries were generally dwarfed by those of less-developed states, particularly those classed as "lower middle income" economies (per-capita GDPs of $906 to $3,595 a year). According to World Bank statistics, the energy demands of these economies dropped by half in the period 1990 to 2003 (compared with a ten percent reduction for the high-income countries).[36]

As more states move beyond current income and efficiency levels, it stands to reason that future gains will be even less dramatic. This is not to say, however, that gains beyond the current levels are impossible, or strictly hypo-

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thetical, as Denmark, Ireland, and Hong Kong have more than adequately demonstrated.[37] It is only fair to note that the decade of the 1990s was a period of relatively cheap energy, and that future energy markets and greater political pressure to pursue ecologically sound policies will encourage greater efforts at efficiency in this arena. It may also be possible for revolutionary technologies to account for unforeseen gains, permitting advances in energy efficiency to outpace economic growth. In the scenario sketched in the "Factor Four" study by Ernst von Weizacker, et al., the high projection for global economic growth mentioned previously—160 percent—might be realized with even less energy than the world economy consumes today.[38]

Alternative Energy Sources

There is a very real possibility that what energy the world does consume may be increasingly derived from alternatives to both fossil fuels and nuclear energy. The rapidly growing array of renewable sources is only beginning to be exploited.

At present, wind appears to be the renewable energy resource with the greatest potential, given the current state of the technology. As is often noted, the United States could meet its entire energy needs with current power generation technology simply by harnessing the wind energy of the Dakotas.[39] Affluent, densely populated Denmark, the world leader in wind energy when production is measured on a per-capita basis, gets nearly 25 percent of its electricity from wind.[40] Innovations such as windmills based on floating platforms may revolutionize the field with their mobility, flexibility, and potential for tapping high-speed winds at sea, as might the still more radical "flying windmills."[41]

Solar energy is also an ever-increasing source. Its more efficient size and comparatively easy set-up is an asset, and when incorporated into energy-efficient buildings, can actually turn them into net energy producers.[42] There are also a number of ideas related to large-scale electricity production from photovoltaics. One of the more well-known is a recent plan to build solar power stations in North Africa, transmitting the electricity generated to Europe via underwater cable.[43]

While long overlooked due mainly to high capital costs, tidal energy holds potential that is comparable to wind. One projection even indicates that Great Britain could meet a fifth of its current energy needs through the use of tidal technology.[44] Biofuels (e.g., ethanol) production also has potential as a substitute for fossil fuels, though the degree to which it can succeed depends heavily on the particular crops and agricultural techniques used to produce them.[45] These are qualitatively as well as quantitatively notable solutions, because they incorporate the prospect of reducing transportation burdens on electrical power generation. There are other developing technologies that hold similar possibilities, such as the biological techniques for generating hydrogen and other fuels.[46]

Conclusion

The worst-case scenario is one in which the global throughput of the nuclear fuel cycle is enlarged by an order of magnitude or more, and dispersed globally, at a moment of rising economic, ecological, and political strain. While plausible, this scenario is not inevitable. Ultimately, the risk of nuclear proliferation during the twenty-first century will have as much to do with how the world copes with the problems posed by scarcity and the ecological impact of fossil fuels. Were nuclear energy used to substantially compensate for the shortfall in oil and other fossil fuels, it holds the possibility for taxing the current nonproliferation regime's surveillance and enforcement mechanisms beyond their breaking point. Consequently, every effort should be made to curtail the need to increase nuclear energy production, at least until many of the problems associated with it are significantly ameliorated (as Generation IV reactors may do).

In the meantime we should focus our efforts on investment in improving energy efficiency and increasing energy production from nonnuclear, as well as nonfossil, fuel sources. This process is already under way, but history has shown that if it is to be successful, rapid, large-scale development requires maximum government support, not only on the domestic front, but also internationally.[47]

This is not to say there may not be a legitimate requirement to increase the production of nuclear energy, as would certainly be true if fossil fuel production were to drop more rapidly than we could compensate for with improved energy efficiency and production. Nor is this to say that more conventional steps to secure nuclear energy production against proliferation need not be taken. Rather, what we should take away from this analysis is that it is best for all of mankind to minimize the expansion of nuclear energy production during this century and to strengthen nonproliferation regimes.

NOTES

1. Nader Elhefnawy, "Toward a Long-Range Energy Security Policy," *Parameters*, 36 (Spring 2006), 101-14; "The Impending Oil Shock," *Survival*, 50 (April/May 2008), 37-66.

2. US Department of Energy, Energy Information Administration, "World Net Nuclear Electric Power Generation, 1980-2006," 29 September 2008, http://eia.doe.gov/pub/international/iealf/table27.xls.

3. World Bank, "World Bank Urges More Balanced Global Approach to Development," News Release, 21 August 2002, http://siteresources.worldbank.org/NEWS/Resources/pr082102-mna.pdf.

4. A calculation using World Trade Organization data on economic growth for this period, and Energy Information Administration data on energy consumption, suggests a 35 percent drop in energy-intensity during this time (10 percent for the 1970-1980 period, 12 percent for the years 1980-1990, and another 10 percent for 1990-2000). See World Trade Organization, *International Trade Statistics 2001* (Geneva: World Trade Organization, 2001), Table II.1; US Department of Energy, Energy Information Administration, "World Primary Energy Production by Source, 1970-2005," *Annual Energy Review 2006*, 27 June 2007, http://eia.doe.gov/emeu/aer/pdf/pages/sec11_3.pdf. The Intergovernmental Panel on Climate Change estimated a similar 33 percent improvement for the 1970-2004 period. See Intergovernmental Panel on Climate Change, *Climate Change 2007—The Physical Science Basis* (New York: Cambridge Univ. Press, 2007), 3.

5. James Muckerheide, "How to Build 6,000 Nuclear Plants by 2050," *Twenty-First Century Science and Technology*, 18 (Summer 2005), 36-53.

6. World Nuclear Association, "World Nuclear Power Reactors 2006-08 and Uranium Requirements," 14 January 2008, http://www.world-nuclear.org/info/reactors-jan08.html.

7. Ibid.

8. As of 2006 China, not included here, generated some 51 billion kilowatt-hours from 11 plants, with five more plants under construction, 30 planned, and a staggering 86 proposed in all. Ibid.

9. Generally speaking, the Energy Information Administration projects growth rates of 2.3 to 2.4 percent a year in primary energy consumption across Latin America, Africa, and the Middle East for the 2004-2030 period, roughly doubling over three decades. The rate of growth in China, India, and the developing nations of Asia averages more than three percent a year. See US Department of Energy, Energy Information Administration, *International Energy Outlook 2007*, Table A1, "World Total Primary Energy Consumption by Region, Reference Case, 1990-2030," May 2007.

10. Joby Warrick, "Spread of Nuclear Capability is Feared," *The Washington Post*, 12 May 2008, A1.

11. Ibid.

12. The current procedure for reprocessing nuclear fuel, plutonium uranium extraction, was specifically designed to produce plutonium for nuclear weaponry.

13. William H. Hannum, Gerald E. Marsh, and George S. Stanford, "Smarter Use of Nuclear Waste," in David L. Green, ed., *Oil and the Future of Energy* (Guilford, Conn.: Lyons Press, 2007), 100. Also see Victor Gilinsky, Marvin Miller, and Harmon Hubbard, *A Fresh Examination of the Proliferation Dangers of Light Water Reactors* (Washington: Nonproliferation Policy Education Center, 2004).

14. Gilinsky, Miller, and Hubbard, 13. The difference is in the higher radioactivity of the plutonium, making it more difficult to work with, and its lower reliability in achieving a given yield, due to the lower quantity of plutonium-239 in the substance. Charles D. Ferguson, "Risks of Civilian Plutonium Programs," Nuclear Threat Initiative, Issue Brief, July 2004, http://nti.org/e_research/e3_52a.html. Improving weapons technology may make the unreliability issues minor for most purposes. Gilinsky, Miller, and Hubbard, 29-33.

15. Alfred Meyer, et al., "Letter to Senators Byron L. Dorgan and Pete V. Domenici (Subcommittee on Water and Energy Development, Senate Appropriations Committee)," Union of Concerned Scientists, 31 October 2007, http://www.ucsusa.org/assets/documents/nwgs/community-letter-gnep-congress_final.pdf.

16. Joseph Cirincione, "Controlling Iran's Nuclear Program," *Issues in Science and Technology*, 22 (Spring 2006), 75-82.

17. David Albright, "Shipments of Weapons-Usable Plutonium in the Commercial Nuclear Industry," Institute for Science and International Security, 3 January 2007, http://isis-online.org/global_stocks/end2003/plutonium_shipments.pdf.

18. Ian Bellany, *Curbing the Spread of Nuclear Weapons* (New York: Manchester Univ. Press), 23.

19. World Nuclear Association, "Supply of Uranium," Briefing Paper 75, June 2008, http://world-nuclear.org/info/inf75.html. There may even be a revival of the "plutonium economy" schemes of the 1970s un-

der the circumstances. See Harold A. Feiveson, Theodore B. Taylor, Frank von Hippel, and Robert H. Williams, "The Plutonium Economy," *Bulletin of the Atomic Scientists*, 32 (December 1976), 10-21, 46-55.

20. Jaswant Singh defended India's May 1998 nuclear tests with the argument that "India's nuclear policy . . . [is] committed to a basic tenet . . . national security lies either in global disarmament or in exercise of the principle of equal and legitimate security for all." See Singh, "Against Nuclear Apartheid," *Foreign Affairs*, 77 (September/October 1998), 41-52. An examination of the ethical issues at stake can be found in Steven Lee, "Nuclear Proliferation and Nuclear Entitlement," *Ethics & International Affairs*, 9 (March 1995), 101-31.

21. John M. Deutch and Ernest J. Moniz, "The Nuclear Option," in Green, 112.

22. Stephen M. Meyer, *The Dynamics of Nuclear Proliferation* (Chicago: Univ. of Chicago Press, 1984), 141.

23. Herman Kahn and Anthony J. Wiener, *The Year 2000: A Framework for Speculation on the Next Thirty-three Years* (New York: Macmillan, 1967).

24. Meyer's estimate was $210 million in 1982 dollars, which is approximately $473 million in 2007 dollars. Meyer, 40. Adjusted for inflation this approximates the low estimate of the cost of South Africa's nuclear program: $300 million to $600 million in early 1990s dollars, or $450 million to $900 million today. Mitchell Reiss, *Bridled Ambition*: *Why Countries Constrain Their Nuclear Capabilities* (Washington: Woodrow Wilson Center Press, 1995), 15.

25. Meyer, 149-50.

26. A nuclear program the size of Belgium's can generate a bomb per year by diverting one percent of the uranium consumed by its reactors. See John Holdren and Matthew Bunn, "Blocking the Terrorist Pathway to the Bomb," Nuclear Threat Initiative, 25 November 2002, http://nti.org/e_research/cnwm/overview/technical4.asp.

27. See Elhefnawy, "The Impending Oil Shock," 42-53.

28. Jon B. Wolfsthal, "Asia's Nuclear Dominos?" *Current History*, 102 (April 2003), 170-75.

29. Gawdat Bahgat, "Nuclear Proliferation: The Case of Saudi Arabia," *The Middle East Journal*, 60 (Summer 2006), 421-43. Also see Warrick.

30. Saira Khan, *Nuclear Proliferation Dynamics in Protracted Conflict Regions: A Comparative Study of South Asia and the Middle East* (Aldershot, U.K.: Ashgate, 2002), 59-75.

31. Hannum, Marsh, and Stanford, 104. This eliminates the need for uranium enrichment, and diminishes the problem of uranium scarcity.

32. Ibid., 98-106.

33. Ibid., 105.

34. For each dollar of GDP (as measured in year 2000 dollars) they produced in 2005, Japan needed 6,500 British Thermal Units (BTUs), Italy 5,800. US Department of Energy, Energy Information Administration, "World Energy Intensity—Total Primary Energy Consumption per Dollar of Gross Domestic Product Using Market Exchange Rates, 1980-2005," *International Energy Annual 2005*, June-October 2007, http://eia.doe.gov/pub/international/iealf/tablee1g.xls.

35. According to World Bank estimates, the United States saw a 21 percent gain in the 1990-2003 period, the United Kingdom 20 percent. By contrast, this data set posts a seven percent improvement for France through the whole decade, and the progress of Japan and Italy is flat. World Bank, *World Development Indicators 2006* (Washington: World Bank, 2006), 158-60. As of 2005, the United States used 9,100 BTUs for each dollar of GDP, the United Kingdom 6,000. US Department of Energy, "World Energy Intensity."

36. World Bank, *World Development Indicators 2006*, 160.

37. Denmark got by on 5,200 BTUs to the dollar, Ireland 4,900, and Hong Kong, 4,200. US Department of Energy, "World Energy Intensity."

38. Ernst von Weizacker, Amory B. Lovins, and L. Hunter Lovins, *Factor Four*: *Doubling Wealth*, *Halving Resource Use*, *The New Report to the Club of Rome* (London: Earthscan, 1997).

39. William Hoagland, "Solar Energy," in Green, 203.

40. Wendy Williams, "Blowing Out to Sea," in Green, 209.

41. Ker Than, "Floating Ocean Windmills Designed to Generate More Power," *LiveScience*, 18 September 2006, http://livescience.com/technology/060918_floating_windmills.html. Flying windmills exploit the wind stream and return the energy produced from it to electrical grids on the ground through a tether. W. Wayt Gibbs, "Plan B for Energy," in Green, 214-15.

42. Daniel M. Berman and John T. O'Connor, *Who Owns the Sun*? *People*, *Politics*, *and the Struggle for a Solar Economy* (White River Junction, Vt.: Chelsea Green Publishing, 1996). Also see Andrew Murr, "No More Electric Bills," *Newsweek*, 15 August 2005, 43.

43. Robin McKie, "How Africa's Desert Sun Can Bring Europe Power," *Guardian*, 2 December 2007, http://guardian.co.uk/environment/2007/dec/02/renewableenergy.solarpower.

44. Gibbs, 220.

45. Daniel M. Kammen, "The Rise of Renewable Energy," in Green, 198.

46. See Sam Jaffe, "Mutant Algae is Hydrogen Factory," *Wired.com*, 23 February 2006, http://wired.com/science/discoveries/news/2006/02/70273.

47. Elhefnawy, "Toward a Long-Range Energy Security Policy" 108-10.