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THE PARDEE PAPERS / No. 3 / November 2008

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Does Nuclear Energy Have a Future?

Moeed Yusuf

Abstract

Nuclear energy optimists suggest that a nuclear renaissance is under way. However, beyond such claims there is little objective analysis that corroborates the positive outlook. In fact, literature on nuclear energy is highly polarized, with much of the debate being situated within the ideological and normative realms. This paper moves away from the what should *to the what* is likely *in order to present a realistic projection of the potential for the increased development of nuclear energy over the next two to three decades. It examines the relative importance of the key determinant factors likely to affect the future of nuclear power in a cost-benefit framework. The factors examined include economic competitiveness, concern for climate change, safety and security issues related to nuclear technology, public perception about the energy source, and the quest for energy security. This analysis suggests that nuclear energy is likely to remain economically uncompetitive and investment-starved over the projected period. Public perceptions, both in the developed and developing world, are also likely to become increasingly wary. Measures required to improve the popular sentiment–better safety and security–would increase costs substantially without guaranteeing positive transformation in the outlook. This is especially true as the proliferation risks present a virtually insurmountable barrier. These impediments would overshadow nuclear power's merit in terms of carbon emission reductions as well as its partial attractiveness in terms of reducing energy vulnerability of countries.*

The author wishes to thank Adil Najam, Cutler Cleveland, Miquel Muñoz, and Subrata Ghoshroy for their comments, Cynthia Barakatt for editing support, and the Pardee Center for managing the publication process.

I. INTRODUCTION

The dream of making the 21st century the most economically successful in human history hinges on a number of supply-side concerns. One essential prerequisite to attaining this feat is availability of sustainable energy sources. The challenge is to ensure adequate supply of energy while limiting the negative implications of energy production. Today, 86 percent of global energy consumption is fulfilled by fossil fuels. This is worrisome due to rising costs of fossil-based sources, the 'peak oil' concerns that signal the likely dwindling of supplies in the coming decades, as well as the global warming effects linked to the use of fossil fuels. With supply concerns and as much as 75 percent of the anthropogenic carbon dioxide, a key agent of climate change, linked to the burning of coal, gas, and oil,[1] there seems to be a growing convergence of the view that the future lies in moving away from carbon-based energy sources. This has invigorated interest in the non-carbon alternatives; it is this backdrop in which the so-called 'nuclear renaissance' is said to be taking place.

Nuclear power is one of the few commercially tested sources of energy that is virtually free of greenhouse gas emissions. This automatically makes it of interest to climate change pundits. Yet, the future of nuclear power is far from settled. In fact, few other subjects can boast of having literature that is as divided as the one on the future of nuclear energy. Notwithstanding some noteworthy exceptions, views are largely ideological and range from unconditional support to normative perspectives that are equally deterministic in their opposition.[2]

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This paper moves away from the normative arguments. We seek to examine not what *should* happen, but what *is likely* to happen given the global context that is expected to prevail over the next two to three decades. The question is important as it provides policymakers—who have thus far been fed with normative arguments—a reality check in terms of what is truly possible over the projected time period. In order to present a balanced picture, we examine factors that the literature suggests are likely to determine the future of nuclear energy. These include economic competitiveness, concern for climate change, safety and security issues related to nuclear technology, public perception about the energy source, and the quest for energy security. The relative importance of each of these and the interplay among them is analyzed to indicate the overall prospects for a nuclear renaissance. The analysis suggests that nuclear energy is likely to remain economically uncompetitive and investment-starved over the projected period. Public perceptions, in both the developed and developing world, are also likely to become increasingly wary. Measures required to improve the popular sentiment—better safety and security—would increase costs substantially without guaranteeing positive transformation in the outlook. This is especially true as the proliferation risks present a virtually insurmountable barrier. These impediments would overshadow nuclear power's merit in terms of carbon emission reductions as well as its attractiveness in reducing energy vulnerability of countries.

This paper begins by presenting the existing projections regarding the future of nuclear energy. Section III discusses nuclear power's economic competitiveness as compared to alternative sources, the impact of nuclear power expansion on climate change, the safety concerns related to the spread of the energy source, the proliferation risks involved, the link between safety and security and the public perception about the use of nuclear power, and issues relating to energy security. Section IV summarizes the future outlook and recommends means to optimize the projected scenario.

II. IS THE RENAISSANCE REAL?

Since U.S. President Dwight D. Eisenhower introduced the 'Atoms for Peace' vision in 1953, nuclear energy has had a mixed experience.[3] A euphoric reception to Eisenhower's idea saw aggressive growth of the nuclear industry early on. By 1970 as many as 90 nuclear plants with a capacity of 16,500 Megawatt-electric (MWe) were operational in 15 countries; by

1980, the figure had jumped to 253 plants with a capacity of 135,000 MWe spread across 22 countries.[4] Although the number of plants continued to grow steadily until 1985, this time frame reflected the long lead times in plant construction. In reality, for a host of reasons—slower than expected economic growth and consequent reduction in electricity demand, rise in price of nuclear energy, inefficiencies within the nuclear industry, and accidents at nuclear plants—the period from the mid-1970s onwards saw a steep decline in the demand for nuclear energy.[5] During the 1990s, there was an overall increase of merely 19 nuclear plants and that, too, was courtesy of a positive trend in Asia.[6] In the West, nuclear energy was viewed as approaching oblivion by the late-1990s.[7]

While the rate of nuclear expansion has been no greater since the turn of the century, some of the world's major economies like the U.S., China, and India, among others, have revived a focus on the nuclear option by floating energy plans that envision accelerated growth in nuclear capacity. Nuclear energy optimists view this as the beginning of a potential renaissance. They also take heart from the fact that overall global primary energy demand is expected to increase by 55 percent by 2030.[8] Within the energy sector, electricity generation—the only aspect towards which nuclear energy is ready to contribute for the better part of this century—will increase from the current 16,930 Terawatt-hour (TW-h) to 38,191 TW-h by 2030.[9] Those who are hopeful see compelling reasons why nuclear energy should experience a corresponding increase in usage.

Today, there are 439 power plants with a combined gigawatt electric (Gwe) capacity of 372 spread across 31 countries.[10] Moreover, 36 plants are under construction and another 93 are planned.[11] Nuclear energy contributes 16 percent to global electricity generation and six percent to the world's primary energy production.[12] Most future projections are optimistic and have been revised upward since the 1990s. A summary of the most prominent projections is provided in Table 1.

Table 1: Projections for Nuclear Power Capacity (GWe) through 2050

Source	Year of Projection	Actual capacity	1990	1995	2000	2005	2010	2015	2020	2030	2050
Average of various sources [1]	1985		372-400	415-518	502-702						
Average of various sources [2]	1990	319		378	404-430	450-528					
Average of various sources [3]	1995	343			367-375		391-476	369-516			
Average of various sources [4]	2000	350				363-378	366-417		300-520		
Average of various sources [5]	2005	368					380		416-516	418-640	
NEA [6]	1997	343									1120
IPCC [7]	2000	350								819	1607
MIT [8]	2003	360									1000-1500
NUKEM [9]	2006	370								535	
IAEA [10]	2006	370							423-520		
IEA [11]	2006	370								416-519	
EC [12]											
EIA [13]	2008	372								498	
Existing and under construction plants [14] *	2008	372							401		
Existing, under construction, and planned plants [15] **	2008	372							504	697	
Present, under construction plants, and combined targets of China, U.S, Japan, South Korea, and Russia [16] ***	2008	372						455			

* Combined total of existing nuclear plants and ones that are under construction and are scheduled to come on line by 2020.
** Combined total of existing nuclear plants, ones that are under construction and are scheduled to come on line by 2030, and those that are notified as 'planned' by countries. For all 'planned' units, we assume that they will be operational by 2030.
*** Combined total of existing nuclear plants, ones that are under construction and are scheduled to come on line by 2015, and the total installed capacity targets of the listed states by 2015. Official targets have been used. Where official projections are contradictory or unavailable, the mean value of available projections is used.

Sources: [1,2,3,4,5, 10] International Atomic Energy Agency, "Energy, Electricity and Nuclear Power: Developments and Projections – 25 Years Past and Future," 2007, p.56; [6] Nuclear Energy Agency, "Nuclear Power and Climate Change," 1997, http://www.nea.fr/html/ndd/climate/climate.pdf (accessed on June 10, 2008), p.6; [7] Intergovernmental Panel on Climate Change, Special Report on Emissions Scenarios *(Cambridge: Cambridge University Press, 2000); [8] Massachusetts Institute of Technology, "The Future of Nuclear Power," 2003, http://web.mit.edu/nuclearpower/ (accessed on June 4, 2005); [9] NUKEM,* Data Feature: 2005/2006 World Nuclear Electricity Generating Capacity, *December 2006; [11] International Energy Agency,* World Energy Outlook 2006, *OECD/IEA, 2006; [12] European Commission, "World Energy Technology Outlook-2050," Directorate Energy, 2006, ftp://ftp.cordis.europa.eu/pub/fp7/energy/docs/weto-h2_en.pdf; [13] Energy Information Administration, "Annual Energy Outlook 2008," Department of Energy,* Report No. DOE/EIA-0383, *June 2008; [14,15,16] Compiled from "World Nuclear Power Reactors 2007-08 and Uranium Requirements,"* World Nuclear Association, *June 9, 2008, 0h ttp://www.world-nuclear.org/info/reactors (accessed on June 9, 2008); and International Atomic Energy Agency "Nuclear Power's Changing Future: Fastest Growth in India," Press Release 2004/05, June 26, 2004, http://www.iaea.org/NewsCenter/PressReleases/2004/prn200405.html (accessed on June 1, 2008).*

The projected increase in nuclear energy capacity is expected to be concentrated in a handful of countries. The hope of a renaissance is largely hinged on the world's largest nuclear industry, the U.S., and to a lesser extent on Japan, South Korea, and Russia among the developed countries, and China and India from the developing world. Together, these six countries account for 25 of the 36 nuclear plants currently under construction; this makes up two-thirds of the generating capacity likely to come on line by 2015.[13] From within this group, China remains the most important in terms of the industry's future growth. Its long-term plans amount to approximately 96 GWe of additional nuclear power, which is more than twice that of any other country.[14] Apart from the frontrunners, the Middle East is expected to play a moderate role in the so-called renaissance. Finally, all but the few most optimistic estimates discount the role of Europe as peripheral. Overall then, the future seems to have pinned greater hopes on the developing world than was the case during the initial growth of the nuclear industry five decades ago.[15]

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III. WILL RENAISSANCE BECOME REALITY?

The ultimate outcome of the drive towards a nuclear renaissance will depend on how factors correlated with the increase of nuclear energy capacity weigh relative to each other over the projected time frame. Some of them, namely economic competitiveness, global warming concerns, public perceptions, and energy security considerations, are common to all energy sources. However, nuclear power also carries unique attributes such as high safety and proliferation risks that are certain to impact its growth trajectory in the coming years. In the following pages, we examine each of these concerns to determine just how they are likely to affect the future of nuclear power.

Economic Competitiveness

The foremost prerequisite for a renaissance is the nuclear industry's economic competitiveness vis-à-vis the alternatives. Nuclear power's principal competitors in electricity generation over the projected period will be two fossil fuels, coal and natural gas. These fuels dominate today's electricity market with a combined share of 60 percent and will likely retain their preeminence irrespective of the growth trajectory nuclear energy follows.[16] Yet, any gains that nuclear energy makes will essentially be at the expense of coal or gas. Despite receiving significant policy support from a number of Western governments, 'new' renewable energy sources—these constitute wind and solar energy—are not likely to be major determinants of the global energy mix over the projected period.[17] Currently, wind and solar account for only two percent of the world's energy; latest estimates suggest a meager growth rate of 2.1 percent per year until 2030.[18] Even studies that take a normative stance on the need to expand renewable energy admit that substantial technological progress is required before these energy sources can capture a significant share of the market.[19] Therefore, we limit the following comparison of economic competitiveness to nuclear and fossil fuel-based energy.

The cost structure of nuclear energy production is much different than that for fossil-based alternatives. Among overall energy production expenses—these include capital and marginal costs[20]—expenses for the nuclear option are heavily skewed towards capital costs while coal and gas entail a much heavier burden of marginal costs. Therefore, any meaningful comparison between the two ought to be conducted for baseload operation. The most systematic attempt to do so has been undertaken by the Massachusetts Institute of Technology (MIT)'s study, "The Future of Nuclear Power." Comparing levelized plant lifetime costs[21] in the U.S., the study determines that nuclear power remains substantially more expensive than pulverized coal and Combined-Cycle Gas Turbine (CCGT) options. Nuclear energy does not acquire a cost advantage even after considering a steady rise in future gas prices and far-fetched assumptions entailing a 25 percent decrease in nuclear plant construction costs, a decrease by the same proportion in operation and management costs (this would mean perfect operations), and a shortened, four-year construction period for nuclear power plants. Only after an even more farfetched assumption that equates nuclear financing costs with those for coal and gas plants is introduced does the nuclear option become competitive with CCGT; however, it is still unable to match coal.[22]

Table 2: Costs of Alternatives to Nuclear Electricity Generation
(Real levelized costs in cents/kWe-hr at 85 percent capacity factor)

Base case		
	25-year	40-year
Nuclear	7.0	6.7
Coal	4.4	4.2
Gas (low price)	3.8	3.8
Gas (moderate price)	4.1	4.1
Gas (high price)	5.3	5.6
Gas (high price)—advanced CCGT design	4.9	5.1
Reduced Nuclear Cost Scenarios		
Reduced construction cost by 25 percent	5.8	5.5
Reduced construction time by 1 year	5.6	5.3
Cost of capital brought down to coal and gas level	4.7	4.4

Source: Massachusetts Institute of Technology, "The Future of Nuclear Power," 2003, http://web.mit.edu/nuclearpower/ (accessed on June 4, 2005), p.52.

Latest estimates concur with the MIT study's findings. The Keystone report (2007) estimates levelized lifetime costs for nuclear power at 8.3 to 11.1 cents per Kilowatt-hour (kWh), a figure even higher than that estimated by the MIT study.[23] In order to become competitive, Exelon, the U.S.' largest nuclear energy operator, estimates that the overnight costs for nuclear plants would have to decline to $1,000–1,200/kilowatt (kW) from the current $3,600–4,000/kW.[24] Even the most optimistic voices do not envision such a dramatic reduction in the foreseeable future.

The story is much the same in the other countries deemed to be at the forefront of the nuclear renaissance dream. In China and India, total expenditures on gas and coal plants tend to be between 30 and 60 percent of nuclear plant costs, a differential that provides the former with a cost advantage.[25] For India, M.V. Ramana calculates a cost advantage for thermal power for any real discount rate above 3.9 percent for new reactors and 2.7 percent for currently operating units.[26] Similarly, official Russian estimates point to a figure of less than $1,000/kW for nuclear plant construction costs if nuclear energy is to remain competitive. However, actual costs are much higher; for example, the ongoing construction of the AES-600 plant containing a third generation reactor is expected to cost $2,100/kW.[27] While the picture is not as clearly negative for Japan—this owes to the limited indigenous supply and high cost of alternatives—even there high-end estimates suggest that nuclear power's current market competitiveness is only due to the 1.38 cents/kWh subsidy provided by the state.[28] Indeed, the economic scenario is truly favorable only in a few European countries and in Canada.[29] However, slowing growth in energy demand is not likely to make these states relevant to the renaissance dream.

The above-mentioned cost comparisons do not present the full picture of the differentials. There are a number of additional costs that are not internalized in such basic calculations but still remain pertinent to the future increase of nuclear energy capacity. One serious concern is investment-uncertainty. Nuclear energy's upfront capital costs and longer plant construction timeframes make it highly sensitive to interest rates.[30] This is problematic since the history of nuclear power plants is notorious for huge cost overruns, substantial delays in construction, high procedural hurdles, and extreme uncertainty about political acceptability of nuclear power over time.[31] These factors played a major role in bringing about the slump in the Western nuclear industry during the 1980s; energy sector investors preferred more predictable, short-term, less capital-intensive investments.[32]

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Even today, from the investors' perspective, the nuclear industry presents a higher-risk proposition than fossil fuels; its risk-adjusted cost, the chief benchmark for investment decisions, is seldom lower than that for the alternatives.[33] Notwithstanding claims by proponents that investor interest in the industry has revived and that procedural impediments have been lowered in the West, the fact is that cost and construction time overruns have persisted even in the most recent experiences.[34] Moreover, despite the fact that hefty investment stimuli—the U.S. government, for example, has accorded a $2 billion subsidy and investor guarantees to the nuclear industry—have generated some interest, there is yet to be an actual commitment for purchase of a new nuclear plant in countries like the U.S.[35] In fact, credit raters such as Standard and Poor's argue that "from a credit perspective, provisions may not be substantial enough to sustain credit quality and make [nuclear energy] a practical strategy."[36]

As nuclear energy expands to the developing world, the problem of investment-uncertainty is likely to intensify as the relatively new entrants to the nuclear energy club pass through their own learning curves. In India's case, for example, the country's 10 major nuclear reactors have had cumulative cost overruns of over 300 percent; against an estimated cost of approximately $5.2 billion, revised costs were $17.7 billion.[37] This is when every additional $500 per Kilowatt-electric (kWe) capacity in overnight capital costs ends up raising electricity cost by 1.5 cents/kWh in the developing world.[38] Moreover, efficiency levels of nuclear plants are generally lower in developing countries and consequently operation and management costs could reasonably be expected to exceed even liberal Western estimates. Not to mention, political uncertainty and policy reversals are also major worries for investors eyeing nuclear industries in the global South.[39] Perhaps a reflection of this sentiment, the Organization for Economic Cooperation and Development (OECD) already charges a one percent additional interest on the loans it provides against exports of nuclear power plants.[40]

The developing world is also unlikely to be able to benefit from its theoretical advantage of having tightly regulated energy industries. The argument is that states could conceivably provide fuel buy-back guarantees and offer higher-than-market returns on capital to offset some of the investment risk. However, in reality, for most developing countries, this will be an unbearable resource drain. Their resource crunches imply that such privileges would compete with other development needs.[41] While thus far countries like Russia, China, and India have funded the expansion of the nuclear sector through public allocations or deferred loan payments to exporting states, perhaps in a bid to prove the sector's worth to investors, their resource constraints and the market imperfections caused by continuous state intervention in the energy sector are already prompting them to privatize sections of the energy industry. Both India and Russia plan to have substantially privatized energy sectors by 2020.[42] In fact, none of the nuclear frontrunners will be able to come close to their nuclear energy expansion targets without enormous private sector investment in the coming years. Deregulation then will force states to pass on the investment risks completely to the investors. This will remove any artificially created competitiveness for nuclear energy; the investors' risk-adjusted cost for the industry will thus be substantially higher than any strict cost-accounting exercise would suggest.

The high-risk investment demand of the nuclear industry creates a chicken-and-egg problem for nuclear enthusiasts. While they may rightly contend that nuclear plants have enhanced their capacity factors across the world and that newer designs for smaller and even more efficient plants could put nuclear energy at an advantage over the long run, even for these promises to be demonstrated, massive commercial nuclear expansion is required.[43] This demands *ex ante* investment; however, investors will not be forthcoming because of the poor legacy of the nuclear industry and the aforementioned investment risks in the developing world unless competitiveness is demonstrated on a large scale and over a prolonged period in advance. In essence then, as aptly summed up by Cochran: "….the bottom line is that in the current economic climate, commercial nuclear generation is not even close to being competitive with fossil-fueled plants and there is no easy path to a competitive market for new nuclear plants."[44]

Nuclear Energy's Impact on Climate Change

The strongest push for nuclear energy is emanating from the climate change lobby that sees global warming as the 21st century's most formidable challenge. It is this cohort that is responsible for much of the 'positive determinism' regarding nuclear energy's future outlook. The impetus to this normative view is provided by the growing consensus on the urgency to tackle climate change; a number of recent reports have emphasized the need for immediate and drastic reductions in carbon emissions.[45] In order to stabilize the atmospheric quantity of carbon dioxide at 500 parts per million, global emissions must be reduced by 50 percent by mid-century.[46] Given the taxing nature of fossil fuels vis-à-vis carbon levels, should the current energy policies remain unaltered, baseline greenhouse gas emissions will increase by 9.7 to 36.7 Gigatons (Gt) of carbon dioxide equivalent between 2000 and 2030.[47] This implies a 40 to 110 percent increase in carbon dioxide emissions from energy use.[48]

Although not explicitly stated under the Kyoto Protocol as a source against which countries can obtain credits, nuclear energy is a non-carbon-emitting source.[49] The entire nuclear production chain contributes between 10 and 25 grams of carbon dioxide equivalent per kWh, which is approximately 20 to 60 times less than fossil fuel chains.[50] The International Panel on Fissile Material's "Global Fissile Report 2007" estimates that an installed nuclear capacity of 1072 GWe (an addition of 700 GWe to the current level) instead of an equivalent additional capacity for modern high-efficiency coal-electric plants would reduce projected emissions by 1 billion tons of carbon (tC) per year.[51] Nuclear Energy Agency puts the emissions savings from an additional 748 GWe at 200 Gt by 2050.[52] Even today, nuclear energy reduces the energy sector's contribution to atmospheric carbon dioxide by eight percent assuming that it substitutes fossil fuel units; this amounts to 600 million tC annually, twice as much as the Kyoto Protocol is expected to save by 2010, according to IAEA estimates.[53]

On the climate change count then, nuclear energy's merit is indisputable. The often-heard argument that even the most optimistic projections for the increase of nuclear energy would only reduce global carbon emissions by a small proportion is misplaced.[54] The frame of reference ought not to be relative; the actual benefit is the reduction in overall emissions, no matter how small, which would otherwise be foregone. In the same vein, those who argue for diverting expenditures towards improving efficiency of fossil fuels or exploring other technologies instead exaggerate the potential carbon emission savings from such a move. Efficiency gains are not likely to reduce emissions by more than 30 percent at most.[55] Nordhaus and

Shellenberger argue that in the U.S., efficiency, conservation, and a $50 per ton carbon surcharge combined will only bring about a 22.5 percent reduction in emissions.[56] Moreover, carbon capture and storage options are still to be demonstrated on a wide scale and the geological storage space available for carbon dioxide remains a matter of some debate.[57] The point is not to say that efficiency gains should not be pursued—indeed, they are an imperative in their own right—but simply to suggest that they should not be looked at as perfect substitutes for the carbon emissions-reduction benefits of nuclear power.

The above said, however, the future of nuclear power cannot be judged strictly through the narrow confines of the climate change prism since the attraction in terms of carbon emissions reduction alone will not be sufficient to allow for a rapid deployment of nuclear technology. While climate change has indeed become a salient issue in the developed world—industrialized countries are bound to reduce their emissions to five percent below the 1990 levels under the Kyoto Protocol—few are moving to curb emissions as swiftly as required.[58] Moreover, even those who see non-carbon-emitting sources as the only long-term solution to climate change retain disproportionate focus on renewables like wind and solar energy. This is despite their cost-ineffectiveness and the uncertainty surrounding their actual capacity. The bias against nuclear energy points to the comparatively greater importance the Western world pays to the safety and security implications of nuclear energy (we discuss these in the next two sections). Europe has been adamant about keeping nuclear energy off the global climate change negotiation agenda. Given its weight in international politics and the extreme negative outlook towards nuclear power in much of the continent, Europe's stance is not likely to change in the near

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term. Moreover, even the U.S., while having renewed its interest in nuclear technology, has retained a bias towards renewable sources. In addition to offering greater benefits to new renewable energy sources through domestic policy, the U.S.' official stance in climate change negotiations has continued to focus on renewables, efficiency enhancement, and carbon capture and sequestration options.[59]

Next, despite a global drive towards penalizing high-carbon-emitting sources, nuclear energy's positive attributes with regard to global warming will not make it economically competitive. There are existing proposals that aim at encouraging non-carbon-emitting sources by internalizing societal costs of emissions. The most prominent is the option of a carbon emissions tax on fossil fuels; Sweden, Finland, England, and New Zealand have already instituted a carbon tax in different forms.[60] However, the level of taxes required to induce competitiveness for clean sources is extremely high. In the U.S., a $200/tC tax is believed to be adequate to induce a large enough shift away from fossil fuel-generated electricity such that atmospheric carbon concentrations will stabilize.[61] According to the earlier-mentioned MIT study, this is also the tax rate at which nuclear energy becomes decisively competitive with coal and gas, presuming lowered per unit costs for construction and capital for nuclear energy.[62] However, since such a tax would increase the price of coal and gas-generated energy by a factor of seven and 1.6, respectively, a decision to impose this hefty surcharge is likely to remain politically untenable.[63] In the U.S., proposals currently under discussion are contemplating a tax below $50/tC.[64] Similarly, Japan recently proposed a carbon tax amounting to a mere $20.85/tC.[65] Even this move has been politically unpopular and has forced the government to delay the actual implementation of the levy. Naturally, the prospects are dimmer in the developing world, where even a debate to tax the energy sector so heavily is inconceivable for the most part.[66] Having clearly stated their unwillingness to accept any environmental binds that undermine their economic and social growth objectives, China and India are beginning to speak the climate change language. But even if they were to introduce such taxes, the amounts will not be anywhere near the $50/tC level, let alone $200/tC.[67]

Unique Safety Requirements

Unlike fossil fuels, nuclear technology presents unique safety requirements, a breach in which can have drastic consequences for humans as well as the environment. While each stage of the nuclear-fuel cycle presents a risk in varying degrees, we focus on the two key stages: reactor core functioning and waste disposal requirements.

Reactor core damage in nuclear power plants can cause catastrophic consequences for people within the impact radius. The world's two most deadly nuclear accidents, the Three Mile Island incident in 1979 and Chernobyl in 1986—the latter affected a total of nine million people and 155,000 square kilometers of land—were caused by reactor core damage.[68] Moreover, over 300 minor-to-moderate nuclear accidents were recorded in the global nuclear industry by the mid-1990s.[69] Further, despite claims of improvement, accidents have continued over the last decade. The most severe nuclear incident after Three Mile Island and Chernobyl took place at Tokaimura in Japan in 1999 when a massive uranium leak pushed atmospheric radiation levels up by a factor of 10,000 to 20,000.[70] Among the renaissance front-runners, accidents have been reported in the U.S. and India since 2000.[71]

The probability of a mishap would rise astronomically if the nuclear renaissance was to materialize. According to the MIT study, with a much higher number of nuclear reactors, the probability of reactor core damage given the current Light Water Reactor (LWR) Technology will remain unacceptably high.[72] Moreover, alternatives like the 'advanced LWRs' are still unproven in their safety record and other fresh technologies like the High-Temperature Gas Reactors with passive safety features and Generation IV reactors are some time away from maturing.[73]

The second potential danger comes from the spent fuel at the back end of the reactor. The nuclear-fuel cycle discharges waste that remains radioactive over thousands of years.[74] Reprocessing plants used to recycle spent fuel release 'high level' waste that presents a different and even more dangerous proposition.[75] Any release of radioactive material—this can occur due to the slightest negligence—could cause either a slow leakage into the air or water or a sudden burst resulting in widespread human and environmental damage.[76]

Elaborate waste disposal requirements add another dimension to the safety debate. While interim disposal steps such as temporary storage and transport also exacerbate safety hazards, the real danger emanates from the absence of any permanent solution to the problem of 'final' disposal of reactor and reprocessed waste.[77] The most scientifically promising avenue today is to store nuclear waste in deep geological repositories that entail dump mines several meters below the earth's surface at geologically suitable locations.[78] However, there is still no fully functional repository and it is not even clear if all sites can handle spent fuel and reprocessed waste equally efficiently.[79] Under a high-end nuclear renaissance scenario, one large repository of roughly 70,000 Metric tons (MT) capacity will be required somewhere in the world every 3–4 years to cater to the 20,000 MT of spent fuel discharge per year.[80] Both the requirement of suitable land and the sheer volume of high-level waste are alarming and cannot realistically be matched even by aggressive capacity upgrades in the next two to three decades.[81]

The absence of positive empirical evidence on the safety count presents the same chicken-and-egg dilemma discussed earlier. Investors are unlikely to be forthcoming unless the nuclear industry gains acceptability as a safe source in state policies and the public perception at large. Yet, unless investment in commercial plants is coupled with improved interim storage protocols and development of new final disposal sites on a reasonable scale, the existing safety track record cannot be reversed. In fact, on the safety front, the conundrum is even more complex. This is so since a successful demonstration of improved safety will not take away the fact that ultimately the fate of the entire industry depends on one major accident; the catastrophic proportion of this potential event trumps all claims pointing to the extremely low probability of its occurrence.[82] From the investor's point of view, it is not an actual accident but simply the *prospect* of such a development that will cause averseness to the nuclear energy sector. And for the

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investors that do enter the market, it is only natural to expect them to demand a high-risk premium.[83] This is especially true for developing countries where safety cultures are weak and implementation of safety protocols is believed to be lax.[84] The attendant cost implications are obvious.

The Risk of Nuclear Weapons Proliferation

Intrinsically linked to the concerns about nuclear accidents are the chilling prospects of nuclear weapons proliferation that the spread of nuclear technology and material inherently bring with them. The current outlook towards the threat of proliferation makes this the most intractable impediment, one that could by itself stall any prospects of a nuclear renaissance.

As with accidents, each stage of the nuclear-fuel cycle presents proliferation risks. To begin with, nuclear fuel is highly susceptible. Uranium known as "yellow cake"—the input for a nuclear reactor—can be enriched to weapons-grade Highly Enriched Uranium (HEU). Under a scenario where nuclear power capacity grows roughly by a factor of four, the uranium enrichment demand would jump from the current 44 million Separative Work Units (SWU)/year to 225 million SWU/year; this would necessitate a substantial increase in enrichment plants around the world.[85] While uranium-enrichment technology is extremely sophisticated, Pakistan, North Korea, and Iran's experience has shown that developing countries with otherwise weak technological grounding can manage to attain enrichment capacity even against all odds.

More so than uranium, however, the nuclear fuel from reprocessing plants employed in 'closed' nuclear fuel cycles provides a relatively easier route to nuclear weapons development.[86] The prevalent reprocessing technology that separates plutonium from spent fuel—PUREX—and recycles it in mixed-oxide fuel (MOX) allows the plutonium to be used directly for weapons manufacture.[87] The technology to do so is elementary and is well understood.[88] Further, even if the full fuel-cycle operations are not available to a particular country or non-state actor, the ever-increasing amount of weapon-usable plutonium stocks in the world can be siphoned away and used to manufacture weapons with moderate difficulty. Already, the global capacity to deal with excess plutonium stockpiles is found wanting. For instance, the scientific community has been raising persistent alarms about the ease with which Russian fissile material stockpiles could be diverted.[89] Finally, the transport of nuclear fuel also raises proliferation risks. As put by Chaim Braun: "as the global nuclear energy system increases in size and diversity, and as nuclear fuel recycling evolves, the number of international fuel shipments over land, by air, or by ship will increase, thus increasing the temptation for diversion along the transport routes. Even more worrisome is the eventual commercialization of FRs [fast reactors] and associated fuel reprocessing and refabrication facilities. . . . the plutonium contained in MOX fuel may be directly usable in weapons if successfully diverted and separated."[90]

Table 3: Current Global Stocks of Weapons Usable Fissile Material (Metric tons)

Category	Separated Plutonium	HEU**	Total	Bomb Equivalent***
Civil stocks*	229.5	437.5	667	46,187.5
Military	260.1	958.4	1,218.5	70,848.5
Total	489.6	1,395.9	1,885.5	117,036
Bomb equivalent	61,200	55,836	117,036	

Note: The estimates for HEU have an error range of +/- 300 due to uncertainty about Russian uranium stockpile.
* For HEU, civil stocks include excess uranium for blend-down.
** Estimates exclude 328 MT of fresh and irradiated HEU possessed by U.S. and Russia for naval use.
*** To calculate bomb equivalent, the official IAEA benchmark of 25 kg of HEU and 8 kg of Plutonium for each warhead has been used.
Source: International Panel on Fissile Materials, "Global Fissile Material Report 2007," 2008, http://www.fissilematerials.org/ipfm/site_down/gfmr07.pdf (accessed on June 2, 2008).

Nuclear proliferation is now widely believed to be the world's most complex security challenge. Moreover, the non-proliferation debate is increasingly shifting from its traditional emphasis on international safeguards and verification—there is now a consensus that these are mere stop-gap arrangements[91]—to blaming the Non-Proliferation Treaty's (NPT) provision that allows signatory states to develop indigenous nuclear-fuel cycles and grants them the right to access civil nuclear technology. The current sentiment is that as long as the NPT allows countries access to civilian technology, military spin-offs will be inevitable. American strategic expert Joseph Cirincione argues that supply of sensitive nuclear materials for civilian purposes puts aspiring states a "screwdriver's turn" away from converting it into a weapons capability.[92] What is more, the concern is no longer limited to states. Non-state actors, with their threat of conducting nuclear terrorism, are now at the forefront of the debate as well.[93]

The prospects for a universally acceptable solution to the proliferation problem remain bleak. The problem is that on one hand, the non-proliferation world is convinced that any move to reshape the NPT will risk unraveling the entire regime; there is a virtual consensus against attempting this.[94] On the other hand, the current regime has been ineffective as those who chose to stay outside its purview or cheated the system managed to do so rather successfully.[95] Moreover, diffusion of the requisite technology has convinced most that the pace of weapons acquisition will be faster in the future.[96]

Remaining within the confines of the NPT, the option currently being exercised is to pick and choose countries that are considered 'responsible' enough to be privy to the nuclear exchange benefits while 'suspect' states (as defined by Western powers) are increasingly being denied the privileges in addition to being subjected to enhanced safeguard inspections by the International Atomic Energy Commission (IAEA). For one, this defies the spirit of the NPT; the very basis for the non-nuclear powers' acceptance of the treaty was the provision for civilian nuclear exchange.[97] More importantly, it creates an 'us versus them' dichotomy and inevitably ends up increasing the determination of those outside the privileged club to pursue indigenous programs.[98] Indeed, critics of the Bush administration's foreign policy argue that the single most important take-home lesson for countries at the receiving end of coercive U.S. tactics is that to be safe, one needs nuclear weapons.[99]

While there is a plethora of proposals that seek to redress the technology diffusion-proliferation paradox, all end up creating a world of nuclear 'haves' versus 'have nots'. Even the most promising recommendation—creating multilateral nuclear fuel supply and reprocessing hubs—would rob developing countries of an indigenous fuel-cycle and increase fuel acquisition costs substantially.[100] This, like any other dichotomous arrangement, will remain a non-starter. In a statement representative of the view prevalent in the much of the global South, a senior ambassador from a developing country aptly summed up the problem: "Any system that is not perceived to be fair and aimed at universal rights is bound to fail and risks unraveling the whole structure of non-proliferation.... Limitations on technological development will need to be universal, not just for some and not for others."[101]

It is the realization of the impossibility of the task at hand that has led to the currently prevailing pessimism regarding the future of nuclear proliferation. Even the most optimistic views admit that technological buffers are unlikely to be sufficient to prevent proliferation.[102] Notwithstanding, no matter how inadequate, tough supply-side safeguards are the only option available to the global non-proliferation sheriffs—read Western powers—for now. Therefore, they will continue to single out 'suspect' states to be subjected to perpetual monitoring while being denied Article IV rights.[103] While this will allow the global North to retain control of the non-proliferation strategy, it will inevitably serve as further impetus to those at the receiving end to seek an indigenous weapons capability. Moreover, as resentment among the excluded group of countries grows, we may face the prospect of the unraveling of the entire NPT regime. Inevitably, the dream of nuclear energy expansion will be an obvious loser.

Public Sentiment Towards the Nuclear Industry

The safety and proliferation concerns regarding nuclear energy go beyond state policies and international conventions. An equally important variable affecting the future of the energy source is the public outlook towards these risks. The importance of popular sentiment to the nuclear industry is well-established. The outcry following the Three Mile Island and Chernobyl accidents was a major factor that contributed to the industry's slump in the 1980s. Today, while public opinion varies from country to country—among other factors, this depends on

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historic experience of the nuclear industry, level of general awareness, and costs of various energy sources—an overarching generalization suggests that the majority remains wary of nuclear expansion. A global opinion survey commissioned by the IAEA in 2005 showed that while citizens are willing to allow currently operating plants to continue, safety and security concerns lead them to remain skeptical about initiating new plants.[104]

The impact of negative sentiment on state policies is most obvious in the case of the European Union. Backed by the majority's opposition, a number of countries are gradually moving away from nuclear power. A large number of European states do not have a nuclear program, are phasing out reactors, or have decided not to build new ones.[105] The preference for renewable energy in countries like Germany and Britain is also in large part a function of the adverse popular sentiment towards the nuclear industry.[106] Even elsewhere, as in the case of Japan, the adverse outlook is extreme and has already caused the government to tone down its plans to expand reprocessing capacity.[107] The sentiment is just as averse in Russia;[108] however, in this case the government seems to be pressing ahead with its industry expansion plans regardless. That said, among the nuclear frontrunners, the U.S., India, and South Korea do enjoy support for nuclear expansion.[109]

While a global consensus among popular sentiment is hard to envision on the issue, as long as the safety and security concerns remain, no outright support for nuclear expansion can be expected. In fact, a number of future safety, proliferation, and nuclear terrorism-related developments may tilt the overall public opinion further into the negative. With regard to safety, the persistent problem with reactor accidents has already been mentioned. Moreover, a fresh development-country argument that is creating hurdles even in countries like the U.S. is that deregulation of nuclear energy markets provides too much leeway to the private sector, which has an interest in minimizing safety-related expenditures in order to maximize profits. The argument has gained credibility as U.S. nuclear operators have been found in breach of basic safety protocols in the recent past. For instance, a near-catastrophe at an Ohio-based nuclear station was avoided in 2002 when a 6-inch deep boric acid created-hole was exposed in a reactor vessel head at an extremely late stage. Both the plant operator and the U.S. Nuclear Regulatory Commission, which is mandated to conduct inspections, remained unaware of the damage.[110]

In the developing world, the situation is quite the opposite. Countries like India and China, where the nuclear industry is largely run at the behest of the public sector, currently take advantage of the lack of mass awareness regarding the potential hazards posed by the nuclear industry by ignoring stringent safety requirements.[111] Under a high-expansion scenario, foreign investment may well alter the apathy of the public in this regard. For one, given the higher risk, investors would not be forthcoming in countries that employ lax safety protocols. A demand to improve the safety apparatus would be natural; it may also be reinforced by pressure from the investors' home countries to associate only with ventures meeting established safety practices. The IAEA is already advocating an internationally agreed upon standard which will force all nuclear activities to meet stipulated safety requirements. Such a drive would also inevitably bring the global anti-nuclear advocacy groups to the forefront as they prompt the public in developing countries to become more proactive in demanding transparency in the nuclear industry.

The above development would be welcome from a safety perspective. It would also be necessary if the public—both home and host country sentiment—is to be convinced of the safe nature of the industry. Notwithstanding, such an outcome will create a public support-economic competitiveness paradox. The revamped safety apparatus would likely entail developing comprehensive safety plans, building human capacity that specializes in nuclear plant management, identifying final disposal sites after thorough geological and seismic analysis, storing waste in uninhabited areas in the interim, and adopting advanced technologies less prone to accidents. Moreover, the bureaucratic procedures would become excessively complex, perhaps even more so than in the developed world, given lack of experience and the generally slow and often corrupt nature of developing country bureaucracies. These ventures will further add to the cost differential between nuclear and fossil alternatives, leaving the former unattractive both to the investors and perhaps even to the developing country governments.[112] The paradox should be obvious: investment in the nuclear industry is unlikely to take off until public perception transforms for the better; however, the way to ensure the latter makes the cost of investment prohibitive in the first place.

As for the risk associated with nuclear terrorism and proliferation, the sentiment is likely to remain equally wary. It is well-established that public concerns about these aspects have grown in recent years.[113] As the 2005 IAEA survey showed, a majority of the respondents considered the threat of a nuclear terrorist attack to be 'high' and the IAEA's capability to check proliferation to be 'ineffective.'[114] The worry is not unfounded. Specifically in terms of nuclear terrorism, nuclear power plants have been singled out as one of the potential targets of terrorist outfits.[115] In terms of proliferation, states on the wrong side of Western policy create unease. Given that negatively perceived countries like Pakistan are vying for a civilian nuclear deal with the U.S. and China and as many as 13 Middle Eastern states have expressed an interest in nuclear technology in the wake of the Iran crisis, it is difficult to envision a positive change in this perception.[116] Indeed, a recent Pew Survey suggests that nuclear weapons proliferation is considered to be the single biggest danger in the Middle East.[117] Tied to this is the fact that if Western powers insist on maintaining a dichotomous order with regard to civilian nuclear technology access, they will necessarily have to legitimize their breach of the NPT by persistently reminding their citizens of the threat that the spread of nuclear technology poses in terms of weapons proliferation. By implication, this would reinforce the negative sentiment regarding the expansion of nuclear power among their populous.

Another conundrum stems from the intrinsic link between transparency and positive public opinion. The nuclear industry suffers from a negative legacy, one that turned mass opinion decisively against it at the time of the first slump. As Yim and Vaganov argue, entities facing such a trust and confidence deficit require "nothing less than a new culture;" they stress the need for transparency and new and heavy investments in efforts to alter the popular perception.[118] This is especially true for a sector where the reasons for the historic opposition to the industry have not disappeared. That said, however, under the kind of proliferation and terrorist threat presently faced by the nuclear industry, transparency runs counter to the industry's security compulsions. In fact, that the nuclear industry cannot operate on the basis of full disclosure is already taken to be a foregone conclusion; the current debate revolves around the extent to which information can be revealed.[119] Arguably, as the menace of proliferation and terrorism grows, safety and security demands will tend to drive the industry towards further opacity. Moreover, free-riding will become more common. Countries that may find elaborate transparency a costly exercise would tend to hide behind the 'doctrine of necessity' to keep their operations out of the public eye. To add to the complexity, the growing influence of the ideologically driven anti-nuclear advocacy lobby implies intensified efforts to expose every minute mishap in the industry. As Yim and Vaganov contend, this would create adverse behavioral reactions, an effect they attribute to the "predominance of negative aspect of all nuclear issues and due to the social amplification of risk."[120]

Energy Security

As the global economy develops, the world's finite energy sources will face increasing pressure. This is worrisome for growing economies as they require predictable and abundant supplies of energy to retain growth momentum. Absence of the same can leave the country economically compromised and strategically vulnerable. Yet, with skewed global distribution of fossil fuels and prices projected to increase over the long run, some of the fastest developing countries are already finding their economies vulnerable to external disruptions. Interestingly, each of the countries at the forefront of the nuclear renaissance dream also harbors significant energy security concerns.

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Once again, China and India lie at the heart of the debate. Projected to account for 45 percent of the rise in global energy consumption by 2030, their dependence on foreign fossil fuel will grow commensurately.[121] While both have been engaged in aggressive attempts to diversify their traditionally narrow import sources for some time, geo-political overtones have resulted in painstakingly slow progress.[122] This has strengthened their resolve to seek fresh domestic energy supply options in parallel. The situation is much the same in developed countries like Japan and South Korea. Lack of alternatives and vulnerability to global price shocks is a key reason for Japan to persist with its nuclear program despite public opposition. In the U.S., an astronomically high energy import bill—a trend predicted to grow—is behind calls for exploring additional domestic options.[123] Even in Europe, for countries like Finland and Ukraine—both exceptions to the downward trend in nuclear energy growth in the continent—reducing vulnerability to Russian energy supplies is a high priority.[124]

Nuclear energy compares favorably to fossil fuels in terms of enhancing energy security for states with full fuel-cycle facilities. Compared to fossil fuels, the input of the nuclear fuel cycle, uranium, is relatively democratically distributed and is in abundance. As many as 43 countries possess sizable uranium reserves.[125] Estimates suggest that proven reserves extractable through currently available techniques will last 80 years.[126] Next, nuclear energy benefits from a much higher energy density—this is a measure of the amount of fuel input required to produce a given amount of energy—than fossil-based alternatives.[127] For instance, the per annum concentrated uranium requirement for a 1,000 MWe nuclear power plant is 25 tons as compared to 2,300,000 tons of coal for a coal-based plant.[128] Therefore, uranium stocks lasting over long periods can be imported in one consignment. Currently, countries regularly using nuclear energy can store two to three years worth of uranium but the period can be extended should uranium supply concerns arise.[129] Finally, while coal and natural gas constitute 45 and 70 percent of production costs for these two fossil fuels, respectively, uranium constitutes only 15 to 20 percent of the same at nuclear plants.[130] According to Lauvergeon, even a 50 percent increase in uranium prices would result in a four percent tariff increase for nuclear energy as compared to 38 percent for coal or gas.[131]

Nuclear power's preferential position with regard to energy security explains why countries like China and India are adamant about following this path despite the source's lack of competitiveness, the heavy resource burden it will end up laying on states, and its excessive safety and security concerns. That said, the mere pursuit of energy security will not eliminate these impediments. For one, safety and proliferation concerns may well lead to deliberate tightening of uranium supplies some time in the future. Already, there are concerns about supplying uranium to non-NPT members like Pakistan and India. Although for now, India has managed to conclude bilateral deals for civil nuclear energy cooperation with the U.S., France, and Russia, these arrangements have been highly unpopular and had to face legal and moral hurdles.[132] Pakistan's requests for the same have been persistently denied.[133] Admittedly, while 'likable' countries may still find means to acquire necessary fuel, the process will become increasingly unpredictable as nuclear power expands. The advantage of natural abundance of uranium would thus be artificially neutralized. To be sure, nuclear proponents could point to the fact that availability of uranium can be increased immensely by employing 'fast reactor' reprocessing technology. Indeed, if the entire nuclear industry were to use fast reactors instead of the currently prevalent once-through fuel cycles, the presently extractable uranium can be made to last 3,000 years.[134] However, this view ignores the economic imperatives that would make such a move untenable. Recent estimates suggest that reprocessing raises costs of electricity production by a factor of 2.42.[135]

High costs for the state and investor averseness will also take their toll on the quest for energy security. In fact, for most countries, costs may become unbearable at some point. This view gains credibility when one considers that irrespective of their determination to expand nuclear capacity, nuclear energy will account for a minority share in overall energy consumption of each of the frontrunners for the foreseeable future.[136] This implies a lower than expected resource-drain threshold; if cost overruns and delays continue to make nuclear energy much more expensive than optimists promise, the cost-benefit equation would become unfavorable to nuclear energy despite taking energy security concerns into account. At that point, even the most determined states may refocus attention on alternatives.

IV. CONCLUSION: OPTIMIZING THE PROJECTED NUCLEAR FUTURE

The interplay of the determinant variables of the nuclear industry's future seems to create a number of irreconcilable conundrums. Steps to tackle investor uncertainty end up raising the already unfavorable cost differential between nuclear power and its alternatives, thus prompting investors to shy away in the first place. Alleviating fears about nuclear safety requires additional costs (at least in the developing world) and successful demonstration. For one, costs make the investment unattractive. Moreover, investors prefer *ex ante* demonstration; that is impossible unless investment is forthcoming. Next, redressing security concerns affords no obvious solution. However, the current drive towards the investment/demonstrated safety dichotomy is inherently contradictory to the goal of nuclear power expansion. It limits nuclear industries to select countries and deliberately emphasizes the dangers in the spread of nuclear technology. The outcome is self-defeating given the aim of transforming public opinion positively. Moreover, transparency in the functioning of the industry, another prerequisite for altering popular perception, is mutually exclusive from robust security requirements given the current proliferation and terrorism threats. Finally, the high resource burden and current anti-proliferation strategies limit the utility of nuclear energy as a means of reducing energy vulnerability. In the final outcome, even the obvious merits of nuclear energy are overshadowed; a case in point is the climate change benefit, which is being discounted in favor of more costly renewable alternatives in much of the developed world.

The high resource burden and current anti-proliferation strategies limit the utility of nuclear energy as a means of reducing energy vulnerability. In the final outcome, even the obvious merits of nuclear energy are overshadowed; a case in point is the climate change benefit, which is being discounted in favor of more costly renewable alternatives in much of the developed world.

Looking ahead, the projected scenario ought to inform measures taken in the global energy sector in the coming years. This implies a move away from ideological debates towards a realization of the on-the-ground reality regarding the nuclear industry's prospects. The analysis presented here points to a bleak picture with regard to the climate change agenda. Neither will the nuclear renaissance be strong enough, nor will renewables become available at the level required to stabilize atmospheric carbon. Therefore, in the interim, measures designed to enhance efficiency of fossil fuels and options such as carbon capture and sequestering ought to receive attention.

Moreover, countries that see energy security as the chief concern and are thus adamant about taking the nuclear route will need to balance their developmental needs with the expenditure on nuclear energy over the long run. Developing countries like China and India seem to have based all projections on overly optimistic scenarios, ones that are unlikely to be realized. Realistically, the renaissance frontrunners are only likely to reduce their energy vulnerability marginally over the long run despite intense efforts. Clearly then, the focus of initiatives aimed at enhancing energy security ought to be diverted to securing more credible and predictable traditional energy supplies.

Next, given the magnitude of any potential nuclear incident, perhaps the most important concern remains with regard to safety and security in the nuclear industry. This is true irrespective of the future trajectory of nuclear power; safe and secure operations must be ensured wherever nuclear energy production, transport, or storage is taking place. The IAEA is already mandated to establish safety benchmarks, but the global practice varies from country to country.[137] There is a need to apply these standards uniformly using the highest common denominator. Moreover, possibilities of allowing the IAEA a mandate to ensure adequate physical protection of plants through bilateral or multilateral arrangements should be explored.

Specifically with regard to the nuclear fuel cycle, reprocessing of spent fuel must be abandoned in favor of the once-through alternative. Apart from being cost-ineffective, reprocessing raises the likelihood of an accident, generates a larger number of waste streams, and makes proliferation easier. Further, even if reprocessing continues, the presently applied MOX fuel cycle must be upgraded or new, less dangerous technologies must be tried.[138] MOX is a highly susceptible option, both in terms of safety and security.

Simultaneously, efforts to strengthen the security protocol to ensure safe transport of nuclear fuel and waste will be needed. Although a legally binding convention for nuclear material in international transit exists, the current security arrangements will become inadequate even if nuclear energy grows moderately. The IAEA should consider revising its guidelines to develop a multilateral framework; it has already been talking about the need to do so.

Finally, few options are available in terms of halting proliferation. The ultimate solution lies in addressing the demand-side incentives for countries to seek nuclear weapons. This, however, requires a revamping of geopolitical interests of global and regional powers, more equitable developmental opportunities for the global South, and resolution of long-standing disputes between countries, among other things. By any standard, this is a tall order; the non-proliferation agenda surely cannot wait for this to come about. The most realistic option for now is to further strengthen supply-side anti-proliferation measures as well as the international safeguards regime. On that count, steps like the IAEA's Additional Protocol, the Proliferation Security Initiative, and tightening of the Nuclear Suppliers Group guidelines are welcome.[139] However, these ought to be applied judiciously across the board.

The 2006 World Energy Outlook stated: "Nuclear power will only become more important if the governments of countries where nuclear power is acceptable play a stronger role in facilitating private investment, especially in liberalized markets" and "if concerns about plant safety, nuclear waste disposal, and the risk of proliferation can be solved to the satisfaction of the public."[140] Our analysis suggests that this is unlikely to happen. Granted, China, India, U.S., Japan, South Korea, and Russia may remain steadfast in their bid to expand nuclear capacities in the near term. Nonetheless, all states will face the impediments—to varying degrees—discussed in this paper. The implication is that the nuclear renaissance dream will remain unfulfilled. Growth of the industry, if any, will be modest; to the contrary, an overall decline over the next two to three decades cannot be ruled out.

Appendix 1

Nuclear Plants, Capacity, and Relative Importance of Nuclear Energy

	Nuclear Electricity Generation			Reactors operational		Reactors under construction		Reactors on order or planned	
	billion kWh	% share in total electricity	% share in primary energy	No.	MWe	No.	MWe	No.	MWe
Argentina	6.7	6.2	2	2	935	1	692	1	740
Armenia	2.35	43.5	*	1	376	0	0	0	0
Bangladesh	0	0	0	0	0	0	0	0	0
Belarus	0	0	0	0	0	0	0	2	2000
Belgium	46	54	15	7	5728	0	0	0	0
Brazil	11.7	2.8	2	2	1901	0	0	1	1245
Bulgaria	13.7	32	22	2	1906	0	0	2	1900
Canada	88.2	14.7	7	18	12652	2	1500	3	3300
China	59.3	1.9	1	11	8587	7	6700	24	26320
Czech Republic	24.6	30.3	14	6	3472	0	0	0	0
Egypt	0	0	0	0	0	0	0	0	0
Finland	22.5	29	20	4	2696	1	1600	0	0
France	420.1	77	39	59	63473	1	1630	0	0
Germany	133.2	26	12	17	20339	0	0	0	0
Hungary	13.9	37	12	4	1826	0	0	0	0
India	15.8	2.5	1	17	3779	6	2976	10	8560
Indonesia	0	0	0	0	0	0	0	2	2000
Iran	0	0	0	0	0	1	915	2	1900
Israel	0	0	0	0	0	0	0	0	0
Japan	267	27.5	13	55	47577	2	2285	11	14945
Kazakhstan	0	0	0	0	0	0	0	0	0
North Korea	0	0	0	0	0	0	0	1	950
South Korea	136.6	35.3	15	20	17533	3	3000	5	6600
Lithuania	9.1	64.4	24	1	1185	0	0	0	0
Mexico	9.95	4.6	2	2	1310	0	0	0	0
Netherlands	4.0	4.1	1	1	485	0	0	0	0
Pakistan	2.3	2.34	1	2	400	1	300	2	600
Romania	7.1	13	3	2	1310	0	0	2	1310
Russia	148	16	5	31	21743	7	4920	10	11960
Slovakia	14.2	54	23	5	2064	2	840	0	0
Slovenia	5.4	42	*	1	696	0	0	0	0
South Africa	12.6	5.5	2	2	1842	0	0	1	165
Spain	52.7	17.4	9	8	7442	0	0	0	0
Sweden	64.3	46	33	10	9016	0	0	0	0
Switzerland	26.5	43	22	5	3220	0	0	0	0
Taiwan	39	19.3	8	6	4884	2	2600		
Thailand	0	0	0	0	0	0	0	0	0
Turkey	0	0	0	0	0	0	0	0	0
Ukraine	87.2	48	15	15	13168	0	0	2	1900
United Kingdom	57.5	15	8	19	11035	0	0	0	0
USA	806.6	19.4	8	104	99049	0	0	12	15000
Vietnam	0	0		0	0	0	0	0	0
WORLD	**2608**	**16**	**6**	**439**	**371,989**	**36**	**29,958**	**93**	**101,395**

* Data not available

Source: Compiled from "World Nuclear Power Reactors 2007-08 and Uranium Requirements," World Nuclear Association, June 9, 2008, http://www.world-nuclear.org/info/reactors (accessed on June 9, 2008); Mycle Schneider, "The World Nuclear Industry Status Report 2007," Greens-EFA Group in the European Parliament, January 2008, http://www.greens-efa.org/cms/topics/dokbin/206/206749.pdf (accessed on June 14, 2008), p.17.

NOTES

1. Intergovernmental Panel on Climate Change (IPCC), "Carbon Dioxide Capture and Storage," 2005, Special Report, http://www.mnp.nl/ipcc/pages_media/SRCCS-final/IPCCSpecialReportonCarbondioxideCaptureandStorage.htm (accessed on June 9, 2008), p. 55.

2. For a snapshot of the two sides of the debate, see Malcolm C. Grimston, "Nuclear Energy: Public Perceptions and Decision-Making," paper presented at World Nuclear Association, Annual Symposium 2002, September 5–6, http://www.world-nuclear.org/sym/2002/grimston.htm (accessed on June 1, 2008).

3. Eisenhower promoted the idea of diverting nuclear technology for peaceful uses to support economic development. The text of his 'Atoms for Peace' speech on peaceful uses of atomic energy before the U.N. General Assembly on December 8, 1953 is available at http://www.atomicarchive.com/Docs/Deterrence/Atomsforpeace.shtml (accessed on January 4, 2008).

4. Hans Blix, "Nuclear Power in the 21st Century," *Nu–Power,* Nuclear Power Corporation of India Limited, Vol. 11, No. 1–3 (1997), http://www.npcil.nic.in/nupower_vol11_1-3/hansblix.htm (accessed on March 29, 2006).

5. Richard L. Itteilag and James Pavle, "Nuclear Plants' Anticipated Costs and Their Impact on Future Electric Rates," *Public Utilities Fortnightly,* March 21, 1985, pp. 35–37; Ibid.

6. The East Asian region accounted for an increase of 21 power units while South Asia and Middle East operationalized eight new reactors. International Atomic Energy Agency (IAEA), "Energy, Electricity and Nuclear Power: Developments and Projections—25 Years Past and Future," 2007, p. 45.

7. Ibid. In North America, there was a decline of 13 nuclear power units between 1995–2000 and Europe remained stagnant during this period.

8. International Energy Agency (IEA), *World Energy Outlook 2007: Fact Sheet—Global Energy Demand,* 2007, http://www.iea.org/textbase/papers/2007/fs_global.pdf (accessed on June 11, 2008).

9. IAEA, "Energy, Electricity and Nuclear Power," p. 68.

10. "World Nuclear Power Reactors 2007-08 and Uranium Requirements," *World Nuclear Association,* June 9, 2008, http://www.world-nuclear.org/info/reactors.htm (accessed on June 10, 2008).

11. Ibid.

12. Mycle Schneider, "The World Nuclear Industry Status Report 2007," *Greens-EFA Group in the European Parliament,* January 2008, http://www.greens-efa.org/cms/topics/dokbin/206/206749.pdf (accessed on June 14, 2008), p. 6.

13. Calculated from "World Nuclear Power Reactors 2007–08," 2008.

14. The figure is the summation of China's under construction, planned, and proposed plants. Ibid.

15. During the initial upsurge, technological constraints kept the developing world out the mainstream for the most part. In 1985, Latin America, Africa, South Asia, Middle East, and South East Asia together accounted for merely 12 of the 363 operational nuclear power units in the world; this came to five GWe generating capacity as compared to 242 GWe for the rest of the world. IAEA, "Energy, Electricity and Nuclear Power," pp. 44, 49.

16. The quoted figure is for 2004. "Lighting the Way: Toward a Sustainable Energy Future," *Inter Academy Council,* October 2007, http://www.interacademycouncil.net/Object.File/Master/12/060/1.%20The%20Sustainable%20Energy%20Challenge.pdf (accessed on March 4, 2008), section 1, p.9; Aviel Verbruggen, "Renewable and Nuclear Power: A Common Future?" *Energy Policy,* doi:10.1016/j.enpol.2008.06.024 (2008), p. 3.

17. Massachusetts Institute of Technology (MIT), "The Future of Nuclear Power," 2003, http://web.mit.edu/nuclearpower/ (accessed on June 4, 2005), p. 37.

18. Jia Hu, "The Future of Renewable Energy," *Harvard Political Review Online,* 2006, http://hprsite.squarespace.com/the-future-of-renewable-enegy/ (accessed on July 30, 2008); Energy Information Administration, "Annual Energy Outlook 2008," Department of Energy, Report No. DOE/EIA-0383, June 2008.

19. Michael Toman, James Griffin, and Robert J. Lempert, "Impacts on U.S. Energy Expenditures and Greenhouse-Gas Emissions of Increasing Renewable-Energy Use," technical report, *RAND Corporation,* 2008, p. xii. For a somewhat more optimistic view, see Quirin Schiermeier, et al., "Electricity Without Carbon," *Nature,* Vol. 454, Issue No. 7206, August 14, 2008, pp. 816–23.

This view should not be taken to be dismissive of the potential of new renewables as commercial energy sources over the long run. In fact, renewable energy continues to generate intense interest as is obvious from the support to the sub-sector in a number of countries. The environmentally clean nature and abundant supply of these sources clearly make them stand out as obvious candidates to underpin a viable long-term energy scenario. However, as indicated, given the level of technology and development of the sub-sector at the moment, it remains largely irrelevant to the projected time frame of this study.

20. Capital costs include construction costs of plants, labor, and regulatory expenses. Marginal costs comprise fuel and operation and management expenditures.

21. This is a measure of the total project cost from construction to retirement and decommissioning spread evenly over the useful output (kWh) of the project and expressed in present value.

22. For the description and methodology of the cost comparison conducted in the study, see MIT, "The Future of Nuclear Power," pp. 38–43, 131–56.

23. The higher estimates are a consequence of the rising construction material costs spurred by growing international demand for these items, capacity bottlenecks along the supply chain, and higher uranium fuel costs, among others. The Keystone Center, "Nuclear Power Joint Fact-Finding," June 2007, http://www.keystone.org/spp/documents/FinalReport_NJFF6_12_2007(1).pdf (accessed on August 4, 2008), pp. 33, 38–42.

New renewable energy sources are even more expensive than the nuclear option. The World Nuclear Association estimates onshore and offshore wind energy costs at 3.5–11 cents per kWh and 6–15 cents per kWh respectively. Estimates for solar photovoltaic energy are as high as 20–50 cents per kWh and wide-scale power generation capacity is still not believed to be on the horizon. Further, renewable energy sources have a problem of being intermittent and thus lacking predictability. Costs increase as they require feed-forward control and also have to be complemented by backup energy sources. Verbruggen argues that the future competitiveness of renewable energy remains critically dependent on the ongoing efforts at end-use energy improvements and thus, intensity reductions. Hu, "The Future of Renewable," 2008; John Twidell and Tony Wier, *Renewable Energy Sources,* second edition (London: Spon Press: 2006), pp. 10–15; Aviel Verbruggen, "Electricity Intensity Backstop Level to Meet Sustainable Backstop Supply Technologies," *Energy Policy,* Vol. 34 (2006), pp. 1310–17.

24. Overnight costs do not include escalation and interest costs during construction. Marilyn C. Kray, "Long-Term Strategy for Nuclear Power," presentation made at a workshop on The 10–50 Solution: Technologies and Policies for a Low-Carbon

Future, Pew Center National Commission on Energy Policy, March 26, 2004; The Keystone Center, "Nuclear Power Joint," p. 34.

25. India's most prominent nuclear plant, the Kudankulam, is expected to cost $1,550/kWe. China's Ling Ao-2 and Tianwan reactors that came on line recently cost $2,200/kWe and $1,600/kWe respectively (costs calculated from project particulars available at R.Y. Narayanan, "Kudankulam Nuclear Power Project Ahead of Schedule," *The Hindu,* January 2, 2003, http://www.thehindubusinessline.com/2003/01/02/stories/2003010200881700.htm; and "China's Nuclear Power Reactors," *Nuclear Threat Initiative,* http://www.nti.org/db/china/pwrrctr.htm (accessed on June 3, 2008). In India, coal plants utilizing the latest, supercritical technology cost little over $1,000/kWe. See for example, project details of the Tata Mundra coal plant, India's most advanced electricity generation venture. International Finance Corporation, "Tata Mundra Project," http://www.ifc.org/ifcext/southasia.nsf/Content/TataMundra_FAQ (accessed on June 11, 2008).

26. Ramana assumes lifetime costs of 30 years for coal plants, 40 years for a nuclear reactor, and a capacity factor of 80 percent. He argues that assigning such a low value of capital is unrealistic for a country like India which is capital-starved and thus has multiple competing infrastructural demands on the pie of capital. Indeed, even for developed countries, the Nuclear Energy Agency considers a discount rate of 10 percent as realistic in a privatized nuclear energy market. M. V. Ramana, "Nuclear Power in India: Failed Past, Dubious Future," presentation made at the Nonproliferation Policy Education Center, May 10, 2006, http://www.npec-web.org/Frameset.asp?PageType=Single&PDFFile=Ramana_NPEC_May10&PDFFolder=Presentations (accessed on March 23, 2008); M.V. Ramana, "Nuclear Power in India: Failed Past, Dubious Future," paper presented at the *Nonproliferation Policy Education Center,* May 10, 2006, http://www.npec-web.org/Essays/Ramana-NuclearPowerInIndia.pdf (accessed on Marc 23, 2008), p.16; Nuclear Energy Agency, "Nuclear Energy in a Sustainable Development Perspective," OECD/NEA, Paris, 2000.

27. World Nuclear Association, "Nuclear Power in Russia," March 2008, http://www.world-nuclear.org/info/inf45.html (accessed on June 11, 2008).

28. Japan's Citizen's Nuclear Information Center argues that official estimates do not take all costs of nuclear energy production into account. "Cost of Nuclear Power in Japan, *Citizen's Nuclear Information Center,* http://cnic.jp/english/newsletter/nit113/nit113articles/nit113cost.html (accessed on March 24, 2008). However, opposing views have been arguing for some time that the cost of nuclear energy in Japan has been decreasing steadily and has made nuclear energy cheaper than alternatives. For this view, see "The Cost Structure of Japan's Nuclear Power Generation

and Its Future Outlook," *Central Research Institute of the Electric Power Industry,* Y98019, June 1999; Tatsujiro Suzuki, "Energy Security and the Role of Nuclear Power in Japan," *Central Research Institute of the Electric Power Industry,* undated, http://www.nautilus.org/archives/energy/eaef/Reg_Japan_final.PDF (accessed on June 11, 2008), pp. 21, 37–39.

29. Examples of European countries where nuclear power is cheaper include France, Finland, Switzerland, Netherlands, Slovakia, Romania, Czech Republic, and Belgium. See World Nuclear Association, "The Economics of Nuclear Power," May 2008, http://www.world-nuclear.org/info/inf02.html (accessed on June 4, 2008). Figures are for 2003.

30. Tae Joon Lee, Kyung Hee Lee, and Keun-Bae Oh, "Strategic Environments for Nuclear Energy Innovation in the Next Half Century," *Progress in Nuclear Energy,* Vol. 49 (2007), p. 404.

31. In the U.S., the cost of 75 of the current nuclear plants was estimated at $45 billion in 1986 while the actual cost came out to be $145 billion; this represented a cost overrun of over 200 percent. Energy Information Administration, "An Analysis of Nuclear Power Plant Construction Costs," *U.S. Department of Energy,* 1986; Ibid., p. 3.

32. Such a move is usual for investors under deregulated markets where investors become the principal bearers of risk; this essentially amounts to an increase in the capital cost. MIT, "The Future of Nuclear Power," p. 38.

33. For a snapshot of some of the major investment risks, see Peter Bradford and David Schlissel, "Why a Future for the Nuclear Industry is Risky," *Friends of Earth (with others),* January 2007, http://www.iccr.org/issues/globalwarm/risky_Jan07.pdf (accessed on June 9, 2008), pp. 2–3.

34. A pertinent example is Finland's third-generation Olkiluoto-3 nuclear power reactor which has been under construction since 2005. The reactor is 18 months behind schedule and is now scheduled for commercial launch in 2011. The final construction cost of the plant is estimated at $3,750/kW as compared to the original estimate of $2,350. "Areva, Siemens Warn of Further Delay in Finnish Nuclear Reactor Project: Update," *Forbes,* October 8, 2007, http://www.forbes.com/business/fee/afx/2007/08/10/afx4007127.html (accessed on August 4, 2008); The Keystone Center, "Nuclear Power Joint," p. 32.

35. Gail H. Marcus, "Innovative Nuclear Energy Systems and the Future of Nuclear Power," *Progress in Nuclear Energy,* doi:10.1016/j.pnucene.2007.10.009 (2007), p. 93.

The U.S. has introduced concessions for the nuclear industry through its 2005 Energy Act. The Act does reflect a revival of the government interest. It provides for construction loan guarantees, construction completion insurance, and energy production credits. The U.S. has also revamped its licensing procedures including the introduction of a new option of combined construction and operating licenses. These concessions are responsible for a modest number of investors having expressed interest in the sector (there have been applications for early site permits and some investors have made commitments to purchase long-lead time components). For details of the measures taken by the U.S., see Larry Parker and Mark Holt, "Nuclear Power: Outlook for New U.S. Reactors," *Congressional Research Service,* Resources, Science and Industry Division, March 9, 2005, http://www.fas.org/sgp/crs/misc/RL33442.pdf (accessed on June 3, 2008), pp. 6–13. The 2005 Energy Act is available at http://www.epa.gov/oust/fedlaws/publ_109-058.pdf (accessed on September 26, 2007). For a critique of the logic of U.S. concessions and the mounting costs, see Thomas B. Cochran, "Issues: Nuclear Weapons, Waste and Energy: The Future Role of Nuclear Power in the United States," paper presented at Western Governors' Association North American Energy Summit, April 15, 2004, http://www.nrdc.org/nuclear/pnucpwr.asp (accessed on June 14, 2008).

36. "Credit Aspects of North American and European Nuclear Power," *Standard & Poor's,* January 9, 2006. Other rating agencies share the same sentiment. See Schneider, "The World Nuclear Industry," pp. 11–12.

37. Ramana, "Nuclear Power in India" (presentation). Figures have been converted from Indian rupees using 2006 exchange rates.

38. International Panel on Fissile Materials, "Global Fissile Material Report 2007," 2008, http://www.fissilematerials.org/ipfm/site_down/gfmr07.pdf (accessed on June 2, 2008), p. 86.

39. While China and India do not have a history of abrupt policy reversals in their energy sectors, one example of a reversal with catastrophic consequences in the region was Pakistan's move not to honor its investment agreements with foreign Independent Power Producers (IPPs) during the mid-1990s. The result was a prolonged diplomatic and legal tussle which shattered Pakistan's investment climate and led to exodus of foreign capital. For a brief overview of the IPP controversy, see "Foreign Investment Falls in South Asia," *BBC,* September 28, 1999, http://news.bbc.co.uk/2/hi/south_asia/459748.stm (accessed on September 3, 2006). More recently, India had to defer temporarily a controversial civilian nuclear energy deal with the U.S. While a number of factors were at play, the most prominent factor behind the delay was the insistence of the leftist political parties who were part of

the domestic ruling coalition to reject the U.S. offer on symbolic grounds. This was after India had desperately lobbied to have the U.S. make the offer in the first place. "U.S.-India Nuclear Deal Appears to be in Trouble," *International Herald Tribune*, June 18, 2008, http://www.iht.com/articles/ap/2008/06/18/news/India-US-Nuclear.php (accessed on June 18, 2008).

40. Joon, Lee, and Oh, "Strategic Environments for Nuclear Energy," p. 404.

41. The dearth of investment prospects is compounded by the fact that the multilateral donors refuse to undersign nuclear power projects given the energy source's controversial nature. A quote from a World Bank report in the early 1990s still accurately reflects current donor sentiment: "Nuclear plants in the power sector would not be economic; they are large white elephants." World Bank, "Guideline for Environmental Assessment of Energy and Industry Projects," Technical paper No.154/1992, Environmental Assessment Sourcebook, Vol. III, 1992.

42. India's Electricity Act 2003 explicitly states the need to develop nuclear energy on a competitive basis. Russia, which initially planned to fund nuclear energy from the public sector, has realized the enormity of funding a $492 billion project and now plans to have the power sector under market competition by 2020. For the text of India's 2003 Electricity Act, visit the Ministry of Power's official website at http://powermin.nic.in/acts_notification/electricity_act2003/preliminary.htm (accessed on June 7, 2008). For information on Russia's nuclear power expansion and investment plans, see World Nuclear Association, "Nuclear Power in Russia," 2008.

43. After years of low capacity factors, the U.S. began to operate plants at 90 percent plant availability post-2000. MIT, "The Future of Nuclear Power," p. 47.

44. Cochran, "Issues: Nuclear Weapons," 2004.

45. In 2001, IPCC estimates suggested that global temperatures could rise by 1.4–5.8 degree Celsius by the end of the century. However, these projections are now considered gross underestimations. The actual rise in temperatures could be two and a half times as much. IPCC's recent reports are unequivocal that global warming is now a virtually irreversible trend with catastrophic consequences including higher disease incidences, drought, water scarcity, and flooding. IPCC, "Climate Change 2001: The Scientific Basis" (Cambridge: Cambridge University Press, 2001), *W*orking Group I Report, p.13; Ted Nordhaus and Michael Shellenberger, "Scrap Kyoto," *Democracy,* Issue 9 (Summer 2008), p. 10; IPCC, "Climate Change 2007: The Physical Science Basis," Working Group I Report, 2007, pp. 5–8.

46. IPCC creates different scenarios for carbon emissions increase over the years to provide a sense of the level of emission reductions that are required. This is the level at which scientists tend to agree melting of the major ice caps can be prevented. Nordhaus and Shellenberger, “Scrap Kyoto,” p. 13.

47. IPCC, “Climate Change 2007: Mitigation of Climate Change,” Working Group III Report, 2007, p. 4. In 2006, carbon emissions linked to fossil fuels stood at 7 billion MT per year. International Panel on Fissile Materials, “Global Fissile Material Report 2007,” p. 87.

48. Ibid.

49. The Kyoto Protocol stipulates that countries would increase use of “new and renewable forms of energy, of carbon dioxide sequestration technologies, and of advanced and innovative environmentally sound technologies.” However, nuclear energy is not mentioned explicitly. Therefore, nuclear energy does not provide countries the benefit of obtaining credits against their emissions for investments that reduce emissions in the developing world. For the text of Kyoto Protocol, visit http://unfccc.int/resource/docs/convkp/kpeng.html (accessed on November 26, 2007).

50. Nuclear Energy Agency, “Nuclear Power and Climate Change,” 1997, http://www.nea.fr/html/ndd/climate/climate.pdf (accessed on June 10, 2008), p. 11; IAEA, “Nuclear Power’s Changing,” 2004; Anne Lauvergeon, “Reliable and Sustainable: Towards a New Image of Nuclear Energy,” speech delivered at the World Nuclear Association, Annual Symposium, September 5–7, 2001, www.world-nuclear.org/sym/2001/lauvergeon.htm (accessed on June 17, 2008).

51. International Panel on Fissile Materials, “Global Fissile Material Report 2007,” p. 87.

52. The Nuclear Energy Agency sketches different scenarios. The scenario that sees a constant growth in nuclear power envisions the mentioned emissions savings. Nuclear Energy Agency, “Nuclear Power and Climate Change,” p. 7.

53. Ibid., p. 11; IAEA, “Nuclear Power’s Changing,” 2004.

54. A ten-fold increase in the installed capacity of nuclear energy will cumulatively reduce 15 percent of the carbon emissions by the end of the century. Joon, Lee, and Oh, “Strategic Environments for Nuclear Energy,” p. 399.

55. Nordhaus and Shellenberger, “Scrap Kyoto,” p. 15.

56. This was the finding of the U.S. Department of Energy's famous "Five-Labs Study." The cited figure is quoted in Ibid.

57. While most studies suggest that geological storage capacity between 1,000 and 2,000 Gt of carbon dioxide is likely (some outliers even suggest global aquifer capacity as high as 11,000 Gt), only about 200 Gt is guaranteed at the moment. Moreover, carbon capture and storage options are estimated to raise the cost of coal and gas generated energy by 30–60 percent. For estimates of carbon dioxide storage space and costs of capture and storage, see IPCC, "Carbon Dioxide," pp. 220–24; 341–62. For views that highlight the enormity of the task to make carbon storage commercially viable and importance of the uncertainty about storage capacity in terms of determining future energy choices, see Schiermeier, et al., "Electricity Without Carbon," *Nature,* p. 822; and Williams, "Can We Afford to Delay," 2006.

58. Individual countries have specific targets in line with the goal of reduction at five percent below the 1990 levels. The provision is contained in Article 3 of the Protocol. Countries are either likely to fail in achieving their reduction targets under Kyoto or do so only by purchasing emissions reductions under the Protocol's Clean Development Mechanism. Nordhaus and Shellenberger, "Scrap Kyoto," p. 13.

59. While the U.S. instituted a nuclear production tax credit of 1.8 cents/kWh for a maximum of 6,000 megawatts of new nuclear capacity for the first eight years of operation through the 2005 Energy Act, renewable energy sources like wind get this concession for the entirety of their productive life. For details of loan guarantees, see Parker and Holt, "Nuclear Power: Outlook for New U.S. Reactors," p. 12.

In the recent U.N. Climate Change Conference in Bali, Indonesia, the U.S. team's envisioned "Bali road map" did not explicitly include nuclear power as an option. "U.S. Still Refuses Agreement on Binding Emissions Limits," *World Resources Institute,* Part V, December 13, 2007, http://earthtrends.org/updates/node/268 (accessed on December 14, 2007).

60. "Where Carbon is Taxed," *Carbon Tax Center,* June 19, 2008, http://www.carbontax.org/progress/where-carbon-is-taxed/ (accessed on June 20, 2008).

61. "Economics of Climate Change," *The Encyclopedia of Earth,* March 14, 2008, http://www.eoearth.org/article/Economics_of_climate_change (accessed on June 4, 2008).

62. MIT, "The Future of Nuclear Power," p. 42.

63. “Economics of Climate Change,” 2008.64. Nordhaus and Shellenberger, “Scrap Kyoto,” p. 15.

65. “Japan Should Introduce Carbon Tax in 2007—Ministry,” *Reuters,* October 27, 2005, www.planetark.com/dailynewsstory.cfm/newsid/33193/story.htm (accessed on June 2, 2008).

66. Nordhaus and Shellenberger call this the “pollution regulation paradigm.” In effect, the argument is that the requisite amount of carbon tax from an environmental perspective is politically untenable but what satisfies political concerns is irrelevant to the climate change agenda. Nordhaus and Shellenberger, “Scrap Kyoto,” p. 15.

67. The very premise for China and India to avoid any binding commitments on emissions is their unwillingness to compromise economic and social growth objectives. That said, there are signs that the two sides are beginning to realize the need to address the climate change agenda. For instance, China softened its previously deterministic stance on commitments and the need for emissions reductions in the recent climate change negotiations in Bali, Indonesia in December 2007. Richard Harris, “China Softens Stance on Emissions at Bali Meeting,” *National Public Radio,* December 13, 2007, http://www.npr.org/templates/story/story.php?storyId=17196587 (accessed on December 24, 2007).

68. The U.N. called Chernobyl “the greatest environmental catastrophe in the history of humanity.” For details of the incident, see “Chernobyl: Remembering the World’s Worst Nuclear Accident,” *Nuclear Age Peace Foundation,* http://www.wagingpeace.org/menu/action/urgent-actions/chernobyl/ (accessed on June 6, 2008). For details of the Three Mile Island Incident, see “Fact Sheet on the Three Mile Island Accident,” *U.S. Nuclear Regulatory Commission,* http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html (accessed on May 30, 2008).

69. For a list of accidents, see “Calendar of Nuclear Accidents and Events,” *Green Peace,* http://archive.greenpeace.org/comms/nukes/chernob/rep02.html (accessed June 4, 2008).

70. For a step by step timeline of the event and the damage it caused, see “Chronology and Press Reports of the Tokaimura Criticality,” *Institute for Science and International Security,* http://www.isis-online.org/publications/tokai.html (accessed on June 4, 2008).

71. See “Calendar of Nuclear Accidents.”

72. The study estimates the probability of accidents to the reactor cores would be 4 if 1,500 GWe were to come on line. An acceptable level, the study posits, would be 1 in 100,000 reactor-years. MIT, "The Future of Nuclear Power," p. 48.

73. For a positive view on the potential for Generation IV systems to be 'safe,' see Jacques Bouchard, "Nuclear Energy: New Challenges for the Future," in Joseph F. Pilat, ed., *Atoms for Peace: A Future after Fifty Years* (Washington, D.C.: Woodrow Wilson Center Press, 2007), pp. 148–55. For the potential for innovative nuclear technologies, see Marcus, "Innovative Nuclear Energy Systems," pp. 94–96.

74. MIT, "The Future of Nuclear Power," p. 53.

75. There are two kinds of nuclear fuel-cycles operational today. The 'once-through' fuel-cycle discards as waste, the spent fuel that comes out of the back end of the nuclear reactor. The 'closed' fuel-cycle reprocesses spent-fuel in reprocessing plants, a process that separates the uranium and plutonium isotopes contained therein and allows the separated fuel to be reused in the reactor. Ibid., p. 29.

76. Ibid., p. 51.

77. Presently, the majority of the spent fuel is stored on-site or near plant sites in tight confinements or water-filled cooling ponds.

78. Experimental testing and modeling exercises suggest that depositories could isolate the waste from human interaction such that the radioactive exposure in the vicinity would be well within 'safe' limits. MIT, "The Future of Nuclear Power," p. 54.

79. There are hardly any countries which have developed long-term strategies for final waste disposal. The only three states which have moved positively to tackle the nuclear waste problem are Finland, the U.S., and Sweden. Finland has approved a repository for spent fuel near Olkiluoto, the U.S. is developing one at its Yucca Mountain site in Nevada, and Sweden is conducting geological surveys to identify a suitable location. Marcus, "Innovative Nuclear Energy Systems," p. 93; IAEA "Nuclear Power's Changing," 2004.

80. The MIT figure assumes that all reactors would be operating once-through fuel cycles. The study refers to the U.S.' Yucca Mountain repository as the benchmark for capacity of repositories required in the future. We have replaced the mention of the Yucca Mountain with its actual capacity of 70,000 MT to give a more concrete estimate. MIT, "The Future of Nuclear Power," p. 61.

81. Like nuclear plants, repositories also have long preparation lead times. For example, the U.S. Yucca Mountain site was approved in 2002 but it is not expected to be operationalized till 2020. In fact, there are renewed concerns over the geological merit of the site as the U.S. Environmental Protection Agency has acknowledged that the site will leak radiation. Cochran, "Issues: Nuclear Weapons," 2004; The Keystone Center, "Nuclear Power Joint," p. 14. Finland will start construction on its site in 2011 and expects it to take nine years to prepare. The enormity of the task in terms of storing nuclear waste under a renaissance scenario is obvious.

82. Verbruggen, "Renewable and Nuclear Power," p. 10.

83. According to Itteilag and Pavle, the Three Mile Island incident led to safety-related retrofits which raised costs by $27–100 million per reactor unit. Itteilag and Pavle, "Nuclear Plants' Anticipated," p. 36.

84. Developing countries are generally believed to have lower safety standards. For example, in India radioactive waste is dumped near ultra-poor, 'Adivasi' villages without following adequate safety protocols. Even Russia, which has voluntarily acted as a dump of nuclear waste for other countries in the past, has followed questionable disposal practices, for instance around the region of Murmansk. See Sanat Mohanty, "Nuclear Energy in India: Feasible?" *The South Asian,* April 16, 2006, http://www.thesouthasian.org/archives/2006/nuclear_energy_in_india_feasib.html (accessed on May 23, 2006). Also see, Paul Keysers, "See Murmansk and Die," *Maxim* (Belgium), No. 20, December 2002, http://www.eng.yabloko.ru/Publ/2003/PAPERS/2/maxim_no_20_040203.html (accessed on June 17, 2008) [the article was originally published in Dutch as "Moermansk zien en dan sterven!"].

85. The estimate presumes that the increase in reactors would solely come by way of additional LWRs. International Panel on Fissile Materials, "Global Fissile Material Report 2007," p. 88.

86. Simply put, nuclear weapons can be manufactured in one of two ways. Either, the low-enriched uranium fuel that is used as input to nuclear reactors can be enriched using centrifuge technology to convert it into Highly Enriched Uranium. Alternatively, the separated plutonium from reprocessed fuel can be used to manufacture weapons.

87. MIT, "The Future of Nuclear Power," p. 66.

88. Ibid.

89. The most comprehensive work on this issue is contained in National Academy of Sciences' Committee for International Security and Arms Control (CISAC) studies on the threat from excess plutonium. CISAC estimated in 2005 that the U.S. and Russia could conceal enough fissile material to manufacture "several hundred nuclear weapons" while the other states could escape detection for another 15–30 weapons. The danger of theft is largely limited to Russia however. Committee on International Security and Arms Control, National Academy of Sciences, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials* (Washington, D.C.: The National Academies Press, 2005), p. 195. Also see Committee on International Security and Arms Control, National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium* (Washington, D.C.: National Academy Press, 1994), pp. 1–18.

90. Chaim Braun, "The Nuclear Energy Market and the Nonproliferation Regime," *Nonproliferation Review,* Vol. 13, No. 3 (November 2006), p. 639. Fast Breeder reactors produce plutonium from uranium isotopes but are yet to be employed on a commercial scale. They carry a greater risk of a nuclear accident as they utilize molten sodium as coolant which has chemical properties that makes it react violently to water and burn in air.

91. The Keystone Center, "Nuclear Power Joint," pp. 86–88. For a negative view on the ability of supply-side restraints to curb proliferation, see Tariq Rauf and Fiona Simpson, "Atoms for Peace and the Nuclear Fuel Cycle: Is it Time for a Multilateral Approach?" in Joseph F. Pilat, ed., *Atoms for Peace: A Future after Fifty Years* (Washington, D.C.: Woodrow Wilson Center Press, 2007), pp. 200–01. For a more nuanced argument, see Lawrence Scheinman, "Atoms for Peace: Facing Emerging Challenges," in Joseph F. Pilat, ed., *Atoms for Peace: A Future after Fifty Years* (Washington, D.C.: Woodrow Wilson Center Press, 2007), pp. 183–93.

92. Joseph Cirincione, Bomb Scare: *The History and Future of Nuclear Weapons* (New York: Columbia University Press, 2007), p.107.

93. While concerns about nuclear terrorism have been on the rise since the break up of the Soviet Union, projections have become especially alarmist since the revelation of the global nuclear black market in 2003 that was allegedly supplying weapon designs, technology, expertise, and hardware clandestinely to states and was even in contact with aspiring non-state terrorist outfits. The black market was allegedly being headed by A.Q. Khan, the "father" of the Pakistani nuclear bomb. For a scintillating account of the black market, see *Nuclear Black Markets: Pakistan, A.Q. Khan and the Rise of Proliferation Networks* (London: International Institute for Strategic Studies, 2007).

94. For reservations about reinventing the NPT, see Rauf and Simpson, "Atoms for Peace and the Nuclear Fuel Cycle," pp. 198–200.

95. India, Pakistan, Israel, and South Africa crossed the nuclear weapons threshold while remaining outside the NPT regime. North Korea managed to do so first by violating the NPT and then withdrawing altogether. Iran was also found in violation of its reporting requirements and enrichment activities under the NPT and remains a potential threat in terms of proliferation. Iraq and Libya also acknowledged having attempted to acquire a nuclear weapons capability.

96. Cirincione, *Bomb Scare,* pp. 105–09.

97. NPT is an inherently discriminatory treaty as it allows states that had demonstrated a nuclear weapons capability prior to 1968 to retain the capability with an in-principle promise to disarm (Article VI) in the future while denying the developing world the option to pursue a weapons program (Article I). The provision for 'full-exchange' on civilian nuclear technology (Article IV) was included to compensate the developing world for this discrimination. The text of the NPT is available at http://www.un.org/events/npt2005/npttreaty.html (accessed on March 10, 2007).

98. One pertinent example is the almost instantaneous reaction of a handful of countries that expressed interest in indigenous uranium enrichment programs after U.S. President George Bush had requested the Nuclear Suppliers Group to stop exporting enrichment technology to countries that did not possess full fuel-cycle capabilities. Interesting is the fact that none of the countries that reacted (Argentina, Australia, Canada, Kazakhstan, South Africa, and Ukraine) have an overtly antagonistic outlook towards the U.S, thus reflecting that a dichotomous landscape does not bode well even with those who do not feel threatened by the U.S. International Panel on Fissile Materials, "Global Fissile Material Report 2007," p. 89, 141 (note 348).

99. See for example, Wolfgang K. H. Panofsky, "Nuclear Insecurity," *Foreign Affairs,* Vol. 86, No. 5 (September/October 2007). Also see, Cirincione, *Bomb Scare,* pp. 101–02; and John P. Holdren, "The Proliferation Challenge and the Future of Nuclear Energy," presentation at a break-out session at the Annual Meeting of the National Academy of Sciences, Washington, D.C., May 1, 2005.

100. A number of variants of the multilateral approach have been tabled in the past. These include proposals to set up regional nuclear supply hubs, international enrichment parks, a clear cut division between nuclear exporters and importers,

joint enrichment through bilateral or multilateral arrangements, ownership of all nuclear fuel supplies by multinational corporations, among others. For various proposals, see Lawrence Scheinman, "The Nuclear Fuel Cycle: A Challenge for Nonproliferation," *Disarmament Diplomacy,* Issue No. 76 (March/April 2004), http://www.acronym.org/uk/dd/dd76/761s.htm (accessed on June 11, 2008); William Luers, Thomas R. Pickering, and Jim Walsh, "A Solution for the US-Iran Nuclear Standoff," *The New York Review of Books,* Vol. 55, No. 4, March 20, 2008; Rauf and Simpson, "Atoms for Peace," pp. 194–205; John Deutch, "Making the World Safe for Nuclear Energy," *Survival,* Vol. 46, No. 4, (Winter 2004–05), pp. 65–80.

101. Comment is non-attributable. It was made by a non-weapon state representative during an IAEA special event on Assurances of Nuclear Supply and Non-proliferation, Vienna, Austria, September 2006.

102. Man-Sung Yim, "Nuclear Nonproliferation and the Future Expansion of Nuclear Power," *Progress in Nuclear Energy,* doi:10.1016/j.pnucene.1005.10.003 (2006), p. 524.

103. U.S. National Security Strategy clearly hints at such a policy for the future. The entire emphasis is on denying "aspiring nuclear states or nuclear terrorists…access to the essential ingredient of fissile material." 'Aspiring states' remain undefined and open to interpretation. *The National Security Strategy of the United States of America,* March 2006, p. 20, http://www.whitehouse.gov/nsc/nss/2006/nss2006.pdf (accessed May 24, 2008). Republican U.S. Presidential candidate for the 2008 elections, John McCain also emphasized that Article IV of the NPT needs to be reconsidered. See John McCain, "An Enduring Peace Built on Freedom," *Foreign Affairs,* Vol. 86. No. 6 (November/December 2007).

104. See for example, the findings of the IAEA-sponsored survey conducted by Globe Scan, "Global Public Opinion on Nuclear Issues and the IAEA—Final Report from 18 Countries." The survey showed that while 62 percent of respondents favored retaining existing plants, 59 percent were opposed to building new ones. Summary findings are available at "Global Nuclear Survey: Public Support for New Power Plants Remains Tentative," Press Release 2005/16, December 14, 2005, http://www.iaea.org/NewsCenter/PressReleases/2005/prn200516.html (accessed on January 21, 2007). For the full survey report, visit http://www.iaea.org/Publications/Reports/gponi_report2005.pdf (accessed on January 21, 2007).

105. At least four states—Sweden, Germany, Belgium, and Netherlands—have a phase-out program. Italy, Switzerland, and Austria held referendums that showed that majority were opposed to nuclear power. Moreover, countries like Ireland, Norway, Denmark, Greece, and Poland have created policy or legal hurdles to nuclear energy. Grimston,

"Nuclear Energy: Public Perceptions," 2002. That some of these countries were earlier listed as examples where nuclear energy production is cost-competitive (see footnote 29) clearly suggests that at least in these states, nuclear energy's safety concerns trump its economic benefits. Belgium and Sweden took the phase-out decision even though nuclear energy contributed 54 and 46 percent of their electricity respectively (see appendix 1). The only European countries that continue to pursue the nuclear energy path aggressively are France, Ukraine, and Russia.

106. Germany has made tremendous investment in wind energy. Its efforts resulted in a 300-fold increase in wind power usage between 1990–2003. Hu, "The Future of Renewable," 2008.

Britain put any decision to build new nuclear plants on hold in 2003 pending public consultations. However, the renewable sector is supported by the public sector; renewable energy receives 1 billion British pounds in benefits from the government, a figure that is likely to be doubled by 2020. Department of Trade and Industry, "Meeting the Energy Challenge: A White Paper on Energy," May 2007, U.K., http://www.berr.gov.uk/energy/whitepaper/page39534.html (accessed on August 4, 2008).

107. While Japan has always been one of the leaders of the global anti-nuclear campaign, perceptions of its citizens became excessively negative after the 1999 nuclear accident at Tokaimura. For the impact this accident had on public sentiment, see Tsunoda Katsuya, "Public Response to the Tokai Nuclear Accident," *Risk Analysis,* Vol. 21, No. 6 (December 2001), pp. 1039–1046. The averseness in Japan is especially strong on the issue of siting. Yutaka Tanaka, "Major Psychological Factors Determining Public Acceptance of the Siting of Nuclear Facilities," *Journal of Applied Social Psychology,* Vol. 34, No. 6 (2004), pp. 1147–65. For a general overview of the averse perception in the country over the past two decades, see Tatsujiro Suzuki, "Energy Security and the Role of Nuclear Power in Japan," *Central Research Institute of the Electric Power Industry,* undated, http://www.nautilus.org/archives/energy/eaef/Reg_Japan_final.PDF (accessed on June 11, 2008), pp. 7–12.

108. "Nuclear Power in Russia," *Public Opinion Foundation,* Population Poll, February 16, 2006, http://bd.english.fom.ru/report/map/az/0-9/edomt0607_1/ed060723 (accessed on August 1, 2008).

109. IAEA, "Global Nuclear Survey," 2005. The current U.S. sentiment reflects a significant shift from the negative outlook since the 1980s. See Eugene A. Rosa and Riley E. Dunlap, "Poll Trends: Nuclear Power: Three Decades of Public Opinion," *The Public Opinion Quarterly,* Vol. 58, No. 2 (Summer 1994), pp. 295–324.

110. The Keystone Center, "Nuclear Power Joint," p. 64; Cochran, "Issues: Nuclear Weapons," 2004.

111. See footnote 84.

112. As an example, just the cost of a final repository—if comparable to the U.S.—would be to the tune of $43.6 billion that Yucca Mountain is expected to cost, even without any overruns.

113. The Keystone Center, "Nuclear Power Joint," p. 12.

114. Globe Scan, "Global Nuclear Survey," 2005.

115. FBI Director, Robert Mueller stated during his testimony to the U.S. Senate Intelligence Committee that nuclear power plants were on Al Qaeda's target list. "Testimony of Robert S. Mueller, III, Director, Federal Bureau of Investigation Before the Senate Committee on Intelligence of the United States Senate," February 16, 2005, http://www.fbi.gov/congress/congress05/mueller021605.htm (accessed on June 13, 2008).

116. The interest is believed to have been spurred by the actual goal of manufacturing nuclear weapons. Dan Murphy, "Middle East Racing to Nuclear Power," *The Christian Science Monitor,* November 1, 2007, http://www.scmonitor.com/2007/1101/p01s03-wome.html (accessed on November 2, 2007).

117. "Global Unease with Major World Powers and Leaders," *Pew Research Center,* Pew Global Attitudes Survey, June 27, 2007, http://pewresearch.org/pubs/524/global-unease-with-major-world-powers-and-leaders (accessed on July 30, 2008).

118. Man-Sung Yim and Petr A. Vaganov, "Effects of Education on Nuclear Risk Perception and Attitude: Theory," *Progress in Nuclear Energy,* Vol. 42, No. 2 (2003), p. 230.

119. The Keystone report discusses the concern about transparency specifically with regard to the U.S. nuclear industry regulations. The Keystone Center, "Nuclear Power Joint," pp. 13, 63–64.

120. Yim and Vaganov, "Effects of Education," p. 230.

121. IEA, *World Energy Outlook 2007: Fact Sheet,* 2007. Both China and India are already net importers of energy. They have insufficient domestic oil and natural gas resources. Specifically with regard to electricity, as far back as 2002, India imported 1,520 gigawatt-hour (GWh). The figure for China stood at 2,300 GWh. Energy

security is further exacerbated due to threat of disruption in their sea lanes of communication. For instance, China's only import route is through the Straits of Malacca, which is fraught with piracy and, more importantly, has always remained susceptible to a U.S. blockade that could be exercised in case of an eventuality in the Taiwan Straits. For data on electricity imports, see Indian and Chinese profiles in IAEA's Energy and Environment Data Reference Bank at http://209.85.215.104/search?q=cache:sbeWnm4UmoUJ:www.iaea.org/inisnkm/nekr/eedrb/data/IN-elim.html+india+electricity+imports&hl=en&ct=clnk&cd=1&gl=us; and http://iaea.org/inisnkm/nkm/aws/eedrb/data/CN-elim.html respectively (accessed on November 17, 2007).

122. A classic example of this is the protracted negotiations on the Iran-Pakistan-India gas pipeline project. Despite interest from India, and recently China, the U.S. has been successfully pressuring the Indian government not to conclude any deal with Iran. China has been equally wary of Indian and U.S. alarms over its involvement in Pakistan's Gwadar port aimed at expanding its oil and gas import routes, as well as its $70 billion, 25-year oil and gas import deal with Iran. Experts predict that India, China, and the U.S. may become increasingly confrontational in attempting to establish preeminence over the Indian Ocean's sea lanes of communication. See Moeed Yusuf, "Pakistan's View of Security in the Indian Ocean," paper presented at the Levy Chair Conference on The Indian Ocean: Security Challenges and Opportunities for Cooperation, Naval War College, May 14–15, 2008.

123. This fact is stressed in most recent official energy related documents. The Energy Act 2005 is the latest document that puts excessive emphasis on energy security.

124. Russia itself plays into the energy security equation in a different way. While it possesses substantial indigenous fossil fuels, it is developing the nuclear industry as a revenue-generating sector. It plans to reduce domestic gas consumption, instead benefiting from the monopoly it enjoys in gas exports to Eastern Europe. Nuclear energy will meet domestic demand in addition to producing 20 GWe of exportable surplus by 2030. While the impediments we have pointed out make this strategy risky, Moscow seems to be building on the promise of nuclear optimists. It has invested $55 billion of public funds to jump-start the beleaguered industry. Braun, "The Nuclear Energy Market," pp. 632–33; World Nuclear Association, "Nuclear Power in Russia," 2008.

125. The most comprehensive information about uranium reserves and availability is contained in the periodically updated publication, OECD and IAEA, *Uranium 2005: Resources, Production and Demand* (Paris: Nuclear Energy Agency, 2006).

126. The figure is based on the 5.5 million tons of known uranium reserves and holds the current rate of uranium production and consumption constant. Schiermeier, et al., "Electricity Without Carbon," p. 817.

127. Ibid.

128. Ibid. Another measure of the energy density advantage for the nuclear option is that one miniscule uranium fuel pellet (0.3 inches in diameter and 0.5 inches in length) produces energy equal to 17,000 cubic feet of natural gas and 1,780 pounds of coal. Mark Brandly, "The Case for Nuclear Power," *Virginia Viewpoint,* No. 9, October 2001, http://www.virginiainstitute.org/viewpoint/_vvbrandly.html (accessed on May 29, 2008).

129. Lauvergeon, "Reliable and Sustainable," 2001.

130. Lee and Oh, "Strategic Environments," p. 401. Some estimates put uranium's share in the total cost as low as eight percent. Lauvergeon, "Reliable and Sustainable," 2001. In terms of costs of electricity production, the World Nuclear Association puts uranium fuel cost at 0.50 cents/kWh. World Nuclear Association, "The Economics of Nuclear Power," 2008.

131. Lauvergeon, "Reliable and Sustainable," 2001.

132. The Indo-U.S. deal has remained at the forefront of the non-proliferation debate since 2005. It was even put in cold storage temporarily after India declined to go through with it in the summer of 2008, citing domestic political reasons. The deal also faced tremendous international pressure and continues to be hotly debated among non-proliferation pundits. For a brief timeline of the progress and eventual failure of the deal, see "Timeline: Twists and Turns in the India-U.S. Nuclear Deal," *Reuters,* August 24, 2007, http://www.reuters.com/article/newsOne/idUSDEL8109820070824 (accessed on August 25, 2007). For information on the other mentioned bilateral deals, see "India and Russia in Nuclear Deal," BBC, January 25, 2007, http://www.bbc.co.uk/go/pr/pf/-/2/hi/south_asia/6298071.stm (accessed on January 30, 2008); "France and India in Nuclear Deal," BBC, February 20, 2006,http://www.bbc.co.uk/go/pr/fr/-/2/hi/south_asia/4731244.stm (accessed on January 30, 2008).

With regard to uranium supplies, one of the key officially cited reasons for India to pursue the deal with the U.S. was a shortage of indigenous uranium and lack of willing sellers given India's non-inclusion in the NPT. For a quoted statement to this effect from a senior Indian official, see Sanjeev Srivastava, "Indian PM Feels the Heat," July 25, 2005, BBC, http://news.bbc.co.uk/2/hi/south_asia/4715797.stm (accessed on December 17, 2005).

133. Elisabeth Bumiller and Carlotta Gall, "Bush Rules Out a Nuclear Deal with Pakistanis," *New York Times,* March 5, 2006, http://www.nytimes.com/2006/03/05/international/asia/05prexy.html (accessed on April 4, 2007).

134. Fast reactor technology allows for as much as 60 times greater energy production with the same amount of uranium input. Schiermeier, "Electricity Without Carbon," p. 818.

135. The Keystone Center, "Nuclear Power Joint," p. 41.

136. While estimates vary, none suggest that nuclear energy would become a majority of their energy production. In fact, even as a share of electricity generation, nuclear power will remain well behind coal and gas combined. For India and China, majority of the estimates of the share of nuclear energy in electricity generation in 2030 stand at less than 10 percent. The figures are highest for U.S., South Korea, and Japan but even these are below 50 percent.

137. The IAEA regularly provides assistance to countries to ensure safety of their power plants. It also publishes its benchmarks in the Safety Standards Series. Moreover, the Convention on Nuclear Safety requires countries to submit their nuclear power plant safety procedures. Further, the IAEA also set up an International Nuclear Safety Advisory Group (INSAG) which provides advisory opinion on safety matters. IAEA's mandate is contained within its statute, available at http://www.iaea.org/About/statute_text.html (accessed on January 30, 2008). None of IAEA's opinions or assistance, however, is binding.

138. Recently, there has been a revival of interest in Fast Reactors used for reprocessing spent fuel. Virtually all major nuclear operators are pursuing some form of Fast Reactor program. The latest impetus to this drive has been provided by U.S. Department of Energy's Global Nuclear Energy Partnership (GNEP) program that proposes expansion of Fast Reactor reprocessing. See Braun, "The Nuclear Energy Market," pp. 634–36.

139. The IAEA Additional Protocol was prepared in 1997 and is essentially a mechanism that allows the Agency expanded inspection and verification powers. It was developed in response to proliferation challenges North Korea and Iraq were believed to be posing at the time. For a brief summary, see "The 1997 IAEA Additional Protocol at a Glance," *Arms Control Association,* January 2008, http://www.armscontrol.org/factsheets/IAEAProtocol.asp (accessed on May 13, 2007). The Proliferation Security Initiative is a 2008 U.S. led development aimed at preventing worldwide shipment of Weapons of Mass Destruction (WMD) related material.

For details, see U.S. Department of State's International Information Programs brief titled "The Proliferation Security Initiative," http://usinfo.state.gov/products/oubs/proliferation/ (accessed on June 10, 2008). The Nuclear Suppliers Group, a multinational body made up of states that possess materials or technology relevant to nuclear weapons development, was asked by the U.S. President George Bush to deny exports to any country that did not already possess full enrichment capabilities. See "Fact Sheet: Strengthening International Efforts against WMD Proliferation," *The White House,* February 11, 2004, http://www.globalsecurity.org/wmd/library/news/usa/2004/20040211-5.htm (accessed on January 27, 2006).

140. International Energy Agency, *World Energy Outlook 2006,* OECD/IEA, 2006; quoted in Schneider, "The World Nuclear Industry," p. 7.

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