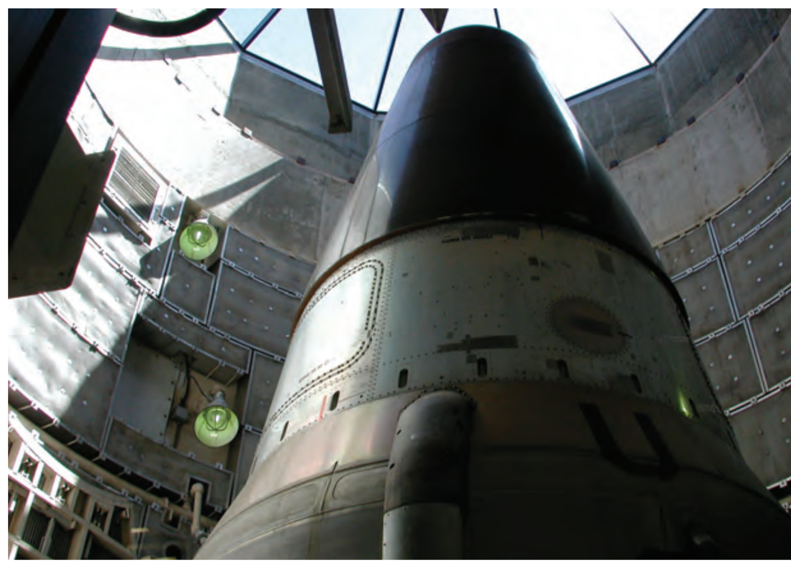
THE FUTURE OF NUCLEAR ENERGY TO 2030 AND ITS IMPLICATIONS FOR SAFETY, SECURITY AND NONPROLIFERATION

Part 1 – The Future of Nuclear Energy to 2030



TREVOR FINDLAY

CIGI
The Centre for International Governance Innovation
Centre pour l'innovation dans la gouvernance internationale

Addressing International Governance Challenges

The Future of Nuclear Energy to 2030 and its Implications for Safety, Security and Nonproliferation

Part 1 – The Future of Nuclear Energy to 2030

Trevor Findlay

CIGI's Nuclear Energy Futures Project is conducted in partnership with the Canadian Centre for Treaty Compliance (CCTC) at the Norman Paterson School of International Affairs, Carleton University, Ottawa. The project is chaired by CIGI Distinguished Fellow Louise Fréchette and directed by CIGI Senior Fellow Trevor Findlay, director of CCTC. CIGI gratefully acknowledges the Government of Ontario's contribution to this project.

Table of Contents

List of Tables and Figures

Technical Glossary

Units

BTU	British thermal unit
g	gram
kWh	kilowatt hour – a unit of electrical energy equal to the work done by one kilowatt acting for one hour
SWU	separative work unit – a measure of work done by a machine or plant in separating uranium into higher or lower fractions of U-235
t	tonne
We	watt (electric)
Wth	watt (thermal)

Elements and Compounds

C	carbon
CO2	carbon dioxide
Pu	plutonium
U	uranium
UF6	uranium hexafluoride

Metric Prefixes

k	kilo	10^3
M	mega	10^6
G	giga	10^9
T	tera	10^{12}

All dollar values in this report, unless otherwise noted, are in US dollars.

Foreword

By Louise Fréchette

2010 will be a pivotal year for nuclear issues. In April, President Obama will host a special summit on nuclear security. In May, parties to the Nuclear Non-proliferation Treaty will gather in New York for a review conference and in June, at the G8 Summit hosted by Canada, nuclear proliferation issues will occupy a prominent place on the agenda. New challenges to the nuclear nonproliferation regime by countries such as North Korea and Iran and growing concerns about the possible appropriation of nuclear material by terrorist groups arise at a time when there is much talk about a major increase in the use of nuclear energy for civilian purposes.

This so-called "nuclear renaissance" was the starting point of the Nuclear Energy Futures project which was initiated in May 2006. The purpose of this project was three-fold:

- to investigate the likely size, shape and nature of the purported nuclear energy revival to 2030 – not to make a judgement on the merits of nuclear energy, but rather to predict its future;
- to consider the implications for global governance in the areas of nuclear safety, security and nonproliferation; and
- to make recommendations to policy makers in Canada and abroad on ways to strengthen global governance in these areas.

The project commissioned more than a dozen research papers, most of which have been published in CIGI's *Nuclear Energy Futures Papers* series; held several workshops, consultations and interviews with key Canadian and foreign stakeholders, including industry, government, academia and non-governmental organizations; convened two international conferences, one in Sydney, Australia, and one in Waterloo, Ontario; and participated in conferences and workshops held by others. The project has assembled what is probably the most comprehensive and up-to-date information on possible additions to the list of countries that have nuclear power plants for civilian purposes. Along with this Survey of Emerging Nuclear Energy States (SENES), the project has produced a compendium of all the nuclear global governance instruments in existence today which will, I believe, prove to be a valuable reference tool for researchers and practioners alike.

The project was generously funded and supported by The Centre for International Governance Innovation and was carried out in partnership with the Canadian Centre for Treaty Compliance (CCTC) at Carleton University, Ottawa. I was very fortunate to have found in Dr. Trevor Findlay, director of the CCTC, the perfect person to oversee this ambitious project. I am very grateful to him and his small team of masters students at the Norman Paterson School of International Affairs, especially Justin Alger, Derek de Jong, Ray Froklage and Scott Lofquist-Morgan, for their hard work and dedication.

Nuclear issues are quintessential global issues. Their effective management requires the collaboration of a broad range of actors. Canada, with its special expertise in nuclear technology and its long history of engagement in the construction of effective global governance in this area, is particularly well placed to help deal with the new challenges on the horizon. My colleagues and I hope that the findings and recommendations of the Nuclear Energy Futures Project will be of use to policy makers as they prepare for the important meetings which will be held later this year.

Louise Fréchette
Chair of the Nuclear Energy Futures Project
Distinguished Fellow,
The Centre for International Governance Innovation

Preface to the Final Report of the Nuclear Energy Futures Project: Parts 1 to 4

This report culminates three-and-a-half years' work on the Nuclear Energy Futures (NEF) project. The project was funded and supported by The Centre for International Governance Innovation (CIGI) and carried out in partnership with the Canadian Centre for Treaty Compliance (CCTC) at Carleton University, Ottawa.

The purported "nuclear renaissance" was the starting point of the Nuclear Energy Futures project, which was initiated in May 2006. The purpose of this project was three-fold:

- to investigate the likely size, shape and nature of the purported nuclear energy revival to 2030 – not to make a judgment on the merits of nuclear energy, but rather to predict its future;
- to consider the implications for global governance in the areas of nuclear safety, security and nonproliferation; and
- to make recommendations to policy makers in Canada and abroad on ways to strengthen global governance in these areas.

Numerous outputs have been generated over the course of the study, including the Survey of Emerging Nuclear Energy States (SENES) online document, the GNEP Watch newsletter and the Nuclear Energy Futures papers series. The final installment from the project comprises six outputs: the Overview, an Action Plan, and a four-part main report. A description of how the project was conducted is included in the Acknowledgements section at the front of the Overview.

Part 1, The Future of Nuclear Energy to 2030, provides a detailed look at the renewed interest in global nuclear energy for civilian purposes. Growing concerns about energy security and climate change, coupled with increasing demand for electricity worldwide, have prompted many countries to explore the viability of nuclear energy. Existing nuclear states are already building nuclear reactors while some non-nuclear states are actively studying the possibility of joining the nuclear grid. While key drivers are spurring existing and aspiring nuclear states to develop nuclear energy, economic and other constraints are likely to limit a "revival." Part 1 discusses the drivers and challenges in detail.

Parts 2 through 4 of the main report consider, respectively, issues of nuclear safety, security and non-proliferation arising from civilian nuclear energy growth and the global governance implications.

PART 1: The Future of Nuclear Energy to 2030

The first decade of this millennium has seen a revival of global interest in the use of nuclear energy for generating electricity.[1] From around 2000 onwards several trends began to convince many observers that the coming years would witness a so-called nuclear energy "renaissance."[2] These have included the urgent need for "decarbonizing" the world's energy supply to mitigate global warming; the ravenous energy demands of China, India and other emerging economic powerhouses; the call for energy security or diversity; the new profitability but rapid ageing of the existing reactor fleet; the promise of new reactor technologies; and the challenges facing traditional energy sources, particularly recurrent spikes in the price of oil and natural gas and fears about their availability over the long term.

The nuclear industry, in the doldrums since the 1979 Three Mile Island accident and the 1986 Chernobyl disaster, has sensed a "second coming" and ramped up its research and development (R&D) and promotional and marketing activities accordingly. Governments, desperate for relatively "green" alternatives to extravagant carbon emitters like oil, coal and gas, and unconvinced that renewables like wind and solar energy can do the trick, have seized on the idea of nuclear power generation as a means of fulfilling their commitments to reduce greenhouse gas emissions. The hope would be not only to meet future baseload power requirements, but to sustain existing rates of economic growth (at least those that pertained prior to the current economic recession) and living standards.

Several countries, notably in East Asia, have already begun building new reactors as part of ambitious nuclear energy programs, while many others have announced plans, are studying the possibilities or are simply floating ideas. The countries with the most far-reaching targets for domestic expansion are China, India, Russia, the United Kingdom and the United States. The nuclear industries of these and other established players like France, Japan and South Korea have anticipated reactor sales opportunities and talked up the prospects of a revival (Thomas et al., 2007). Some states and companies are considering other ways to profit, such as increasing uranium exploration and mining or expanding uranium enrichment capacity.

Internationally, the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD), responding to their members' growing enthusiasm, have issued relatively optimistic forecasts. The World Nuclear Association (formerly the Uranium Institute), whose membership largely comprises uranium producers and reactor vendors, has done likewise. The launch of the Global Nuclear Energy Partnership (GNEP) and the Generation IV International Forum (GIF) has added to the enthusiasm. The nuclear trade press and the general media have touted the revival, mostly unquestioningly. There is certainly, then, a revival of interest in nuclear energy. The question is whether this interest is likely to be translated into action.

The purpose of this first part of the report is not to assess the merits of a nuclear revival but its likelihood. This involves the tricky business of attempting to predict the collective and cumulative impact of scores of decision makers in various guises. The future growth of nuclear energy is ultimately dependent on the confluence of decisions by governments, electricity utilities, the nuclear industry, private and institutional investors and international organizations. Perhaps most important of all will be the decisions of non-nuclear stakeholders, notably the general public as expressed through elections, opinion polls or other means, and the activities of civil society in supporting or opposing nuclear energy. One way of considering how policy makers will reach their decisions is to consider the balance of drivers and constraints. This first part of the study is thus devoted to analyzing the drivers and constraints most likely to influence decision making about nuclear energy in the coming decades and seeking to discover where the balance will lie.

The Drivers

The three most important drivers of the current revival of interest in nuclear energy are: the perceived increasing global demand for energy, specifically electricity; the quest for energy security or diversity; and the need to tackle climate change. Technology, in the form of improved efficiency of existing reactors and the promise of advanced reactor design, is also a driver. In addition there are political and strategic motivations that merit consideration.

Growing Energy Demand

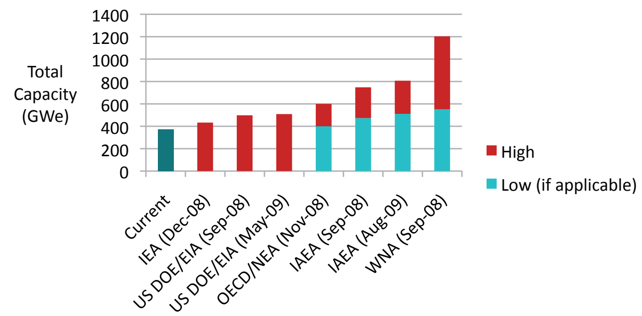
The International Energy Agency (IEA) projects world primary energy demand will increase by 45 percent between 2006 and 2030, an average annual rate of growth of 1.6 percent (International Energy Agency, 2008a: 78), slower than the average growth of 1.9 percent per year from 1980 to 2006. World electricity demand, which is more relevant for nuclear power — since electricity generation is by far its most important civilian application — is projected to grow at a higher rate annually than world primary energy demand. According to the IEA, demand will increase by 3.2 percent between 2006 and 2015, slowing to 2 percent annually on average from 2015 to 2030. The projected drop reflects a shift in the economies of non-OECD countries away from energy-intensive heavy manufacturing towards lighter industries and services, as well as "saturation effects in the OECD and some emerging economies" (IEA, 2008a: 139).

Where nuclear energy fits into this picture is often taken for granted, the assumption being that nuclear will automatically increase its share of the global energy mix, or at least maintain its current share in line with growth in energy and electricity demand overall. The IAEA, the most authoritative international source of information on nuclear energy, predicted in August 2009, as its high scenario, a doubling of global nuclear power capacity by 2030, from the current 372 gigawatts electric (GWe)[3] to 807 GWe; it assumes an end to the present financial crisis, continued economic growth and electricity demand, and the implementation of policies targeted at mitigating climate change (International Atomic Energy Agency, 2009a: 6-7).[4] Its low scenario projected an increase to just 511 GWe, reflecting a "conservative but plausible" revival.

The Nuclear Energy Agency, in its first ever *Nuclear Energy Outlook*, released in 2008, projected a total of just under 600 GWe by 2030 as its high scenario, while its low scenario indicated only a negligible increase over the current level, with new plants built only to replace old ones (Nuclear Energy Agency, 2008a: 19, 27). This puts both its high and low scenarios above the IAEA's. The NEA's study of various "business as usual" energy scenarios devised by other international organizations concludes that by 2030 and even by 2050 "fossil fuels (coal, oil and natural gas) will provide a growing share of energy supply, while nuclear power will not make a significant contribution to meeting demand growth" (NEA, 2008a: 94-95). "Business as usual" includes no significant effort to tackle carbon emissions through a carbon tax or "cap and trade" system and no effort to promote (and presumably subsidize) nuclear energy.

The IEA, traditionally more skeptical about nuclear energy and with a much broader energy mandate than its fellow OECD Agency the NEA, predicted in its 2008 nuclear reference scenario that world nuclear capacity would rise to just 433 GWe by 2030. This puts its estimate considerably below the IAEA's low estimate and on a par with that of the NEA (NEA, 2008a: 148). Although nuclear electricity output is expected to increase in absolute terms in all major regions except OECD Europe, the largest increases occurring in Asia, the IEA assumes that by 2030 nuclear's share of global electricity production will have fallen from 15 percent in 2006 to 10 percent, "reflecting the assumption of unchanging policies towards nuclear power" (NEA, 2008a: 142-143). In comparison, coal's share of the total world electricity production is projected to grow from 41 percent currently to 44 percent by 2030, 85 percent of the increase coming from China and India. Oil is expected to drop to just 2 percent. Gas demand was expected to drop due to higher prices, leaving its percentage share slightly lower by 2030 at 20 percent, but new plants, using high-efficiency gas turbine technology, will mostly meet the bulk of incremental gas demand. Since 2008 falling gas prices and the discovery of new methods of extracting gas from shale will have affected this projection. While plants with carbon capture and storage are likely to make only a minor contribution to electricity generation by 2030, the share of renewables is likely to rise considerably, from 18 percent in 2006 to 23 percent by 2030.

Global Nuclear Energy Projections at 2030



Sources: IAEA (2008b: 17; 2009a); EIA (2008: 233), IEO (2009: 251); OECD/NEA (2008a: 19); WNA (2008b)

The WNA, an organization devoted to promoting nuclear energy expansion, postulated in its 2008 *Nuclear Century Outlook* a low scenario of 552 GWe and a high of 1203 GWe for 2030, both considerably higher than the IAEA's projection. It describes these not as "growth" scenarios as such, but "rather the boundaries of a domain of likely nuclear growth" (World Nuclear Association, 2009d). The US Energy Information Agency (EIA), part of the US Department of Energy, predicted in September 2008 that, "despite considerable uncertainty about the future of nuclear power," world nuclear generating capacity would rise to 498 GWe in 2030, slightly higher than the IAEA's low scenario (Energy Information Administration, 2008). This would be the equivalent, it said, of adding approximately 124 new 1,000 MW reactors[5] to the current world reactor fleet of approximately 436 reactors of varying capacities (IAEA, 2009d).

A 2003 multidisciplinary study by the Massachusetts Institute of Technology (MIT) projected 1,000 GWe of operating nuclear power globally by 2050 (Massachusetts Institute of Technology, 2003: ix). Six years later its 2009 update estimated that this is "less likely than when it was considered in the 2003 study" (MIT, 2009: 5).

The Problem with Global Demand Projections

As even a cursory examination indicates, projections of a global nuclear revival are highly variable and not necessarily predictive.

First, they are often based on extrapolations of national and global demand for electricity, which are based in turn on predictions of national and global economic growth. Others take into account population growth and/or greenhouse gas reduction targets. None of these indicators necessarily translates into increased demand for nuclear energy. The WNA *Outlook*, for instance, is "built on country-by-country assessments of the ultimate growth potential of national nuclear programs, based on estimates of need and capability with projected population a key factor" (WNN, 2008b). Four of the scenario sets used by the NEA for its 2008 *Nuclear Energy Outlook*, the exception being those of the IAEA, used computer-based energy modeling incorporating such assumptions (NEA, 2008a: 92-93). As the recent economic downturn indicates, such "guesstimates" may be ill-founded. As the IAEA concedes of its own figures, these "should be viewed as very general growth trends whose validity must constantly be subjected to critical review" (IAEA, 2008a: 5). As the NEA points out, a larger role for nuclear depends crucially on government policies (NEA, 2008a: 100).

Second, there is often an assumption in such projections that nuclear energy will at least maintain its existing share of expanding electricity production. While it seems undeniable that global electricity demand will continue to rise due to population growth, economic growth, pressure from developing states for developed-world living standards and demand for electric cars to replace current vehicles (The Economist, 2009d: 15),[6] it cannot be assumed that nuclear will retain its share. That share has gradually fallen from its historic peak of almost 18 percent in 1996 to just below 14 percent in 2008 (BP, 2009). In terms of generating capacity, nuclear has also experienced a fall: after reaching a peak of 12.6 percent of world electricity generating capacity in 1990, nuclear declined to 8.4 percent in 2007 (IAEA, 2008a: 17; 2007a: 47). This occurred not only because other forms of energy generation expanded faster, but because old nuclear power plants were being shut down and not replaced. Between 1990 and 2007, 73 new reactors were connected to the grid worldwide and 62 were closed, resulting in a net global increase of only 11 reactors over this 17-year period (NEA, 2008a: 47-49).

Some of these closures have been for historic reasons that are unlikely to be repeated, notably the admission of former Soviet bloc states, Bulgaria, Slovenia and Lithuania, to the European Union (EU), which required the shutdown of their old Soviet reactors. Even so, the world's nuclear fleet is old. By January 2008 there were 342 reactors aged 20 years or older (78 percent of the total) (NEA, 2008a: 49). A major industrial effort will thus be required just to replace the current fleet — notwithstanding the possibility of life extensions to some existing plants of up to 30 years and maybe more.

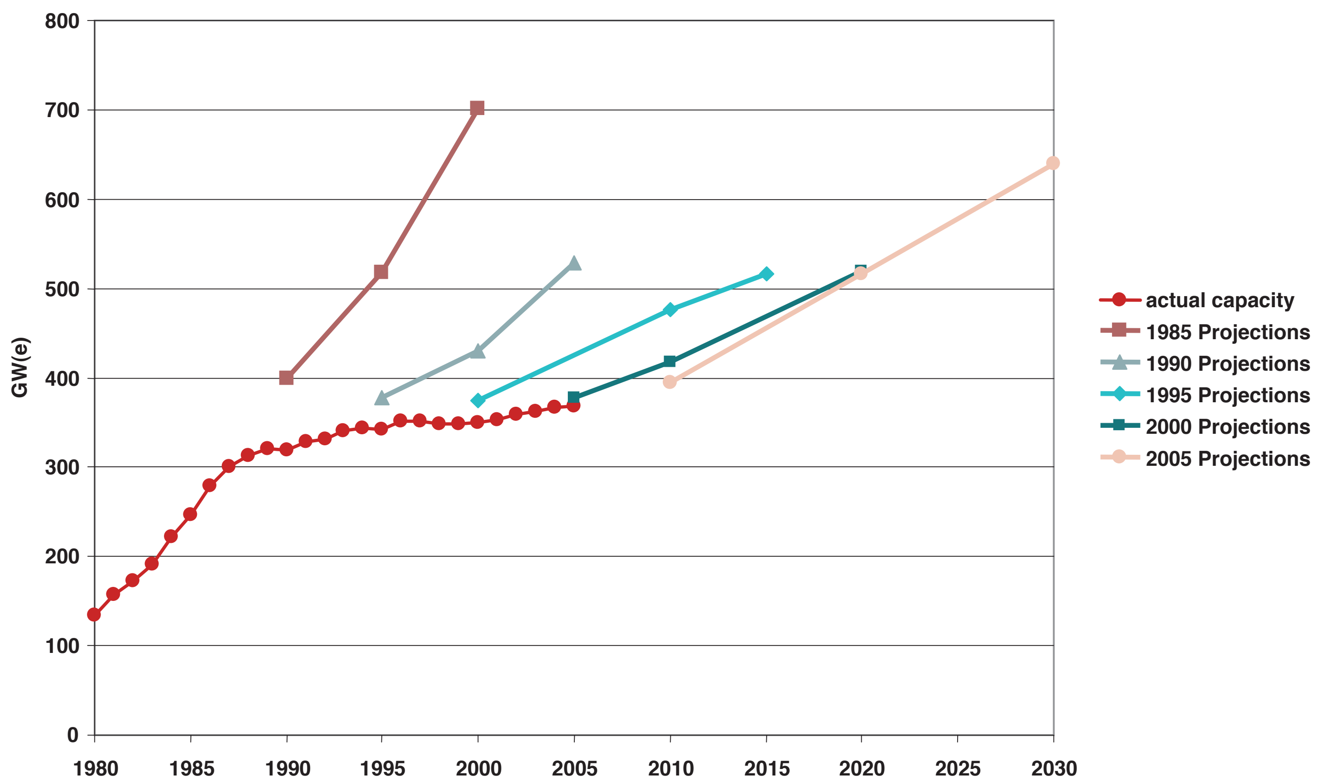
A third reason for skepticism about nuclear energy projections is the fact that aggregate figures are usually derived from totaling governments' announced policies and plans, in what the IAEA calls a "bottom up approach" (IAEA, 2007a: 3). An exception is the IEA, which says its figures reflect "the consistency of our rule not to anticipate changes in national policies — notwithstanding a recent revival of interest in nuclear power" (IEA, 2008a: 39). Nuclear explansion plans by governments are often overly optimistic, designed for internal political consumption and/or to impress neighbouring states, their immediate region or even international bodies like the IAEA. In some regions, notably Southeast Asia and the

Gulf, this project has observed discernible competition between states to be the first to acquire such "modern" technological artifacts. This is not a new phenomenon, but has characterized the history of nuclear energy from the time of the Atoms for Peace program in the 1950s and 1960s onwards (Pilat, 2007).

In compiling their aggregate global data, international organizations, especially those whose members are governments, have difficulty refuting national estimates, including those derived from political ambition rather than fact-based analysis. The IAEA's current low projection, for instance, is based on the assumption that "all nuclear capacity currently under construction or in the development pipeline gets constructed and government policies, such as phase-outs, remain unchanged" (IAEA, 2008b). Its high scenario is based on "government and corporate announcements about longer term plans for nuclear investments, as well as potential new national policies, such as responses to international environmental agreements to combat climate change." Essentially, these scenarios assume "full implementation of the long-term plans announced by governments and power utilities" (IAEA, 2007a: 3). To its credit, the Agency's estimates are not prepared in-house, but are established by an expert consultancy on Nuclear Capacity Projections (IAEA, 2008a: 6). Yet they are ultimately reliant on information supplied by member states. Hence their projections are often overinflated and are never exceeded by reality, as shown in the charts on pages 13 and 14.[7]

Some past projections have been wrong not just because of governments' over-optimism about future projects, but because of cancellations of projects already underway. The chart on page 14 shows the additional global nuclear electricity generating capacity planned between 1975 and 2005 that was never built due to cancellations. Had the plans proceeded, the world would have seen

IAEA Projections of World Nuclear Power Capacity (High Estimates)



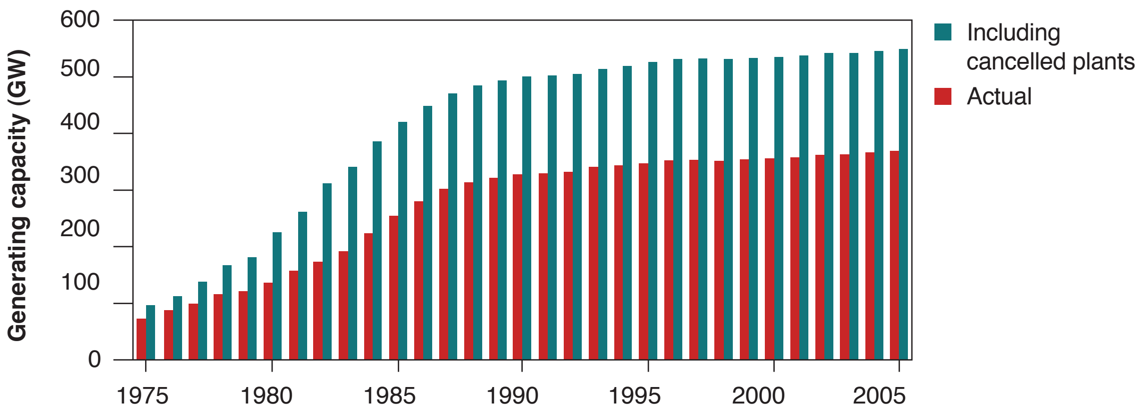
Source: IAEA (2007a: 54).

an additional 11 GWe of nuclear power commissioned every year. Of the 165 cancelled plants, construction had started on 62 and some were completed but never commissioned (IEA, 2008b: 300).

A final compounding problem is that global estimates produced by bodies like the IAEA, the IEA and the EIA are used by others without reference to the caveats attached to them in their original form. The IEA, for example, in its 2008 report *Energy Technology Perspectives*, uses figures from the WNA for a chart on "Plans and proposals for new nuclear power reactors" without mentioning how these are derived (IEA, 2008b: 298-299). The WNA naturally has a vested interest in promoting the greatest accretion in nuclear energy possible. Its *World News Report* of September 2008 thus emphasized the IAEA's high rather than low projections in reporting that "Nuclear Capacity Could Double by 2030" (WNN, 2008b).

Analysis and commentary in the media begins to feed on itself, creating hyperbole reminiscent of the nuclear hucksterism of the Atoms for Peace era (Boyer, 1985: 133-140). Journalistic books and academic tomes reinforce the image of the inevitability of a revival.[8]

Global Nuclear Generating Capacity



Source: IAEA, 2006, cited in IEA, 2008b: 300

Predictions for Developing Countries

Predictions about the demand for nuclear power in the developing world are especially problematic. It is sobering to consider a special *Market Survey for Nuclear Power in Developing Countries* issued by the IAEA in September 1973. It concluded that "the projected markets for nuclear plants which *will* [emphasis added] be commissioned" in 14 participating developing countries would total, by the end of the 1980s, 52,200 MW in the low estimate and 62,100 in the high (IAEA, 1973: 5). The chart below compares the predictions to the reality. The only states that ended up with nuclear power were the ones already engaged in building a reactor — Argentina, Mexico, Pakistan, South Korea and Yugoslavia. Of the rest only one — the Philippines — started to build a plant, but then stopped. Some of these states are, 30 years later, again talking about acquiring nuclear energy.

Predicted Versus Actual Additions to Nuclear Generation Capacity, 1980-1989

Country	Predicted capacity		Actual capacity	No. of reactors[10]
	Low	*High*		
Argentina	6,000	6,000	600	1
Bangladesh	0	600	0	0
Chile	1,200	1,200	0	0
Egypt	4,200	4,200	0	0
Greece	4,200	4,200	0	0
Jamaica	0	300	0	0
Republic of Korea	8,800	8,800	6,977	7
Mexico	14,800	14,800	650	1
Pakistan	600	600	0	0
Philippines	3,800	3,800	0	0
Singapore	0	2,600	0	0
Thailand	2,600	2,600	0	0
Turkey	1,200	3,200	0	0
Yugoslavia	4,800	9,200	666	1
Total	52,200	62,100	8,893	10

Source: IAEA (1973)

While all governments are prone to exaggerating their nuclear plans, one of the most egregious examples is India, which has consistently trumpeted huge increases in nuclear power generation, only to see its plans crumble. In 1970, India announced a 10-year plan calling for the construction of 2,700 MW of nuclear capacity by 1980, a level it reached only in 2,000 (Ramana, 2009: 5). Since receiving a waiver in 2008 from the Nuclear Suppliers Group (NSG) to import foreign nuclear equipment and materials, the Indian Atomic Energy Commission has projected that by 2050 nuclear power will generate 445 GWe, 35 percent of India's electricity generation, more than a hundred times today's figure (Ramana, 2009: 5-6).

Energy Security

A second driver of current increased interest in nuclear energy is the perceived need of states to ensure their energy security. Energy security — if taken to mean complete national self-sufficiency in energy or "energy independence" — is a chimera. No country in today's globalized world, with the possible exception of Russia, is able to be energy self-sufficient. Although governments and other observers often use the quest for "energy security" to make the case for nuclear power, what they are really calling for is *more* energy security or energy diversity. Diversity may in fact be the most important guarantee of energy security. As the Switkowski report on Australia's consideration of nuclear energy concluded, the most flexible and efficient national energy system "is likely to include numerous technologies, each economically meeting the portion of the system load to which it is best suited … a diversity of sources can also provide greater reliability and security of electricity supply" (Commonwealth of Australia, 2006: 48).

Nuclear energy has some inherent drawbacks in helping achieve energy security, however defined. Nuclear also cannot currently provide energy security to the vital transport sector — although a widespread switch to electric-powered vehicles would give it a bigger role. Nuclear power is also relatively inflexible in meeting peaks and troughs in electricity demand and can therefore never replace more flexible generation means like natural gas and coal if they suddenly become unavailable. Even France, which relies on nuclear for 77 percent of its electricity, and which since the 1970s' "oil shocks" has had a deliberate strategy for achieving "energy security," must fire up 40-year old oil plants to meet peak demand and rely on electricity exports to shed load in non-peak periods (Schneider, 2009: 55). Nuclear electricity is only usually suitable for baseload electrical power and reactors must be run at full capacity to be economic. Mycle Schneider has calculated that France's real energy independence, including the nuclear sector, is just 8.5 percent of its total energy generation capacity (Schneider, 2009: 64).

Uranium

The main argument in favour of nuclear energy providing energy security appears to be the ready availability and cheapness of uranium. In fact, the relative cheapness of the fuel compared with its energy intensity is one of the enduring advantages of nuclear energy. As the NEA puts it,

> The main advantages of nuclear power for energy security are the high energy density of uranium fuel combined with the diverse and stable geopolitical distribution of uranium resources and fuel fabrication facilities, as well as the ease with which strategic stockpiles of fuel can be maintained (NEA, 2008a: 154).

These claims are credible. One quarter of a gram of natural uranium in a standard fission reactor provides the same amount of energy as 16 kg of fossil fuels (MacKay, 2009: 161). Stockpiling large strategic reserves of uranium is easier and cheaper than for oil, coal or gas, thereby avoiding the risk of a sudden shutdown of supply. While there are only a handful of major uranium suppliers (see chart), two of those with the largest reserves, Australia and Canada, are judged to be politically stable and commercially reliable.

World's Major Uranium Producers (tonnes U)

Country	2007 (est.)	%
Canada	9,850	**22.73%**
Australia	7,600	**17.54%**
Kazakhstan	7,245	**16.72%**
Namibia	3,800	**8.77%**
Niger	3,633	**8.38%**
Russian Federation	3,381	**7.80%**
Uzbekistan	2,300	**5.31%**
United States	2,000	**4.62%**
Ukraine	900	**2.08%**
China	750	**1.73%**
South Africa	750	**1.73%**
Rest of World	1,119	2.58%
Total	**43328**	**100%**

Source: OECD/NEA (2008b: 39)

Moreover, uranium is ubiquitous. Global conventional reserves are estimated to be 4.7 million tons, with another 22 million tons in phosphate deposits and 4,500 million tons in seawater (currently economically unrecoverable). If the price of uranium ore goes beyond $130 per kg, phosphate deposits that contain low concentrations of uranium would become economic to mine (MacKay, 2009: 162). Prices at that level would also stimulate exploration for traditional sources, such as when the spot market price for uranium reached a record $234 per kg in December 2007 (they have since declined).

According to the NEA, sufficient uranium resources have been identified, if current usage rates apply, for 100 years of reactor supply (NEA, 2008a: 159). If the NEA's low scenario for expanded nuclear energy to 2030 of up to 404 GWe eventuates, the market will readily cope. However, if the NEA's high scenario to 2030 of 619 GWe is accurate, it cautions that "all existing and committed production centres, as well as a significant proportion of the planned and prospective production centres, must be completed on schedule and production must be maintained at or near full capacity throughout the life of each facility" (NEA, 2008a: 164). This seems a tall order in view of the recent record of uranium mining development delays, including in Australia and Canada, and may lead to uranium price rises in the future, followed inevitably by further bouts of exploration.

Price, not just reliability of supply, is a key consideration in assumptions made about uranium as a source of energy security. Most studies concur that the cost of natural or enriched uranium will not be a barrier to increased use of nuclear energy. From 1983 to 2003 uranium was in a 20-year price slump and thus an energy bargain. This was partly due to over-production in the 1970s when the price was high, but also due to the availability of "secondary" material held in various forms by civil industry and government, including military material (notably highly enriched uranium (HEU)) and recyclable material (spent fuel). Secondary sources have supplied 40-45 percent of the market in recent years (NEA, 2008a: 164). The surge in price between 2003 and 2007 was partly due to speculators in energy futures. Since most uranium sales are in the form of long-term contracts, the spot market volatility was misleading from an energy security perspective. But the price rise also represented a "market correction" based on the expectation of increased demand due to the anticipated revival in nuclear energy production. In addition the agreement between Russia and the US for the down-blending of HEU from dismantled Russian nuclear weapons for use in American reactors will expire in 2013, making this "secondary" source of uranium no longer available, although there is a possibility the agreement will be extended.

Thorium

Thorium, which is about three times as abundant as uranium, is sometimes touted as a possible fuel for extending the future of nuclear power. Although not fissionable in its natural state, a fissionable form, thorium 233, can be created in a normal reactor if added to the uranium fuel, or can be bred in a fast breeder reactor. Experiments with a thorium fuel cycle have been conducted in several countries during the past 30 years, including Canada, Germany, India, Russia and the US. India, which has four times as much thorium as uranium, is the most advanced in its plans. Norway, which has up to one- third of the world's thorium deposits, commissioned a report in 2007 by the Research Council of Norway, which concluded that "the current knowledge of thorium based energy generation and the geology is not solid enough to provide a final assessment regarding the potential value for Norway of a thorium based system for long term energy production" (Research Council of Norway, 2008). It recommended that the thorium option be kept open and that further research, development and international collaboration be pursued. According to the NEA:

> Much development work is still required before the thorium fuel cycle can be commercialized, and the effort required seems unlikely while (or where) abundant uranium is available. In this respect, recent international moves to bring India into the ambit of international trade might result in the country ceasing to persist with the thorium cycle, as it now has ready access to traded uranium and conventional reactor designs (WNA, 2009g).

It is clear that thorium will not be a commercially viable option before 2030.

Mixed Oxide (MOX) Fuel

Some in the nuclear industry suggest that the possibility of recycling plutonium reprocessed from spent nuclear fuel in the form of mixed oxide fuel (MOX) is one reason for a bright future for nuclear. MOX is composed of reprocessed plutonium and uranium (either natural or depleted). Thus a reprocessing capability is required. Only three countries currently have commercial-scale plutonium reprocessing plants, France (La Hague), Russia (Mayak) and the UK (Sellafield).

France is the pioneer and leading producer and user of MOX, deploying it in 20 light water reactors with up to 30 percent of MOX fuel in their cores (Schneider, 2009: 14). Altogether, some 39 conventional light water reactors (LWR) in Belgium, France, Germany and Switzerland operate with some MOX fuel (NEA, 2008a: 404). MOX has also been used to dispose of excess weapons-grade plutonium in commercial reactors in the US. (For reactors like the CANDU that use natural uranium it is considered economically unattractive to reprocess spent fuel for MOX) (NEA, 2008a: 400).

Japan has had ambitious plans for using MOX for some time. It imported a batch from the UK in 1999, but it was returned due to a scandal over falsified quality control documents, while a second batch imported in 2001 went unused after a series of accidents at Japanese nuclear facilities (Katsuta and Suzuki, 2006: 15; WNA, 2009c). In May 2009 Japan imported a third batch, according to Greenpeace "the largest shipment of plutonium in history," for use by three small utility companies (Agence France-Press, 2009). In October 2009 MOX was loaded into a Japanese reactor for the first time (WNN, 2009b). Japan has a small, underperforming pilot reprocessing plant at Tokai. Most of its spent fuel has traditionally been reprocessed in France and the UK and the plutonium stored (both at home and abroad), making its stockpile of commercial plutonium the biggest in the world. Its full-scale Rokkasho reprocessing plant, long delayed and over budget ($20 billion or three times the cost estimated in 1993) (Smith, 2007), is currently undergoing test operations. A MOX fuel fabrication plant is expected to be built by 2012, after which time Japan plans to use plutonium for MOX in 16-18 existing reactors and later in its planned fast breeder reactors by 2015 (delayed from the original date of 2010) (Oshima, 2009: 131).

The use of MOX has significant disadvantages. The fabrication process for MOX fuel is potentially more hazardous than for uranium fuel, requiring expensive protective measures which increase the price (Garwin and Charpak, 2001: 137). The 2003 MIT study concluded from its simple fuel cycle cost model under US conditions that "the MOX option is roughly 4 times more expensive than once-through Uranium Oxide" (MIT, 2003: 151). Spent fuel from MOX reactors is thermally hotter and more radiotoxic than spent uranium fuel, as well as more voluminous (Paviet-Hartman et al., 2009: 316),[10] making it more difficult to dispose of in a repository (Bunn et al., 2003: 39). Unused plutonium from MOX spent fuel can be reprocessed and "multi-recycled" but this "becomes a burden on light water reactors because it yields less energy per kilogram of reprocessed fuel" (Garwin and Charpak, 2001: 138). Only the fast breeder reactor can totally consume reprocessed plutonium and burn the minor actinides.

Reprocessing of reactor-grade plutonium, whether for MOX or use in fast reactors, has itself significant drawbacks. The Plutonium Uranium Extraction (PUREX) process for obtaining plutonium from spent fuel, the most common method, generates massive volumes of waste. This has spurred efforts to develop new aqueous processes or radically different approaches, none of which is yet commercially proven (Paviet-Hartmann et al., 2009: 316). In fact, "recycling" plutonium "only reduces the waste problem minimally" (von Hippel, 2008). French used MOX fuel, which still contains 70 percent of the plutonium it did when it was manufactured, is returned for further reprocessing. Thus France is, in effect, using reprocessing to move its spent fuel problem from reactor site to reprocessing plant and back again (von Hippel, 2008).

Reprocessing is also much more expensive than the "once-through" method and direct disposal of spent fuel, costing more than the new fuel is worth (von Hippel, 2008). An official report commissioned by the French prime minister in 2000 concluded that using reprocessing instead of direct disposal of spent nuclear fuel for the entire French nuclear program would be 85 percent more expensive and increase average generation costs by about 5.5 percent or $0.4 billion per installed GWe over a 40-year reactor life span (Charpin et al., 2000). For countries that have sent their spent fuel to France, the UK and Russia for reprocessing, the cost, about $1 million per ton, is 10 times the cost of dry storage (von Hippel, 2008). The customer is, moreover, required by contract to take back the separated plutonium and other radioactive waste. The three commercial reprocessing countries have thus lost virtually all of their foreign customers, making their reprocessing plants more uneconomical than they were before. The UK proposes to shut Sellafield in the next few years at a cost of $92 billion, including site cleanup (von Hippel, 2008).

Finally, MOX also carries proliferation risks since, despite earlier assumptions to the contrary, even non-weapons grade material can be used in a crude nuclear weapon. A 1994 report by the Committee on International Security and Arms Control (CISAC) of the US National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, claimed that it is much easier to extract plutonium from fresh MOX fuel than from spent fuel. Hence MOX fuel must be closely monitored to prevent diversion (NAS, 1994). The proliferation risks of reprocessing will be considered further in Part 2 of this report, but the complications associated with this technology constitute a constraint on expansive plans for nuclear energy beyond the once-through system.

Dreams of a self-sustaining "plutonium economy," in which breeder reactors provide perpetual fuel without the need for additional imports of uranium, are likely to remain dreams. Japan, the country most determined to achieve this, due to its reliance on imports for 80 percent of its energy supplies, has pursued the idea for decades, but does not now envisage deploying fast reactors until 2050 (NEA, 2008a: 68).

Nuclear Technology Dependence

Perhaps the most telling argument against the proposition that nuclear energy can provide energy security is the fact that the entire civilian nuclear fuel cycle is supplied by a small number of companies and countries. Nuclear reactor design, manufacturing and construction, the associated techniques and skills, plus fuel fabrication, uranium enrichment and reprocessing are concentrated in fewer hands than ever, making most countries more rather than less dependent on others for this energy source. The nuclear power plant construction industry for instance has seen significant consolidation and retrenchment over the last 20 years. Even the US no longer has a "national" nuclear reactor manufacturing capability after the famed nuclear divisions of Westinghouse were sold to British Nuclear Fuels in 1999 and then to Toshiba of Japan in 2006 (NEA, 2008a: 317). Various takeovers and mergers have resulted in just two large consolidated nuclear power plant vendors, Westinghouse/Toshiba and Areva NP of France. Even Areva only designs and makes the reactors themselves and must partner with others, like Siemens or Electricité de France (EDF), to build entire nuclear power plants. Mitsubishi Heavy Industries, the new vertically integrated Russian company Atomenergoprom and Canada's Atomic Energy Canada Limited (AECL) are other players. China, and farther in the future, India, are mooted as potential new suppliers, but have yet to secure any sales, although a South Korean-assembled conglomerate achieved its first overseas sale, to the United Arab Emirates (UAE), in January 2010. As the NEA points out, however, "There is no single company that can build a complete nuclear power plant by itself" (NEA, 2008a: 320).

This situation renders even the most advanced nuclear energy states dependent on companies in other countries. It also makes all other states mere importers of materials, skills and technology and therefore subject to the decisions of exporters, whether on political, commercial or nonproliferation grounds. On nonproliferation grounds alone there are significant constraints on states acquiring the full nuclear fuel cycle, whether uranium enrichment at the "front end" or spent fuel reprocessing at the "back end." The Nuclear Suppliers Group (NSG), a group of nuclear technology and materials exporting countries, is currently seeking agreement among its members to further constrain the export of sensitive enrichment technologies to additional countries. There are also continuing attempts to establish multilateral mechanisms, such as an IAEA "fuel bank," to assure states with nuclear power that they will always be able to obtain the necessary fuel without resorting to enrichment themselves. The vast majority of states with nuclear reactors will therefore continue to be dependent on importing fuel and nuclear technology. This should be sufficient to convince policy makers that while nuclear power can add to national energy diversity, and may provide additional energy security in the sense of security of fuel supply, it cannot provide the elusive energy independence.

Climate Change

One of the arguments increasingly used to promote nuclear power is the need to tackle climate change. The British government in laying out the case for "new build" in the UK has used this justification most explicitly of any government, claiming that: "Set against the challenges of climate change and security of supply, the evidence in support of new nuclear power stations is compelling" (WNN, 2008l). Some "Greens," notably the former founding member of Greenpeace, Patrick Moore (Moore, 2006: BO1), and British atmospheric scientist James Lovelock, father of the Gaia theory, have been converted to a pro-nuclear stance on the grounds that climate change is so potentially catastrophic that all means to reduce greenhouse gases must be utilized (Norris, 2000). Pro-nuclear energy non-governmental organizations have emerged to campaign for increased use of nuclear energy, such as Environmentalists for Nuclear Energy and the US-based Clean and Safe Energy Coalition.

The threat from climate change is now well established. In its 2008 report, the Intergovernmental Panel on Climate Change (IPCC) concluded that climate change is a reality and that the main cause is anthropogenic sources of greenhouse gases (GHG) (Intergovernmental Panel on Climate Change, 2007). A major source of the most damaging GHG, carbon dioxide, is the combustion of fossil fuels — coal, oil and natural gas — for energy production. Nuclear power, like hydropower and other renewable energy sources, produces virtually no CO^2 directly. *Nuclear Energy Outlook* notes of nuclear that "On a life-cycle basis an extremely small amount of CO^2 is produced indirectly from fossil fuel sources used in processes such as uranium mining, construction and transport" (NEA, 2008a: 121). The generation of nuclear electricity does, however, in addition, emit carbon by using electricity from the grid for fuel fabrication, the operation of nuclear power plants themselves, and in other aspects of the nuclear fuel cycle, especially enrichment and reprocessing.

The international climate change regime is currently based on the 1997 Kyoto Protocol to the 1992 United Nations Framework Convention on Climate Change

(UNFCCC). It mandates legally binding cuts by developed states in their GHG emissions of a collective average of 5.2 percent from 1990 levels in the commitment period 2008-2012. While nuclear power may be used by such states to help them meet their own Kyoto targets, the treaty regime has not permitted them to build nuclear power plants in developing countries in order to obtain certified emission credits under the so-called Clean Development Mechanism (CDM). This was due to strong opposition to nuclear energy from influential state parties on the grounds of sustainability, safety, waste disposal and weapons proliferation.

Most Kyoto Protocol parties will fail to achieve their reduction targets by 2012 as required. The emergence of China and India, so far unconstrained by binding targets, as growing emitters of carbon (China is now estimated to be the largest gross carbon emitter) have created demands for a new climate change deal. In December 2009 a meeting of the treaty parties in Copenhagen was unable to reach such a deal, although non-binding cuts were agreed among major emitters. Any new global regime that eventually emerges is likely to include deeper mandated cuts, the involvement of a broader range of states in such cuts and, potentially, a global carbon cap and trade system (accompanied in some states by a carbon tax). The latter would be favourable to nuclear energy. Nuclear energy may even find greater official encouragement in a new climate change treaty, due to the growing urgency of tackling climate change with as many means as possible and resulting changes in attitude of some key governments, like the UK, Italy and Sweden, about nuclear power.

The IPCC has meanwhile reached the startling conclusion that to stabilize global temperatures at 2 degrees above pre-industrial levels (widely regarded as the only way to avoid potentially catastrophic consequences) would require greenhouse emissions to be cut by 50-85 percent below 2000 levels by 2050. Scenarios devised by international agencies for doing this all propose a significant role for nuclear on the grounds that it is one of the few established energy technologies with a low-carbon footprint.

A famous study by Pacala and Socolow published in the scientific journal *Science* in 2004 demonstrated how current technologies, including nuclear energy, could help reduce carbon emissions by 7 billion tons of carbon per year by 2050 through seven "wedges" of 1 billion tons each (Pacala and Socolow, 2004). The nuclear wedge, 14.5 percent of the total, would require adding 700 GWe capacity to current capabilities, essentially doubling it, by building about 14 new plants per year. While this is a reasonable rate (the historical annual high was around 33 reactors in 1985 and 1986 (NEA, 2008a: 316)), the Pacala/Socolow estimates did not take into account that virtually all existing reactors will have to be retired by 2050, even if their operating lives are extended to 60 years (Squassoni, 2009b: 25). Thus 25 new reactors in total would have to be built each year through 2050 to account for retirements.

The IEA, in its 2008 *Energy Technology Perspectives*, suggested that as part of its radical Blue Map scenario there should be a "substantial shift" to nuclear to permit it to contribute 6 percent of CO^2 savings, considerably lower than the 14.5 percent wedge, based on the construction of 24-43 1,000 MW nuclear power plants each year (32 GWe of capacity) between now and 2050 (IEA, 2008b: 41). The figures differ from the Pacala/Socolow wedge analysis because the Blue Map envisages higher carbon levels by 2050 and more severe cuts in carbon (half of 2005 levels rather than a return to 2005 levels). The IEA implied that not all countries would need to choose nuclear, noting that "considerable flexibility exists for individual countries to choose which precise mix of carbon capture and storage (CCS), renewables and nuclear technology they will use" (IEA, 2008b: 42). The IEA called for nothing less than an energy revolution, arguing that "Without clear signals or binding policies from governments on CO^2 prices and standards, the market on its own will not be sufficient to stimulate industry to act with the speed or depth of commitment that is necessary" (IEA, 2008b: 127).

IEA recommendations for achieving GHG targets by 2050 are pertinent to this report because industry would need to gear up now to sustain a substantial and steady increase in nuclear energy. More relevant to this report, however, is the question of what is likely to be the role of nuclear by 2030. The NEA posits two scenarios (NEA, 2008b: 134-135). Its low estimate projects that nuclear will displace only slightly more carbon per year by 2030 than it does now, estimated at 2.2-2.6 Gt of coal-generated carbon (NEA, 2008b: 123). This assumes that carbon capture and storage and renewable technologies are successful, "experience with new nuclear technology is disappointing," and that there is "continuing public opposition to nuclear power." The high scenario for 2030, on the other hand, projecting almost 5 Gt of carbon displacement, assumes that "experience with new nuclear technologies is positive," and "there is a high degree of public acceptance of nuclear power." A 2003 MIT study estimated that a three-fold expansion of nuclear generating capacity to 1,000 billion watts by 2050 would avoid about 25 percent of the increment in carbon emissions otherwise expected in a business-as-usual scenario (MIT, 2003: ix).

These hedged scenarios reveal that the barriers to nuclear contributing significantly to meeting GHG reduction targets are two-fold: technological and political. Opinions differ as to how high these barriers are. Members of the 2007 Keystone Nuclear Power Joint Fact-Finding (NJFF) Dialogue — drawn from a broad range of "stakeholders," including the utility and power industry, environmental and consumer advocates, non-governmental organizations, regulators, public policy analysts and academics — reached no consensus on the likely rate of expansion of nuclear power over the next 50 years in filling a substantial portion of its assigned carbon "wedge" (Keystone Center, 2007: 10). The MIT study recommended "changes in government policy and industrial practices needed in the relatively near term to retain an option for such an outcome," (MIT, 2003: ix) but in a 2009 review of its earlier report despaired at the lack of progress (MIT, 2009: 4).

On the political side, there appears to be consensus that a "business-as-usual" approach to nuclear energy will not increase its contribution to tackling climate change. Nuclear's long lead times (reactors take up to 10 years to plan and build) and large up-front costs, compared to other energy sources and energy conservation measures, mean that without a determined effort by governments to promote nuclear it would by 2030 have little impact in reducing greenhouse gas emissions. Even replacing the existing nuclear fleet to maintain the current contribution of nuclear to GHG avoidance will require a major industrial undertaking in existing nuclear energy states. Despite the rhetoric, there is scant evidence that governments are taking climate change seriously enough to effect the "energy revolution" that the IEA has called for, much less taking the policy measures that would promote nuclear energy as a growing part of the solution.

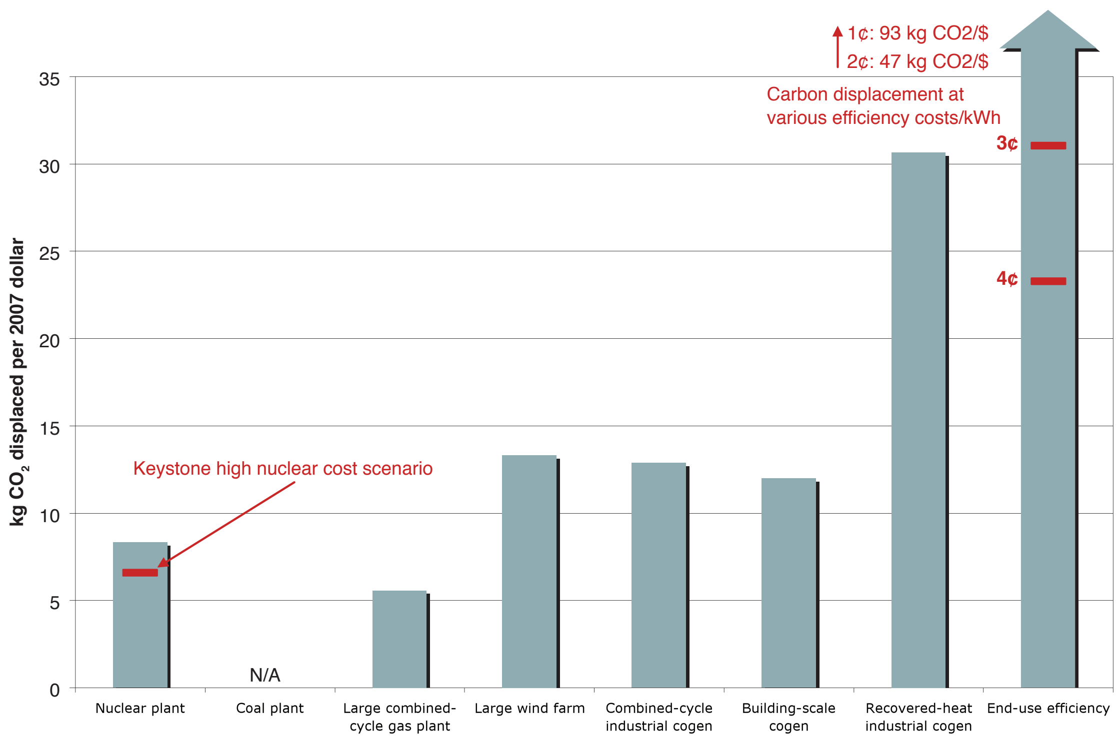
Only China is both planning and undertaking the type of new build program that could be described as "crash." The US could, in theory, mount such a program, but its federal/state division of power, deregulated market, mounting public debt, environmental regulations and still strong anti-nuclear movement are likely to slow it. France, given its past track record of building reactors, could, in theory, despite its saturated domestic market, mount a crash new build program to supply its neighbours with even more nuclear electricity than it currently does. This may be politically unacceptable in France, since accepting the risks associated with producing nuclear energy in return for national energy security is quite a different proposition to doing so for export earnings.

Even if carbon taxes or emissions trading schemes help level the economic playing field by penalizing electricity producers that emit more carbon, these measures are likely to take years to establish and achieve results. They will also benefit, probably disproportionately, cheaper and more flexible low- or non-carbon emitting technologies such as renewables, solar, and wind and make conservation and efficiency measures more attractive (see economics section below for further analysis of the effects of carbon taxes and/or emissions trading schemes on the economics of nuclear power).

One of the seemingly plausible arguments in favour of using nuclear to tackle climate change is that the problem is so potentially catastrophic that every means possible should be used to deal with it. However, this ignores the fact that resources for tackling climate change are not unlimited. Already governments and publics are balking at the estimated costs involved. Therefore, the question becomes what are the most economical means for reducing a given amount of carbon. One way of answering this is to compare the cost of reducing coal-fired carbon emissions through various alternative means of generating electricity.

It turns out that nuclear power displaces less carbon per dollar spent on electricity than its rivals, as the chart on page 23 illustrates. Nuclear surpasses only centralized, traditional gas-fired power plants burning natural gas at relatively high prices. Large wind farms and cogeneration are 1.5 times more cost-effective than nuclear in displacing carbon. Efficiency measures are

Coal-Fired CO_2 Emissions Displaced Per Dollar Spent on Electrical Services



Source: Reprinted (with permission) from Lovins and Sheikh (2008) about 10 times more cost effective. In sum, "every dollar spent on nuclear power will produce 1.4-11+ times less climate solution than spending the same dollar on its cheaper competitors" (Lovins and Sheikh, 2008: 16). This is where the opportunity cost argument has sway: put simply, it is not possible to spend the same dollar on two different things at once. Although such considerations have not yet seeped into political consciousness in many countries (the UK government notably keeps promoting the idea that all alternatives to carbon must be pursued simultaneously regardless of cost), this is increasingly likely to happen as the price of alternatives drops and governments focus on "big wins," the measures that will have the greatest impact at the lowest price.

There is a possibility that runaway global warming will become more apparent and politically salient through a catastrophic event like a sudden halt to the North Atlantic sea current or the disappearance of all summer ice from the North Pole. Since the 2008 IPCC report was released, a growing number of climatologists has concluded that the report underestimated both the scale and pace of global warming, notably changes in the Arctic ice sheet and sea levels. NASA's Jim Hansen, perhaps the world's foremost climatologist, has calculated that the situation is so dire that "the entire world needs to be out of the business of burning coal by 2030 and the Western world much sooner" (Hansen et al., 2008: 217-231).[11] In such circumstances massive industrial mobilization to rapidly build nuclear power plants, along the lines of the Manhattan Project to build the US atomic bomb or the Marshall Plan for European economic recovery after World War II, may be politically and technologically feasible.

But as indicated in the Constraints section below, nuclear would face numerous barriers in responding to such a catastrophe that other alternatives do not. As Sharon Squassoni notes, "If major reductions in carbon emissions need to be made by 2015 or 2020, a large-scale expansion of nuclear energy is not a viable option" for that purpose (Squassoni, 2009b: 28). It is simply too slow and too inflexible compared to the alternatives. As the 2007 Keystone report noted: "to build enough nuclear capacity to achieve the carbon reductions of a Pacala/Socolow wedge would require the industry to return immediately to the most rapid period of growth experienced in the past (1981-99) and to sustain this rate of growth for 50 years" (Keystone Center, 2007: 11).

The Promise of Nuclear Technology – Current and Future

While the notion of a mechanistic "technological imperative" is now discredited, in the current case of renewed interest in nuclear energy the promise of improved technology is at least a partial driver. The following section considers both the technologies themselves and programs designed to research and promote new technologies.

Improvements in Current Power Reactors (Generation II)

Most reactors in operation today are "second generation," the first generation being largely experimental and unsuited for significant grid electricity. The global fleet is dominated, both in numbers and generating capacity, by light water reactors derived from US technology originally developed for naval submarines. These comprise two types: pressurized water reactors (PWR) and boiling water reactors (BWR). The rest are pressurized heavy water reactors (PHWR) based on the Canadian Deuterium Uranium (CANDU) type; gas-cooled reactors (CCRs); or Soviet-designed light-water-cooled, graphite-moderated reactors (LWGRs or RBMKs — the Russian acronym for high power channel reactor). Most current reactors operate on the "once-through" system: the original fuel, low enriched uranium (LEU) or natural uranium, is used in the reactor once and the spent fuel treated as waste and stored rather than being reprocessed for further use.

Significant improvements have been made in the past few decades in existing reactor operations, leading to higher fuel burn-up and improved capacity factors. According to the NEA, these developments have resulted in savings of more than 25 percent of natural uranium per unit of electricity produced compared to 30 years ago, and a significant reduction in fuel cycle costs (NEA, 2008a: 401). In addition to higher "burn-up" rates, current nuclear reactors worldwide are also being overhauled and receiving significant life extensions of up to 30 years rather than being closed down. Given that much of the initial capital investment has been paid or written off, such reactors are highly profitable. This improvement in the profitability of existing reactors has been one of the drivers of renewed interest in nuclear energy, although the assumption that new reactors would be equally profitable is unproven.

Generation III and Generation III+ Reactors

One of the main technological arguments for a nuclear revival rests on the emergence of so-called Generation III and Generation III+ reactors. According to their manufacturers, these types promise several advantages over Generation II: lower costs through more efficient fuel consumption and heat utilization; a bigger range of sizes; and increased operational lifetimes to approximately 60 years. They are also reportedly able to operate more flexibly in response to customer demand. Perhaps most important, they are reputedly safer, incorporating "passive" safety systems that rely on natural phenomena — such as gravity, response to temperature or pressure changes and convection — to slow down or terminate the nuclear chain reaction during an emergency. This contrasts with the original designs, which relied on human intervention.

The industry is also promising that economies of scale through standardization, modular production techniques and advanced management systems will bring prices down after the initial first-of-a-kind (FOAK) plants have been built. Nuclear Energy Institute (NEI) President and CEO Marvin Fertel claims that "If you are using standardized plants, everything from licensing to construction isn't a 10-year period anymore," resulting in a much greater rate of deployment in the decade 2020 to 2030 than in the decade 2010 to 2020 (Weil, 2009: 4). This implies that the real revival is likely to emerge in the latter decade of the period being considered by this report. Economies of scale are also premised on the size of the reactors: since construction cost is the biggest factor in the price of a nuclear power plant, building a bigger one that produces more electricity is said to reduce the "levelized" cost of the power produced. These issues are discussed extensively in the section on the economics of nuclear power below.

The distinction between Generation III and Generation III+ seems arbitrary and more a question of marketing strategy than science. According to the US Department of Energy (DOE), Generation III+ reactors promise "advances in safety and economics" over Generation III (US Department of Energy, 2009). The NEA suggests vaguely that Generation III+ designs are "generally extensions of the Generation III concept that include additional improvements and passive safety features" (NEA, 2008a: 373-374). It advises, somewhat worryingly, that "the difference between the two should be defined as the point where improvements to the design mean that the potential for significant off-site releases [of radioactivity] has been reduced to the level where an off-site emergency plan is no longer required."

Several companies in France, Japan and the US are developing Generation III or Generation III+ designs for light water reactors. Other countries, notably China, Japan, Russia and South Korea, have plans to produce their own Generation III or Generation III+ LWRs. China plans to "assimilate" the Westinghouse AP1000 technology and "re-innovate" its design, but in addition has its own second generation CPR-1000 reactor, derived from French designs imported in the 1980s. It hopes to build both designs en masse in China (WNN, 2009g). Canada is developing an Advanced CANDU Reactor (ACR), the ACR1000, based on its original pressurized heavy water reactor, but using slightly enriched rather than natural uranium. See table on page 27 for advanced thermal reactors currently being marketed.

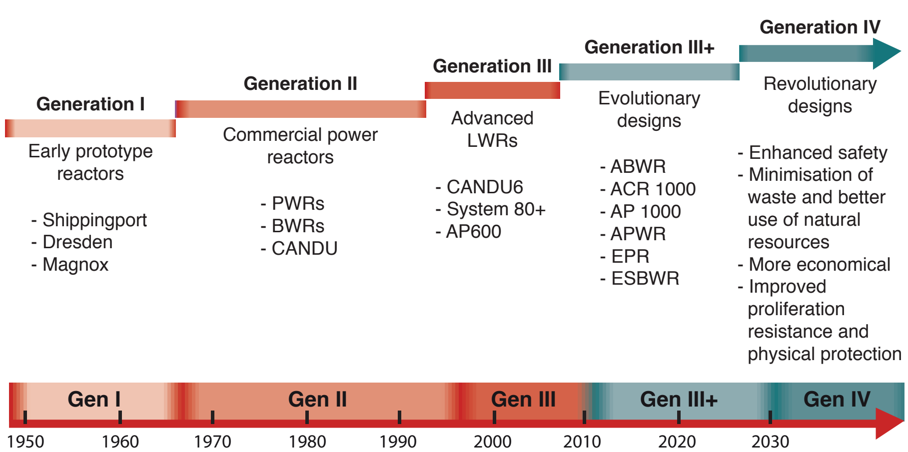
Although all of these designs are "evolutionary" rather than "revolutionary," their performance is to date unproven since they are, with one exception, not yet in existence.

Areva's Evolutionary Power Reactor (EPR), formerly known as the European Pressurized Water Reactor, is based on the German Konvoi and the ill-fated French N4 design (Thomas et al., 2007: 18). The N4 was the first all-French PWR design, drawing on more than a decade of building and operating PWRs based largely on the Westinghouse design licensed to Framatome. Only four were built, all of them suffering technical problems which, for the first time in the French PWR program, extended the period from placing the order to criticality to more than six years. Each of the units took between six and 12 years to build. Far from being cheaper than their predecessors, the reactors produced more expensive electricity. Reliability was also initially poor, although it has improved over time.

Westinghouse's Advanced Passive (AP1000) reactor is a scaled-up version of the AP600, which was given safety approval by the US regulatory authorities in 1999. By then it was clear, according to Thomas *et al.* that the design would not be economic and the AP600 was never offered in tenders. Its size was increased to about 1,150 MW in the hope that scale economies would make the design economically competitive, with an output increase of 80 percent and a cost increase of only 2 percent (Thomas et al., 2007).

The only reactors marketed as "evolutionary" Generation III+ that are presently in operation are four General Electric/Hitachi Advanced Boiling Water Reactors (ABWRs) in Japan that went online between 1996 and 2005. Two more are under construction in Taiwan and one in Japan. Two additional types are under construction. Two Areva EPRs are being built, one in Finland and one in France. The first Westinghouse AP1000 commenced construction in China in 2009 at Sanmen in Zheijiang province (WNN, 2009g). No new CANDUs have commenced construction or even been ordered.

Progression of Nuclear Reactor Technologies



Source: OECD/NEA (2008a: 373)

It is already clear that the market for new nuclear plants to 2030 will be dominated by large (1000 MW and above) light water reactors with both Generation III and III+ characteristics (MIT, 2003).[12] Areva's market research apparently indicates that about half the global demand is for large reactors between 1350 and 1700 MW and the other half is for what it calls "midsize" reactors of 1000 to 1350 MW (MacLachlan, 2009a: 5). However the number of new generation reactors built and their global spread will depend, at least in market economies, on fulfilling their promised advantages in reducing capital costs and construction times. As the 2009 MIT study asks of the US:

> Will designs truly be standardized, or will site-specific changes defeat the effort to drive down the cost of producing multiple plants? Will the licensing process function without costly delays, or will the time to first power be extended, adding significant financial costs: Will construction proceed on schedule and without large cost overruns? … The risk premium will be eliminated only by demonstrated performance (MIT, 2009).

Small, Medium-Sized, Miniaturized and Other Novel Reactors

Much has been made of the need for small- and medium-sized reactors (SMRs), below the current trend of 1000MW and above. The IAEA officially defines small reactors as those with a power output of less than 300 MWe, while a medium reactor is in the range of 300-700 MWe. Although such reactors have been investigated, developed and in some cases deployed since the 1950s, there is currently renewed interest. The NEA reports that some 60 different types of SMRs are "being considered" globally, although none has yet been commercially established (NEA, 2008a: 380). Countries involved in researching them include Argentina, Canada, South Korea, Japan and Russia. Currently only India has successfully utilized such types of units with its domestically produced 200 and 480MWe heavy water reactors.

SMRs are advertised as overcoming all of the current barriers to wider use of nuclear energy, especially by developing countries. Such reactors are said to be ideal

The International Nuclear Industry

	Areva	Westinghouse-Toshiba	General Electric-Hitachi	Rosatom	AECL
Headquarters	France	United States	United States/Japan	Russia	Canada
Ownership Structure	87% French Government 13% Private Sector	67% Toshiba 20% Shaw Group 10% Kazatomprom	Hitachi owns 40% of GE and GE owns 20% of Hitachi	100% Russian Government	100% Canadian Government
Reactors, Services, and Fuel Revenue	US$4,706 million	US$4,116 million	US$2,939 million	US$2,293 million	US$513 million
Reactor Type	Pressurized Light Water EPR-1000	Pressurized Light Water AP-1000	Boiling Water ABWR	Pressurized Light Water VVER-1200	Pressurized Heavy Water CANDU
Reactors Operating	71	119	70	68	30
Reactors Under Construction	6	5	4	16	0
Countries that have reactor design	7	10	7	12	7

Source: Reprinted (with permission) from Bratt (forthcoming).

for countries with relatively small and undeveloped electricity grids (as well as huge countries like Russia with large areas unconnected to the national grid). They promise to be cheaper and quicker to build, installable in small increments as demand grows, and able to be sited close to population centres, thereby reducing the need for long transmission lines. They can allegedly be more safely connected to smaller grids, operate off-grid, or be used directly for heating, desalination or hydrogen production. Some SMR designs reportedly would have "reduced specific power levels" that allow plant simplification, thereby enhancing safety and reliability and making them "especially advantageous in countries with limited nuclear experience" (NEA, 2008a: 380). Half of the SMR designs under consideration would have built-in fuel, with no on-site refueling necessary or possible (NEA, 2008a: 380). SMRs are seen as "an elegant solution to problems requiring autonomous power sources not requiring fuel delivery in remote locations" (Statens Strålevern, 2008: 6).

Such reactors remain, however, in the research and development phase (NEA, 2008a: 381-382)[13] and will remain unproven for many years with respect to their reliability, safety, security and weapons nonproliferation potential. Their economic viability is also unproven. Although they might be cheaper per unit than a large reactor, they miss out on economies of scale and may thus produce electricity at a higher levelized cost. While the NEA predicts that some will be available commercially between 2010 and 2030, such a 20-year lead time does not inspire confidence. The practicalities and economics of small reactors may be more favourable for off-grid applications such as heating and providing electricity in small communities or for incremental grid additions, especially if they were built assembly-line style (Hiruo, 2009).[14]

Several companies, some with decades of experience in reactor design and construction, have already tried unsuccessfully to develop and market small and medium-sized reactors. For example, as previously mentioned, the 600MW AP600 was judged to be uneconomic at that size (Thomas et al., 2007: 19). CANDU's ACR was originally being developed in two sizes, 750 MWe and 1,100-1,200 MWe, but the smaller size was dropped after its investment partner, US utility Dominion, withdrew on the grounds of lack of US demand (Thomas et al., 2007: 21).

South African Pebble Bed Reactor

Since 1993 the South African electricity utility Eskom has been collaborating with other partners in developing the Pebble Bed Modular Reactor (PBMR), a type of high temperature gas reactor (HTGR) advertised as Generation III+, with a capacity of 165 MWe. In 1998 Eskom forecast that a demonstration plant would be built by 2004 and at least 10 commercial orders per year placed worldwide from then onwards. Presently, the demonstration plant is unfinished, 10 times over budget (most of it borne by the South African taxpayer) and there are no customers (Thomas, 2009: 22). Greater than anticipated problems in completing the design, the withdrawal of funders and uncertainties about the commitment of other partners are among the causes (Thomas, 2009). In February 2009 Eskom announced that the PBMR was longer intended for electricity production, but would be promoted for "process heat" purposes, such as extracting oil from tar sands. Research published in June 2008, based on the German experience with two experimental pebble bed reactors in the late 1980s, suggested that the "safety behaviour" of pebble bed reactors is less benign than earlier assumed and that major R&D is necessary to fix the problem (Moormann, 2009: 16-20). According to Professor Steve Thomas of the University of Greenwich, such technical flaws could have been foreseen by 2002, raising the question of "whether decision makers continued to allow funding for the project despite the existence of a problem that had the potential to derail it" (Thomas, 2009: 22).

In April 2006 Russia commenced construction of the world's first floating nuclear power plant. It will comprise two 35 MWe reactors based on the KLT-40 PWR design used in Soviet icebreakers. Its construction at Severodvinsk in northwest Russia is expected to take five years. The plant, essentially on a large barge, will have to be towed to the deployment site, as it is not self-propelled. Every 12 years it will be towed back to its construction site for maintenance. The reactors will reportedly be capable of supplying a combination of electricity and heat, some of which can be used for production of potable water. While a "lifetime core option" is being considered for future plants, the one currently being built will be refuelled sequentially every year, permitting continuous plant operation. Although the reactor is being produced initially for use in remote areas of northern Russia, Rosatom's focus on SMRs and floating reactors in particular, "appears to be a key part of Russia's positioning itself as a future leader in the global nuclear energy market" (Statens Strålevern, 2008: 55).

Notwithstanding more than 50 years of Soviet and Russian experience with nuclear powered civilian ships allegedly "without major incident," non-self-propelled floating nuclear reactors for civilian use are unprecedented and untested (Statens Strålevern, 2008: 11). They also raise safety, security, environmental and nonproliferation issues beyond those of stationary reactors, which may dampen their market prospects.

Generation IV Reactors

Generation IV reactors promise revolutionary advances on even the Generation III+ models. But as Ian Davis puts it, Generation IV reactors are "'revolutionary' only in the sense that they rely on fuel and plants that have not yet been tested" (Davis, 2009: 19). Generation IV reactors in most cases will seek to "close" the nuclear fuel cycle, leading to higher energy usage per amount of uranium or recycled fuel, less nuclear waste due to the more efficient burning of plutonium and other highly radioactive actinides, reduced capital costs, enhanced nuclear safety and less weapons proliferation risk. It is envisaged that such reactors will rely on new materials and metals yet to be developed, including those able to resist corrosion far in excess of today's levels.

Research and development for such revolutionary designs is expensive, which has led to international cooperative efforts to share the burden. Nine countries and Euratom formed the Generation IV International Forum (GIF) in 2001, under the auspices of the NEA, to develop new systems "intended to be responsive to the needs of a broad range of countries and users," (Generation IV International Forum, 2008a). Now with twelve country members plus Euratom,[15] GIF has chosen the six most promising systems to investigate further (see box on page 30).

Generation IV Reactors Being Studied By GIF

- Gas-Cooled Fast Reactor (GFR): features a fast-neutron-spectrum, helium-cooled reactor and closed fuel cycle;
- Very-High-Temperature Reactor (VHTR): a graphite-moderated, helium-cooled reactor with a once-through uranium fuel cycle;
- Supercritical-Water-Cooled Reactor (SCWR): a high-temperature, high-pressure water-cooled reactor that operates above the thermodynamic critical point of water;
- Sodium-Cooled Fast Reactor (SFR): features a fast-spectrum, sodium-cooled reactor and closed fuel cycle for efficient management of actinides and conversion of fertile uranium;
- Lead-Cooled Fast Reactor (LFR): features a fast-spectrum lead or lead/bismuth eutectic liquid-metal-cooled reactor and a closed fuel cycle for efficient conversion of fertile uranium and management of actinides;
- Molten Salt Reactor (MSR): produces fission power in a circulating molten salt fuel mixture with an epithermal-spectrum reactor and a full actinide recycle fuel cycle.

Source: GIF (2008b)

The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), established under IAEA auspices in 2001, aims to bring together technology holders and users to "consider jointly the international and national actions required for achieving desired innovations in nuclear reactors and fuel cycles" (IAEA, 2009e). As of August 2009, 30 countries and the European Commission had joined (IAEA, 2009d).[16] In February 2006, the United States launched the Global Nuclear Energy Partnership (GNEP), which was, inter alia, designed to facilitate the global expansion of nuclear energy through advanced nuclear reactors. Developing countries' needs were said to be of particular importance. In addition, and more controversially, GNEP sought to demonstrate critical technologies needed for a closed fuel cycle, enabling "recycling and consumption of some long-lived transuranic isotopes" (US Department of Energy, 2006: 5). This program sought to abandon bipartisan US policy, dating from the administration of President Gerald Ford in the 1970s, which discouraged on nonproliferation grounds the use of plutonium for civilian energy production. GNEP was also controversial because it sought to ensure the continuation of nuclear fuel supply from existing suppliers while discouraging new entrants into the enrichment business.

The administration of President Barack Obama cancelled the domestic side of GNEP in 2009 and the program's ambitious plan for demonstration facilities was reduced to long-term R&D. Meanwhile, the international side of GNEP, currently with 21 members (see map in section on political and promotional drivers below), will reportedly seek to shift the balance away from recycling to nonproliferation (Pomper, 2009). This will act as a brake on the nuclear energy revival rather than an enabler.

None of the Generation IV reactors is expected to be available before 2030 (Sub-Committee on Energy and Environmental Security, 2009: 13, para. 12). As the World Business Council for Sustainable Development puts it, such technology is "promising but far from being mature and competitive" (World Business Council for Sustainable Development, 2008: 16).

Fast Neutron and Breeder Reactors

A fast neutron reactor differs from a traditional thermal reactor in using for its core a composite of 90 percent natural uranium, uranium-238, with about 10 percent plutonium, or enriched uranium. Such a reactor can produce up to 60 times more energy from uranium than thermal reactors (NEA, 2008a: 80). Fast reactors can operate in two ways. If the amount of HEU used is limited, they operate in "burner" mode and are able to dispose of redundant nuclear and radioactive material. Some nuclear scientists have advocated recycling spent fuel in fast reactors as a way of dealing with the nuclear waste problem while also improving usage of the energy source (Hannum et al., 2005). Since a fast reactor has no moderator, it is compact compared to a normal reactor. A 250 MWe prototype in the UK had a core "the size of a large dustbin" (NEA, 2008a: 450). Such reactors are usually cooled by liquid sodium, which is efficient at removing heat and does not need to be pressurized.

With the addition of an extra uranium "blanket," normally depleted uranium, fast neutron reactors have the remarkable quality of "breeding" more plutonium than they use. Operated in this way they are known as fast breeder reactors (FBR) and are the basis for the notion that states could acquire the ultimate in energy security and operate a "plutonium economy" that exploited an endless supply of fuel. According to the NEA, FBRs could thus potentially increase the available world nuclear fuel resources 60-fold (NEA, 2008a: 450).

There is currently only one operational FBR, in Russia, although around 20 have been built and operated in a handful of countries at various times (NEA, 2008a: 450). France has taken its Phénix reactor offline and is preparing to shut it down permanently (MacLachlan, 2009d: 9). China, India and Japan are attempting to develop FBRs. Japan plans to operate a demonstration reactor by 2025 and a commercial model by 2050 (Oshima, 2009: 131). In the meantime, its shutdown Monju reactor was supposed to be restarted in 2008 after design changes and a safety review (WNN, 2008k). But as Kenichi Oshima notes, "In reality, however, the fast breeder reactor development [in

Fast Breeder Reactors by Status and Country, 2009

Unit	Country	Status	Construction Date	Shutdown Date	Power Output (MWe)
Currently Operating					
Beloyarsky-3	Russian Federation	Operational	1969		560
Under Construction					
PFBR	India	Under Construction	2004		470
Beloyarsky-4	Russian Federation	Under Construction	2006		750
Shut Down					
Phénix	France	Shut Down*	1968	2009	130
Super-Phénix	France	Shut Down	1976	1998	1200
Kalkar (KKW)	Germany	Cancelled	1973	1991	295
KNK II	Germany	Shut Down	1974	1991	17
Monju	Japan	Shut Down	1986	1995	246
BN-350	Kazakhstan	Shut Down	1964	1999	52
South Urals 1	Russian Federation	Suspended	1986	1993	750
South Urals 2	Russian Federation	Suspended	1986	1993	750
Dounreay DFR	United Kingdom	Shut Down	1955	1977	11
Dounreay PFR	United Kingdom	Shut Down	1966	1994	250
Enrico Fermi-1	United States	Shut Down	1956	1972	60

* Phénix is presently undergoing an "end-of-life" test program prior to being shut down (Nucleonics Week, 2009a).
Source: IAEA (2009c)

Japan] has been delayed repeatedly and there is no chance of it being feasible" (Oshima, 2009: 131).

The history of fast neutron and breeder reactors is discouraging. In the 1960s and 1970s the leading industrialized countries, including the US, put the equivalent of more than $50 billion into efforts to commercialize fast neutron reactors in the expectation that they would quickly replace conventional reactors (von Hippel, 2008). They have proved costly, unreliable and accident-prone due to the explosive nature of sodium on contact with air or water. Serious accidents occurred at the Fermi reactor near Detroit in 1966 and at the Monju reactor in 1995. The French Superphénix breeder reactor closed in 1998 with an effective lifetime capacity factor of just 6.3 percent (Byrd Davis, 2002: 290) after 12 years of operation, during which it intermittently delivered around 1,200 MWe to the grid. It is the only breeder reactor that has ever been capable of producing electricity comparable to the largest thermal reactors commonly in operation. According to Garwin and Charpak, "The decision to build an expensive industrial prototype breeder in France was premature; it was due in part to technological optimism on the part of the participants, coupled with a lack of appreciation for alternatives" (Garwin and Charpak, 2001: 135).

Advanced fast breeders are among the Generation IV designs, including those being considered under GIF, where Japan has the lead role for this type of technology. Such reactors will not, however, be technologically or commercially viable on a large enough scale to make a difference to the provision of nuclear energy to electricity grids by 2030.

Fusion Power

Barring a technological miracle, fusion reactors will also not be available for the foreseeable future and will contribute nothing to the current nuclear revival (US Presidential Committee of Advisors on Science and Technology, 1995). Research and development, at enormous cost, is nonetheless continuing. The International Thermonuclear Experimental Reactor (ITER), financed by six countries, China, India, Japan, South Korea, Russia and the US, and the EU,[17] is being built in Cadarache, France. The US National Ignition Facility (NIF) in Livermore, California, began operations in May 2009 at a cost so far of $4 billion, almost four times the original estimate, and is more than five years behind schedule. Its principal role is to simulate thermonuclear explosions as part of the stockpile stewardship program for US nuclear weapons, but it can also be used for fusion energy experiments. In the case of both programs, full experiments to test nuclear fusion as a power source seem likely to be delayed until 2025 (The Economist, 2009b: 82). Even the IEA notes that "Fusion is not likely to be deployed for commercial electricity production until at least the second half of the century" (IEA, 2008b: 306).

Political and Promotional Drivers

Wider considerations than those analyzed above will always come into play for government policy makers when considering nuclear energy. A decision to launch or significantly expand a nuclear power program is hugely complex, involving an array of international and domestic political, legal, economic, financial, technical, industrial and social considerations. Nuclear energy has been so controversial in the past and involves so many "stakeholders" that it is the quintessential candidate for politicization, to the chagrin of those seeking "rational" energy policies.

Political Drivers

The political drivers that may motivate a state to seek nuclear energy for the first time include: the quest for national prestige; a perceived need to demonstrate a country's prowess in all fields of science and technology; a predisposition towards high-profile, large-scale projects of the type that nuclear represents; and the desire for modern, cutting-edge technology no matter how suited or unsuited to an individual country's requirements. These considerations do not generally apply to the acquisition of other forms of electricity generation and may make the difference in decision making. Intimations by such states as Ghana, Nigeria, Venezuela and others included in this project's SENES database that they are considering nuclear power probably represent a triumph of national ambition over sound energy policies. But in considering the likelihood of a nuclear revival it cannot be discounted that such states may nonetheless actually succeed in acquiring nuclear energy. Autocratic states, partially democratic states and/or those with command economies may be able to politically override other considerations weighing against nuclear energy. Venezuelan President Hugo Chavez, for example, in nurturing nuclear cooperation arrangements with Iran, France and Russia, may actually lead his oil-rich country towards acquiring an energy source that, on the face of it, it does not need.

Nuclear Weapons "Hedging"

"Nuclear hedging," based on a belief that a nuclear power program will help provide the basis for a future nuclear weapon option, may also be a critical, if unacknowledged driver in some cases. There has been speculation that the reason for so much interest in nuclear energy from states in the Middle East and North Africa is that it may provide a latent nuclear capability to match that of Iran (International Institute of Strategic Studies, 2008). Such motivations are likely to be confined to a tiny number of states. In any event, it is not the easiest and fastest way to acquire nuclear weapons (Alger, 2009). The implications for weapons proliferation arising from an increase in nuclear energy use will be considered in Part 4 of this report.

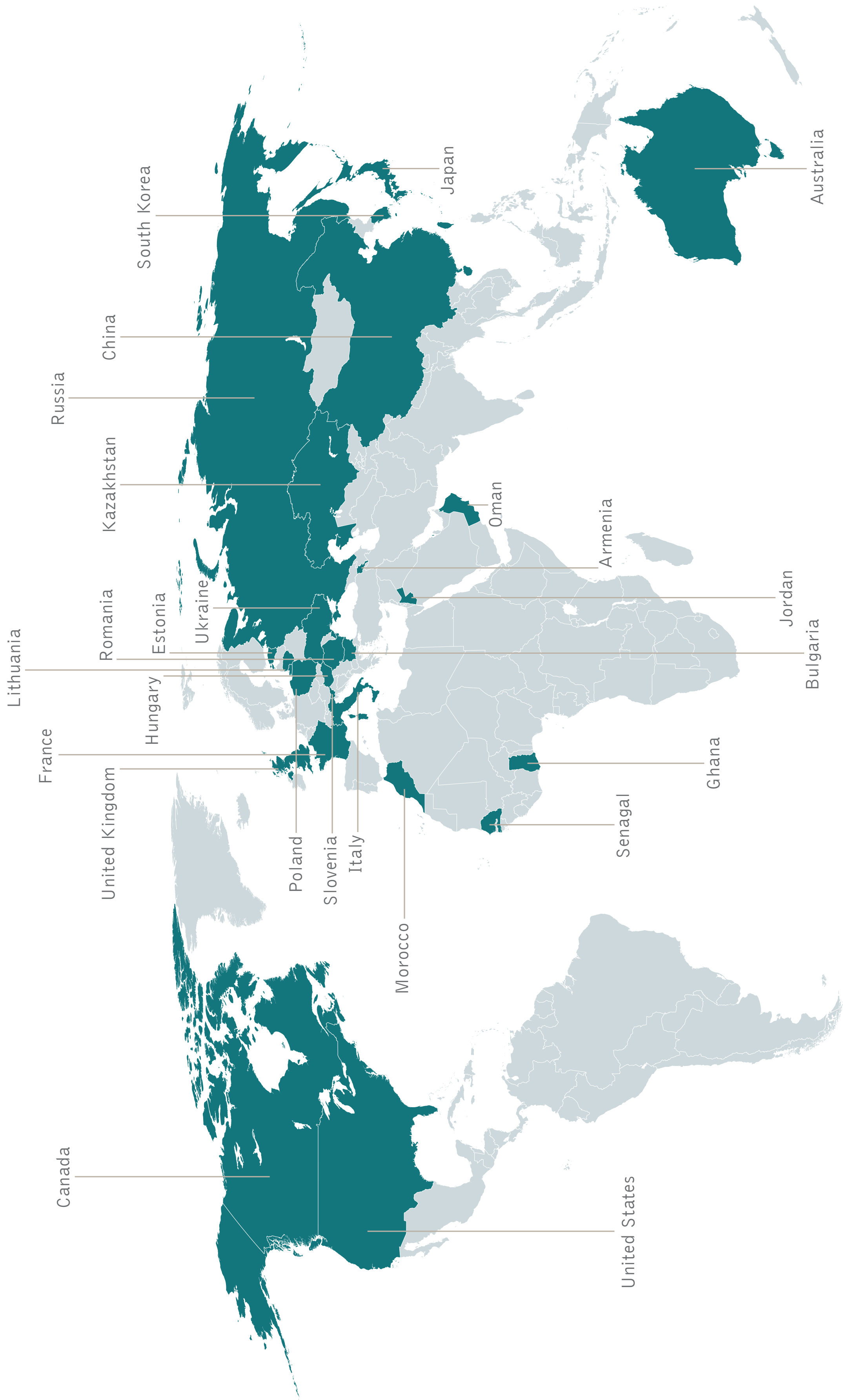
Nuclear Promotion Internationally

Since 2000 the nuclear industry and pro-nuclear energy governments have sensed a second chance for nuclear energy and have themselves become important drivers of interest. Emphasizing all the substantive drivers considered above, with the notable addition of climate change as a new motivator, they have vigorously promoted what they call a nuclear energy "renaissance."

United States

The US, where the term "renaissance" was invented, has, at least until recently, been one of the greatest proponents of a nuclear revival, with strong support from industry, the bureaucracy (notably the Department of Energy), Congress and some state governments. President George W. Bush's administration, after announcing its Nuclear Power 2010 program in 2002, was active both domestically in supporting nuclear energy and in promoting it internationally, especially through the establishment of GNEP (Pomper, 2009).[18] Internationally, GNEP has stirred interest in nuclear energy where it might otherwise not have existed, most noticeably in the cases of Ghana and Senegal. Paradoxically, the original GNEP principles, which implied that advanced nuclear energy assistance would be available only if recipients renounced enrichment and reprocessing, served to stimulate interest on the part of some states in preserving such options for the future. Australia, Canada and South Africa, all with significant uranium resources that could become "value added" if enriched prior to export, were among the most critical of such conditions. The US later quietly dropped these from the GNEP charter. The Obama administration is noticeably less enthusiastic about nuclear energy, has cancelled the domestic part of GNEP and is likely to refocus the international program on nonproliferation objectives (Pomper, 2009), perhaps under a different name.

GNEP Members, January 2010



Source: Pomper (2009)

Meanwhile, the controversial US-India nuclear cooperation agreement, concluded in 2006, was promoted as a lucrative commercial opportunity for US businesses to participate in India's ambitious nuclear energy plans — despite the country's status as a nuclear-armed non-party to the Nuclear Non-proliferation Treaty (NPT). The US has also been active in concluding nuclear cooperation agreements with several developing states, such as the UAE and Jordan.

France

Pinning its hopes on a global export market for Areva and Electricité de France (EDF), France has been even more active than the US, especially in promoting reactor sales. President Nicholas Sarkozy has personally pursued such benefits for his country in a series of international visits during which bilateral nuclear cooperation agreements have been reached, most notably in the Middle East and North Africa. Since 2000 France has signed at least 12 of these[19] and become particularly engaged in promoting the use of nuclear energy in Algeria, Jordan, Libya, Morocco, Tunisia, Qatar and the UAE. Indonesia and Turkey have also considered reactor purchases from France. Areva has already taken advantage of the opening up of the Indian market by signing a contract for up to six reactors (Dow Jones Newswires, 2009a). Sarkozy has been matched in his efforts by high-profile Areva CEO Anne Lauvergeon, dubbed by the *New York Times*' Roger Cohen as "Atomic Anne" (Cohen, 2008).

France's aggressive nuclear marketing tactics have drawn criticism, including from then IAEA Director General Mohamed ElBaradei who warned that they are "too fast" (Smith and Ferguson, 2008). It has also been reported that French national nuclear regulator Andre-Claude Lacoste, who has some say in approving French reactor exports, has suggested to President Sarkozy that he be "a little bit more pragmatic" about signing nuclear cooperation agreements with countries now devoid of nuclear safety infrastructure (MacLachlan, 2008b). Former chair of the US Nuclear Regulatory Commission (NRC) Dale Klein has noted that as Sarkozy "goes around the world trying to sell the French reactor, it puts Lacoste in a challenging position in terms of the time it will take for such countries to develop such infrastructure" (MacLachlan, 2008a).

The French government, to its credit, has established an international nuclear cooperation Agency, L'Agence France Nucléaire International (AFNI), as a unit of the Commissariat à l'Énergie Atomique (Atomic Energy Commission), to "help foreign countries prepare the institutional, human and technical environment necessary for installation of a civilian nuclear program under conditions of safety, security and nonproliferation" (MacLachlan, 2008a). In addition, France's Nuclear Safety Authority (ASN) issued a position paper in June 2008 saying it will impose criteria for cooperation with countries seeking to commence or revive a nuclear power program, since building the infrastructure to safely operate a nuclear power plant "takes time," and that it would be selective in providing assistance (Inside NRC, 2008: 14).

Russia

Russia is the third major promoter of nuclear energy internationally, having reorganized its nuclear industry in 2007 into a vertically integrated holding company, Atomenergoprom, to compete with Areva and other emerging vendors (Pomper, 2009). Russia envisages Atomstroyexport (ASE), the nuclear export arm of Atomenergoprom, becoming a "global player," capturing 20 percent of the worldwide market and building about 60 foreign reactors within 25 years (Pomper, 2009). Past Russian reactor exports have been to eastern European states, India, Iran and China. Russia has actively pursued nuclear cooperation agreements with other countries in recent years, including some considering nuclear energy programs, notably Algeria, Armenia, Egypt and Myanmar (Burma) where it is supplying a research reactor. Russia has also signed sales agreements with China, Bulgaria, India, Myanmar and Ukraine, although these do not necessarily relate to reactors but to fuel services.

Having always seen spent fuel as a resource rather than waste, Russia enthusiastically embraced GNEP, and in May 2008 signed a nuclear cooperation agreement with the US to further its bilateral and global nuclear energy activities. The agreement is currently in limbo in the US Congress allegedly due to the conflict with Georgia in 2008, although this may be a pretext for Congressional reluctance to support civilian nuclear cooperation with a country that has not always been helpful on the Iran nuclear issue (McKeeby, 2008). Russia, on the other hand, has also sought to ease US and other countries' proliferation concerns about a nuclear energy revival — and seize commercial advantage — by establishing an International Uranium Enrichment Centre at Angarsk in Siberia, which includes a fuel bank to help provide assurances of supply to countries considering nuclear power. Kazakhstan and Armenia have become partners in this venture.

International organizations

These are also playing an international promotional role and to that extent are prominent among the drivers of the revival. The key multilateral players are the IAEA and the NEA. The IAEA is constrained in promoting nuclear energy too enthusiastically by its dual mandate, which enjoins it to both advocate the peaceful uses of nuclear energy and help ensure that this occurs safely, securely and in a non-proliferating fashion. These dual roles are reflected in its organizational stove-piping, with separate departments for promoting nuclear energy, safety, security and safeguards. Having learned its lesson in over-optimistically forecasting the growth of nuclear energy in the 1980s, the IAEA is today usually more sober in its projections than industry or some of its member states. It also usefully advises new entrants to the nuclear energy business to carefully consider all the requirements for successfully acquiring nuclear energy, notably through its exhaustive *Milestones in the Development of a National Infrastructure for Nuclear Power* (IAEA, 2007b).

Outgoing Director General Mohamed ElBaradei has claimed: "In fact, I never preach on behalf of nuclear energy. The IAEA says it's a sovereign decision, and we provide all the information a country needs" (Bulletin of Atomic Sciences, 2009: 7). More pointedly, in regard to the current enthusiasm for nuclear energy, he told the *Bulletin of the Atomic Scientists* in an interview in September 2009 that:

> In recent years, a lot of people have talked about a nuclear renaissance, but I've never used that term. Sure, about 50 countries were telling us they wanted nuclear power. But how many of them really would develop a nuclear power program? Countries such as Turkey, Indonesia and Vietnam have been talking about building nuclear power plants for 20 years. So it's one thing to talk about nuclear power: it's another thing to actually move forward with a program (BAS, 2009: 7).

It remains to be seen whether the new IAEA Director General, Yukiya Amano, will have the same attitude. Unlike ElBaradei, an Egyptian with a long career at the IAEA, Amano is from Japan, a country with a longstanding interest in promoting nuclear energy, at least domestically.

Even under ElBaradei the IAEA occasionally became overly enthusiastic about nuclear energy, such as its claim on its website in July 2009 that "A total of 60 countries are now considering nuclear power as part of their future energy mix" (IAEA, 2009b), a figure apparently derived from a list of countries that had at any time, at any level, approached the Agency for information on civilian nuclear energy. This project has identified half of that number with serious intentions of acquiring nuclear energy.

The NEA, whose 28 member states have 85 percent of the world's installed nuclear energy capacity, is in theory freer to promote nuclear energy generally and among OECD member states, since its mandate is not complicated by safety, security and nonproliferation considerations to the same extent as the IAEA. However, as the NEA itself notes, the positions of its member countries regarding nuclear energy "vary widely from firm commitment to firm opposition to its use" (NEA, 2008a: 2). The Agency's role is thus supposedly confined to providing "factual studies and balanced analyses that give our members unbiased material on which they can base informed policy choices" (NEA, 2008a: 2). In practice, NEA publications often read like a paean to nuclear energy, highlighting the advantages while playing down the disadvantages. The NEA also competes for attention with another part of the OECD, the IEA, which, with its broad energy mandate, has traditionally been less enthusiastic about nuclear.

For industry's part, it has the World Nuclear Association (WNA) as its principal cheerleader. Since its transformation from the fuel-oriented Uranium Institute in 2001, the WNA has attempted to promote the civilian nuclear power industry as a whole worldwide. It holds conferences and specialized workshops and engages with the multilateral bodies on the industry's behalf. While it performs a useful information function through its various publications and website, it naturally has a vested interest in promoting the rosiest view of nuclear energy that it can (Kidd, 2008: 66). For example, its November 2008 publication "The economics of nuclear power," a survey of studies by others, reaches the tautological conclusion that "Nuclear power is cost competitive with other forms of electricity generation, except where there is direct access to low-cost fossil fuels" (WNA, 2008c: 1; MIT, 2003: 7).[20] The WNA faces the challenge of representing a fragmented industry lacking a "critical mass of strong powerful companies with good public images to stand up for it" (Kidd, 2008: 182). The association has been seeking to expand its membership to research institutes and university faculties. Other industry organizations like the World Association of Nuclear Operators (WANO) are explicitly not devoted to advocating nuclear energy, but promote other aspects such as safety and security.

Nuclear Promotion Domestically

National political pressures have emerged in many countries for revisiting nuclear energy: from public opinion, from within government and from domestic industry. Paradoxically, one of the domestic drivers of a reconsideration of nuclear energy in several countries has been a rise in public acceptance — if not support. This has apparently been stimulated by other drivers, including worries about climate change, economic growth and energy prices, availability and long-term security of supplies (MIT, 2003: 72).[21] The results of a global public opinion poll, which surveyed 10,000 people online in 20 countries in November 2008, were released in March 2009 by Accenture, a UK-based management consultancy firm. While only 29 percent supported "the use or increased use" of nuclear power outright, another 40 percent said they would change their minds if given more information (Accenture Newsroom, 2009). Twenty-nine percent said they were more supportive of their country increasing the use of nuclear energy than they were three years ago, although

19 percent said they were less supportive. The top three reasons for opposition were: waste disposal (cited by 91 percent), safety (90 percent) and decommissioning (80 percent). Demands for improved safety and security have become progressively greater since the nuclear industry emerged, sometimes to such an extent that, according to the industry, the economics of nuclear have been adversely affected due to delays in approvals, the need for public hearings and constantly evolving safety and other regulatory requirements. Yet the industry has benefited in the past from public input (Smith, 2006: 183), and in any case needs to keep public opinion on side by complying fully with regulatory requirements.

In the US, a Zogby International poll in 2008 revealed that 67 percent of Americans support the construction of new nuclear power stations (WNN, 2008g). Public support is also apparently rising in Britain: over half the respondents in an April 2008 survey felt that the UK should increase its nuclear capacity. Those living closest to existing nuclear plants were most strongly in favour (WNN, 2008f). A 2008 survey in Italy, the only country ever to completely abandon an existing nuclear power program, showed that 54 percent of respondents were now in favour of new nuclear plants in the country (WNN, 2008d). Support appears to run highest in Russia, where a Levada Center poll in 2008 found that 72 percent of Russians felt that nuclear power should be "preserved or actively developed" (WNN, 2008i).

A European Commission opinion poll in the EU in 2007 showed opinion divided. Only 20 percent supported the use of nuclear energy, while 36 percent had "balanced views" and 37 percent were opposed (NEA, 2008a: 343). A Eurobarometer poll conducted in 2008 showed opinion moving in favour of nuclear: since 2005 support increased from 37 percent to 44 percent, while opposition dropped from 55 percent to 45 percent (Public Opinion Analysis Sector, European Commission, 2008). Support was highest in countries with operating nuclear power plants and where residents feel well-informed about radioactive waste issues. Forty percent of opponents would reportedly change their minds if there were a safe, permanent solution to the radioactive waste problem.

However, large sectors of public opinion in many countries remain skeptical about nuclear power and increased support is often conditional and fragile. A poll for the Nuclear Industry Association (NIA) in the UK in November 2007 indicated a falling back from previous increases, a growth in the number of people undecided and 68 percent of respondents admitting they knew "just a little" or "almost nothing" about the nuclear industry (WNN, 2007). NIA Chief Executive Keith Parker described the result as a "reality check" for the industry. Meanwhile, an academic study based on five years of research on how local residents view their nearby nuclear reactors has concluded that the "landscape of beliefs" about nuclear power does not conform to "simple pro- and anti-nuclear opposites" (Pidgeon et al., 2008). It concludes that even among those accepting of a nuclear power station in their midst, support is conditional and could easily be lost if promises about local development of nuclear power are not kept or if there is a major accident anywhere. One also needs to be careful about cause and effect. Rather than representing a deep-felt reconsideration of nuclear energy which is then reflected in public policy, increased public support may be due to changes in politicians' attitudes and increased advocacy of the nuclear alternative by governments. Public support may thus wither with a change of government.

In general therefore, public opinion seemingly is either mildly encouraging, a constraint or in flux rather than a driver of nuclear energy plans, and remains especially preoccupied with the issues of nuclear waste, nuclear safety and security and weapons proliferation. The industry itself is aware that it would only take another serious nuclear reactor accident to kill public support for a nuclear revival.

Domestic support for new nuclear build in many cases may depend crucially on the strength of the pro-nuclear lobby compared with other energy lobbyists and the anti-nuclear movement. American and French companies appear to be best at promoting their industry and seeking government subsidies and other support. Traditionally there has been a close relationship between the US Department of Energy (DOE) and American nuclear companies and utilities, but this may be changing due to the rise of alternative energy sources for dealing with climate change. DOE's budget was almost entirely devoted to nuclear energy until the Obama administration's recent addition of millions of dollars for alternative energy. Mycle Schneider makes the case that France's nuclear industry has consistently advanced due to the close relationship between government and industry, particularly due to the virtual monopoly of Corps des Mines graduates on key positions (Schneider, 2008b). In Japan and Russia, too, a close relationship between the nuclear industry and government helps drive promotion of nuclear energy.

Nonetheless, the nuclear industry's influence should not be exaggerated. Steve Kidd notes that a significant problem in encouraging a more positive image of the industry is that it "isn't really an industry at all, but a separate set of businesses participating in various parts of the nuclear fuel cycle" (Kidd, 2008: 66). Some vendor companies have interests in other forms of energy, as do utility companies, making it difficult to find strong industrial advocates for nuclear energy.

The Constraints

Multiple factors act as constraints on the expansion of the use of nuclear energy worldwide. Their strength and mix varies from country to country. Moreover, what is a constraint in one country, for example, the availability of finance, may be a driver in others. Generally, the factors discussed below are widely considered to hold back a nuclear revival.

Nuclear Economics

According to the NEA, "Economics is key in decision making for the power sector" (NEA, 2008a: 173). Promoters and critics of nuclear power are in agreement. According to the WNA's Steve Kidd, "Whether or not nuclear power plants are built and whether they keep operating for many years after commencing operation is these days essentially an economic decision" (Kidd, 2008: 189). Nuclear energy critic Brice Smith notes that "The near-term future of nuclear power … rests heavily on the predictions for the cost of building and operating the next generation of reactors compared to the cost of competing technologies" (Smith, 2006: 29).

Stark disagreement exists regarding what the comparative costs are. The IEA in 2008 proclaimed: "Projected costs of generating electricity show that in many circumstances nuclear energy is competitive against coal and gas generation" (IEA, 2008b: 283). Mark Cooper, senior fellow for economic analysis at the Institute for Energy and the Environment at Vermont Law School, concludes: "Notwithstanding their hope and hype, nuclear reactors are not economically competitive and would require massive subsidies to force them into the supply mix" (Cooper, 2009b: 66). The WNA's Director General John Ritch says, "In most industrialized countries today, new nuclear power offers the most economical way to generate base-load electricity — even without consideration of the geopolitical and environmental advantages that nuclear energy confers" (WNA, 2008c: 4). For Steve Thomas of the Public Services International Research Unit at the University of Greenwich, "If nuclear power plants are to be built in Britain, it seems clear that extensive government guarantees and subsidies would be required" (Thomas, 2005). According to the Washington, DC-based lobby group, the Nuclear Energy

Institute "… nuclear power can be competitive with other new sources of baseload power, including coal and natural gas" (Nuclear Energy Institute, 2009a: 1).

Assessing the current and future economics of nuclear power, whether on its own, or in comparison with other forms of generating electricity, is complex. First, this is due to the large number of variables and assumptions that must be taken into account, notably the costs of construction, financing, operations and maintenance (O&M), fuel, waste management and decommissioning. Second, the size and character of the industry make the costs and benefits of government involvement significant and often critical. Such involvement includes: direct and indirect subsidies (sometimes amounting to bailouts); the establishment and maintenance of a regulatory framework to ensure safety, security and nonproliferation; and in recent years the possible imposition of a carbon tax and/or greenhouse gas cap and trade system. Third, is the lack of recent experience in building nuclear power plants, rendering the real costs of construction and likely construction periods unknowable. According to Joscow and Parsons, the confusion and debate about costs is largely a consequence of "the lack of reliable contemporary data for the actual construction of real nuclear plants" (Joskow and Parsons, 2009). As the Nuclear Energy Agency has noted, "These factors are likely to make the financing of new nuclear power plants more complex than in previous periods" (NEA, 2008a: 203).

Finally, there is an unprecedented degree of uncertainty in the energy sector across the board, which in turn affects the economics of nuclear power: climate change considerations are forcing governments to consider all forms of energy production and compare their comparative costs and other advantages and disadvantages; recent wild fluctuations in the price of fossil fuels and other commodities has made predictions of future prices appear less reliable; and the 2008 global financial crisis and resulting global economic slowdown have sharpened investor scrutiny of capital-intensive projects like nuclear. As the May 2007 UK White Paper on Energy put it:

> In considering whether it is in the public interest to allow private sector companies to invest in new nuclear power stations, we need to take account of the wide range of uncertainties that make it difficult to predict the future need for and use of energy. For example, it is difficult to predict how fossil fuel, raw materials and carbon prices will change in the future, all of which will affect the relative economics of different electricity generation capacities (UK Department of Trade and Industry, 2007: 16).

The Effects of Deregulation of Electricity Markets

Unlike the initial boom in nuclear plant construction in the 1970s and 1980s, many countries' energy markets have today been deregulated or partially deregulated. A competitive situation now exists in most OECD countries and several non-OECD ones (IEA, 2008a: 155). This has made realistic assessments of the economics of all forms of energy, including nuclear, more important. Private investors and electricity utilities are today much more likely than in the past to base their decisions to invest in nuclear power on its projected cost compared to other forms of generating electricity and the likely rate of return on their investment compared to the alternatives. The IEA also claims that power companies increasingly use portfolio investment-valuation methodologies to take into account risks over their entire plant portfolio, rather than focusing on the technology with the lowest stand-alone projected generating cost. Investors may accept different risk profiles for different technologies, depending on project-specific circumstances (IEA, 2008a: 155).

Deregulation has changed risk assessment across the energy sector. When markets were regulated, utilities were not required to bear the full risk of investment in nuclear power plants. Instead, they employed reactor technology that had been developed by governments, often as by-products of a nuclear weapons program, and the costs of which had been written off. In addition, reactor companies and utilities were directly or indirectly subsidized by governments to build nuclear power plants. And finally, utilities were able to pass on costs to the consumer without fear of being undercut by competition.

Today, as the 2003 MIT study notes, "Nuclear power will succeed in the long run only if it has lower costs than competing technologies, especially as electricity markets become progressively less subject to regulation in many parts of the world" (MIT, 2003: 7). No new nuclear power plant has yet been built and operated in a liberalized electricity system, although Finland is attempting to do so (Mitchell and Woodman, 2007: 155). Even for non-competitive markets like China, with the most grandiose plans for nuclear energy and where it might be thought that public funding is no barrier, the economics are important. The head of the China Atomic Energy Authority, Sun Qin, has explained that once China's nuclear power plants are operating the power is competitive, but "we must resolve the problem of initial investment" (Nuclear News Flashes, 2007). In Turkey, where by law the state guarantees to pay the plant owner-operator a fixed price for electricity, a legal challenge has erupted and the unit price negotiated between the two sides has been deemed "too high for the Turkish state to guarantee" (Hibbs, 2009a: 6).

The (Rising) Cost of Nuclear Power Plants

Nuclear power plants are large construction undertakings. In absolute terms they are dauntingly expensive to build. The Olkiluoto-3 1600 MW EPR currently being built in Finland had a fixed price of €3 billion ($4 billion) in 2003, but is now 50 percent more (World Nuclear News, 2009g). The UK's Department of Trade and Industry (DTI) used as its central case a reactor cost of £2.8 billion (NEA, 2008a: 180).[22] In Canada, the quote from AECL for two new CANDU reactors at Darlington, Ontario, was reportedly CAD$26 billion, while Areva's bid came in at CAD$23.6 billion (Toronto Star, 2009). In 2007, Moody's quoted an "all-in price" of a new 1,000 MW nuclear power reactor in the US as ranging from $5-6 billion each.[23] Lew Hay, chairman and CEO of Florida Power and Light has noted that "If our cost estimates are even close to being right, the cost of a two-unit plant will be on the order of magnitude of $13 to $14 billion" (Romm, 2008: 4). "That's bigger," he quipped, "than the total market capitalization of many companies in the U.S. utility industry and 50 percent or more of the market capitalization of all companies in our industry with the exception of Exelon.… This is a huge bet for any CEO to take to his or her board" (Romm, 2008: 4). The WNA is not sure about whether nuclear is unique or not, asserting that "Although new nuclear power plants require large capital investment, they are hardly unique by the standards of the overall energy business, where oil platforms and LNG [liquid natural gas] liquefaction facilities also cost many billions of dollars," but then noting that "Nuclear projects have unique characteristics. They are capital intensive, with very long project schedules..." (WNA, 2009e: 6, 21).

Since 2003 construction costs for all types of large-scale engineering projects have escalated dramatically (MIT, 2009: 6). This has been due to increases in the cost of materials (iron, steel, aluminum and copper), energy costs, increased demand, tight manufacturing capacity and increases in labour costs (IEA, 2008a: 152). Yet, not only are costs of nuclear plants large, they have been rising disproportionately. According to the 2009 MIT study update, the estimated cost of constructing a nuclear power plant has increased by 15 percent per year heading into the current economic downturn (MIT 2009: 6). The cost of coal and gas-fired plants has also risen but not by as much. Companies in the US planning to build nuclear power plants have announced construction costs at least 50 percent higher than previously expected (IEA, 2008a: 152). While some of these costs may currently be falling due to the global economic downturn, they are likely to rebound once the slump reverses and demand from China, India and Japan begins to increase once more. Some price rises are, however, unique to nuclear, brought about by shortages of reactor components, notably large forgings.

Cost Comparisons with Other Baseload Power Sources

The major traditional competitors with nuclear for "baseload" power are coal, natural gas and, to a declining extent, oil. Competitive energy markets tend to heighten the disadvantages of nuclear. Coal and natural gas plants are cheaper and quicker to build, they obtain regulatory approval more easily, are more flexible electricity generators (they can be turned on and off easily) and can be of almost any size. The IEA projects 2-3 years for a combined cycle gas turbine (CCGT) and 1-2 years for an open-cycle turbine (IEA, 2008a: 143-144). The MIT and University of Chicago studies give lead times of 2-3 years for natural gas (Smith, 2006: 38). All of these factors explain the boom in gas-fired construction in the UK, the US and elsewhere in recent years, notwithstanding the rising price of fuel (currently receding from its peak). Coal-fired plants can also be built relatively quickly. The MIT and Chicago studies agree on four years' construction time for coal-fired plants, as does the NEA (NEA, 2005: 36).[24] Nuclear plants take up to 10 years to plan, obtain regulatory approval for and build, their up-front costs are huge and they are inflexible generators. Essentially, in order to be economic, nuclear power plants need to be kept operating at full power and they cannot readily be shut down and restarted to cope with fluctuations in electricity demand. Light water reactors need to be shut down periodically to refuel (although CANDU and other heavy-water plants do not).

To calculate the total cost of nuclear energy in order to compare it with other forms of energy production, two concepts are commonly used. The industry tends to use "overnight costs," the spending on construction materials and labour as if the plant were to be constructed "overnight," expressed as the cost per kilowatt (kW). This hypothetical construct, a "form of virtual barn raising," does not include the cost of financing the construction and other costs such as escalation of expenses due to increased material and labour costs and inflation (Cooper, 2009b: 20). The term "all-in cost," expressed in the same units as overnight costs, attempts to include these and is thus useful for determining the effects of construction delays (WNA, 2008c: 4). But as Mark Cooper points out, "facilities are not built overnight, in a virtual world" and what utilities and governments wish to know is the cost of electricity that needs to be passed on to the consumer.

Hence the use by economists of the "levelized cost" (sometimes known as the "busbar" cost). This is the minimum price at which a particular technology can produce electricity, generate sufficient revenue to pay all of the costs and provide a sufficient return to investors (Congressional Budget Office, 2008: 16).[25] The levelized cost traditionally takes into account the overnight construction cost, plus the costs of financing, fuel, operation and maintenance (O&M), waste disposition and decommissioning. These are calculated for the lifetime of the plant, averaged over that lifetime and expressed as the price of delivered electricity per kilowatt hour (KWh) or megawatt hour (MWh).

After construction costs, the next biggest cost is the money used for the project, whether borrowed or drawn from savings or other funds already held. A "discount rate" is used, denoted as a percentage figure, to express the value of such money over the time it is used for the project. The rate fluctuates depending on the assessed risk of the project: the higher the estimated risk, the higher the discount rate. The discount rate is presumed to take into account all known risk factors, including political, technical and environmental.

Some caveats about levelized cost models are, however, necessary. First, they produce widely varying results depending on the assumptions made in selecting the input data (particularly for the so-called base case or starting point). Second, the models, which are strictly economic, do not normally take into account all the factors influencing the choices of investors in deregulated electricity markets, notably income taxes and financial conditions (the level of investor confidence in all electricity generation projects).[26] Moreover, the discount rate, although said in theory to encompass "perfect knowledge" of all risk factors, relies on judgement calls by financial experts about some risks which are not necessarily quantifiable, notably political risks. The discount rate applied to nuclear power plants can vary enormously (in the chart on page 44 they range from 5 percent to 12.5 percent, although they can go higher). Finally, the sheer size, expense and unpredictability of nuclear projects may introduce risk factors that cannot be "internalized" into cost estimates. As the NEA notes:

> Many of the risks of a nuclear power project are of a similar type to those of any large infrastructure project, differing only in proportion… Nevertheless, experience with earlier nuclear power plant construction has shown that there are some risks unique to nuclear power projects which are outside the control of investors and which may be difficult or even impossible to price for the purposes of commercial financing (NEA, 2008a: 204).

Economist David McLellan also points out that while the gap between the levelized costs of nuclear and gas may appear narrow, the latter "should be more attractive to private investors than the costs difference alone suggests," since it requires much less up-front investment and repays the investment more quickly (McLellan, 2008: 6).

Fortunately, cost estimates for nuclear power are today made by a much wider variety of stakeholders than ever before. While in the 1970s and 1980s boom they were made largely by nuclear vendors, utilities and governments, today these have been joined by independent analysts, academics and investment consultants, including Wall Street firms like Moody's and Standard and Poor's. These produce an enormous range of cost estimates both for nuclear power by itself and in terms of comparison with other types of energy production, as illustrated in the chart on page 44. Even accounting for currency conversion difficulties, the ranges are enormous. The overnight cost per kilowatt ranges from $690 to more than $3,000, while the generating cost ranges from $15 per MWh to $78 per MWh. The variance illustrates the complexity of the decisions facing potential investors in nuclear energy.

Several of the most prominent studies on the economics of nuclear power are considered in the following section.

Results of Recent Studies on the Cost of Nuclear Power

Study	Year	Original Currency	Cost of Capital	Overnight Cost (per kW)		Generating Cost (per MWh)	
				Original	2000 USD	Original	2000 USD
Massachusetts Institute of Technology (MIT)	2003	USD	11.5%	2000	1869	67	63
Tarjamme and Luostarinen	2003	EUR	5.0%	1900	1923	24	25
Canadian Energy Research Institute	2004	CAD	8.0%	2347	1376	53	31
General Directorate for Energy and Raw Materials, France	2004	EUR	8.0%	1280	1298	28	28
Royal Academy of Engineering	2004	GBP	7.5%	1150	725	23	15
University of Chicago	2004	USD	12.5%	1500	1362	51	46
IEA/NEA (High)	2005	USD	10.0%	3432	3006	50	41
IEA/NEA (Low)	2005	USD	10.0%	1089	954	30	25
Department of Trade and Industry, UK (DTI)	2007	GBP	10.0%	1250	565	38	18
Keystone Center (High)	2007	USD	11.5%	4000	3316	95	89
Keystone Center (Low)	2007	USD	11.5%	3600	2984	68	63
MIT Study Update	2009	USD	11.5%	4000	3228	84	78

Source: Adapted from IEA (2008b: 290). Historical exchange rates and GDP deflator figures adapted from US GPO (2009a, 2009b).

2008 NEA Study

The most recent official study on nuclear economics is contained in *Nuclear Energy Outlook 2008* released by the NEA, on the occasion of its fiftieth anniversary. A first of its kind, the study was released in response to "renewed interest in nuclear energy by member countries" (NEA, 2008a: 2). It bases its analysis on a 2005 NEA/IEA study of electricity generation costs for 18 OECD member states and three non-member states (Bulgaria, Romania and South Africa). It concluded that at a 5 percent discount rate the levelized cost of nuclear electricity ranged from $21 to $31/MWh, with the exception of two plants in the Netherlands and Japan, which had higher costs (NEA, 2008a: 184-185). At a 10 percent discount rate, the generation costs in all countries increased, producing a range of $30 to $50/MWh, except again for the Netherlands (just above $50) and Japan (approaching $70). Comparing the levelized costs for nuclear, coal and gas power plants in the same group of countries, using the same discount rate for all three technologies, the study estimated that the price range for nuclear was narrower than for both coal and gas. The lower limit of the range was considerably lower at the 5 percent discount rate, although only marginally lower at the 10 percent discount rate (NEA, 2008a: 189). Hence nuclear, it claimed, was cheaper.

There are several problems with the NEA study that call its conclusions into question. First, it is based on four-year old questionnaire responses from national authorities in OECD member states. Some countries, notably the UK among nuclear energy producers, did not respond, while some responded only for some types of technologies but not others, potentially producing a non-response bias. Moreover, responding states were asked to provide data on only one or two facilities and the criteria for their choice is opaque. They might well have nominated their most economic plants. The US, for instance, reported data on the cost of one new 1000 MWe Generation III nuclear facility, which has not yet been built, using an "ordered plant price" "based upon costs of units built in the Far East" (NEA/IEA, 2005: 30), presumably the only existing Generation III plants, in Japan.[27] The Netherlands apparently reported on its single nuclear power plant built in 1969 and connected to the grid in 1973, with a capacity of 482 MWe (but recorded incorrectly as 1,600 MWe). The survey thus includes existing old facilities as well as projected new ones.

A further problem is that in order to remove the cost "outliers," the 5 percent lowest and highest values for each of the technologies were excluded. Given that the values for nuclear costs tend to be more spread out than those for coal and gas and that there were only 13 nuclear plants involved in the survey, compared with 27 coal and 23 gas-fired plants, this seems questionable. As Thomas *et al.* conclude, "It is difficult to evaluate the report because of the huge range of national assumptions, with Eastern European countries often providing very low costs and Japan very high" (Thomas et al., 2007: 34).

The biggest problem with the 2005 study, given the level of risk represented by the track record of nuclear energy, is the use of the same discount rate for all types of power generation.[28] As the NEA itself concedes coyly in its 2008 *Nuclear Energy Outlook*, other studies have not done this "because it might (sic) be argued that some sources or technologies are perceived as more risky than others by potential investors" (NEA, 2008: 192). When the Performance and Innovation Unit (PIU) of the UK Cabinet Office examined nuclear economics for the British government's 2003 energy review, it used a range of discount rates from 8 percent to 15 percent (which it referred to as the real post-tax costs of capital) (Thomas et al., 2007: 45). At the time 15 percent was widely seen as the minimum rate required for any plant operating in a competitive market, while 8 percent was the rate applied to appraisal of the Sizewell B nuclear plant when the UK electricity industry was a publicly owned monopoly. The 15 percent discount rate resulted in costs per KWh about 50 percent higher than the 8 percent rate. Thomas *et al.* claim that the higher rate would be a more realistic for nuclear in the UK given the government's assertion that there will be no government subsidies (Thomas et al., 2007). Steve Kidd of the WNA says, "In general, financing needs to be available at under 10% per annum to make new nuclear build work economically" (Kidd, 2008: 51).

The NEA's *Nuclear Energy Outlook* goes beyond the 2005 study in making further calculations that take into account income tax imposed on generating plant revenues and assumptions about "financial conditions" (the level of investor confidence in all electricity generation projects). Although, surprisingly, it assumed that financing conditions "will be the same for nuclear, gas and coal," its calculations revealed that under "moderate" financial constraints the inclusion of income tax would increase the generation costs of nuclear by 10 percent, for coal by 7 percent and only 2 percent for gas. This would leave nuclear cheaper than gas but more expensive than coal. Under "tight" financial constraints, the differential increase due to tax is greater: 22 percent for nuclear, 16 percent for coal and only 5 percent for gas — due to nuclear's high capital costs. This makes nuclear more expensive than both coal and gas. Stating the obvious, the NEA concludes that the impact of tax regimes on generation costs may not be technology-neutral (NEA, 2008a: 194).

2003 MIT Study and 2009 update

In 2003 the Massachusetts Institute of Technology (MIT) published what is probably the most widely cited study on the future of nuclear power. Although having a strong US policy emphasis, this multidisciplinary study also produced findings that it implied were applicable worldwide. The MIT group began from the premise that the need to reduce greenhouse gas emissions to tackle climate change was so great that re-evaluating the role of nuclear energy was justified. In that sense the report was predisposed towards a nuclear revival. Unlike the IEA/NEA though, the MIT group applied a higher weighted cost of capital (essentially the discount rate) to the construction of a new nuclear plant (10 percent), compared to one for coal or natural gas (7.8 percent) (MIT, 2009: 8). The result of its calculations was that nuclear was likely to be more expensive than coal and Combined Cycle Gas Turbine (CCGT), even at high natural gas prices. At such prices for nuclear and gas, it was coal rather than nuclear that would attract new plant investment. The report bluntly declared: "Today, nuclear power is not an economically competitive choice" (MIT, 2003: 3).

For deregulated electricity markets, in which private capital might be expected to invest in nuclear, it concluded that:

> The bottom line is that with current expectations about nuclear plant construction costs, operating cost and regulatory uncertainties, it is extremely unlikely that nuclear power will be the technology of choice for merchant plant investors in regions where suppliers have access to natural gas or coal resources. It is just too expensive (MIT, 2003: 40).

Merchant plants are those built by investor developers who take on the permitting, development and construction and operating costs, but who sell their output to distribution companies, wholesale and retail marketers under supply contracts (MIT, 2003: 44, fn 2). The traditional alternative has been ownership, operation and distribution of output by electricity utility companies.

As for states that still have regulated electricity markets, the report noted that:

> In countries that rely on state owned enterprises that are willing and able to shift cost risks to consumers to reduce the cost of capital, or to subsidize financing costs directly, and which face high gas and coal costs, it is possible that nuclear power could be perceived to be an economical choice (MIT, 2003: 41).

Convinced that nuclear energy should still make a contribution to the energy mix in tackling global warming, the MIT researchers suggested that progressive achievement of cost reductions in the nuclear industry (by reducing construction costs, construction times, O&M costs and securing financing on the same terms as gas and coal), could make it comparable in price with coal and gas. This assumed moderate prices for coal and gas, but not when gas was cheap. The authors judged — in 2003 — that such cost improvements by the nuclear industry, while "plausible," were not yet "proven." They added that nuclear would become more competitive if the "social cost of carbon emissions is internalized, for example through a carbon tax or an equivalent 'cap and trade' system" (MIT, 2003: 7). They also advocated government financial incentives for a few first-of-a-kind new entrants, to "demonstrate to the public, political leaders and investors the technical performance, cost and environmental acceptability of the technology" (MIT, 2009: 19).

The principal conclusions of the MIT study are broadly consistent with those of a 2004 University of Chicago analysis of the cost of power plants that could be put into service by 2015. Like the MIT study, and despite differences in their models, the Chicago researchers concluded that electricity from new nuclear plants would be more expensive than coal (29-115 percent more, compared to 60 percent in the MIT study) and more expensive than natural gas (18-103 percent more, compared to the MIT's 20-75 percent). The Chicago report expressed no surprise at this outcome since:

> No observers have expected the first new nuclear plants to be competitive with mature fossil power generation without some sort of temporary assistance during the new technology's shake-down period of the first several plants (Tolley and Jones, 2004: 5-25).

In a 2009 update, the MIT group expressed disappointment that six years later the economics of nuclear remained essentially unchanged (MIT, 2009: 6). While the price of natural gas had risen dramatically, making nuclear more attractive (although gas has since retreated from its peak), the construction costs for all types of large-scale engineered projects had also escalated dramatically — but more so in the case of nuclear. MIT's estimated overnight cost of nuclear power had doubled from $2,000/kW to $4,000/kW in six years. The following chart illustrates the MIT researchers' assessment of the worsening economic prospects of nuclear energy, at least in the US.

Costs of Electricity Generation Alternatives

	Overnight Cost	Fuel Cost	Base Case	w/carbon charge $25/ton CO_2	w/same cost of capital as coal/gas
	$/kW	$/m BTU	¢/kWh	¢/kWh	¢/kWh
2003 (2002 USD)					
Nuclear	2,000	0.47	6.7	n/a	5.5
Coal	1,300	1.20	4.3	6.4	n/a
Gas	500	3.5	4.1	5.1	n/a
2009 (2007 USD)					
Nuclear	4,000	0.67	8.4	n/a	6.6
Coal	2,300	2.60	6.2	8.3	n/a
Gas	850	7.00	6.5	7.4	n/a

Source: MIT (2009: 3)

The 2009 update noted that "While the US nuclear industry has continued to demonstrate improved operating performance [for existing reactors], there remains significant uncertainty about the capital costs, and the cost of its financing, which are the main components of the cost of electricity from new nuclear power plants" (MIT, 2009: 6). It suggested, unsurprisingly, that lowering or eliminating the risk premium would make a significant contribution to making nuclear more competitive. This will only occur, it said, through "'demonstrated performance' by 'first movers'" which will in turn only occur because of government subsidies to lower the risk.

The 2005 US Energy Policy Act (EPact) — which the 2003 MIT study may have helped inspire — provided such government support. Yet four years later the MIT researchers judged that the program had not been effective in stimulating new build. This may be in part because, as the MIT researchers themselves had advocated, all low-carbon technology alternatives have been subsidized. This confirms Mark Cooper's claim that technology neutral subsidies do "not change the consumer economics much" (Cooper, 2009b: 61). (See below for further analysis of the impact of subsidies.)

Keystone Report

The 2007 Keystone Center's Nuclear Power Joint Fact-Finding Dialogue, involving 11 organizations, nine of which are corporations or utilities involved in selling or buying nuclear power plants, estimated that the life-cycle levelized cost of future nuclear power in the US would have a "reasonable" range of between 8 and 11 cents per kWh delivered to the grid (Keystone Center, 2007: 11). This is higher than MIT's 7.7-9.1 cents per kWh (in 2007 dollars). Reportedly, at some of the sponsors' insistence, the report did not consider comparable costs for other energy sources (Lovins and Sheikh, 2008: 5). The study took into account a likely range of assumptions on the critical cost factors, such as escalation in material costs, length of construction period and capacity factor. It noted that while some companies have announced their intention to build "merchant" plants, "it will be likely be easier to finance nuclear power in states where the costs are included in the rate base with a regulated return on equity" (Keystone Center, 2007: 12) (see chart on page 51).

Financial Market and Other Independent Analysts

Since it is investors, both private and public, whose money would be at risk in investing in nuclear power, it is instructive to consider their views. In short, private capital remains skeptical, as do utilities being pressed to invest in new build. Mark Cooper has calculated the overnight cost of completed nuclear reactors since the "great bandwagon market" of the 1970s and 1980s compared to projected future costs. He notes a dramatic escalation in cost estimates since the current "nuclear renaissance" was heralded, as Wall Street and independent analysts, along with utilities, began to examine the early estimates of vendors, governments and academics (Cooper, 2009b: 3).

In October 2007, Moody's Investors Service declared that "the ultimate costs associated with building new nuclear generation do not exist today — and that the current cost estimates represent best estimates, which are subject to change" (Moody's Corporate Finance, 2007). It estimated that the overnight cost of a new nuclear power plant in the US could range from $5,000 to $6,000 per kW. For the new build in Ontario, Canada, Moody's is forecasting an overnight cost of $7,500 per kW (compared to the Ontario Power Authority's claim of $2,900 per kW) (Ontario Clean Air Alliance, 2009). As for levelized costs, according to Mark Cooper, numerous studies by Wall Street and independent energy analysts estimate efficiency and renewable costs at an average of 6 cents/kWh, while nuclear electricity is in the range of 12-20 cents/kWh (Cooper, 2009b: 1).

Cost Comparisons with Non-Baseload Alternatives: Conservation, Efficiency and Renewables

One argument used for increasing the use of nuclear energy is that no other relatively carbon-free alternatives exist for providing "reliable baseload power," especially for large urban areas. Although the term is often misused, baseload power in the parlance of the electricity industry means power at the lowest operating cost. This baseload is supplemented during peak periods by costlier forms of generation. Mark Cooper claims that utilities promote a narrow focus on traditional central power station options since "large base load is what they know and they profit by increasing the base rate" (Cooper, 2009b: 43). Yet renewable energy like wind and solar could, in theory, be run as baseload power since the operating costs are marginal compared with large power plants.

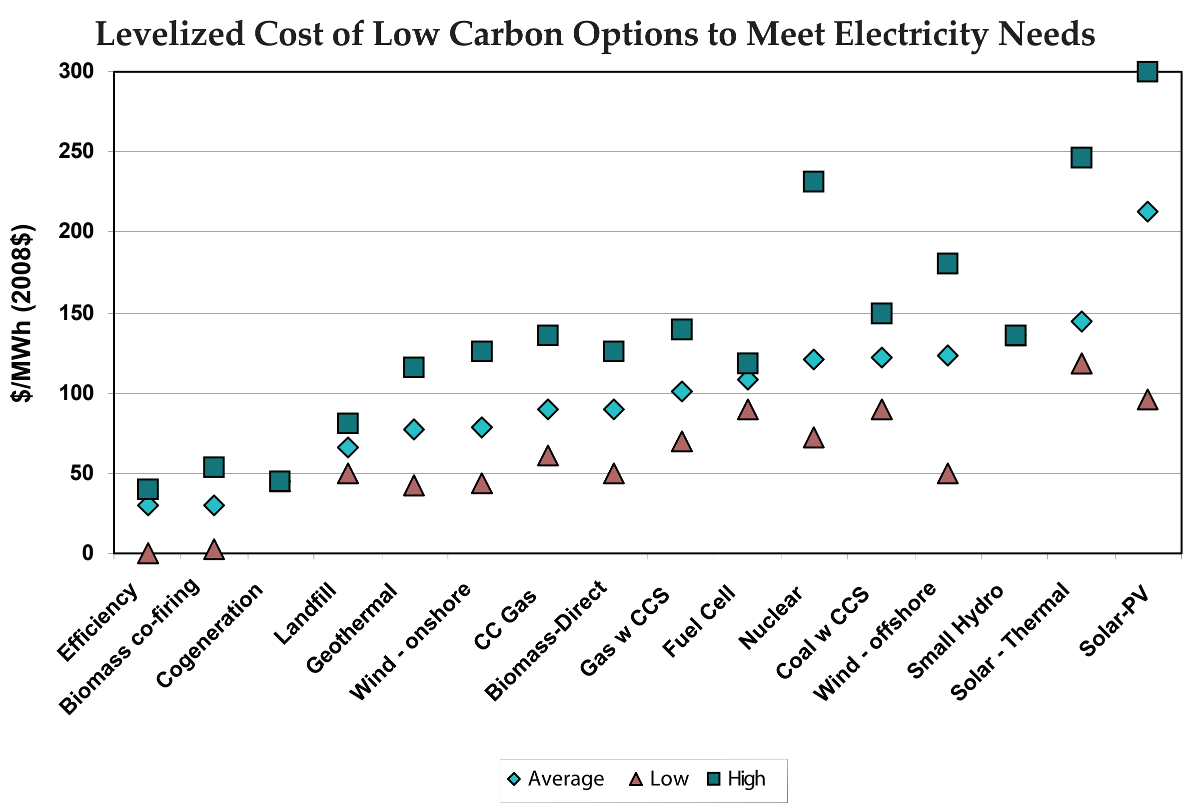
Baseload power also does not mean "most reliable," since all sources of electricity are unreliable and power grids are designed to cope with highly variable supply. Nuclear power plants must be shut down periodically for refueling and maintenance, prolonged heat waves may deprive them of cooling water as occurred in France in 2003, and they also automatically shut down for safety reasons during electricity blackouts, at the very time they are most needed, as occurred in the great Northeast America blackout in August 2003 and in Brazil in November 2009 (WNN, 2009c). In fact, a portfolio of many smaller units is inherently more reliable than one large unit as it is unlikely that many units will fail simultaneously.

While most baseload power is projected to continue to come from centralized power stations, simply because they already exist and already supply major portions of total electricity demand, there are many cheaper alternatives. At the very least nuclear will find itself competing in terms of both investment and subsidies, as governments seek to adjust their energy mix for reasons of climate change and energy diversity (IEA, 2008a: 45).[29]

Some of the alternatives, such as conservation and efficiency measures, will reduce demand for baseload power. In the IEA's ACT and BLUE scenarios to 2050, energy-efficiency improvements in buildings, appliances, transport, industry and power generation represent the largest and least costly savings (IEA, 2008a: 40). One example is combined heat and power (CHP), which by generating electricity and heat simultaneously, can increase overall efficiency and reduce the combined environmental footprint. For existing industrial facilities or power stations using biomass, natural gas or coal (but not nuclear), only a modest increase in investment costs is required for CHP. Despite some loss of efficiency in electricity generation (increasing heat production hurts electricity production) (MacKay, 2009: 146, 149), CHP can be "very profitable" according to the IEA (IEA, 2008a: 143).

Other alternatives, such as solar, wind and biofuels, would seek to replace baseload power, in many cases combined with greater use of "distributed generation" from smaller plants closer to the consumer (IEA, 2008a: 143). Cost comparisons between nuclear and such alternatives can be even more complex than comparing baseload alternatives. Yet, as Mark Cooper points out, compared to the diversity of nuclear cost estimates, there is much less diversity in the cost estimates of alternatives, so the figures tend to be more convincing. In a comparison of six recent studies, Cooper reveals that:

> New nuclear reactors are estimated to be substantially more expensive than a variety of alternatives, including biomass, wind, geothermal, landfill, and some solar and conventional fossil fuels. The studies find that nuclear is cost competitive with advanced coal, natural gas and some solar (Cooper, 2009a: 43).



Source: Cooper (2009a: 30)

Naturally, the levelized cost is only one aspect of the choices policy makers will face in choosing their national energy mix. As David McLellan confirms, "The economics of nuclear plants vary from one country to another, depending upon energy resource endowments, government policies and other factors that are country specific" (McLellan, 2008: 18). As indicated in the section on climate change above, calculations of the cost of carbon emissions avoided per dollar spent on different types of electricity generation (as opposed to simply considering the levelized cost of electricity of each alternative) reveal that nuclear is among the more expensive ways of tackling climate change.

It is beyond the scope of this report to analyze all of the pros and cons of these technologies and the likelihood that they could supplant significant amounts of baseload power generation to the point of persuading policy makers to forego new nuclear builds. Clearly, many alternative energy sources face significant challenges, including the intermittency of supply (wind and solar); the need for enormous tracts of land in order to generate sufficient amounts of energy (wind, solar, biofuels) and energy storage capacity (battery technology). Other technologies, such as "clean coal" and CCS are unproven and subject to great skepticism. However, R&D is proceeding at such a pace for some technologies that improvements in performance and cost will arrive more quickly than they can for nuclear technology — which has demonstrated long lead times, poor learning rates and large cost-overruns.

The IEA notes that "technology learning" is an important factor in R&D and investment decisions for emerging energy technologies. Over time the costs of new technology should be lowered through technology learning as production costs decrease and technical performance increases. The IEA has surveyed observed historic learning rates for various electricity supply technologies (IEA, 2008b: 205). The learning rate for nuclear in the period 1975-1993 in the OECD area was just 5.8 percent, the lowest except for offshore wind and CCS. Onshore wind achieved learning rates of between 8 and 32 percent, while photovoltaics ranged from 20-23 percent. A study by McDonald and Schrattenholzer shows the learning rates of the nuclear industry compared to other selected energy technologies to be low (6 percent compared to 17 percent for wind, 32 percent for solar and 34 percent for gas turbine combined cycle (GTCC)) (McDonald and Schrattenholzer, 2001: 355-361). Observed learning rates for various "demand-side" technologies were all higher than for nuclear, including selective window coatings (17 percent), facades with insulation (17-21 percent), double-glazed coated windows (12-17 percent) and heat pumps (24-30 percent). While such comparisons need to be treated with care due to the difficulty of comparing different technologies, especially those starting from a low base like wind, compared with more mature ones like nuclear, they do give an indication of the competition for investment in R&D and deployment that nuclear faces.

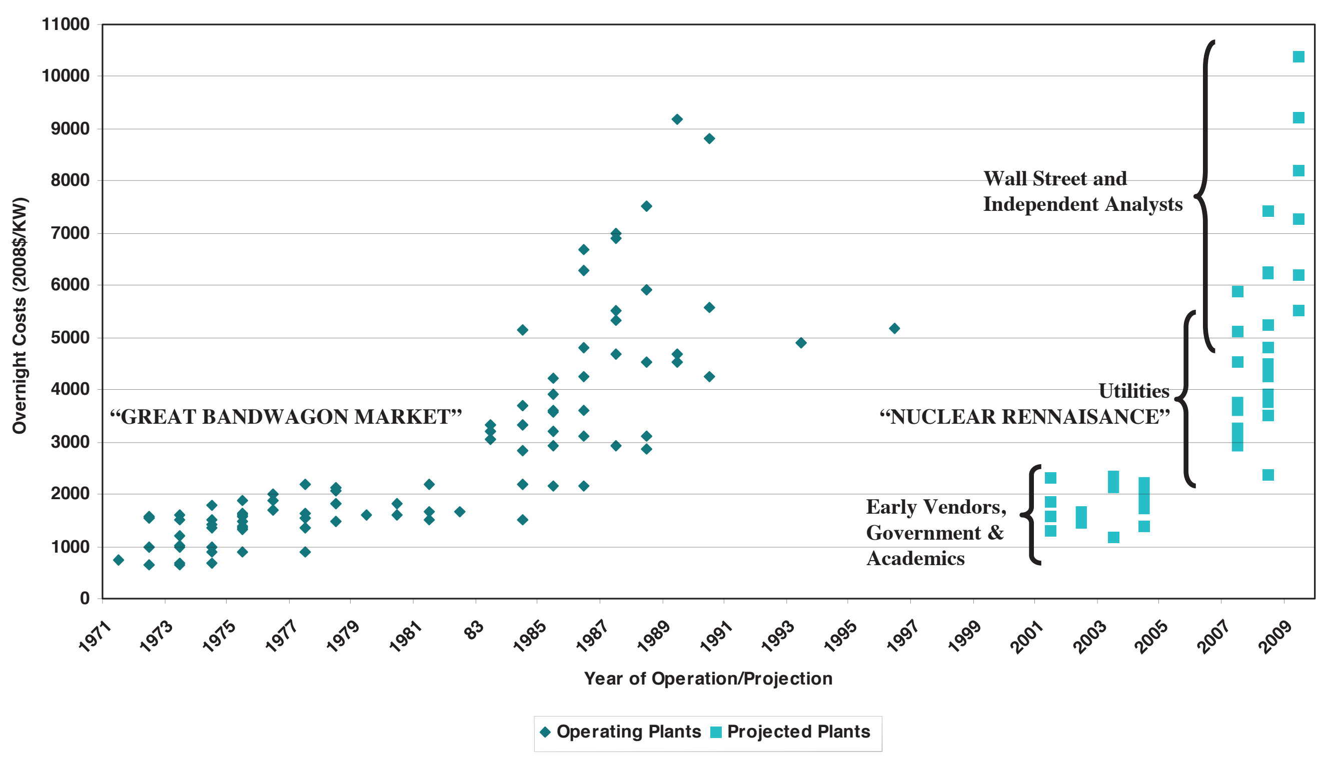
Construction Delays and Cost Overruns

Major one-off engineering and construction mega projects like bridges, tunnels and Olympic stadiums almost invariably take longer to build and cost more than originally estimated. In the nuclear industry, however, delays and cost overruns are legion. According to the World Energy Council, the average construction time for nuclear plants has increased from 66 months in the mid-1970s to 116 months (nearly 10 years) between 1995 and 2000 (Thomas et al., 2007: 10).[30] Since 2000 there has been a decline, but average construction time remains at seven years (Thomas et al., 2007: 10). Nuclear plant construction projects are so capital intensive, attract such high interest rates, are so complex and are of such duration, that even relatively minor delays can result in significant cost overruns. Mark Cooper notes that "Reactor design is complex, site-specific, and non-standardized. In extremely large, complex projects that are dependent on sequential and complementary activities, delays tend to turn into interruptions" (Cooper, 2009b: 41). The challenge for the nuclear industry is that unlike other one-off projects, like bridges and stadiums, nuclear power plants must compete with cheaper alternatives.

Part of the rationale for Generation III+ reactors is the hope that costs will come down with "learning experience" from subsidized first-of-a-kind reactors, economies of scale from multiple new builds, modularization and assembly-line production of components (Schneider, 2009b: 32),[31] as well as "advanced project management techniques" (Boone, 2009: 8-9).[32] In addition, the industry is pinning its hopes on streamlined government regulation, as in the UK and US. However, as we have seen, the learning that usually lowers costs over time has not generally occurred in the nuclear power business. A study by Mark Cooper demonstrates that during the "great bandwagon" era of American nuclear build in the 1960s and 1970s "on average, the final cohort of … market reactors cost seven times as much as the cost projection for the first reactor" (Cooper, 2009b: 2). Although the IEA estimates that a learning rate of just 3 percent is required to reduce the current estimated cost of Generation III+ nuclear power plants from $2,600/kW in 2010 to a "commercialization target" of $2,100/kW by 2025, this seems a gross underestimate, especially since the MIT 2009 update gives a current overnight cost for new reactors in the US of $4,000/kW (IEA, 2008b: 206). (For Generation IV the figures are even less convincing: a 5 percent learning rate to bring the estimated current cost of $2,500 in 2030 to a post-2050 figure of $2,000.)

Faster construction times are currently being recorded in Asia. Of the 18 units built in Asia between 2001 and 2007,

Overnight Cost of Completed Nuclear Reactors Compared to Projected Costs of Future Reactors



Source: Cooper (2009b: 3)

three were connected to the grid in 48 months or less (IEA, 2008b: 287). The fastest was Onagawa 3, a Japanese 800 Mw boiling water reactor (BWR) connected in 2002 after a 41-month construction period (IEA, 2008b: 287). According to AECL, its CANDU-6 reactors built in China were delivered ahead of schedule and under budget (Oberth, 2009). In fact, AECL claims that in the last 13 years it has contractually delivered seven reactors on time and on budget in China, South Korea and Romania.

These may be exceptions that prove the rule, since the current nuclear "revival" is showing "eerie" parallels to the 1970s and 1980s. Cooper claims that "startlingly low-cost estimates prepared between 2001 and 2004 by vendors and academics and supported by government officials helped create what has come to be known as the 'nuclear renaissance'" (Cooper, 2009b: 2). David McLellan suggests that this was inspired by "the dramatic increase in the efficiency of [existing] US nuclear power plants" — an exception to the nuclear industry's poor learning curve (McLellan, 2008: 4). Yet according to Cooper's research, the most recent cost projections for new nuclear reactors are, on average, more than four times as high as the initial "nuclear renaissance" projections (Cooper, 2009b: 1). This has not prevented nuclear boosterism of the type that characterized the 1970s and 1980s from re-emerging. According to Steve Kidd, "What is needed is the courage to get over the initial period of pain of high initial capital costs to enter the "land of milk and honey" in subsequent years, where nuclear plants can be almost "money machines" for their owners (Kidd, 2007: 203-204).

Such cost overruns are not restricted to the US. India's reactors have all been over budget, ranging between 176 and 396 percent (Thomas et al., 2007: 11). In Canada, the Darlington facility built in the period 1981-93 so compromised the financial position of the provincial utility, Hydro Ontario, that its CAN$38 billion debt was orphaned into a separate fund. Provincial electricity consumers to this day see an amount added to their electricity bill to pay off this debt (Ontario Clean Air Alliance, 2004).

The Olkiluoto-3 Project in Finland

The first nuclear reactor to be built in a deregulated electricity market is currently under construction at Olkiluoto in Finland. It is also the first order for Areva's Evolutionary Power Reactor (EPR). The turnkey project is being constructed for Finnish energy company Industrial Power Corporation (Teollisuuden Voima Oyj (TVO)), originally by a consortium of the French company Areva and Germany's Siemens, at a fixed price of €3 billion. The contract was signed at the end of 2003, a construction licence obtained in February 2005 and construction began in mid-2005. The 1,600 MWe plant was supposed to begin operation in 2009. By the end of 2009 the project was more than three years behind schedule and is now expected to open "beyond" June 2012 (TVO, 2009). The project is also more than 50 percent (€1.7 billion) over budget (WNN, 2009i). Areva has allowed for a €2.3 billion ($2.8 billion) loss on the project so far (WNN, 2009e).

Since work began there have been several complications: the Finnish Radiation and Nuclear Safety Authority (*Säteilyturvakeskus* or STUK) has expressed concerns about the safety culture at the site; local contractors have been faulted for poor quality work on the concrete for the reactor "island"; a dispute between Areva-Siemens and TVO over compensation for the cost of replacement power has gone to international arbitration and Siemens has left the consortium. Some of these problems are common in so-called first-of-a-kind projects, which is why the nuclear industry seeks government guarantees to cover unexpected losses.

Steve Kidd, director of strategy and research at the WNA, calls the delays in the Finnish project a "significant blow" to demonstrating the viability of new build in deregulated markets (Kidd, 2008: 50). Yet the project is actually not operating in a truly deregulated environment; it obtained export credits from French and Swedish government agencies which enabled the project owners to obtain a bank loan for 60 percent of the total cost at an interest rate of 2.6 percent, which, taking into account inflation, is an effective interest rate of zero (Thomas et al., 2007). Areva, moreover, in offering a turnkey project at a fixed price, appears to have kept the price unreasonably low as a "loss leader" to attract new orders. It was also reportedly concerned that the regulatory approval it obtained from the French and German authorities in 2000 for the EPR would lapse if an order was not placed soon and the design proven in practice (Thomas et al., 2007: 39). Finally, TVO is 60 percent owned by the not-for-profit Nordic Power Corporation (Pohjolan Voima Oyj (PVO)), whose shareholders are entitled to purchase electricity at cost in proportion to their equity. This arrangement is "effectively a life-of-plant contract for the output of Olkiluoto-3 at prices set to fully cover costs" (Thomas et al., 2007: 40), hardly a model of a deregulated environment.

Despite the long, largely positive experience of Finland with nuclear power in the past and its reputation as an efficient, well-governed and highly regulated state, the Olkiluoto-3 project suggests several lessons for the nuclear revival:

- Turnkey contracts represent a huge risk for plant vendors, which in the future are likely to be wary of them (this has already occurred in Ontario, where the bids were starkly realistic and thus too expensive for the government to contemplate).
- New nuclear build may not be economically viable even in partially deregulated markets.
- The skills needed to successfully build a nuclear plant to the engineering and safety standards required are considerable and a lack of recent experience of such construction may make the task much more difficult.
- There are serious challenges for regulatory bodies, even those as professional and experienced as Finland's, in overseeing new generation reactor construction, especially first-of-a kind plants (STUK had not assessed a new reactor order for more than 30 years) (Thomas et al., 2007: 41).

The Impact of the 2008-2009 Current Financial Crisis

The 2008-2009 financial crisis and global economic recession have added to existing investor uncertainty about the economic fundamentals of nuclear energy. An IEA background paper for the G8 energy ministers meeting in May 2009 reported that energy investment worldwide was plunging in the face of a tougher financial environment, weakening "final" demand for energy and falling cash flows (IEA, 2009). It estimated that global electricity consumption could drop by as much as 3.5 percent in 2009 — the first annual contraction since the Second World War. The IEA expects to see a resulting shift to coal- and gas-fired plants at the expense of more capital-intensive options such as nuclear and renewables, although it added that "this will depend on the policies and support mechanisms individual countries and regions have in place" (IEA, 2009: 4). Platts reported in September 2009 that according to industry leaders at the WNA annual symposium in London "the international financial and economic crisis that began a year ago has cast a chill over the burgeoning nuclear 'renaissance'" (MacLachlan, 2009: 1-3).

Meanwhile, the US Nuclear Energy Institute (NEI) has dramatically scaled back its "Vision 2020" plan launched in 2002 to foster the addition of new US plants by 2020. It now projects only 20,000 MW compared to 50,000 MW. Marvin Fertel, NEI president and CEO, said this was due to the current economy and the absence of new units demonstrating that they could be successfully built. Plans for new build in Ontario, Canada, have been cancelled due to both falling demand for electricity and rising costs.

It could be, however, that the global recession has mixed effects on the fortunes of nuclear energy. While private investors may be more reluctant to invest and utilities less able to take out loans since the capital markets seized up, interest rates are historically low. Moreover, governments around the world have sought to attenuate the effects of the recession by pumping government funds into their economies, notably by supporting infrastructure projects. However, nuclear vendors may have trouble arguing that their projects have the desired "shovel-readiness" and that they can produce instant jobs. Probably more likely than significant outright funding would be an expansion of existing government subsidies.

The Impact of Government Subsidies

Governments, like utilities and the nuclear industry, will take economic and financial considerations into account in making public policy decisions about whether or not to permit, support, actively encourage or actually invest in nuclear energy. Some governments, with large reserves derived from oil or other wealth, may simply choose to build nuclear power plants regardless of the economics of nuclear power, but most cannot afford this luxury. Naturally, industry will take into account the willingness of governments to provide a favourable investment environment for nuclear power.

The nuclear energy industry has always been the beneficiary of government financial support, either direct or indirect. This is attributable to several factors: the technology emerged from nuclear weapons or other military programs such as submarine propulsion; the industry requires significant regulation and oversight by governments (in terms of safety, security, nonproliferation and waste); governments need to assume insurance liability above certain limits in case of catastrophic accidents; the earliest reactor projects have tended to lack commercial viability; and construction delays and cost overruns have often forced governments to absorb or retire unmanageable debt incurred by utilities. States with national reactor vendor companies also willingly became financially involved in promoting what was seen in the 1960s and 1970s as a revolutionary technology that promised huge profits from exports. The most famous example is the US Atoms for Peace Program, but other governments joined in, as in the case of Canada's support of its CANDU reactor exports (Bratt, 2006).

The nuclear industry is currently schizophrenic on the issue of subsidies, trumpeting the "new economics" of third generation nuclear reactors, while seeking government assistance to kick-start a revival. According to the WNA's Steve Kidd, "The first new nuclear units to be built should not now need financial subsidies, as the economics now look sound, assuming that investors can take a long-term view" (Kidd, 2008: 79), although "Initial plants of new designs … face substantial first-of-a-kind engineering costs and may need some public assistance to become economic" (Kidd, 2008: 44).

American studies all conclude that for the US, at least, the most critical factor in the future relative cost of different electricity generation technologies is government financial support (along with the price of carbon) (CBO, 2008: 26).[33] The US seems to offer the greatest variety of subsidy mechanisms through its 2005 Energy Policy Act, including loan guarantees, tax credits, regulatory delay insurance and other subsidies for the first six new reactors, as well as funding from the Department of Energy (DOE) for first-of-a-kind reactors (CBO, 2008: 11, 8-9).[34] The Congressional Budget Office (CBO) concludes: "EPAct incentives by themselves could make advanced nuclear reactors a competitive technology for *limited additions* [emphasis added] to baseload capacity" (CBO, 2008: 2). The 2003 MIT calculations do not support this. Despite the magnitude of their proposed subsidies, they still would not be large enough to fully overcome the higher costs of nuclear compared with fossil fuels (this would only be done through a carbon tax and by reducing the risk premium through "demonstrated performance") (MIT, 2009: 8). Under the MIT proposal the levelized cost of electricity from the 10 "first movers" would be approximately 6.2 cents per kWh, still well above the estimated price of electricity from coal or natural gas (Smith, 2006: 49).

The 2009 update of the 2003 MIT study, which had advocated "limited government assistance for 'first mover'" US nuclear plants concludes that this has "not yet been effective in moving utilities to make firm reactor construction commitments" (MIT, 2009: 9). This was due to three reasons: the Department of Energy has not moved expeditiously enough to issue the regulations and implement the program; the requirement of many state governments that utilities obtain a certain fraction of their electricity from low-carbon sources has excluded nuclear; and increased cost estimates are making the industry seek even more assistance. The Nuclear Energy Institute has argued that the current loan guarantee program of $18.5 billion is "clearly inadequate" (the industry has so far applied for loans totalling $122 billion) (Alexander, 2009) and proposed at least $100 billion for all clean energy technologies, including nuclear (WNN, 2009d).

The MIT group opposes increased subsidies, arguing for a level playing field for all energy generation technologies based on a carbon tax or a cap-and-trade system (MIT, 2009: 10). According to Mark Cooper: "Seeking to override the verdict of the marketplace, the industry's lobbying arm has demanded massive increases in subsidies from taxpayers and ratepayers to underwrite the industry," but even with subsidies nuclear would still be more expensive than the alternatives (Cooper, 2009a: 1). Peter Bradford, a member of the US Nuclear Regulatory Commission from 1977 to 1982, argues that "the US can revert to the sensible notion of limited support for a few first mover nuclear projects or it can insist that US taxpayers continue to underwrite a 'revival' that the industry has proven unable to manage" (Bradford, 2009: 64). The Congressional Budget Office considers the risk of default on the part of the nuclear industry to be very high — well above 50 percent (CBO, 2003).

The UK has said it will take active steps to "open up the way" to construction of new nuclear power stations, but conscious that British taxpayers have borne the costs of past failures to achieve nuclear energy profitability (Brown, 2008: 3)[35] has made clear that it is up to private enterprise to fund, develop and build the new stations (Davis, 2009: 26). Ontario, meanwhile, has signaled it is not prepared to subsidize nuclear by guaranteeing cost overruns.

Even for countries with generous subsidies, these may not be enough to make the difference in favour of nuclear power. As the CBO warns for the US, "under some plausible assumptions … in particular those that project higher future construction costs for nuclear plants or lower gas prices — nuclear technology would be a relatively expensive source of capacity, regardless of EPAct incentives" (CBO, 2008: 2).

Currently, many governments engaged in the "revival" are offering "support" for new build, although not necessarily in the form of subsidies. In most countries undertaking or planning significant new build, including China, India, Russia, Japan, Taiwan, South Korea and the Ukraine, a lack of transparency about costs and hidden subsidies makes it impossible to ascertain the complete extent of such support. Even in Western market economies information about costs and subsidies may be difficult to discern. In France, the true total cost of nuclear energy, closely linked as it is to the nuclear weapons fuel cycle, is apparently considered a state secret and has never been disclosed (Brown, 2008: 32).[36] Some countries with oil wealth such as Nigeria, Saudi Arabia and Venezuela, may be able to provide the ultimate in government subsidy by simply buying a nuclear plant outright with government funds, without transparency and little or no legislative oversight.

The Impact of Carbon Pricing

The CBO concludes that "the longer-term competitiveness of nuclear technology as a source of electricity is likely to depend on policy makers' decisions regarding carbon dioxide constraints" (CBO, 2008: 26) that could increase the cost of generating electricity with fossil fuels. The 2003 MIT study, too, noted that while nuclear power was not currently economically competitive , it could become so if future carbon dioxide emissions carried a "significant price" (MIT, 2003: 8). The CBO notes that the effect is most pronounced for coal, which emits nearly a metric ton of carbon dioxide for every megawatt hour of electricity produced (CBO, 2008: 2). Even modern coal- and gas-fired plants designed to use fuel more efficiently would still emit enough carbon dioxide to make nuclear more economic under a carbon regime. Plants that use CCS, which has not yet been proven commercially, are likely to emit just 10 percent of the carbon dioxide of current fossil fuel plants. Yet this still fails to compete with the zero emissions from a nuclear generating plant (Galbraith, 2009).

Cooper points out, however, that imposing a price on carbon makes all low carbon options, including efficiency and renewables, more attractive. It would thus "not change the order in which the options enter the mix" (Cooper, 2009b: 8). Brice Smith notes that an increased focus on efficiency as a result of a carbon price would result in reduced demand for electricity, throwing into question the need for additional large power plants (Smith, 2006: 60). The World Business Council for Sustainable Development notes that some alternative technologies like ultra-supercritical pulverized coal (USSPC) and wind in optimal locations are already "mature" and would be competitive were the value of CO_2 emissions internalized into electricity prices (World Business Council for Sustainable Development, 2008: 3).

Crucially, carbon taxes and/or cap-and-trade systems rely on private enterprise and investors responding to market signals. It could be a decade before the price of carbon stabilizes at high enough levels for confident investment decisions to be made about using nuclear energy instead of other sources. The EU's pioneering system, established in 2005, while understandably fraught with teething problems, has still not priced carbon high enough for nuclear to become economic (Nuclear News Flashes, 2009b).[37] In 2009 the MIT group lamented that a carbon tax, along with other incentives for nuclear had not yet been realized, meaning that "if more is not done, nuclear power will diminish as a practical and timely option for deployment at a scale that would constitute a material contribution to climate change risk mitigation" (MIT, 2009: 4). The system enacted by the US Congress in June 2009 has been watered down by making early distribution of permits largely free, ensuring that politics rather than sound economics will govern the price, at least in its early years.

Essentially the prospects of a global price on carbon are so uncertain as to make it impossible for investors today to assess the effects on the economics of nuclear power. The whole future of the international climate regime is itself uncertain, especially after the failure of the Copenhagen climate change conference in December 2009. Implementation of a global price for carbon through either a tax or a cap-and-trade system is years away, while investment decisions about nuclear energy need to be made now.

Costs of Nuclear Waste Management and Decommissioning

The costs of nuclear waste management and decommissioning of civilian power reactors should ideally be "internalized" in the cost of electricity. Contrary to popular perception, long-term waste management and decommissioning are a negligible part of the overall estimated costs of nuclear, since they are calculated in future dollar values which, due to inflation, become progressively cheaper. Thomas *et al.* note that if a 15 percent discount rate for a new power plant is applied to decommissioning and waste management they essentially "disappear" from the calculations. However, they also claim that it would be wrong to apply such a high rate of return to such long-term liabilities since funds collected from consumers should be placed in low-risk investments to minimize the possibility that they will be lost. Such investments yield a low interest rate (Thomas et al., 2007: 60).

A more pertinent question is whether future costs of waste management and decommissioning are adequately estimated, especially given the fact that "no full-size nuclear power plant that has completed a significant number of years of service has ever been fully dismantled and disposed of" (Thomas et al., 2007: 45). Moreover, there is no experience anywhere in the world with long-term disposal of high-level nuclear waste from civilian nuclear power plants (although the US does have such experience with high-level military waste).

Ideally, funds for nuclear waste management and decommissioning should accumulate from revenues obtained from the electricity generated. Such funds may either be held and managed by the commercial operator (as in France and Germany) or by the government (as in Finland, Sweden and the US). Problems may arise if utilities are unwilling or unable to set aside real funds (as opposed to a notional, bookkeeping entry); if funds are lost through poor investments; or if the company collapses before the end of a plant's expected lifetime. All of these have occurred in the UK, where significant decommissioning costs for old nuclear plants (estimated in 2006 at around £75 billion and rising) will be paid by future taxpayers since real funds were not set aside (Thomas et al., 2007: 26-27, 60). The NEA estimates, alarmingly, that in some cases funds set aside for decommissioning in the EU represent less than 50 percent of the anticipated real costs, although it reports that steps are being taken to redress this situation. In the US the government is being sued by nuclear utilities for collecting monies for centralized nuclear waste management, but failing to provide it at Yucca Mountain. The NEA pleads for decommissioning funds to be "sufficient, available and transparently managed" (NEA, 2008a: 265), something neither the nuclear industry nor governments have achieved to date.

Industrial Bottlenecks

After finance, a second major constraint on rapid expansion of nuclear energy is said to be a lack of industrial capacity. Since the last major expansion of nuclear energy in the 1980s, capacity specific to building nuclear power plants has atrophied everywhere, except in France, Japan and South Korea. Arguments have been advanced that globally, industry would not be able to sustain a major nuclear energy revival to 2030 because the scale of activity required is unprecedented.

In the peak years of 1985 and 1986, 33 power reactors were connected to the grid. In the 1980s approximately 150 reactors were under construction simultaneously (NEA, 2008a: 318) and an average of one reactor was added to the grid every 17 days, mostly in only three countries: France, Japan and the US (NEA, 2008: 316). According to the NEA, extrapolation of this historical experience, taken together with the growth in the global economy since that time, suggests that the capability to construct 35-60 1,000 MWe reactors per year could be rebuilt if necessary (NEA, 2008a: 316). There are currently 52 reactors "under construction" worldwide — although some have been under construction for years or were substantially built and work is resuming to finish them — so the construction of 60 new ones per year is not a ludicrous notion. The NEA claims it is feasible to replicate the rates witnessed in the 1980s to 2030. It is only in 2030-2050, it says, that a much higher build rate will be required, when most existing plants will need replacing — along with further capacity expansion.

The Keystone Center's 2007 Nuclear Power Joint Fact-Finding Dialogue agreed that "the most aggressive level of historic capacity growth (20 GWe/yr) could be achieved or exceeded in the future." However, this would depend on realizing the claims for advanced reactors: larger output per plant (10-50 percent), advanced construction methods, greater use of modularization, advances in information management and "a more competent global supply base" (Keystone Center, 2007: 26). Some of these elements are problematic. The Keystone report also provided a useful reminder that not just nuclear plants would need to be built, but in addition, globally:

- 11-22 additional large enrichment plants to supplement the existing 17;
- 18 additional fuel fabrication plants to supplement the existing 24;
- 10 nuclear waste repositories the size of the statutory capacity of Yucca Mountain, each of which would store approximately 70,000 tons of spent fuel.

Keystone participants reached no consensus about the rate of expansion for nuclear power in the world or in the US over the next 50 years. Some thought it was unlikely that nuclear capacity would expand appreciably above its current levels and could decline; others thought that it could expand rapidly enough "to fill a substantial portion of a carbon-stabilization 'wedge' during the next 50 years" (Keystone Center, 2007: 10).

The rate at which individual countries can ramp up a nuclear energy program will vary. The US has a particularly flexible economy that responds quickly to market opportunities, but other market economies, including some in the EU, such as Italy and former Eastern European bloc countries, are considered less nimble. Semi-command economies with heavy governmental control, like those of China and Russia, may have less difficulty in directing resources where needed.

The French Example – Exemplar or Sui Generis?

France is often cited as an example that others should emulate in the acquisition of nuclear electricity. It has the highest percentage of nuclear electricity, has had the most intensive nuclear building rate of any country and has the most extensive recent experience of nuclear build. Driven by energy security concerns, France added 54 reactors between the late 1970s and early 1990s, employing a highly standardized design (NEA, 2008a: 320). Annual generation of nuclear electricity grew by 43 percent over a 14-year period after 1990. Today nuclear provides 77 percent of

France's electricity, more than in any other country. It is the second largest producer of nuclear electricity after the US and the world's biggest exporter of it, mainly to Belgium, Italy and Germany (although in peak winter periods it is forced to import fossil-fuel generated electricity from the latter to cover its shortfall due to overuse of electric space heating) (Schneider, 2008a: 3).

However, France may be one of a kind, in this as in other fields. Bernard Goldschmidt, who helped found the French Atomic Energy Commission, *Comissariat à l'Énergie Atomique* (CEA) in 1946, says of France, "Whenever a country's nuclear effort has been able to profit from continuity, with a technical and political consensus giving support to competent technical and executive teams, it has reaped benefits …" (Goldschmidt, 1982: 146). He continues, "Because France is more dependent than most other industrialized countries on imported energy resources, her reaction to the energy crises of the 1970s had to be more positive than that of her neighbours: from that moment her nuclear power program had received and retained national priority" (Goldschmidt, 1982: 146).

France also has a uniquely centralized system for the supply of nuclear energy (Garwin and Charpak, 2001: 128). State-owned *Electricité de France* (EDF) owns and operates the reactors; the *Compagnie Général des Matières Nucléaires* (COGEMA) is responsible for all aspects of the nuclear fuel cycle; and the *Agence Nationale pour la gestion des Déchets Radioactifs* (ANDRA) (National Agency for the Management of Radioactive Waste) — has managed radioactive wastes since 1991. The government also has a financial stake in a second utility, GDF Suez (a merger of former state-owned Gaz de France (GDF) and private company Suez). The CEA oversees the development and manufacture of nuclear weapons, as well as much of the research and design work on commercial nuclear reactors.

Areva, a French multinational corporation with a global reach, describes itself a "the world leader in nuclear power and the only company to cover all industrial activities in this field" (Areva, 2009). In addition to the design and construction of nuclear reactors and supply of products and services for nuclear power plant maintenance, upgrades and operations, it also engages in uranium ore exploration, mining, concentration, conversion and enrichment, nuclear fuel design and fabrication and back-end fuel cycle activities such as treatment and recycling of used fuel, cleanup of nuclear facilities and "nuclear logistics." (At the time of writing, Areva was seeking to sell its electricity transmission and distribution business.) Areva claims it can capture about one-third — slightly more than 100,000 MW — of the global nuclear generating capacity that its research has found could be built by 2030 (MacLachlan, 2009a: 5).

The relationship between the French trade unions, the Confédération Français Démocratique du Travail (CFDT), and the nuclear sector has also been "instrumental" in the implementation of the various phases of the nuclear program, the unions having been "pacified" with a generous "social fund" deal (Schneider, 2009: 58). Mycle Schneider makes the case that "the elected representatives always had and have a very minor influence on the development, orientation, design and implementation of energy and nuclear policy in France" and that undue influence has been achieved by graduates of the elite Corps des Mines (Schneider, 2009: 82). No other country has such a unified structure or a national nuclear *zeitgeist*.

However, even France may not be able to emulate its past success. Deregulation of the electricity market is putting pressure on prices, which will affect the old way of doing business. The real cost of France's massive nuclear construction program has never been revealed, but the government may not be prepared indefinitely to write the type of blank cheque demanded by such a program. Problems familiar to other nuclear energy states, including lack of personnel, material shortages, cost overruns and construction delays, may also be affecting France's own program. France is likely to face a shortage of skilled workers (Schneider, 2008a). Some 40 percent of EDF's operators and maintenance staff will retire by 2015.

The EPR currently being built in Flamanville by EDF, the first in France and the second in the world after the one being built in Finland, is experiencing difficulties. A second "quasi replica" of Flamanville-3 is proposed for Penly in southern France by 2020 (Reuters, 2009). According to EDF, the second EPR would be more expensive, as savings on construction costs due to the "learning curve" from Flamanville-3 would be offset by potentially higher site-related costs and tighter market for materials and equipment (Nucleonics Week, 2008: 2).

Since no single company, not even Areva, can construct a complete nuclear power plant by itself, one challenge is to rebuild what the NEA calls global supply chains, involving numerous contractors and sub-contractors, each of which must achieve the high manufacturing and construction standards required for a nuclear plant, extending well beyond the nuclear reactor itself.

The most commonly cited industrial bottleneck relates to ultra-large nuclear forgings used in large nuclear reactor vessels, essentially for units of 1,100 MWe capacity and beyond.[38] Currently the three suppliers of heavy forgings are Japan Steel Works (JSW), China First Heavy Industries and Russia's OMZ Izhora (Kidd, 2009: 10). New capacity is being built in Japan by JSW; in South Korea by Doosan; and in France at Le Creusot. There are plans for new capacity in the UK by Sheffield Forgemasters and India by Larsen & Toubro. Nothing is planned for North America. Industry is therefore ramping up in response to demand yet, as would be expected. However, manufacturers will only respond as long as firm orders are in the pipeline, since investment in major forges and steelmaking lines is not cheap. This a classic investment catch-22.

A further difficulty faced by new large nuclear forging entrants is the length of time it takes to gain the necessary technical quality certification, such as that issued by the American Society of Mechanical Engineers (ASME) (Birtles, 2009: 42). For example, because its EPRs are being built in several countries, Areva has to satisfy both the French manufacturing code and the ASME code. Guillaume Dureau, head of Areva's equipment business unit, has warned that rather than producing standardized, interchangeable forgings, "we will have to know what power plant it's for before starting to pour the forgings" (MacLachlan, 2009b: 3-4). This would appear to attenuate one of the advertised benefits of Generation III+ reactors — standardization. He noted that a combination of larger component size, new designs and stricter safety requirements, coupled with the need for more forged components than previous reactor models, had posed huge challenges for Areva's components plant, but "We have clearly shown we know how to do this" (MacLachlan, 2009b: 3).

Personnel Constraints

The nuclear industry's stagnation since the early 1980s has led to a dramatic decline in enrolment in nuclear science and engineering degrees worldwide, leading to what is now referred to as the "missing generation." The OECD/NEA published a report in July 2000, *Nuclear Education and Training: Cause for Concern?*, which quantified, for the first time, the status of nuclear education in OECD member countries (NEA, 2000). It confirmed that in most OECD countries nuclear education had declined to the point that expertise and competence in core nuclear technologies were becoming increasingly difficult to sustain. Problems included:

- decreasing the number and dilution of nuclear courses;
- declining numbers of students taking nuclear subjects and the significant proportion of nuclear graduates not entering the nuclear industry;
- the lack of young faculty to replace ageing and retiring faculty; and
- ageing research facilities, which are being closed and not replaced (NEA, 2000: 5).

There has also been a significant long-term reduction in government funding of nuclear research in some countries since the mid-1980s, notably in Germany, the UK and the US — although France and Japan have held up comparatively well (NEA, 2008a: 322-323).

The existing nuclear workforce is also declining. The nuclear industry, in a steady state over the last few decades, has had relatively little turnover in employees, leading to an ageing workforce and little recruitment. A large portion of the existing nuclear labour force is set to retire within the next five to ten years, including numbers as high as 40 percent in France and the US (Squassoni, 2009b: 46-47). A shortage of experienced nuclear plant operators — many of the current operators have spent their entire professional lives in the nuclear industry, beginning in the 1960s and 1970s — is particularly troubling. In a 2007 North American Electric Reliability (NERC) survey, 67 percent of respondents said it is highly likely that an ageing workforce and lack of skilled workers could affect electricity reliability (Schmitt, 2008: 3). The impact is likely to be more pronounced for nuclear power because of the special training, experience and licensing criteria required for employment. Such experience cannot be gained simply from training courses. In addition, new skills and competencies will be needed in the new generation technologies envisaged, as well as in decommissioning and nuclear waste management. The skills shortage has been exacerbated by deregulation of electricity markets, which has led to cost-cutting by downsizing the workforce, a loss of research facilities and cuts in financial support to universities (NEA, 2004: 8).

On a global basis a rapid short-term expansion in nuclear energy is thus likely to be limited by the shortage of qualified personnel. As the NEA notes, "It is likely to take several years to redevelop the capability to construct new nuclear power plants, while maintaining the necessary high standards and the ability to keep projects on time and to cost" (NEA, 2008a: 316). The effects will be felt differently from country to country. For the UK, for example, "It is clear that the envisaged new nuclear build programme ... will be almost like establishing a new industry" (Kidd, 2008: 55). Argentina has had to turn to Canada for expertise in resuming construction on its Atucha-II reactor after 14 years since not only had the technology changed but the personnel had moved on (WNN, 2008c). In addition to the industry itself, regulatory bodies and the IAEA will also be competing for experienced personnel.

It will be especially difficult for those states, mostly developing ones, contemplating building a nuclear energy sector from scratch, to attract qualified personnel to build, operate, maintain and regulate their nascent nuclear facilities. Only the wealthiest, such as the oil-rich states, will be able to afford to pay the high salaries necessary in such a competitive market. The UAE has already made a name for itself by siphoning highly trained personnel from other companies and organizations to oversee its nuclear development. As a result, it is one of the more likely aspiring nuclear states to succeed in its plans. Indonesia, Jordan and Vietnam are unlikely to be able to compete.

Ramping up educational and training programs is a long-term project, but a report by the NEA in 2004 noted that steps have been taken by some governments to ameliorate the problem. Efforts have been made in the past decade in the US, Japan and Europe in particular to increase university enrolment in nuclear science and engineering (Elston, 2009). A European Nuclear Education Network (ENEN) has been established to foster high-level nuclear education (NEA, 2008a: 325-327). The UK has launched a National Skills Academy for Nuclear (NSAN) to coordinate recruitment and training of personnel, while the universities of Manchester and Lancaster are expanding nuclear research and education (WNN, 2008j; Nuclear News Flashes, 2008). Canada has a University Network of Excellence in Nuclear Engineering. At the undergraduate level, enrolment in nuclear engineering degrees in US universities has increased from approximately 225 students in 1998 to just under 350 students in 2006, although the number of doctoral engineering degrees has steadily declined (NEA, 2008: 36-37; Osborn, 2008: 36-37). The World Nuclear University is a recent initiative taken by the WNA, with participation from the IAEA, the NEA and WANO (World Nuclear University, 2010).[39] The NEA notes that some OECD governments have not taken any initiatives at all, perhaps because they prefer the private sector to take the lead, because there is a national moratorium on nuclear power or simply because they consider that adequate programs already exist.

Ultimately, the extent of personnel shortages will be dependent on the size and scope of the nuclear revival as determined by its other drivers and constraints, and by the agility of both governments and the private sector in responding. While skills deficits may constrain a significant nuclear revival, governments have the capacity to overcome them if they prioritize skills development and training — a decision that will be based on their own predictions about the future of nuclear energy.

Nuclear Waste

The final major constraint on a global expansion of nuclear energy is the abiding controversy over radioactive nuclear waste disposal. Not only is it controversial among the general public and among the most often cited reason for opposing nuclear power, but industry itself is concerned. Excelon, the largest US nuclear utility has said it has "serious reservations" about proceeding with new nuclear plant construction until the used fuel management issue has been resolved (Nuclear News Flashes, 2009a).

Nuclear power generates radioactive waste containing a variety of substances having half-lives as short as fractions of seconds to as long as millions of years. Such waste is classified according to the level and nature of its radioactivity — low-level waste (LLW), intermediate-level waste (ILW) and high-level waste (HLW). It is also categorized according to its half-life, whether short-lived (SL) or long-lived (LL). Low- and intermediate-level waste is produced at all stages of the nuclear fuel cycle, from uranium mining to decommissioning of facilities. Although together this waste represents the greatest volume, it contains only a small fraction of the total radioactivity produced by the nuclear industry. Most of the radioactivity, but the smallest amount by volume, is in spent fuel or in high-level waste from reprocessing. While nuclear power plants and other nuclear fuel cycle facilities release a small amount of radioactivity directly into the environment, increasingly tight controls, according to the NEA, have led to a "remarkable reduction in the amount of radioactive effluents" (NEA, 2008a: 242).

The risk to human beings from radioactivity is well known but poorly understood by the general public. In addition to the risk of inhalation and ingestion, radiation can pose "external" risks to humans from simply being in proximity to it. The key aim is therefore to concentrate and contain nuclear wastes and isolate them from the environment for as long as they remain hazardous.

Interim Storage

Responsibility for managing the radioactive waste produced at a nuclear power plant initially lies with the facility operator. The waste is usually stored onsite in water-filled cooling ponds to allow short-lived radioactivity to disappear and heat to dissipate. In some countries, such as the Netherlands, Sweden and Switzerland, spent fuel is moved after several years' storage at the reactor site to a centralized national storage facility. If spent fuel is to be reprocessed it will be transported, after cooling, to a reprocessing facility where the recyclable material (95 percent of the mass) is separated from what then becomes a high-level waste stream. This is usually stored in vitrified form either at the reprocessing plant or in purpose-built facilities.

Long-Term Disposition

For the purposes of disposal, low- and intermediate-level waste is sometimes dealt with together. Short-lived low- and intermediate-level waste is disposed of in simple near-surface landfills or in "more elaborately engineered" near-surface facilities. Most countries with a major nuclear power program operate such facilities.

By far the greatest challenge is what to do with high-level waste from nuclear reactors and long-lived intermediate waste from reprocessing (often known as transuranic waste). Storage of such materials at nuclear facilities is regarded only as an interim management solution as it relies on continued active control and maintenance. It is vulnerable to extreme natural events such as earthquakes or fire, and malevolent attacks by terrorists or saboteurs or even attempts at seizure for use in nuclear or radiological weapons. Interim storage areas in some countries, such as Japan, are rapidly filling up, making a permanent solution imperative. From the beginning of the nuclear age, the nuclear industry had expected that governments would move quickly to provide a long-term solution to the commercial nuclear waste problem. Almost six decades later, not a single government has succeeded in doing so.

The principal proposed long-term solution is deep geological burial, involving the emplacement of packaged waste in cavities excavated in a suitable rock formation some hundreds of metres below the surface. According to the NEA, the safety principle is that the rock will provide isolation and containment of the radioactivity to allow for sufficient decay so that any eventual release at the surface will be at levels comparable to that of natural rock formations and "insignificant in terms of potential effects on health and the environment" (NEA, 2008a: 249). This principle is compromised somewhat by a demand by some in the nuclear industry that the "waste" be retrievable if and when technology permits the fuel in it to be used (Tucker, 2009), a concept parodied as envisaging a "deep plutonium mine." Retrievability raises questions about whether illicit retrieval might be possible, as well as the cost of burying a resource that may be dug up and used in the future.

The world's only operating deep geological repository for radioactive waste, the Waste Isolation Plant at Carlsbad, New Mexico, was developed for disposal of transuranic waste from the US nuclear weapons program, not for civilian nuclear waste, but it has demonstrated the feasibility of the concept. Plans to open a site at Yucca Mountain in Nevada for civilian nuclear waste have run aground due to political opposition (see below). Currently, only Finland and Sweden (NEI, 2007: 18-20) are well advanced and could have their repositories operating by 2020. According to the NEA, they are expected to be followed by France and Belgium, then Germany, Japan, Switzerland the UK in the 2030s and 2040s. Several other countries have repositories planned, but have announced no implementation dates before 2050. Others have research and development programs only.

For new entrants into the nuclear power business, with just one or a small number of reactors, establishing their own nuclear waste repositories is likely to be completely unrealistic on the grounds of cost and need. Yet the lack of disposal options may spur opposition to nuclear energy itself, as in existing nuclear energy states. International cooperation is likely to be necessary among the smaller new entrants, although there is great sensitivity in all countries, with the apparent exception of Russia, about acting as a nuclear waste dump for others.

While there is a virtual consensus among scientists that a long-term geological repository for such nuclear waste is a technically and environmentally sound solution, finding a suitable location for such a repository has proven to be a highly volatile political issue in most states, and has been cited as a major reason for opposition to nuclear power. As the NEA cautions: "the time necessary from a primarily technical point of view to move from deciding on a policy of geological disposal to the start of waste emplacement operations could be of the order of 30 years" (NEA, 2008a: 252). This does not take into consideration political and economic barriers which may often be the most daunting. The long lead times, as in the case of Yucca Mountain, provide great opportunity for opposition to develop.

An evolving approach, pioneered by Sweden and Canada, is to undertake a comprehensive, national consultation process aimed at securing agreement on a long-term nuclear waste management strategy. In Canada's case, a three-year study, emphasizing "citizen engagement," was undertaken by a specially established Nuclear Waste Management Organization (NWMO). It proposed a policy of "Adaptive Phased Management" which committed "this generation of Canadians to take the first steps now to manage the used nuclear fuel we have created" (Dowdeswell, 2005: 5). The policy promotes "sequential and collaborative decision making, providing the flexibility to adapt to experience and societal and technological change" (Dowdeswell, 2005: 45). Ultimately, though, it envisages "centralized containment and isolation of used nuclear fuel deep underground in suitable rock formations, with continuous monitoring and opportunity for retrievability" (Dowdeswell, 2005: 151).

Canada's deliberative, democratic process, taking into account the "ethical and social domains as well as the technical questions" is unlikely to be easily emulated in other states, especially those with a strong anti-nuclear movement or those with undemocratic systems. It is not clear, therefore, that the nuclear industry will be able to turn public opinion around in most countries.

One difficulty is the historic link between nuclear weapons programs and nuclear energy. The early weapons programs produced far more nuclear waste than civilian industry and were often undertaken as crash programs with scant regard for public safety or the environment. The massive cleanup of the Hanford nuclear site in Washington state is costing American taxpayers an estimated $200 billion and is scheduled to last for decades (Vandenbosch and Vandenbosch, 2007: 119). High-level waste had been stored in 177 tanks, 149 of them single-walled, 67 of which leaked approximately 100 million gallons of radioactive waste into the subsoil and groundwater. While it is unfair to compare the practices of the 1940s with today's more safety- and environmentally conscious nuclear industry, the legacy of the weapons linkage lingers and affects public attitudes.

A second difficulty for planned new build in existing nuclear energy states is the existing stockpiles of civilian nuclear waste that are a legacy of past procrastination by governments about disposal. Industry projections of a huge increase in the number of nuclear power plants as part of a revival creates the impression of huge increases in the amount of nuclear waste, even though, according to the NEA, "historic" spent fuel will continue to dominate the worldwide inventory to 2050, even with a significant revival (NEA, 2008a: 260). The volume of additional nuclear waste will also pale in comparison to waste volumes from nuclear's continuing biggest rival, coal. As David MacKay points out, whereas the ash from 10 coal-fired power stations would have a mass of 4 million tons per year, the nuclear waste from Britain's 10 nuclear power stations has a volume of just 0.84 litres per year, most of which is low-level (MacKay, 2009: 169). Although there is growing disenchantment with "dirty coal" and increasing demands that it be phased out due to its massive contribution to global warming, this is unlikely to particularly benefit nuclear power in the debate over waste since nuclear's other main competitor, natural gas, produces no solid waste.

A third and related difficulty for the nuclear industry is communicating the concept of relative risk to the public. In the US, coal ash from coal-fired stations, for example, exposes the public to more radiation than nuclear power plants (McBride et al., 1978). Yet the public is almost completely unaware of this fact. The WNA's Steve Kidd calls the nuclear industry's handling of the waste issue a "mess" and an "own goal," and recommends that the industry never admit that it produces waste "unless you really have to," adding another "own goal" by confessing that "Perhaps this is morally not a completely defensible position, but it makes sound business sense" (Kidd, 2008: 155). This illustrates a core issue for the nuclear industry — regaining public confidence through transparent, honest engagement over the nuclear waste issue. As Canada's NWMO reported of its public engagement process in Canada:

> Consistently throughout the dialogue, concern was expressed by some participants about the track record of the nuclear industry and government in terms of accountability and transparency. Many examples were brought forward of incidents in which the industry and/or government have acted in what is perceived to be a self-interested and secretive manner. For these participants, this is a key area in which trust must be built before proceeding with any approach for the long-term management of used nuclear fuel (Nuclear Waste Management Organization, 2005: 75).

Yucca Mountain

A solution to long-term storage of nuclear waste in the US has been elusive despite more than two decades of effort in trying to open a repository at Yucca Mountain in Nevada (Vandenbosch and Vandenbosch, 2007).[40] The 1982 Nuclear Waste Policy Act (NWPA) required that the federal government open a waste repository by 1998 to store all of the waste generated by the US civilian and military nuclear programs. A congressional vote directed the Department of Energy to focus on Yucca Mountain as the location of the first repository, and the NWPA was amended in 1987 to specifically identify the Yucca site (WNN, 2009h). The amendment drew fierce political opposition from Nevada Senator Harry Reid, who has campaigned successfully for more than 20 years to prevent the project from proceeding.

As a concession to Nevada, the Yucca Mountain site had a statutory 70,000 tonne limit attached to it in a 1987 NWMA amendment, but as of 2008 the total amount of existing waste destined for Yucca was 70,800 tonnes, with roughly an additional 2,000 tonnes being added to the total annually (WNN, 2008a). Increasing the limit at the Yucca site was an option, but the earliest it could open would be 2018 — 20 years after originally scheduled (WNN, 2008a). After the DOE saw its budget for the Yucca Mountain project decline year after year during the Bush administration (Nuclear Fuel Cycle, 2008), President Obama fulfilled his campaign promise to scrap the project in February 2009 (WNN, 2009h). Future US policy awaits the recommendations of a panel set up by the Obama administration in January 2010 (Goldenberg, 2010).

Safety, Security and Proliferation

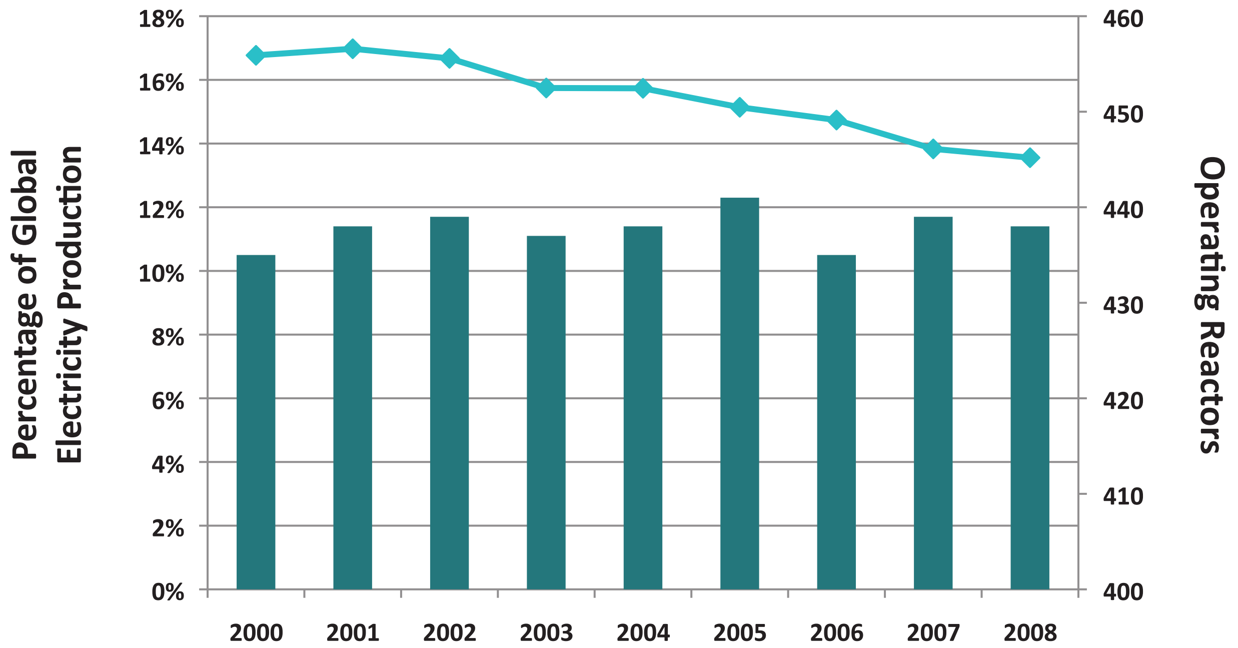
Among the additional constraints on the advance of nuclear energy most commonly cited are concerns about the safety and security of nuclear facilities and materials, and the potential for nuclear energy programs to advance the proliferation of nuclear weapons. These play into public opinion as well as being the concern of opinion leaders, policy makers, governments and international organizations. Since these concerns present profound implications for global governance, they will be considered in detail in Parts 2 to 4 of this report.

The "Revival" So Far

If one dates the revival of interest in nuclear energy from 2000, it is clear a decade later that progress has been slow. The first ten years of the twenty-first century have seen the opposite of a revival in nuclear power. There has, in fact, been a relative decline, and, according to some indices, an actual decline, in the contribution of nuclear power to world energy production. Not only has the number of operating nuclear reactors plateaued since the late 1980s, but the IAEA figure of 436 reactors as of December 2009, with a total net installed capacity of 370 GW(e) (IAEA, 2009c), is eight units less than the historical peak in 2002 of 444 (Froggatt and Schneider, 2008: 4). Five nuclear power reactors remain in long-term shutdown. Since commercial nuclear energy began in the mid-1950s, 2008 was the first year that no new nuclear plant was connected to the grid (Schneider et al., 2009: 5), although two were connected in 2009.

In absolute terms, nuclear grew between 2000 and 2008 from 2,600 to 2,700 TWh, a 6 percent increase (BP, 2009). This was dwarfed by a much greater growth in overall electricity generation during the same period, from 15,400 to 20,200 TWh, a 31 percent increase. In the same period, nuclear's share of global electricity generation fell from 16.7 percent in 2000 to 13.5 percent in 2008 (BP, 2009). Even this level was only sustained due to capacity factor improvements in the existing fleet and extended operating licences (mostly in the US, where reactors set a generation record of 843 million gross MWh and averaged an historical high of 91 percent capacity) (Ryan, 2008: 1). *Nucleonics Week* described the causes of the decline as "ranging from an earthquake in Japan to persistent aging ills in the UK to backfitting outages in Germany" (Ryan, 2008: 1). But the decline has longer-term roots than that, as demonstrated by the chart on page 67 showing nuclear grid connections peaking in the 1980s.

Nuclear Reactor Numbers and Share of Global Electricity Production Since 2000

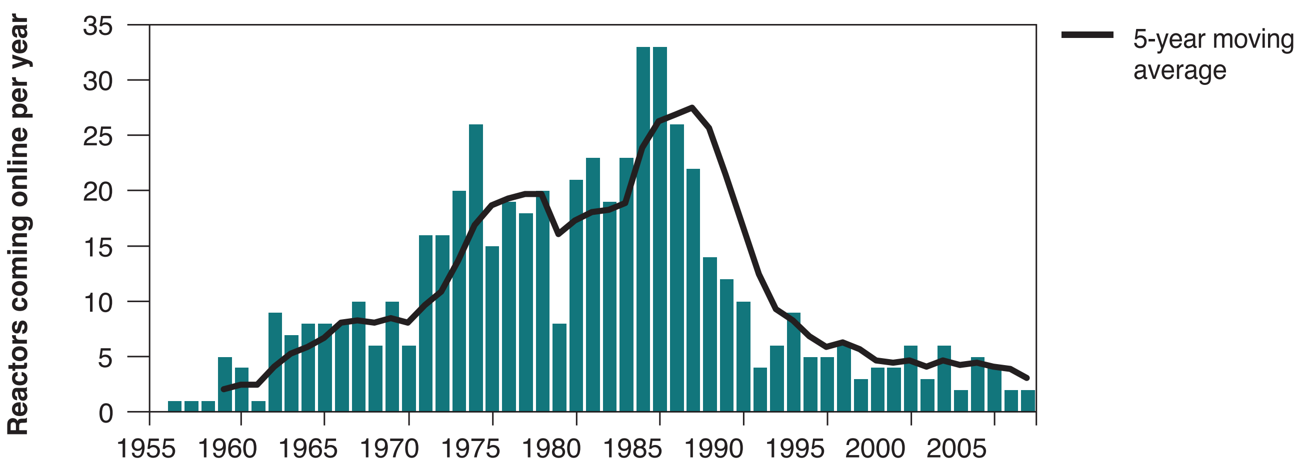


Source: IAEA (2009c); BP (2009a)

Current "New Build"

The number of nuclear power plants currently being built appears impressive. According to the IAEA, 46 were "under construction" worldwide in November 2009 (IAEA, 2009c). Further analysis reveals, however, that current construction activity is confined to 13 countries, all of them, except Iran, with existing commercial nuclear power. Most of the activity — 30 reactors — is taking place in just four countries: China, India, Russia and South Korea.

Global Annual Grid Connections on Five-Year Moving Average



Source: IAEA, 2006, cited in International Energy Agency (OECD/IEA), Energy Technology Perspectives 2008, p. 301.

Almost one-third of what seems like new construction activity (depending on how Russian reactors are counted) is in fact "hang-over" orders from previous eras (Thomas et al., 2007: 11). Fourteen of the units "under construction" have been designated by the IAEA as "under construction" for 20 years or more (Froggatt and Schneider, 2008: 8). Nine reactors currently on the "under construction" list, in Argentina, Bulgaria, Russia, Slovakia and Ukraine, were on an IAEA list in December 2006 as "nuclear power plants on which construction has been stopped."[41]

Nuclear Power Plants Currently Under Construction by Country

Country	No. of Units	Total MWe
Argentina	*1	692
Bulgaria	*2	1906
China	16	15220
Finland	1	1600
France	1	1600
India	6	2910
Iran	*1	915
Japan	2	2191
Pakistan	1	300
Russia	*9	6894
Slovakia	*2	810
South Korea	5	5180
Taiwan	*2	2600
Ukraine	*2	1900
United States	*1	1165
Total:	**52**	**45883**

Source: IAEA (2009c)
* Denotes construction on previously suspended projects.

The two reactors in Bulgaria previously on the "stopped" list, Belene-1 and Belene 2, will help replace four old Soviet RBMK reactors which Bulgaria shut down as a condition of EU membership (NEA, 2008a: 63). Two partially finished reactors in Ukraine, Khmelnitski-3 and Khmelnitski-4, which were, respectively, 75 percent and 28 percent complete when work stopped in 1990, were also on the "construction stopped" list. As the Ukrainian government itself has announced that work will not actually recommence on them until an unspecified date in 2010, they should not yet be on the "under construction" list (WNA, 2009f). As to Russia, it is difficult to obtain information as to whether construction work is actually occurring on some reactors listed as "under construction" or whether site maintenance is simply being carried out. The seemingly impressive total of nine for Russia is distorted by the inclusion of two small floating reactors of just 32 MW each (IAEA, 2009c: 424).[42] Iran is about to bring its Bushehr reactor on line, but only after 35 years of periodically interrupted construction (Bahgat, 2007: 20-22).[43]

The resuscitation of previously defunct projects could be described as a revival of sorts, but is probably not what the nuclear industry has in mind; rather they are pinning their hopes on what they call "new build."

"New Build" by Existing Nuclear Energy States

Plans for real "new build" have been announced by 19 of the 31 countries that already have nuclear power, so to that extent a revival is occurring. Especially extensive are the ambitions of China, India, Japan, Russia, South Korea, Ukraine, the UK and the US. However, close examination of the each country's plans ellicits caution. All of the national case studies commissioned by this project on the major existing nuclear energy states (Canada, China, France, India, Russia, the UK and the US) expressed skepticism about their ambitious plans for expansion.[44]

Canada

While Canada had plans for major new nuclear build, these were set back significantly in June 2009 with the announcement by Ontario that it was indefinitely postponing its decision on a new fleet of reactors (Cadham, 2009).[45] Ontario has 16 of Canada's 18 nuclear reactors, supplying approximately 50 percent of provincial electricity. In July

2009, Bruce Power, an electricity utility, also dropped plans to build new reactors in Ontario due to declining electricity demand (Bruce Power, 2009; CBC, 2009). Meanwhile, the federal government announced in December 2009 that it would privatize the CANDU reactor supply part of Atomic Energy of Canada Ltd (NRCan, 2009), putting into question the future commercial prospects of the company's new Advanced CANDU Reactor.[46] Mooted new build in Alberta and Saskatchewan is a long way from realization, although refurbishment of reactors in Ontario, New Brunswick and Quebec will likely all be accomplished (Cadham, 2009).

China

China has the most ambitious program of any country. A director of its Nuclear Energy Agency, Zhou Xian, has said that "the golden time for China's nuclear power development has come," with some projections as high as 72 GWe by 2020 (compared to 8.2 GWe today), requiring the construction of 60 reactors in 11 years (WNN, 2009f). China is certainly moving rapidly, but from a very low base, with only 1.5 percent of total generating capacity currently provided by nuclear. In June 2008 it had only 11 reactors, compared with Canada's 18 and the United States' 104 (NEA, 2008a: 49). Even its most ambitious plans will see an increase to just 5 percent by 2020. Already there are concerns about finance, labour shortages and costs (Hibbs, 2008: 1, 10).

France

France has only a modest expansion plan since its capacity is already substantial, and, some would argue, saturated. Currently, only one new reactor is being built in France, by EDF at Flamanville. Like the Areva project in Finland, it is a 1,600 MWe EPR intended to demonstrate the superiority of the Generation III reactor. As noted, it is, like the Finnish reactor, experiencing construction difficulties. A second reactor has been proposed for Penly in Northern France for 2020.

India

According to M.V. Ramana, in a study for this project (Ramana, 2009),[47] India has had a unique nuclear trajectory. Ever since independence, its political leadership and technological bureaucracy have been committed to a large future role for nuclear power in generating much needed electricity. As of yet, these plans have not materialized, and the program has been marred by various accidents and poor safety practices. As elsewhere, nuclear electricity has been expensive, a greater problem in a developing country with multiple requirements for scarce capital. India is also unique in that the proposed nuclear expansion is based in part on fast breeder reactors because of a shortage of domestic supplies of cheap and easily mined uranium.

Even six decades after the program's inception, hopes of a large expansion of nuclear power still abound. In the early 2000s, India's Department of Atomic Energy (DAE) projected 20 GW by 2020 and 275 GW by 2052, the latter amounting to 20 percent of India's total projected electricity generation capacity. Following the September 2008 waiver from the Nuclear Suppliers Group permitting India to import foreign civilian nuclear technology and materials, these estimates have gone up. The Atomic Energy Commission chairman has promised that nuclear power will contribute 35 percent of Indian electricity by 2050. Since the DAE has projected that India will have an installed electricity generation capacity of 1,300 GW (a nine-fold increase from the current 145 GW) by that time, the 35 percent prediction implies that installed nuclear capacity would amount to 455 GW, more than 100 times today's figure. Based on past experience, such an increase seems highly unlikely even given the sudden availability of foreign technology and assistance. Several countries have recently signed nuclear cooperation agreements with India, including Canada, France, Russia and the US, with hopes of supplying reactors. However, India has constructed its own reactors based on the CANDU heavy water type which it has re-engineered and proposes to market to others.

Japan

In 2002 Japan laid out a 10-year energy plan for an increase of 13 GWe by 2011. This will not now be met: its 2005 Framework for Nuclear Energy Policy aims by 2030 to simply maintain, or increase by only 10 percent, the contribution of nuclear power to electricity generation (NEA, 2008a: 68). Japan continues to stockpile plutonium and has the world's most advanced plans for operating a "plutonium economy" in the quest for energy independence, but progress has been slow. Operation of its existing fleet has been plagued by earthquake-induced shutdowns and technical problems. In 2009 it had 10 reactors supposedly in operation that were in fact shut down, most since the 2007 earthquake (Schneider et al., 2009: 10).

Russia

Miles A. Pomper, in a study for this project, reports that Russia is facing significant challenges: "It is far from clear whether Russia will be able to fulfill its ambitious goals to more than double its electrical output from nuclear power, increase exports of nuclear reactors, and play an even larger role in providing fuel and fuel-related services for nuclear plants" (Pomper, 2009: 2). Russia's 15 RBMK Soviet reactors will need replacement despite extensive safety improvements since the Chernobyl disaster (NEA, 2008a: 450)[48] and attempted lifetime extensions (Pomper, 2009: 4). Having restructured its nuclear industry for this purpose, Russia is planning to export nuclear reactors, including novel types like floating ones.

South Korea

Like China, the Republic of Korea is one of the more likely candidates to achieve its nuclear energy plans. Currently, its 20 nuclear reactors supply 40 percent of the country's electricity; it is building five more and envisages bringing as many as 60 online by 2050. It also seems determined to establish a closed nuclear fuel cycle on the basis of spent fuel pyroprocessing (currently being perfected by South Korean scientists, but arousing US concerns about its potential proliferation implications) and fast reactors (Nuclear Fuel, 2008: 5). South Korea is also positioning itself to export reactors. South Korean industry has launched a drive to export PWRs to emerging nuclear power markets, including Indonesia, Turkey and Vietnam, but because it leases intellectual property rights from Westinghouse that vendor must approve any such exports (Hibbs, 2008b: 5). South Korea announced its first reactor sales, to the UAE, in December 2009 (WNN, 2009a).

Ukraine

The Ukraine might be considered as having an especially urgent motivation for nuclear "new build" in its desire to escape reliance on Russian gas supplies which have been disrupted in recent years. Currently, Ukraine has 15 reactors, all of the Soviet-designed VVER type, generating about half its electricity. It plans to build 11 new reactors and nine replacement units to more than double its nuclear generating capacity by 2030. However, the drawn-out financing and safety enhancement saga over resuming work on Khmelnitsiki 3 & 4, involving the European Bank for Reconstruction & Development (ERBD) and Russia (WNA, 2009f), as well as Ukraine's parlous economic situation, do not inspire confidence that this schedule is achievable.

United Kingdom

The UK currently has 19 reactors, which generated 15 percent of its electricity in 2007, down from 25 percent in recent years due to plant closures. The government's January 2008 Energy White Paper, after an extensive public consultation process, concluded that nuclear power could be part of a low carbon energy mix needed to meet the country's carbon emission targets. However, the government was careful to stress that it would be "for energy companies to fund, develop and build new nuclear power stations in the UK, including meeting the full costs of decommissioning and their full share of waste management costs" (Hutton, 2008). The UK's plans call for commencing construction of the first new British nuclear power station in decades in 2013-2014, for completion by 2018. Ian Davis, again in a study for this project, notes that "previous British experience with untried nuclear designs suggests it could be much longer"(Davis, 2009: 30). Crucially, in the UK's deregulated market, investment decisions are largely being left to private sector energy companies. The UK regulator has already expressed safety concerns about both prime contenders for the UK's new reactors, the EPR and Westinghouse's AP-1000 and asked for design modifications. EDF, a front-runner for the UK's new build stakes, is purchasing land, mostly near existing plants, for its intended nuclear power fleet.

United States

Seen as a bellwether of the purported nuclear "renaissance" following the Bush administration's launch of its Nuclear Power 2010 program in 2002, the US has added only one new reactor to the grid since then, a shutdown plant at Browns Ferry that was refurbished and restarted. A reactor that was previously ordered but never completed, Watts Bar 2, is currently being finished (MIT, 2009: 4-5). No new reactors are under construction. As of September 2009, 17 applications for licenses to construct and operate 26 new reactors had been filed with the Nuclear Regulatory Commission (NRC), but even industry promoters predict that only four to eight new reactors might come online by 2015, and then only if government loan guarantees are secured (Nuclear Regulatory Commission, US Department of Energy, 2009). As Peter Bradford says: "Year seven of the US nuclear renaissance seems a lot like 1978" (Bradford, 2009: 60). The Congressional Budget Office (CBO) concludes that it is probable that "at least a few nuclear power plants will be built over the next decade" in the US, most likely in states where electricity usage and the corresponding demand for additional baseload capacity are expected to grow significantly (CBO, 2008: 26). The 2003 MIT study argued that for nuclear power to be resurgent in the US "a key need was to design, build and operate a few first-of-a-kind nuclear plants with government assistance, to demonstrate to the public, political leaders and investors the technical performance, cost and environmental accountability of the technology" (MIT, 2009: 19). The 2009 update of the report lamented that this had not happened and that the current assistance program had not been effective (MIT, 2009: 18).

Meanwhile, prices in the US are rising dramatically causing "sticker shock" according to NUKEM, Inc., a company that tracks "The people, issues and events that move the fuel market." It reported in April 2008 that with projects now "spiralling upwards to a dizzying $7 billion per reactor with all-in costs in the range of $5,000 to $7,000/kWe," the "'early' nuclear renaissance in America now looks more like 2015-2020 instead of our originally designated 2013-2017 period" (NUKEM Inc., 2008: 2-4). As Sharon Squassoni, in a study for this project, concludes:

> … just to maintain its share of the electricity market, the nuclear industry would need to build 50 reactors in the next 20 years. Given that only four new reactors might be operational by 2015, significant growth could require build rates of more than four per year. Greater government subsidies and a carbon pricing mechanism are not likely enough

> to achieve such rates of construction. The best outcome for the US nuclear industry over the next five years, particularly under an administration that will probably offer mild rather than aggressive support, will be to demonstrate that it can manage each stage of the licensing, construction and operating processes of the first reactors competently and efficiently. In sum, the industry needs to demonstrate that it has overcome the problems of the past (Squassoni, 2009a: 18).

Other current players

Other states with existing nuclear plants have also announced new build plans, but have not yet begun to implement them. They include Brazil, Romania and Lithuania (in partnership with Estonia, Latvia and Poland). Slovakia is currently building two reactors. South Africa has recently cancelled its expansion plans due to its financial situation (Nucleonics Week, 2009d: 1).[49]

The states with existing nuclear power that are not currently planning "new build" are Belgium, the Czech Republic, Germany, Hungary, Mexico, the Netherlands, Slovenia, Spain and Switzerland. Of the European states that decided to phase out nuclear power after Chernobyl — Belgium, Germany, Italy, Netherlands, Spain and Sweden — only two, Italy and Sweden, have reversed their positions. Italy is planning a whole new fleet of reactors. In Sweden, the governing Conservative-led coalition government has decided to halt the phase-out and plans to replace decommissioned nuclear plants with new ones (although not adding additional units). The opposition, however, has reiterated its collective support for the 1980 referendum that led to the current gradual phase-out of nuclear power in the country (Nucleonics Week, 2009c: 8; Bergenäs, 2009). With the electorate deeply divided, the current government in Germany plans only to extend the existing phase-out period.

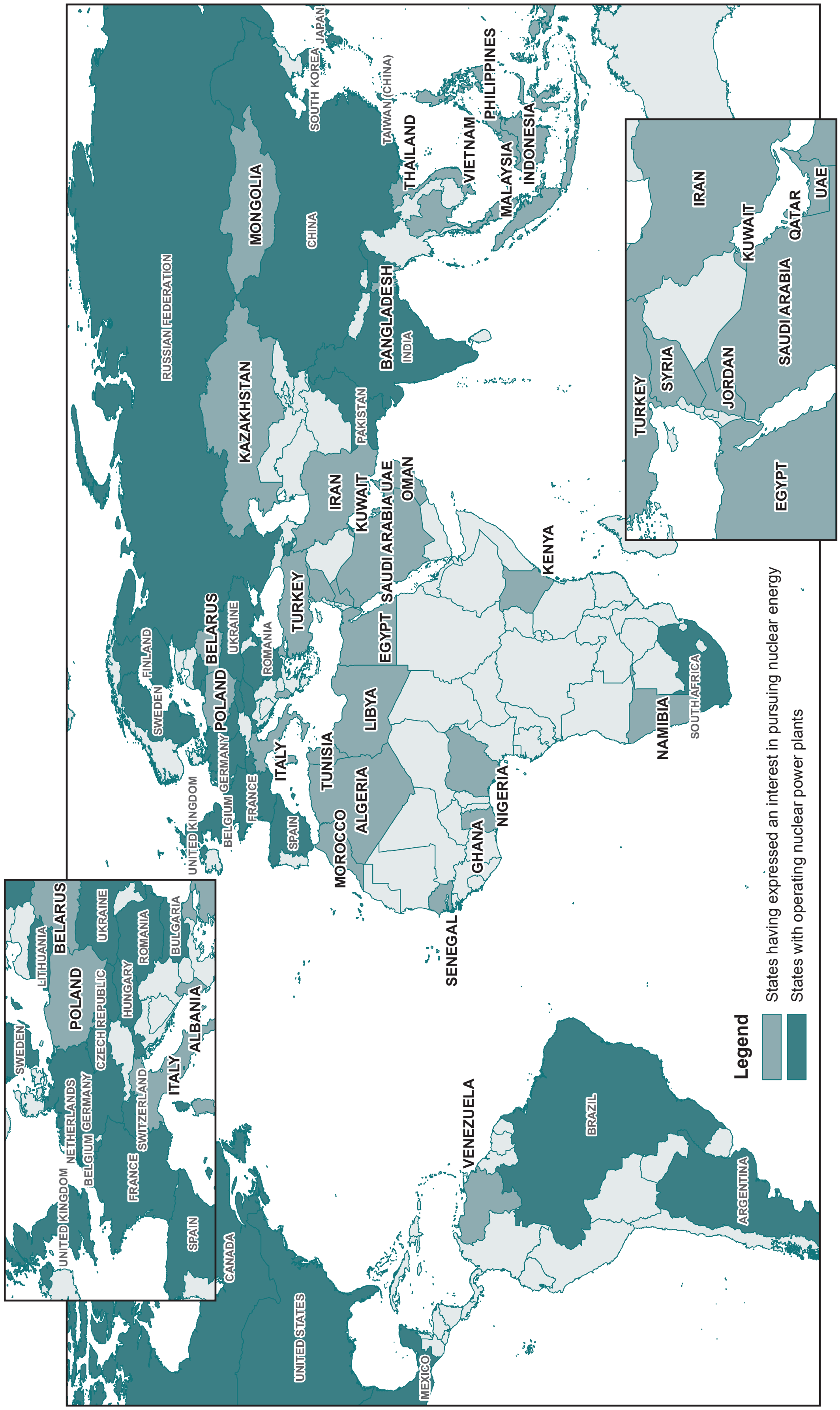
Aspiring Nuclear Energy States

This project's Survey of Emerging Nuclear Energy States (SENES) (CIGI, 2010) tracks progress made by states that have declared an interest in acquiring a nuclear energy capability — from the first official announcement of such an interest to the connection of the first nuclear power plant to the country's electricity grid.

SENES reveals that 33 states, plus the members of the Gulf Cooperation Council (GCC) collectively, have announced "consideration" or "reconsideration" of nuclear energy at a credible ministerial level since 2000. This is fewer than identified in other surveys. The WNA suggests "over thirty countries" are newly interested in nuclear energy (WNA, 2009b).

The IAEA has publicly claimed that "A total of 60 countries are now considering nuclear power as part of their future energy mix, while 20 of them might have a nuclear power programme in place by 2030" (IAEA, 2009b). The number 60 bears an uncanny resemblance to the total number of states that have recently approached the IAEA, at any level and in whatever detail, to discuss nuclear energy. The IAEA's Director General of Nuclear Energy, Yury Sokolev, told representatives of 40 countries attending an Agency workshop on IAEA Tools for Nuclear Energy System Assessment (NESA) for Long-Term Planning and Development in July 2009 that the IAEA is expecting to assist 38 national and six regional nuclear programs, a "three-fold increase from the previous [unidentified] reported period" (IAEA, 2009b). This, of course, does not mean that so many states will decide to proceed with nuclear energy after conducting their assessments. The number may also include states that already have nuclear power. Finally, the question arises as to why only 40 states,

Current and Aspiring Nuclear Energy States



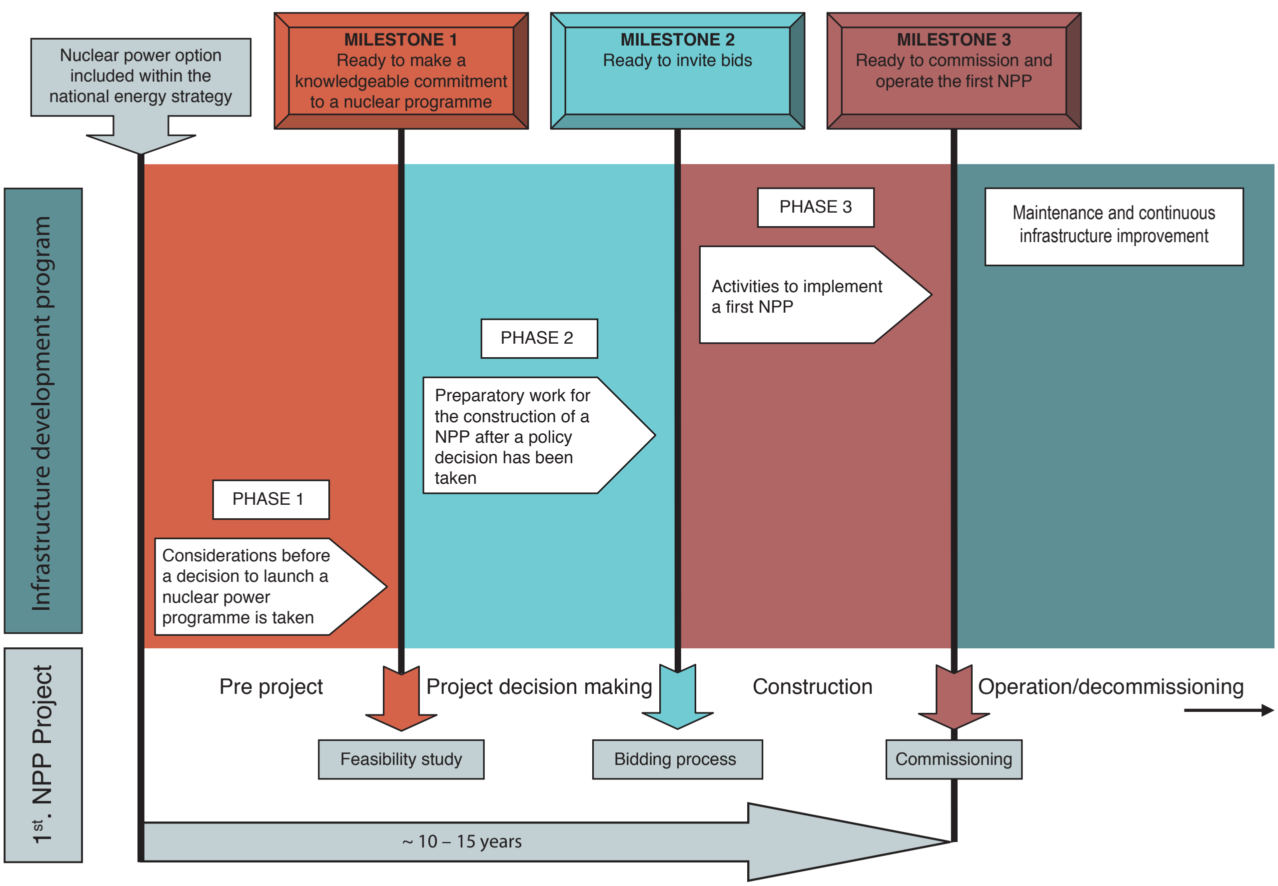
Source: CIGI (2009); IAEA (2009c)

presumably including all of the major nuclear energy states, attended the workshop if 60 are truly interested. Given the IAEA's caution that the timeframe from an initial state policy decision (a nebulous concept itself), to the operation of the first nuclear power plant "may well be 10-15 years" (IAEA, 2007b: 2), a sudden surge in nuclear energy capacity in the developing world by 2030 seems inherently unlikely.

In all of the surveys of states allegedly interested in nuclear energy, the vast majority are developing countries. In the case of SENES only three, Italy, Poland and Turkey, could be considered developed. A couple of others (Belarus and Malaysia) could be considered developed enough to be able to afford a nuclear power plant, although whether they have the other prerequisites is doubtful. Several states could be considered independently wealthy enough as result of oil income to be able to afford a nuclear reactor on a turnkey basis: these include Algeria, Indonesia, Libya, Venezuela and the Gulf States, including Saudi Arabia and the UAE. But all of them lack an indigenous capacity at present to even operate, regulate and maintain a single nuclear reactor, much less construct one.

To track states' progress, SENES uses some of the key steps set out in the IAEA's *Milestones in the Development of a National Infrastructure for Nuclear Power*. This document identifies three broad categories of achievements which must be accomplished before a state is considered ready for a nuclear power program (IAEA, 2007b) see out in the chart on page 74.

Nuclear Infrastructure Development Programme (IAEA)



Source: Evaluation of the Status of National Nuclear Infrastructure Development (No. NG-T-3.2), Nuclear Energy Series, International Atomic Energy Agency, 2008, p. 5.

The vast majority of the states identified in SENES could not, at present, legitimately claim to have reached or gone beyond Milestone 1. Only Iran is close to starting up a reactor (probably in 2010). Save for this one exception, none has begun construction. The Philippines has a partially completed reactor in Bataan, which it may resume work on. Of the rest only Italy, which was among the pioneers of nuclear technology and had a nuclear power industry before scrapping it after the Chernobyl accident, could be said to be completely knowledgeable about nuclear power requirements. As of January 2010 only Egypt, which has aspired to nuclear power for more than 30 years, and Turkey, are known to have invited bids for a plant, which puts them at Milestone 2. Turkey has, however, recently cancelled the initial bid process and restarted it. The UAE is ahead of all the SENES states in having accepted a bid from a South Korean consortium for building and operating up to four new reactors.

Many of the aspiring states listed in SENES have taken some steps, such as consulting the IAEA and establishing an atomic energy commission and/or nuclear regulatory authority, generically known by the IAEA as a Nuclear Energy Programme Implementing Organization (NEPIO). But this is less impressive than it may appear, as these are among the easiest steps and imply nothing about the capacities of such organizations.

Getting beyond Milestone 1 poses increasingly more difficult challenges. While many of these may be difficult to quantify, some indicators that can be identified almost definitely rule out certain countries from acquiring nuclear power over at least the next two decades. Such countries would need to make unprecedented progress in their economic development, infrastructure and governance before nuclear power is feasible. The unpreparedness of most SENES countries is revealed by measurable indicators, including those relating to governance, existing installed electrical capacity, gross domestic product and credit ratings, as outlined in the following sections.

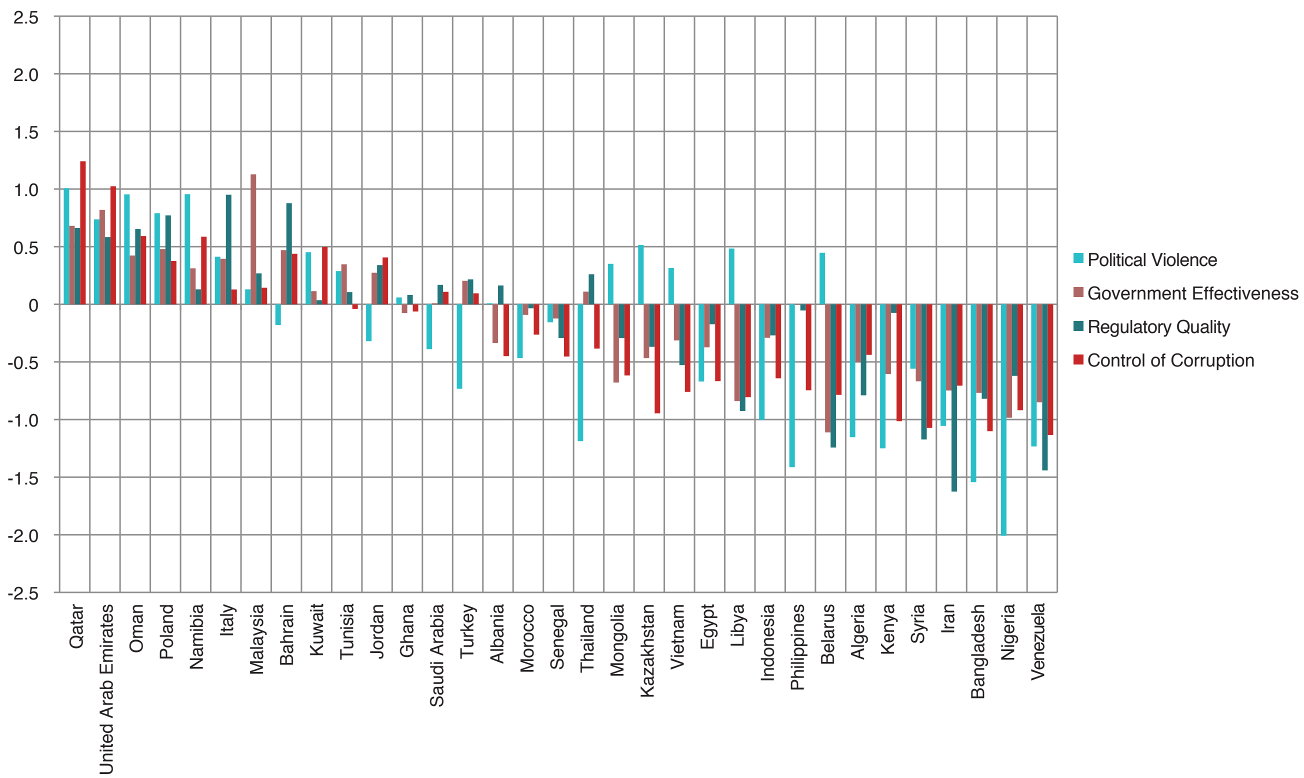
Institutional Capacity

A country's ability to lay the foundations for a nuclear power program depends on its capacity to successfully manage large and complex projects, and its ability to attract or train qualified personnel. It is unlikely that many developing countries will be at this stage by 2030. Not least among the requirements is an effective nuclear regulatory infrastructure, and a safety and security structure and culture (these will be considered further in Parts 2 and 3 of this report). These are not built overnight. The IAEA states that it can take at least 10 years for a state with no nuclear experience to prepare itself for hosting its first nuclear power plant (IAEA, 2007b). Such capacities must be in place well in advance of construction of the first nuclear power plant as part of achieving the IAEA's Milestone 1. Fortunately, the IAEA and responsible vendors, for the sake of their own reputations, will only assist with new build in states that are able to prove they can safely and securely operate a nuclear facility.

Many aspiring nuclear energy states have shown that they struggle with managing any large investment or infrastructure projects, for reasons ranging from political corruption to terrorism. Nigeria, for example, has a long history of mismanaging large, complex projects (Lowbeer-Lewis, 2010: 18), so establishing the regulatory infrastructure and safety culture for a nuclear power plant even over a 10-year period poses an immense challenge.

Many SENES states struggle with governance. Shockingly, all SENES states except Qatar, the UAE

Governance Indicators for SENES States, 2008



Source: World Bank (2009)

and Oman, score five or below on the 10-point scale of Transparency International's Corruption Perception Index (Transparency International, 2009). Considering that the institutional framework for a successful nuclear energy program critically includes an independent nuclear regulator, free from political, commercial or other influence, that must ensure the highest standards of safety and security, the implications of pervasive corruption in potential new entrant states are frightening. The chart above indicates where SENES states fall on indices relating to political violence, government effectiveness, regulatory quality and control of corruption as calculated by the World Bank. It is notable that there is a high degree of correlation between these indicators.

A tiny number of states can probably successfully purchase everything necessary for a nuclear power program, including safety and security personnel for their institutional infrastructure. The UAE is particularly active in paying others to manage its future nuclear power program. According to Philippe Pallier, director of Agence France Nucléaire Internationale, the UAE is creating a new management model for a national nuclear power program, based on contractor services rather than indigenous management expertise (MacLachlan, 2008a: 6). All of the Gulf States, like the UAE, Qatar and Saudi Arabia, are accustomed to using foreign contractors throughout their economy and may indeed do so in the nuclear case. Not many SENES states can afford to emulate them.

Physical Infrastructure

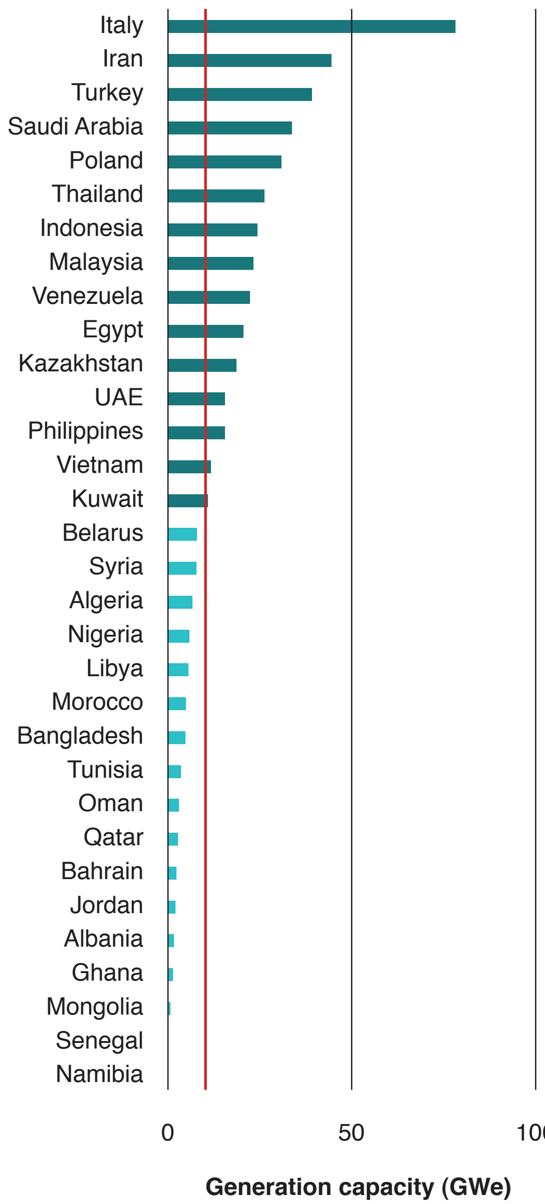
A major barrier to aspiring nuclear states in the developing world is having the physical infrastructure to support a nuclear power plant or plants. This includes an adequate electrical grid, roads, a transportation system and a safe and secure site. The IAEA's milestones document includes a comprehensive list of hundreds of infrastructure "targets" — including physical infrastructure — for aspiring nuclear states to meet before they should commission a nuclear plant. This includes supporting power generators, a large water supply and waste management facilities (IAEA, 2007b). Meeting all of the targets will be a major challenge for most SENES states, requiring them to invest billions of dollars on infrastructure upgrades for several years.

A significant and perhaps surprising constraining factor in terms of infrastructure — and a key measurable of a country's eligibility for nuclear power — is a suitably large or appropriate electricity generating capacity. The IAEA recommends that a single nuclear power plant should represent no more than 5-10 percent of the total installed generating capacity of a national electricity grid (IAEA, 2007b: 39). The WNA claims the number is 15 percent (WNA, 2009a). Taking the IAEA's high estimate of 10 percent as a median, a state would need to already have an electrical grid with an existing capacity of 9,000 MW in order to to support a single 1,000 MW nuclear power plant, or else plan to have it built well before bringing a nuclear reactor online. Even large developed countries with an unevenly distributed population like Canada face such problems. (The Canadian province of Saskatchewan, which is considering nuclear power, has only one million people and a total installed generating capacity of 3,878 MW.)

The main reason for this grid capacity requirement is that if a large power plant represents too great a proportion of grid capacity, it risks destabilizing the system when it goes offline, either in planned or emergency shutdowns (Schwewe, 2001: 117). Nuclear power plants are most efficiently run as baseload generators and thus should be used at full capacity. They cannot be fired up and closed down to match fluctuating grid requirements. In addition, a reliable independent power source is necessary for the construction and safe operation of a nuclear power plant. An incident in Sweden illustrates the importance of the latter. A loss of offsite power for Sweden's Forsmark 1 reactor in July 2006 handicapped the control room functions and deprived operators of information, making it more difficult to shut down the reactor (MacLachlan, 2007: 10). Lennart Carlsson of the Swedish Nuclear Power Inspectorate said the incident showed that "modern power supply equipment is sensitive to grid disturbances and they are complex" (MacLachlan, 2007: 10). The fact that a sophisticated country like Sweden, with decades of experience, is just discovering this fact should give new entrants pause.

Based on installed electricity generation capacity for 2006,[50] (see table on page 78) only 15 of the 33 SENES states currently have such a capacity. These are either developed countries like Italy or large developing states like Indonesia and Kazakhstan. It is no coincidence that the three countries at the top of the table — Italy, Iran and Turkey — are the only SENES states which have clearly passed Milestone 1 and are among the most likely aspirants to succeed.

Installed Electricity Generation Capacity for SENES States, 2005



Source: US Energy Information Administration (2009)

Currently, 17 of the 33 states pursuing nuclear energy cannot support a 1,000 MW reactor without further investment in their generating capacity. Three of these, Belarus, Syria and Algeria, are close to the cut-off point of 10,000 and may be able to increase their capacity while simultaneously planning a new power reactor. The remaining 14 states — those with less than 6,000 MW capacity — would need to increase it by more than 50 percent to bring it to the minimum 9,000 MW. Buying smaller size Generation III reactors is not currently an option as they are not yet technically proven, much less commercially available.

Thus it appears that at least the following SENES states are unlikely have one of the basic prerequisites for successfully initiating a national nuclear energy program within the next one to two decades:

- Albania
- Bahrain
- Bangladesh
- Ghana
- Jordan
- Libya
- Mongolia
- Morocco
- Namibia
- Oman
- Qatar
- Senegal
- Syria
- Tunisia

One possible solution for such states is to share a nuclear reactor with regional neighbours to spread the investment risk and to distribute the electricity generated in a larger grid, or to sell excess electricity from a nationally owned reactor to neighbours with a shared grid system. However, national electricity grids tend not to be internationally integrated, so sharing electricity from a jointly owned nuclear power plant would usually require additional investment in grid extension and connection.

Some aspiring states, like Egypt, which have enough national grid capacity now, already envisage selling electricity to their neighbours, and may in future be connected to the European grid (Shakir, 2008). Those with less than 10,000 MWe, like Algeria, Libya, Morocco and Syria, may also eventually be linked to a European/Mediterranean grid, which would permit them to move ahead with their nuclear plans. Yet this adds a further layer of uncertainty to their aspirations. Jordan is already connected to a regional grid, which means its plans for a reactor, despite having a small national grid capacity, make some sense. Most of the African aspirants have small, poorly maintained and unconnected grids.

The Gulf Cooperation Council (GCC) comprising Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the UAE, all of which are SENES states, is pursuing a jointly owned nuclear plant that would supply electricity to all of the partners. Alone, many of them could not effectively and efficiently use a nuclear power plant due to their limited national power requirements. Bahrain, for instance, which says it is interested in its own nuclear power plant, has a total installed capacity of only 3,000 MWe for a population of less than one million. While collectively the GCC states could use their oil wealth to purchase one or more reactors, there are doubts about the seriousness of their proposal. In addition, their grids are currently not well connected. The group has in fact been advised by the IAEA to make unifying investments in their electricity grids in parallel with any investment in a common nuclear reactor (Hibbs, 2009a: 8). One of the members, the UAE, is already proceeding on its own.

The Baltic states — Estonia, Latvia and Lithuania — and Poland were considering jointly building two 1,600 MW reactors to supply electricity to all four countries (Nuclear Energy Daily, 2007). Even combined, the three Baltic states do not have enough generating capacity, so new nuclear was only considered viable as a joint project with Poland. The project has, however, at the time of writing, been grounded, largely because of political disagreements between Lithuania (the host country) and Poland (Nucleonics Week, 2007b: 5). Similar problems could arise in other projects involving joint owners. Such joint ventures invariably add further complexity to already complex nuclear energy plans and projects.

Financial Indicators

Another main indicator that a state may not be able to follow through with its nuclear plans is its ability to finance a nuclear plant. For relatively poor countries, paying for a nuclear power plant is a massive hurdle, even if the costs are spread out over several years. There is no precise way to measure whether or not a country can afford a nuclear power plant, especially since decisions may be driven by politics, national pride, energy security, industrialization strategy, or, in the worst case, nuclear weapons "hedging," rather than sound financial analysis or a rational national energy strategy. While stretching a national budget to accommodate a nuclear power plant purchase may be in theory possible, this always implies "opportunity costs" — what might have otherwise been purchased, especially in the vital energy sector. The challenge of measuring financing ability is further complicated by the diversity of public-private economies among aspiring nuclear energy states. Where private capital is unable or unwilling to invest in nuclear energy development on financial grounds, governments may be willing to do so.

A country's Gross Domestic Product (GDP) is one crude indicator of "affordability." States with both a low GDP and a poor credit rating are unlikely to be able to secure a loan for nuclear energy development. This is especially true of states with no credit rating, indicating that there is little outside interest in investing in them at all, much less in a major, inherently risky, infrastructure project. The following table displays the GDP and credit ratings for the 33 aspiring nuclear states listed in SENES. Only Italy, Poland and the Gulf states had "A" ratings. Nine states — Albania, Ghana, Jordan, Libya, Mongolia, Namibia, Senegal, Syria and Tunisia — had a GDP less than $100 billion in 2007, along with non-existent or uncertain credit ratings ("BBB" or lower). The possibility that a single nuclear reactor could cost up to $10 billion, more than one-tenth of each of these states' GDPs, illustrates the problem. It is no coincidence that the states identified as having insufficient grid capacity tend to be the same ones with a low GDP and non-existent or poor credit ratings.

The only developing countries that may be able to ignore such constraints are, again, those with oil-based wealth, such as Nigeria, Saudi Arabia, the small Gulf states and Venezuela. Some may be able to afford to buy reactors outright without loans. Others, like the Gulf states, have good credit ratings and would be able to secure commercial loans. The recent drop in the price of oil and international financial turmoil are likely to make even these states wary of committing to expensive new infrastructure projects like a nuclear power reactor. The richest emirate in the UAE, Dubai, is reportedly $80-120 billion in debt, and has had four of its banks downgraded by Standard and Poor's credit rating agency (The Economist, 2009c: 45).

Procuring loans from international lending institutions such as the World Bank or the Asian Development Bank (ADB) is not an option. These lending institutions do not fund nuclear power plants because, in their estimation the costs are too often underestimated, they have high up-front capital costs and nuclear projects are too large and inflexible electricity generators, particularly for developing countries (World Bank Environment Department, 1994: 83-89). According to the World Bank, the possibility of nuclear accidents and nuclear waste that may lead to "involuntary exposure" of civilians to harmful radiation may have "environmental costs [that] are high enough to rule out nuclear power even if it were otherwise economic" (World Bank Environment Department, 1994: 83-89). The only nuclear project it has ever funded was in Italy in the 1950s (World Bank, 2003). While the World Bank has recently acknowledged that nuclear power can contribute to ameliorating climate change, it has not altered its lending policy.

The ADB, for its part, reaffirmed in a June 2009 policy update that it would not fund nuclear projects: "In view of concerns related to procurement limitations, availability of bilateral financing, proliferation risks, fuel availability, and environmental and safety concerns, ADB will maintain its current policy of non-involvement in the financing of nuclear power generation" (Asian Development Bank, 2009: 32). Other regional lending institutions — including the Inter-American Development Bank (IDB), the Islamic Development Bank (IsDB) and the Arab Bank for Economic Development in

GDP and Credit Ratings for SENES States, 2007 and 2009

State	2007 GDP (billion USD)	Credit Rating
Italy	1,834.00	A+
Turkey	893.10	BB-
Indonesia	863.10	BB-
Iran	790.60	
Poland	636.90	A-
Saudi Arabia	553.50	AA-
Thailand	533.70	BBB+
Egypt	414.10	BB+
Malaysia	367.80	
Venezuela	357.90	BB-
Nigeria	318.70	BB-
Philippines	306.50	BB-
Algeria	228.60	
Vietnam	227.70	BB
Bangladesh	213.60	
Kazakhstan	171.70	BBB-
United Arab Emirates	171.40	AA
Kuwait	137.40	AA-
Morocco	129.70	BB+
Belarus	104.50	B+
Syria	90.99	
Libya	83.59	
Tunisia	78.21	BBB
Qatar	76.75	AA-
Oman	62.97	A
Ghana	32.02	B+
Jordan	29.07	BB
Bahrain	25.17	A
Senegal	20.92	B+
Albania	20.57	
Namibia	10.87	
Mongolia	8.70	

Sources: Central Intelligence Agency (2007); Standard and Poor's. (August 2009)

Africa (BADEA) — do not have nearly enough financial resources to make a meaningful contribution to a nuclear power reactor project.

Export/import credit agencies established by governments may assist with finance in order to boost their domestic reactor manufacturers or governments may provide foreign assistance to cover part of the cost. Canada has done both in promoting CANDU exports to developing countries (Bratt, 2006: 79).[51] France and Russia may do so in the future. Of course, states may seek multiple funding sources to spread the risk, including a combination of government finance, commercial loans and foreign aid.

The Most Likely New Entrants

An accurate assessment of a country's probability of success in acquiring a nuclear power program requires in-depth knowledge of the internal political dynamics of each individual state, especially how it makes its energy decisions on and finances energy projects. The following provides a snapshot analysis of the prospects of some of the most likely candidates among the SENES developing states. One of them, Jordan, would appear to be ruled out based on the criteria discussed above, but does appear to be particularly determined and therefore warrants closer attention. Continuously updated summaries of each SENES state's progress are available at www.cigionline.ca/senes.

Algeria

In a statement by Energy Minister Chakib Khelil, Algeria announced its intention in 2008 to build a nuclear power plant within 10 years (Daya, 2008). To expedite this it has signed nuclear cooperation agreements with China, France, Russia and the US (WNA, 2009b). As Africa's largest natural gas producer, the country is looking to diversify its energy sources, including electricity generation from wind, solar and nuclear (GulfNews.com, 2008), as well as for water desalination (Merabet, 2009). The government established the Commissariat pour l'énergie atomique (Comena) in 1996 to cover a range of possible applications for nuclear energy, including in the agriculture and health sectors. Algeria also has an extensive nuclear research establishment, including two research reactors, a pilot fuel fabrication plant and various facilities at the Ain Oussera "site," including an isotope production plant, hot-cell laboratories and waste storage tanks (IISS, 2008: 107-113).

Algeria was involved in controversy in the early 1990s over its nuclear weapons potential, especially as it was not a party to the 1968 Nuclear Non-Proliferation Treaty (NPT) and its facilities were not safeguarded. Algeria acceded to the NPT in 1995 and signed a full-scope safeguards agreement in 1997. Despite its initial steps and research capacities, Algerian nuclear energy plans are still in their infancy, and the country's 2018 target for a nuclear power plant is unrealistic, not least because Algeria's current electrical grid capacity of 6,470 MW is not nearly sufficient to support a nuclear power plant.

Egypt

With a longstanding interest in nuclear energy, Egypt has managed since the 1950s to establish four research facilities, including two research reactors, a fuel-manufacturing plant and a pilot conversion plant. However, after the Chernobyl disaster in 1986, it put its plans for a nuclear power program on hold (Kessler and Windsor, 2007: 13). It has since reinvigorated its efforts with President Hosni Mubarak's announcement in October 2006 that the country would once again try for a nuclear reactor to meet its energy needs. Several feasibility studies were conducted, leading to the announcement in January 2008 that a 1,000 MWe reactor would be built at El-Dabaa on the Mediterranean coast (The Economist, 2007; Shahine, 2007; WNA, 2009b).

Egypt has since taken several concrete steps, including preparing the site and putting out a call for bids for the plant's construction (Egypt News, 2008).

Once a bid is accepted, the Egyptians estimate the project will take 10 years to complete at a cost of between \$1.5 and \$1.8 billion (Global Security Newswire, 2008a). In May 2008 the government began assessing construction tenders (Egypt News, 2008). So far no bid has been selected, no doubt because Egypt's price range is orders of magnitude below the likely real cost of a 1,000 MWe nuclear plant. Financial challenges loom large over Egyptian prospects for a nuclear power plant, and despite the country's recently improved credit rating, the possibility of attracting foreign investors remains remote (IISS, 2008: 28). As the International Institute of Strategic Studies notes, "The Egyptian civil nuclear programme has often been described as 'budding,' meaning that it is both underdeveloped and under development at the same time" (IISS, 2008: 24).

Indonesia

Almost since independence, Indonesia has sought to acquire nuclear energy, sometimes envisaging up to 30 reactors spread across its sprawling archipelago, but its lack of financial, organizational and technical resources has always held it back. Newly democratic and developing economically, it has revived its interest, President Susilo Bambang announcing in 2006 the government's decision to pursue a nuclear energy program to meet rising energy demand (McCawley, 2007). Presently the intention is to build a single plant comprising two 1,000 MWe reactors on the Muria Peninsula in Central Java by 2017 (WNA, 2009b). The project is already at least two years behind schedule. An abiding concern is Indonesia's high levels of seismic activity, which has led to significant public opposition to the construction of the plant on safety grounds (Harisumarto, 2007). A vibrant anti-nuclear movement has, since the advent of democracy in the country, also been able to make its voice heard without fear of repression. The main problem, however, is that the central government has not yet formally approved plans for nuclear energy, and is not expected to do so until 2010 due to delays caused by coalition building and electoral politics. An IAEA official stated in 2007: "We don't see Indonesia moving this program forward" (Nucleonics Week, 2007c).

Jordan

In a statement by King Abdullah II, Jordan announced in January 2007 that it would pursue a nuclear energy program. Jordan has uranium reserves — 2 percent (112,000 tonnes) of the world's reasonably assured supplies (WNA, 2008a) and is planning to mine it to provide fuel for its potential nuclear program. It is still unclear, however, whether Jordan intends to buy reactors fuelled by natural uranium or LEU (World Information Service on Energy, 2010). In April 2007 the government entered discussions with the IAEA to assess the feasibility of building a nuclear power plant (Reuters, 2007). Since then cooperative agreements have been signed with China, Canada, France, South Korea and the UK, and are being pursued with Russia and the US (Global Security Newswire, 2008b, 2008c; Xinhua, 2008; BBC Monitoring International Reports, 2008). Government officials expect to put out a tender for a plant in 2010, with construction starting in 2013 and the plant coming online in 2017-2018 (WNA, 2009b). Reports in 2007 indicated that a site was to be selected in 2009 (Nucleonics Week, 2007), but this deadline has been pushed back to 2011 (Nucleonics Week, 2007a).

Jordan's desire for nuclear energy is partially a result of its dependence on imports for 95 percent of its current energy needs (Dow Jones Newswires, 2009b). With its small 2,098 MW electrical grid, low GDP and poor credit rating, the outlook for nuclear power in Jordan seems grim unless it is able to export electricity, potentially to Israel. The plant may be dedicated, at least in part, to desalinization of water, in which case the existing grid capacity is not as significant an issue. It is unclear, however, where the financing will come from, although Jordan has special characteristics that may help it obtain favourable financial loans and/or foreign aid. Jordan's close relationship with the US, its friendly relationship with all of its neighbours (unique in the Middle East) and its international reputation for moderation and diplomatic savvy may help it succeed in its nuclear energy plans where others fail — and may be the exception that proves the rule.

Kazakhstan

Kazakhstan says it aims to be the world's largest uranium producer by 2010, a significant supplier of nuclear fuel, to initiate a domestic power program and eventually to sell nuclear reactors abroad (Kassenova, 2008). Kazakhstan has 15 percent of the world's uranium reserves (817,000 tonnes) and claims it has overtaken Canada as the world's second largest producer (Australia is currently first).

On November 21, 2007, Prime Minister Karim Masimov announced that his government would address growing energy demands by pursuing a domestic nuclear energy program. Plans to develop nuclear power have always been politically sensitive due to lingering anti-nuclear feelings inspired by Soviet nuclear testing on Kazakh territory at Semipalatinsk. Nonetheless, on September 24, 2008, President Nursultan Nazarbayev announced that a 600 MWe plant will be constructed in the city of Aktau in the Mangistau region with Russian assistance. Although there are no firm plans for additional plants yet, the National Nuclear Centre, Kazakhstan's nuclear research institution, has proposed a total of 20 small-capacity plants. Kazakhstan has three research reactors in operation, brought online in 1961, 1967 and 1971. Kazakhstan also has plans to join Russia in building an enrichment facility in Eastern Siberia. Such grandiose ideas have been greeted with skepticism in some quarters (Kassenova, 2008), but given the country's vast uranium reserves and close ties to Russia it may just succeed in at least acquiring one or two nuclear power reactors by 2030.

Turkey

Turkey is another country that has sought nuclear energy since the late 1960s, but its plans have always been stymied by financial considerations. Turkey has two research reactors, a small-scale pilot facility for uranium purification, conversion and production of fuel pellets and a nuclear waste storage facility for low-level nuclear waste (IISS, 2008: 63-64). It has negotiated nuclear cooperation agreements with several countries, both regionally and more broadly, but a key agreement with the US was approved by the US Congress only in June 2008 after being delayed because of concerns about Turkish companies' involvement with the A.Q. Khan nuclear smuggling network. In 2006 Turkey announced it was planning to build several reactors to produce 5,000MW of electricity by 2015 (IISS, 2008: 65). Construction was originally scheduled to begin on the first reactor in 2007. However, legal and tendering difficulties have led to continuing delays to the point where, in November 2009, the government said it may launch a new tendering process for a second reactor while the courts sort out the first (Nucleonics Week, 2009d: 6). According to the International Institute of Strategic Studies (IISS), it is unlikely that any reactor will be built by 2015 (IISS, 2008: 65).

The United Arab Emirates

The UAE announced in March 2008 that it would pursue nuclear energy (Salama, 2008). It hopes to have three 1,500 MWe reactors running by 2020, accounting for 15 percent of its energy needs (WNA, 2009b; Hamid, 2008). Although the UAE has the world's sixth largest proven oil reserves and fifth largest proven natural gas reserves (Central Intelligence Agency, 2009), it has been making a strong economic case for nuclear power based on its rapid economic growth and a predicted shortage in natural gas (Lawati, 2008). The UAE has an existing electrical grid capacity of approximately 16,000 MW, but analysis has shown that by 2020 peak demand will reach nearly 41,000 MW, a 156 percent increase in just over a decade (Kumar, 2008). Fresh water resources are extremely limited, prompting plans to build a 9,000 MW desalination complex in Dubai that could be powered by nuclear energy (Kessler and Windsor, 2007: 124). By generating electricity using nuclear power, the UAE can also export more oil and natural gas instead of using it for domestic consumption (WNN, 2008e).

Although pundits predicted that the UAE would be "several decades" away from generating nuclear power because it lacks a sufficient technical and legislative framework for a nuclear program (Kessler and Windsor, 2007: 130), the federation has moved aggressively to court foreign reactor vendors, sign nuclear cooperation agreements with other countries and hire foreigners, lured by extraordinary salaries, to set up its regulatory authority. The UAE has sought to be a model for providing reassurances about its peaceful intentions (for further details see Part 4 of this report on nonproliferation). While finance is unlikely to be the obstacle that it is in other developing countries, the financial crisis that hit Dubai in November 2009, as well as fluctuating oil revenues, serve as a reminder that not even oil-rich countries are immune from the travails of nuclear economics. The country may have difficulty meeting its projected energy demand in 2030 using nuclear power, but it is one of the more likely countries to succeed in its long-term development of a nuclear power industry.

Vietnam

In May 2001, the government of Vietnam instructed the Ministry of Industry (MOI), assisted by the Ministry of Science and Technology (MOST), to conduct a "pre-feasibility study" examining the prospect of establishing a nuclear power sector (Van Hong and Anh Tuan, 2004: 5). Its affirmative report led, in 2002 and 2003, to the creation of the Nuclear Energy Programme Implementing Organization (NEPIO) and the Agency for Radiation Protection and Nuclear Safety Control (VARANSAC), respectively. The government approved its *Long-term Strategy for Peaceful Utilization of Atomic Energy up to 2020* in January 2006, and took the decision in June 2008 to construct two nuclear power plants, each comprising two reactors (WNN, 2008h).

In November 2009, the National Assembly gave its approval for the two plants, demonstrating the government's determination to move ahead despite concerns about whether Vietnam can handle the high cost and complexity of the project. Certainly, Vietnam has a low GDP and a relatively small electricity grid. Yet others view the country's real GDP growth rate of more than 7 percent in the past two decades, its quickening industrial development and its authoritarian government as likely to enable it to persist with its plans (Gourley and Stulberg, 2009: 6). But as Vu Trong Khanh and Patrick Barta note, the estimated cost of the two plants, around 200 trillion Vietnamese dong ($11.3 billion) is "a hefty price tag" when Vietnam has just devalued its currency and faces rising debt payments (Khanh and Barta, 2009).

Conclusions

While there is no scientific method for weighing the balance of the drivers and constraints detailed in this report, it is clear that an expansion of nuclear energy worldwide to 2030 faces considerable barriers that will outweigh the drivers. The profoundly unfavourable economics of nuclear power are the single most important constraint and these are worsening rather than improving, especially as a result of the recent global financial and economic turmoil. Private investors are wary of the high risk, while cash-strapped governments are unlikely to provide sufficient subsidies to make even the first new build economic. Developing countries will, by and large, simply be priced out of the nuclear energy market. The pricing of carbon through taxes and/or a cap-and–trade mechanism will improve the economics of new nuclear build compared with coal and gas, but will also favour less risky alternatives like conservation, energy efficiency, carbon sequestration efforts and renewables. Nuclear will simply not be nimble enough to make much of a difference in tackling climate change. The nuclear waste issue, unresolved almost 60 years after commercial nuclear electricity was first generated, remains in the public consciousness as a lingering concern. The nuclear sector also continues to face public unease about safety and security, notwithstanding recent increased support for nuclear. Governments must themselves consider the implications of widespread, increased use of nuclear energy for global governance of nuclear safety, security and nonproliferation, as considered in the rest of this report.

It is thus likely that the nuclear energy "revival" to 2030 will be confined to existing nuclear energy producers in East and South Asia (China, Japan, South Korea and India); Europe (Finland, France, Russia and the UK); and the Americas (Brazil and the US). One or two additional European states, such as Italy and Poland, may adopt or return to nuclear energy. At most a handful of developing states, those with oil wealth and command economies, may be able to embark on a modest program of one or two reactors. The most likely candidates in this category appear to be Algeria, Egypt, Indonesia, Jordan, Kazakhstan, the UAE and Vietnam, although all face significant challenges in achieving their goals.

In terms of technology, most new build in the coming two decades is likely to be third-generation light water reactors, using technology that is expected to be more efficient, safer and more proliferation-resistant, but not revolutionary. Nuclear power will continue to prove most useful for baseload electricity in countries with extensive, established grids. But demand for energy efficiency is leading to a fundamental rethinking of how electricity is generated and distributed that is not favourable to nuclear. Large nuclear plants will continue to be infeasible for most developing states with small or fragile electricity systems. Generation IV systems will not be ready in time, and nuclear fusion is simply out of the question.

In short, despite some powerful drivers and clear advantages, a revival of nuclear energy faces too many barriers compared to other means of generating electricity for it to capture a growing market share by 2030. For the vast majority of aspiring states, nuclear energy will remain as elusive as ever.

Endnotes

1 Since the global governance implications of large-scale use of nuclear energy for peaceful purposes are the same,whatever a particular reactor is used for, this study encompasses all production of electricity from nuclear energy, whether for domestic or industrial uses, as well as for dedicated purposes such as desalination, direct home heating, process heat (such as for the production of oil from tar sands) or hydrogen production. This report will not consider research reactors or radioactive sources since these are not normally considered to be part of the nuclear revival, even though interest in them may be increasing. This study also does not cover research reactors, isotope production reactors or experimental reactors.

2 The first use of the term "renaissance" appears to have occurred as early as 1985 in an article entitled "A Second Nuclear Era: A Nuclear Renaissance." by Alvin M. Weinberg, Irving Spiewak, Doan L. Phung and Robert S. Livingston, four physicists from the Institute for Energy Analysis at Oak Ridge, Tennessee, in the journal *Energy*. The first use of the term in the new millennium appears to have been in an article in *Power*, Vol. 144, No. 3, on May 1, 2000, entitled "Nuclear power embarks on a renaissance." This report will use the more neutral word "revival," except when referring to others' characterization of the revival as a renaissance.

3 GWe or GW(e) is a measure of electrical energy. 1 GWe = 1000 watts of electricity (MWe) or 10^9 watts. GWth is a measure of thermal energy.

4 The projections were higher than in 2007 and 2008, when the Agency predicted 691 and 748 GWe respectively by 2030.

5 The IAEA does not project reactor numbers.

6 A study by Pacific Northwest Laboratory (PNNL) found that in the there is already enough generating capacity to replace as much as 73 percent of the US conventional fleet with electric cars if charging was managed carefully using "smart grid" off-peak electricity in the evenings.

7 In 1974 the IAEA issued the last of its completely optimistic forecasts of global nuclear capacity, predicting that the existing figure of about 55,000 MWe would multiply more than ten-fold by 1985 to almost 600,000 MWe. By 1990 there would supposedly be more than one million and by the year 2000 almost three million. (See Pringle and Spigelman, 1983: 331).

8 Book examples include: Gwyneth Cravens, *Power to Save the World: the Truth About Nuclear Energy*, New York, Alfred A. Knopf, 2007; Alan M. Herbst and George W. Hopley, *Nuclear Energy Now: Why The Time Has Come for the World's Most Misunderstood Energy Source*, Hoboken, NJ, John Wiley & Sons Inc., 2007; W.J. Nuttall, *Nuclear Renaissance: Technologies and Policies for the Future of Nuclear Power*, New York, Taylor & Francis Group, 2005; William Tucker, *Terrestrial Energy: How Nuclear power Will Lead the Green Revolution and End America's Energy Odyssey*, Bartleby Press, Savage, MD, 2008.

9 Argentina: Embalse (600). Republic of Korea: Kori-2 (637), Kori-3 (979), Kori-4 (977), Ulchin-1 (945), Ulchin-2 (942), Wolsong-1 (597), Yonggwang-1 (953) and Yonggwang-2 (947). Mexico: Laguna Verde-1 (650). Yugoslavia: KRSKO (666).

10 The wastes are in the form of the minor actinides such as americium and curium.

11 Hansen has calculated that the maximum amount of carbon in the atmosphere consonant with the planet "on which civilization developed and to which life is adapted" is 350 parts per million CO^2. The current level is 387.

12 The 2003 MIT study recommended a focus on such light water reactors and "some R&D" on the high temperature gas reactor (HTGR) because of its potential for greater safety and efficiency of operation.

13 For details of additional SMR research efforts directed at "near term deployment," see NEA, 2008: 381-382.

14 Sandia National Laboratory has proposed a small, "right sized" reactor (100-300 MW(t)) ready in 5-8 years (Hiruo, 2009).

15 Currently Argentina, Brazil, Canada, Euratom, France, Japan, China, South Korea, South Africa, Russia, Switzerland, the UK and the US. The NEA hosts the Technical Secretariat.

16 Argentina, Armenia, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, France, Germany, India, Indonesia, Japan, South Korea, Morocco, Netherlands, Pakistan, Russia, Slovakia, South Africa, Spain, Switzerland, Turkey, Ukraine, the US and the European Commission.

17 Each country funds 10 percent, while the European Union makes up the remaining 40 percent.

18 See *GNEP Watch* series from October 2007 to June 2008, http://www.cigionline.org; and Miles Pomper, "US international nuclear energy policy: change and continuity," *Nuclear Energy Futures Paper* No. 10, December 2009.

19 With Algeria (2007); Brazil (2002); India (2006, 2008); Jordan (2006); Libya (2007); Morocco (2007); Qatar (2008); Russia (2000); Tunisia (2008); United Arab Emirates (2008); United Kingdom (2008); and Vietnam (2004).

20 It also misrepresented the predicted levelized cost of nuclear electricity from the 2003 MIT study as being 4.2 cents per kWh, when in fact this was the likely figure only after proposed heroic measures by the industry (including a 25 percent reduction in construction costs and the reduction of capital to the same as coal and gas) from the real figure of 6.7 cents per kWh.

21 The 2003 MIT study did not find that concerns about climate change were a factor in its US survey.

22 This included £500 million interest during construction plus on-site waste storage costs.

23 The equivalent of an overnight cost of $5,000-$6,000/kW (Moody's Corporate Finance, Special Comment, "New nuclear generation in the United States," October 2007. Quoted in Squassoni (2009b): 30.

24 See chart showing comparisons in Smith, 2006: 38; also NEA, 2005: 36.

25 As the US Congressional Budget Office (CBO) notes, "If the levelized cost of a technology exceeded anticipated prices for electricity, merchant generators would be unlikely to invest in new capacity based on that technology because the expected return would not justify the amount of risk they would have to incur. State utility commissions commonly direct regulated utilities to meet anticipated demand for new capacity using the technology with the lowest levelized cost."

26 Business schools teach that a decision about the financial viability of a project should not be confused with a decision to invest, since the former is concerned with whether the project is likely to turn a profit, whereas the latter is concerned with comparative risk and rates of return on investment.

27 Despite this, its levelized cost was only around $45/MWh compared to almost $70 for Japan.

28 By comparison, investments in breweries, for instance, typically attract a 5 percent discount rate. Information technology (IT) projects attract around 10 percent since around one-third of them fail.

29 As the IEA notes, however, there do not have to be uniform incentives with the same value for all technologies. It argues for subsidies for the more expensive alternatives.

30 The increase was due in part to changes in political and public views of nuclear energy following the Chernobyl accident, with subsequent alterations in the regulatory requirements.

31 While, as Mycle Schneider points out, France's high level of reactor standardization has multiple technical and economic advantages, it has also led to systematic multiplication of problems in the reactor fleet.

32 For an example, see a program called the business risk management framework (BRMF).

33 See chart in CBO, 2008: 26.

34 For details see Table 1.1, Incentives provided by the Energy Policy Act of 2005, CBO Report: 11. The tax credit provides up to $18 in tax relief per megawatt hour of electricity produced at qualifying power plants during the first eight years of operation. By comparison, the average wholesale price of electricity in the US in 2005 was about $50 per megawatt. The loan program provides a federal guarantee on debt that covers as much as 80 percent of construction costs. The loan guarantee program also applies to innovative fossil fuel or renewable technologies (CBO, 2008: 8-9).

35 According to Paul Brown, the UK taxpayer has already underwritten all the debts and liabilities of British Energy so the company can never go bankrupt (Brown, 2008: 3).

36 A Nuclear Transparency and Safety Act was passed by the National Assembly only in 2006 (Law No. 2006-686, June 13, 2006). This apparently has had limited effects in making financial details available (Schneider, 2008b: 6-7).

37 The 2009 delivery European Union Allowances (EUAs) closed in trading on March 18, 2009, on the European Climate Exchange at €12.50/metric ton (mt). According to Deutsche Bank carbon analyst Mark Lewis, if the value reaches €35/mt between 2013 and 2020 as some predict, nuclear power could become the cheapest form of new electricity in the EU. At that price coal and gas would cost €86/MWh; CSS capacity €102/MWh; and nuclear only €60/MWh.

38 While reactor vendors prefer large forgings to be in a single piece, it is possible to use split forgings welded together, but these need continued checking throughout the plant's lifetime.

39 WNU is a non-profit corporation and public-private partnership, pursuing an educational and leadership-building mission through programs organized by the WNU Coordinating Centre in London. The WNUCC's multinational secretariat is composed mainly of nuclear professionals supplied by governments; the IAEA further assists with financial support for certain WNU activities. The nuclear industry provides administrative, logistical and financial support (WNU, 2010).

40 For a comprehensive history of the 1982 Nuclear Waste Policy Act and proposed Yucca Mountain repository see Vandenbosch and Vandenbosch, 2007.

41 The list does not include the Philippines as no decision has yet been taken to resume construction.

42 The 32MW reactors are the Akademik Lomonosov 1 and 2, KLT-40S Floati. The other seven are between 750–1085MW each (NEA, 2008: 424).

43 Work originally began on the two Bushehr reactors in 1974 by the German firms Siemens and its subsidiary Kraftwerke Union, but stopped when the Shah was overthrown in 1979. The site was bombed during the 1980-88 Iran/Iraq war. The Russians were contracted to complete one of the reactors in 1995 (Bahgat, 2007: 20-22).

44 Most of these have been published in the NEF Working Paper series. Refer to list at the end of the report.

45 For a complete study of Canada's situation see John Cadham, "The Canadian Nuclear Industry: Status and Prospects," *Nuclear Energy Futures Report*, No. 8. Available at: http://www.cigionline.org/publications/2009/11/canadian-nuclear-industry-status-and-prospects.

46 The Canadian Government announced in June 2009 that it intended to take the government out of the radioisotope business, following the latest breakdown in the world's old nuclear reactor at Chalk River, previously the supplier of more than 50 percent of the world's radionuclides market, and the cancellation in 2007 of the two intended replacement reactors, the AECL-designed Maple 1 and 2, due to insurmountable technical difficulties.

47 This section of the report is largely adapted from Ramana, 2009.

48 For details of improvements see Uranium Institute, "Post-accident changes," reproduced in Steed, 2007: 271-274.

49 In December 2008, South African utility Eskom cancelled its tender for a turnkey nuclear power station, saying the magnitude of the investment was too great. In June 2007 Eskom had announced plans for up to 20,000 MW of new nuclear power by 2025. Areva and Westinghouse had both bid for two new power stations. The reported estimated cost of $9 billion had escalated to $11 billion with the devaluation of the Rand.

50 Grid capacity and electricity production are not interchangeable since different factors are involved in calculating them. Nevertheless, because there is a strong correlation between the two, electricity production is a suitable proxy for the size of a country's energy infrastructure.

51 See Table 3.6, Federal financing of nuclear reactor exports, Bratt, 2006: 79.

Works Cited

Accenture Newsroom (2009). "Consumers Warm to Nuclear Power in Fight against Fossil Fuel Dependency," March 17. Available at: http://newsroom.accenture.com/article_display.cfm?article_id=4810.

Agence France-Press (AFP) (2009). "Ship with Reprocessed Nuclear Fuel Docks in Japan." May 17. Available at: http://www.google.com/hostednews/afp/article/ALeqM5gfJ8qzcN681yT81myZAk-5up4njQ

Alexander, Ryan (2009). "The Real Cost of New U.S. Nuclear Reactors," *Bulletin of the Atomic Scientists*. August 21. Available at: http://www.thebulletin.org/web-edition/op-eds/the-real-cost-of-new-us-nuclear-reactors.

Alger, Justin (2009). "From Nuclear Energy to the Bomb: the Proliferation Potential of New Nuclear Energy Programs," *Nuclear Energy Futures Paper*. No. 6. September. Available at: http://www.cigionline.org/publications/2009/9/nuclear-energy-bomb-proliferation-potential-new-nuclear-energy-programs.

Areva (2009). "Operations." Areva Group. Paris. Available at: http://www.areva.com/servlet/operations-en.html.

Asian Development Bank (ADB)(2009). "Energy Policy – June 2009," *Policy Paper*. June.

Bahgat, Gawdat (2007). *Proliferation of Nuclear Weapons in the Middle East*. Gainesville: University Press of Florida.

BBC Monitoring International Reports (2008). "Jordan Seeks Nuclear Plant Cooperation with South Korea." September 8.

Bergenäs, Johan (2009). "Sweden Reverses Nuclear Phase-Out Policy," *Center for Nonproliferation Studies/Nuclear Threat Initiative Issue Brief*. Monterey Institute for International Studies. November. Available at: http://www.nti.org/e_research/e3_sweden_reverses_nuclear_phaseout_policy.html.

Birtles, Peter (2009). "Time to Forge Ahead," *Nuclear Engineering International*. March.

Boone, David (2009). "In at the ground Fluor," Nuclear Engineering International, July, Pp. 8-9.

Boyer, Paul (1985). *By The Bomb's Early Light: American Thought and Culture at the Dawn of the Atomic Age.* New York: Pantheon.

Bradford, Peter (2009). "The Nuclear Renaissance Meets Economic Reality," *Bulletin of the Atomic Scientists.* Vol. 65, No. 6. November/December. Pp. 60–64.

Bratt, Duane (forthcoming) "The Global Nuclear Revival," *Canada and the Global Nuclear Revival.*

___ (2006). *The Politics of CANDU Exports, IPAC Series in Public Management and Governance*. Toronto: University of Toronto Press.

British Petroleum (BP) (2009). 'Electricity Generation' and 'Nuclear Energy – Consumption,' *Statistical Review of World Energy 2009: Historical data*. June. Available at: http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622.

Brown, Paul (2008). "Voodoo Economics and the Doomed Nuclear Renaissance: a Research Paper." Friends of the Earth. May. London. Available at: http://www.foe.co.uk/resource/reports/voodoo_economics.pdf.

Bruce Power (2009). "Bruce Power to Focus on Additional Refurbishments at Bruce A and B." Press Release. July 23. Available at: http://www.brucepower.com/pagecontent.aspx?navuid=1212&dtuid=84013.

Bulletin of the Atomic Scientists (BAS) (2009). "Interview: Mohamed ElBaradei." September/October, Pp. 1-9.

Bunn, Matthew, Bob van der Zwaan, John P. Holdren and Steve Fetter (2003). "The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel," Project on Managing the Atom, Belfer Center for Science and International Affairs, John F. Kennedy School of Government. December.

Byrd Davis, Mary (2002). "La France Nucléaire: Matières et Sites." Paris: WISE-Paris.

Cadham, John (2009). "The Canadian Nuclear Industry: Status and Prospects," *Nuclear Energy Futures Paper*. No. 8. November 9. Available at: http://www.cigionline.org/publications/2009/11/canadian-nuclear-industry-status-and-prospects.

CBC News (2009). "Bruce Power Drops Plans to Build Ont. Reactors." July 23. Available at: http://www.cbc.ca/technology/story/2009/07/23/bruce-power-cancelled-reactors.html.

Central Intelligence Agency (2009). *The World Factbook: United Arab Emirates*. Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/ae.htm.

Centre for International Governance Innovation (CIGI) (2009). "Survey of Emerging Nuclear Energy States (SENES)." Available at: http://www.cigionline.org/senes.

Charpin, Jean-Michel, Benjamin Dessus and René Pellat (2000). "Economic Forecast Study of the Nuclear Power Option," Report to the Prime Minister. July. Paris. Available at: http://fire.pppl.gov/eu_fr_fission_plan.pdf.

Cohen, Roger (2008). "America Needs France's Atomic Anne," *New York Times*. January 24. Available at: http://www.nytimes.com/2008/01/23/opinion/23iht-edcohen.3.9439528.html.

Commonwealth of Australia (2006). *Uranium Mining, Processing and Nuclear Energy — Opportunities for Australia* ("The Switkowski Report"). Canberra: Department of the Prime Minister and Cabinet.

Congressional Budget Office (CBO) (2008). *Nuclear Power's Role in Generating Electricity*. CBO Report. Washington DC: Congress of the United States. May.

___ (2003). *S.14: Energy Policy Act of 2003*. Washington DC: Congressional Budget Office Cost Estimate. May 7. Available at: http://www.cbo.gov/doc.cfm?index=4206&type=0.

Cooper, Mark (2009a). "All Risk, No Reward for Taxpayers and Ratepayers: The Economics of Subsidizing the 'Nuclear Renaissance' with Loan Guarantees and Construction Work in Progress," Vermont Law School. November. Available at: http://www.vermontlaw.edu/x9198.xml.

___ (2009b). "The Economics of Nuclear Reactors: Renaissance or Relapse?" Institute for Energy and the Environment, Vermont Law School. June. Available at: http://www.nirs.org/neconomics/cooperreport_neconomics062009.pdf.

Cravens, Gwyneth (2007). *Power to Save the World: the Truth About Nuclear Energy*. New York: Knopf.

Davis, Ian (2009). "The British Nuclear Industry: Status and Prospects," *Nuclear Energy Futures Paper*. No. 4. January. Available at: http://www.cigionline.org.

Daya, Ayesha (2008). "Algeria Supports Iran's Pursuit of Nuclear Power, APS Says," *Bloomberg*. August 12. Available at: http://www.bloomberg.com/apps/news?pid=20601116&sid=awB7OVsYWMW0.

Dow Jones Newswires (2009a). "Areva, India Nuclear Power Corp in Pact for Reactors," *Wall Street Journal*. February 9. Available at: http://online.wsj.com/article/SB123373837719447385.html.

___ (2009b). "Jordan Seeks To Join Nuclear Club Of Energy Exporters." July 28.

Dowdeswell, Elizabeth (2005). *Choosing a Way Forward: the Future Management of Canada's Used Nuclear Fuel: Final Study*. Toronto: Nuclear Waste Management Organization. November.

Egypt News (2008). "Egypt to Assess First Nuclear Plant Tender Papers." May 5. Available at: http://news.egypt.com/en/200805052457/news/-egypt-news/egypt-to-assess-first-nuclear-plant-tender-papers.html.

Elston, Murray (2009). "Opening Remarks." Speech given at the Canadian Nuclear Association Conference and Trade Show 2009 - The Reality of Renaissance, February 26. Ottawa: Canadian Nuclear Association.

Energy Information Administration (2008). *International Energy Outlook 2008.* Washington DC: Department of Energy. September. Available at: http://www.eia.doe.gov/oiaf/ieo/index.html.

Froggatt, Anthony and Mycle Schneider (2008). "The World Nuclear Industry Status Report 2007," Greens / EFA. European Parliament Brussels. January. Available at: http://www.greens-efa.org/cms/topics/dokbin/206/206749.the_world_nuclear_industry_status_report@en.pdf.

Galbraith, Kate (2009). "U.S.-Private Bid to Trap Carbon Emissions is Revived," *New York Times*. June 15.

Garwin, Richard L. and Georges Charpak (2001). *Megawatts + Megatons: The Future of Nuclear Power and Nuclear Weapons.* Chicago: University of Chicago Press.

Generation IV International Forum (GIF) (2008a) "Generation IV Systems," Available at: http://www.gen-4.org/Technology/systems/index.htm.

___ (2008b) "GIF and Generation-IV," October 9. Available at: http://www.gen-4.org/PDFs/GIF_Overview.pdf.

Global Security Newswire (2008a). "Egypt to Accept Nuclear Construction Bids." January 28.

___ (2008b). "Jordan Pursues Nuclear Trade Deals." July 30.

___ (2008c). "South Korea to Aid Jordanian Nuclear Program." December 1.

Goldenberg, Suzanne (2010). "Barack Obama gives green light to new wave of nuclear reactors.". *Guardian*. February 23.

Goldschmidt, Bernard (1982). *The Atomic Complex: A Worldwide Political History of Nuclear Energy*. La Grange Park, Illinois: American Nuclear Society.

Gourley, Bernard and Adam N. Stulberg (2009). "Nuclear Energy Development: Assessing Aspirant Countries," *Bulletin of the Atomic Scientists.* Vol. 65, No. 6. November/December. Pp. 20-29.

GulfNews.com (2008). "Algeria Plans Law for Nuclear Power this Year." July 1. Available at: http://www.gulfnews.com/region/Algeria/10225217.html.

Hamid, Asma (2008). "N-power to Meet 15 pc of UAE Energy Needs," *Khaleej Times Online*. November 25. Available at: http://www.khaleejtimes.ae/DisplayArticle.asp?xfile=data/theuae/2008/November/theuae_November 557.xml&section=theuae.

Hannum, William H., Gerald E. Marsh and George S. Stanford (2005). "Smarter Use of Nuclear Waste," *Scientific American*. December.

Hansen, James et al (2008). "Target Atmospheric CO2: Where Should Humanity Aim?" *Open Atmospheric Science Journal.* Vol. 2: 217-231.

Harisumarto, Sukino (2007). "Villagers Against Indonesia's Plans for Nuclear Power Plant," *Nuclear Features*. August 26. Available at: http://www.monstersandcritics.com/news/energywatch/nuclear/features/article_1347879.php/Villagers_against_Indonesias_plans_for_nuclear_power_plant.

Herbst, Alan M. and George W. Hopley (2007). *Nuclear Energy Now: Why the Time Has Come for the World's Most Misunderstood Energy Source.* Hoboken: John Wiley and Sons.

Hibbs, Mark (2009a). "Bahrain moving cautiously on nuclear energy deliberations," *Nucleonics Week*. March 12.

___ (2009b). "South Korean PWR bid to Jordan Getting Korean Diplomatic Support," *Nucleonics Week*. March 19.

___ (2009c). "Turkey May Launch New Reactor Tender in Parallel with Court Injunction Appeal," *Nucleonics Week*, November 19.

___ (2008). "Potential Personnel Shortages Loom Over China's Nuclear Expansion," *Nucleonics Week*. Vol. 49, No. 24. June 12.

Hiruo, Elaine (2009). "Sandia Seeks Industry Partner for Small Reactor," *Nucleonics Week.* September 3.

Hong, Le Van and Hoang Anh Tuan (2006). "Preparation Studies for Introduction of Nuclear Power to Vietnam." Vietnam Atomic Energy Commission. Available at: http://www.vaec.gov.vn/Userfiles/file/NP-Vietnam.pdf.

Hutton, John (2008). Statement by Business and Enterprise Minister John Hutton, quoted in "Nuclear Power is 'Vital' to Britain," *World Nuclear News*. January 11.

Inside NRC (2008). "France to Establish Criteria for New Cooperative Agreements." June 23.

Intergovernmental Panel on Climate Change (2007). *Climate Change 2007: Synthesis Report.* Geneva. Available at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

International Atomic Energy Agency (IAEA) (2009a). *Energy, Electricity, and Nuclear Power Estimates for the Period up to* 2030. Vienna: International Atomic Energy Agency.

___ (2009b). "Finding a Role for nuclear: IAEA Helps Developing Countries Assess Readiness for Nuclear Power," Staff Report. July 21. Available at: http://www.iaea.org/NewsCenter/News/2009/nuclearrole.html.

___ (2009c). *Power Reactor Information System (PRIS).* December 3. Available at: http://www.iaea.org/programmes/a2/.

___ (2009d). "INPRO - International Project on Innovative Nuclear Reactors and Fuel Cycles." Available at: http://www.iaea.org/INPRO/.

___ (2009e). "States Briefed on Sustainable Nuclear Future." September 18. Available at: http://www.iaea.org/NewsCenter/News/2009/inpro.html.

___ (2009f). "International Conference on Human Resource Development for Introducing and Expanding Nuclear Power Programmes," *Nuclear Power Newsletter.* Vol. 6, No. 4. December.

___ (2008a). *Energy, Electricity, and Nuclear Power Estimates for the Period up to* 2030. Vienna. September.

___ (2008b). "Nuclear Power Worldwide: Status and Outlook," Press Release. International Atomic Energy Agency. September 11. Available at: http://www.iaea.org/NewsCenter/PressReleases/2008/prn200811.html.

___ (2007a). "Energy, Electricity and Nuclear Power: Developments and Projections — 25 Years Past & Future." Vienna.

___ (2007b). "Milestones in the Development of a National Infrastructure for Nuclear Power," *IAEA Nuclear Energy Series.* No. NG-G-3.1. Vienna.

___ (1973). "Market Survey for Nuclear Power in Developing Countries: General Report." Vienna. September.

International Energy Agency (IEA) (2009). "The Impact of the Financial and Economic Crisis on Global Energy Investment," *International Energy Agency Background Paper for the G8 Energy Ministers Meeting*. Executive Summary. Rome: May 24-25. Available at: http://www.iea.org/Papers/2009/G8_investment_ExecSum.pdf.

___ (2008a). *World Energy Outlook 2008.* OECD/IEA. Paris.

___ (2008b). *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050.* Organisation for Economic Co-operation and Development (OECD). Paris.

International Institute of Strategic Studies (IISS) (2008). *Nuclear Programmes in the Middle East: In the Shadow of Iran.* London: IISS Strategic Dossier.

Joskow, Paul L. and John E. Parsons (2009). "The Economic Future of Nuclear Power," *Daedalus*. Fall.

Kassenova, Togzhan (2008). "Kazakhstan's Nuclear Ambitions," *Bulletin of the Atomic Scientists*. April 28.

Katsuta, Tadahiro and Tatsujiro Suzuki (2006). "Japan's Spent Fuel and Plutonium Management Challenges." Research Report. September. Princeton: International Panel on Fissile Materials, Program on Science and Global Security.

Kessler, Carol and Lindsay Windsor (2007). *Technical and Political Assessment of Peaceful Nuclear Power Program Prospects in North Africa and the Middle East*. Richland, Washington: Pacific Northwest National Laboratory.

Keystone Center (2007). *Nuclear Power Joint Fact-Finding Final Report*, Keystone, CO, June. Available at: http://keystone.org/files/file/about/publications/FinalReport_NuclearFactFinding6_2007.pdf.

Khanh, Vu Trong and Patrick Barta (2009). "Vietnam Assembly Approves Nuclear Plants," *Wall Street Journal*. November 26. Available at: http://online.wsj.com/article/SB125913876138763683.html.

Kidd, Stephen W. (2007). "Nuclear Power Around the World" in *Nuclear or Not? Does Nuclear Power Have a Place in a Sustainable Energy Future*? David Elliott, ed. London: Palgrave-MacMillan. Pp. 197-206.

Kidd, Steve (2009). "New Nuclear Build – Sufficient Supply Capability?" *Nuclear Engineering International*. March 3. Available at: http://www.neimagazine.com/story.asp?storyCode=2052302.

___ (2008). *Core Issues: Dissecting Nuclear Power Today*. Sidcup, UK: Nuclear Engineering International Special Publications.

Kumar, Himendra Mohan (2008). "Nuclear Matters," *Gulf News.* July 31. Available at: http://www.gulfnews.com/business/General/10233061.html.

Lawati, Abbas Al (2008)."UAE to set up Emirates Nuclear Energy Corporation," *Gulf News.* April 21. Available at: http://www.gulfnews.com/nation/Government/10207145.html.

Lovins, Amory B. and Imran Sheikh (2008). "The Nuclear Illusion," Draft Manuscript for *Ambio*. November edition.

Lowbeer-Lewis, Nathaniel (2010). "Nigeria and Nuclear Energy: Plans and Prospects," *Nuclear Energy Futures Paper.* No. 10. Available at: http://www.cigionline.org.

MacKay, David J.C. (2009). *Sustainable Energy Without the Hot Air.* Cambridge: UIT.

MacLachlan, Ann (2009a). "'Areva-MHI's Atmeal midsize PWR said ready for bidding in Jordan," *Nucleonics Week*. March 19.

___ (2009b). "Areva's Olkiluoto-3 Manager Says Engineering Judgment Undermined," *Nucleonics Week*. March 26.

___ (2009c). "Financial crisis nips nuclear revival in the bud, WNA told," *Nucleonics Week*. September 17.

___ (2008a). "French agency, four Arab countries discuss nuclear cooperation," *Nucleonics Week*. September 25.

___ (2008b). "Newcomers to Nuclear Power Urged to Join Nuclear Safety Convention," *Nucleonics Week*. April 17.

___ (2007). "Better International Reporting Surfaces as a New Push for INSAG," *Inside NRC*. October 1.

Massachusetts Institute of Technology (MIT) (2009). *Update of the MIT 2003 Future of Nuclear Power*. Boston, MIT.

___ (2003). *Future of Nuclear Power.* Boston: MIT.

McBride, J. P., R.E. Moore, J.P. Witherspoon and R.E. Blanco (1978). "Radiological Impact of Airborne Effluents of Coal and Nuclear Plants," *Science*. Vol. 202, No. 4372:1045-1050.

McCawley, Tom (2007). "Indonesia looks to a nuclear future," *Asia Times Online*. May 15. Available at: http://www.atimes.com/atimes/Southeast_Asia/IE15Ae01.html.

McDonald, Allan and Leo Schrattenholzer (2001). "Learning Rates for Energy Technologies," *Energy Policy*. No. 29: 355-261.

McKeeby, David (2008). "White House withdraws Russian Nuclear Agreement from Congress: Multibillion-dollar Deal on Hold Over Georgia Crisis, says White House," America.gov. September 8. Available at: http://www.america.gov/st/peacesec-english/2008/September/20080908175454idybeekcm0.6636316.html.

McLellan, David (2008). "The Economics of Nuclear Power: Current Debates and Issues for Future Consideration," *Nuclear Energy Futures Paper*. No. 1. February. Available at: http://www.cigionline.org/publications/2008/2/economics-nuclear-power-current-debates-and-issues-future-consideration.

Merabet, Y. (2009). "*Le nucléaire Algérien et le bavardage de Chakib Khelil (1ère partie)*," *Le Matin*. August 4. Available at: http://www.lematindz.net/news/2735-le-nucleaire-algerien-et-le-bavardage-de-chakib-khelil-1ere-partie.html.

Mitchell, Catherine and Bridget Woodman (2007). "Risk, Economics and Nuclear Power" in *Nuclear or Not? Does Nuclear Power Have a Place in a Sustainable Energy Future*? David Elliott, ed. London: Palgrave MacMillan. Pp. 149-168.

Moody's Corporate Finance (2007). "New Nuclear Generation in the United States," Special Comment, October.

Moore, Patrick (2006). "Going Nuclear," *The Washington Post.* April 16.

Moormann, Rainer (2009). "PBR Safety Revisited," *Nuclear Engineering International*. March. Pp. 16-20.

National Academy of Sciences (NAS) (1994). *Management and Disposition of Excess Weapons Plutonium*. Committee on International Security and Arms Control (CISAC). Washington DC.

Nuclear Engineering International (NEI) (2007). "Without the Fanfare,". July. Pp. 18-20.

Norris, Robert C. (2000). *The Environmental Case for Nuclear Power: Economic, Medical, and Political Considerations*. St. Paul, MN: Paragon House.

NRCan (2009). "Government of Canada Invites Investor Proposals for AECL CANDU Reactor Division," Press Release. No. 2009/123. Natural Resources Canada. December 17. Available at: http://www.nrcan-rncan.gc.ca/media/newcom/2009/2009123-1a-eng.php.

Nuclear Energy Agency (NEA) (2008a). *Nuclear Energy Outlook 2008.* NEA No. 6348. Paris, OECD.

___ (2008b) "Uranium 2007: Resources, Production and Demand" (Red Book), Paris: OECD, p. 39.

___ (2005). *Projected Costs of Generating Electricity, 2005 Update*. Paris: OECD.

___ (2004). "Nuclear competence building: summary report," *NEA No. 5588*. Paris: NEA/OECD.

___ (2000). "Nuclear Education and Training: Cause for Concern? A Summary Report." Paris: OECD.

Nuclear Energy Daily (2007). "Nuclear Power Share-Out not Delaying Grid Deal: Lithuania, Poland." October 10. Available at: http://www.energy-daily.com.

Nuclear Energy Institute (NEI) (2009a). "The Cost of New Generating Capacity in Perspective," *NEI White Paper*. February. Washington DC: Nuclear Energy Institute.

Nuclear Fuel (2008). "US-ROK Negotiation Will be Key to Korea's Closed Fuel Cycle Plans." May 5.

Nuclear Fuel Cycle (2008). "Budget Shortfall Puts Yucca Site in 'Standby."' January 14.

Nuclear News Flashes (2009a). Platt's, September 23.

___ (2009b). Platt's, March 18.

___ (2008). Platt's. September 15.

___ (2007). Platt's. September 19.

Nuclear Regulatory Commission, US Department of Energy (2009). "Expected New Nuclear Power Plant Applications." September 28. Available at: http://www.nrc.gov/reactors/new-reactors/new-licensing-files/expected-new-rx-applications.pdf.

Nucleonics Week (2009a). "Phénix's end of regular operation also stops transmutation tests," Nucleonics Week, Platt's, March 19.

___ (2009b). "Jordan to identify site, technology for first power reactors by early 2011." March 26.

___ (2009c). "Swedish opposition reaffirms gradual nuclear phase-out policy." March 26.

___ (2009d). "Eskom cancels tender for initial reactors." December 11.

___ (2008). "EDF Expected to Announce 20% Rise in Projected Costs of Flamanville-3." December 4.

___ (2007a). "Jordan Reactor Sitting Study to be Done in 2009, Jaec Says." September 27.

___ (2007b). "No Ignalina-2 Replacement Near; Lithuania may Revisit Shutdown." October 18.

___ (2007c). "Politics and Calamities Stalking Jakarta's Nuclear Power Ambitions." September 27.

NUKEM Inc. (2008). "Nuclear Renaissance: USA—Coping with New NPP Sticker Shock," *NUKEM Market Report*. April.

Nuttal, W.J. (2005). *Nuclear Renaissance: Technologies and Policies for the Future of Nuclear Power.* New York: Taylor and Francis Group.

Nuclear Waste Management Organization (NWMO) (2005). "Covering letter from President Elizabeth Dowdeswell," in *Choosing a Way Forward: the Future Management of Canada's Used Nuclear Fuel: Final Study*. November. Toronto.

Oberth, Ron (2009). "Written Submission by Atomic Energy of Canada Limited to Saskatchewan Crown & Central Agencies Energy Options Committee Meeting," Atomic Energy of Canada Limited (AECL). October 14. Available at: http://www.legassembly.sk.ca/committees/CrownCentralAgencies/Tabled%20Documents/AECL_submission.pdf.

Ontario Clean Air Alliance (2004). "Final and Total Capital Cost of the Darlington Nuclear Generating Station." April 27. Toronto: Available at: http://www.cleanairalliance.org/node/483.

___ (2009). "Conservation vs. New Supply," Air Quality Issues Fact Sheet, no. 26, May 7. Available at: http://www.cleanairalliance.org/files/active/0/fs26.pdf.

Osborn, Alan (2008). "Back to school," *Nuclear Engineering International*. November.

Oshima, Kenichi (2009). "Nuclear Power in Japan – Top Priority of National Energy Policy" in *International Perspectives on Energy Policy and the Role of Nuclear Power*, Lutz Mez et al., eds. June. Brentwood: Multi-Science Publishing.

Pacala, S. and R. Socolow (2004). "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science.* August 13.

Paviet-Hartmann, Patricia, Bob Benedict and Michael J. Lineberry (2009). "Nuclear Fuel Reprocessing," in *Nuclear Engineering Handbook.* Kenneth D. Kok, ed. Boca Raton, FL: CRC Press.

Pidgeon, Nick Karen Henwood and Peter Simmons (2008). *Living with Nuclear Power in Britain: A Mixed-Methods Study*. Social Contexts and Responses to Risk (SCARR) Network. September 2008. Available at: http://www.kent.ac.uk/scarr/SCARRNuclearReportPidgeonetalFINAL3.pdf.

Pilat, Joseph F. ed. (2007). *Atoms for Peace: A Future After Fifty Years?* Washington DC: Woodrow Wilson Center Press.

Pomper, Miles A. (2009). "US International Nuclear Energy Policy: Change and Continuity," *Nuclear Energy Futures Paper.* No. 10. December. Available at: http://www.cigionline.org.

Pringle, Peter and James Spigelman (1983). *The Nuclear Barons.* New York: Avon Books.

Public Opinion Analysis Sector, European Commission (2008). "Attitudes towards Radioactive Waste Managementm" *Special Eurobarometer 297 / Wave 69.1 – TNS Opinion & Social*. June. Available at: http://ec.europa.eu/public_opinion/archives/ebs/ebs_297_en.pdf.

Ramana, M. V. (2009). "The Indian Nuclear Industry: Status and Prospects," *Nuclear Energy Futures Paper*, No. 9. December. Available at: http://www.cigionline.org/publications/2009/12/indian-nuclear-industry-status-and-prospects.

Ramavarman, T. (2009). "UAE-US Nuclear Deal Becomes a Reality," *Khaleej Times*. November 17. Available at: http://www.khaleejtimes.com/DisplayArticle08.asp?xfile=data/theuae/2009/November/theuae_November529.xml&section=theuae.

Research Council of Norway (2008). "Thorium Committee Submits Report: Neither Dismisses nor Embraces Thorium Fuel." April. Available at: http://www.forskningsradet.no/servlet/Satellite?c=GenerellArtikkel&cid=1203528274171.

Reuters (2009). "EDF, GDF Suez get OK for French EPR Nuclear Site." January 29. Available at: http://uk.reuters.com/article/idUKLT28869320090129.

___ (2007). "UN's ElBaradei Discusses Jordan's Nuclear Plans." April 15. Available at: http://www.reuters.com/article/topNews/idUSL1557493820070415.

Romm, Joseph (2008). "The Self-Limiting Future of Nuclear Power." Washington DC. Center for American Progress Action Fund. June 2. Available at: http://www.americanprogressaction.org/issues/2008/nuclear_power_report.html.

Ryan, Margaret L. (2008). "US Units Shine, But World Nuclear Generation Lags in 2007," *Nucleonics Week*. February 14.

Salama, Samir (2008). "UAE will be First Gulf State to Develop Civilian Nuclear Power," *Gulf News*. March 24. Available at: http://gulfnews.com/news/gulf/uae/government/uae-will-be-first-gulf-state-to-develop-civilian-nuclear-power-1.92883.

Schmitt, Eric (2008). "Preparing for the Nuclear Power Renaissance," Capgemini. Available at: http://www.capgemini.com/insights-and-resources/by-publication/preparing_for_the_nuclear_power_renaissance/.

Schneider, Mycle (2009). "Nuclear Power in France – Trouble Lurking Behind the Glitter," in *International Perspectives on Energy Policy and the Role of Nuclear Power.* Edited by Lutz Mez, Mycle Schneider and Steve Thomas. Brentwood, UK: Multi-Science Publishing.

___ (2008a). "The Reality of France's Aggressive Nuclear Power Push," *Bulletin of the Atomic Scientists*. June 3. Available at: http://www.thebulletin.org/web-edition/op-eds/the-reality-of-frances-aggressive-nuclear-power-push.

___ (2008b). "Nuclear Power in France: Beyond the myth," December. Available at: http://www.greens-efa.org/cms/topics/dokbin/258/258614.mythbuster@en.pdf.

Schneider, Mycle, Steve Thomas, Antony Froggatt and Doug Koplow (2009). "The World Nuclear Industry Status Report 2009," Commissioned by the German Federal Ministry of Environment, Nature Conservation and Reactor. Available at: Safety. http://www.bmu.de/files/english/pdf/application/pdf/welt_statusbericht_atomindustrie_0908_en_bf.pdf.

Schwewe, Phillip F. (2001). *The Grid*. Washington, DC: National Academies Press.

Shahine, Alaa (2007). "Mubarak says Egypt to build nuclear power stations." Reuters. October 29. Available at: http://uk.reuters.com/article/idUKL2932720220071029?sp=true

Shakir, Mohamed (2008). Presentation given at the "Nuclear Energy Futures Project" conference hosted by the Centre for International Governance Innovation, November 5-7. Waterloo, Canada.

Smith, Aileen Mioko (2007). "The Failures of Japan's Nuclear Fuel Cycle Program 1956-2007," Japan: Green Action Kyoto, May. Available at: http://www.citizen.org/documents/AileenMiokoSmithPresentation.pdf.

Smith, Brice (2006). *Insurmountable Risks: The Dangers of Using Nuclear Power to Combat Global Climate Change*. A Report of the Institute for Energy and Environmental Research (IEER). Muskegon, Michigan: IEER Press.

Smith, Michelle M. and Charles D. Ferguson. (2008). "France's Nuclear Diplomacy," *International Herald Tribune.* March 11.

Squassoni, Sharon (2009a). "The US Nuclear Industry: Current Status and Prospects under the Obama Administration," *Nuclear Energy Futures Paper*. No. 7. November. Available at: http://www.cigionline.org/publications/2009/10/us-nuclear-industry-current-status-and-prospects-under-obama-administration.

___ (2009b). *Nuclear Energy: Rebirth or Resuscitation?* Washington DC: Carnegie Endowment for International Peace.

Statens Strålevern (Norwegian Radiation Protection Authority) (2008). "Floating Nuclear Power Plants and Associated Technologies in the Northern Areas," Strålevern Rapport No. 15. Oslo.

Steed, Roger G. (2007). *Nuclear Power in Canada and Beyond*. Renfrew, Ontario: General Store Publishing House.

Sub-Committee on Energy and Environmental Security (2009). "The Nuclear Renaissance," Draft Report. Brussels: NATO Parliamentary Assembly. March 17.

Teollisuuden Voima Oyj (TVO) (2009). "Start-up of Olkiluoto 3 nuclear power plant may be postponed further." October 15. Available at: http://www.tvo.fi/www/page/3266/.

The Economist (2009a). "Going With the Wind," June 6.

___ (2009b). "On Target, Finally," May 30.

___ (2009c). "The Perils of Autocracy," July 11.

___ (2009d). "Building the Smart Grid," *The Economist Technology Quarterly*, June 6. Pp. 15-17.

___ (2007). "Egypt's Nuclear-Power Programme," November 2.

Thomas, Stephen, Peter Bradford, Antony Froggatt and David Milborrow (2007). "The Economics of Nuclear Power: Technology, Economics, Alternatives & Case Studies." Greenpeace International, Amsterdam, Annex A. Available at: http://www.greenpeace.org.uk/files/pdfs/nuclear/nuclear-economics-report.pdf.

Thomas, Steve (2009). "PBMR: Hot or Not?" *Nuclear Engineering International.* March.

___ (2005). "The Economics of Nuclear Power: Analysis of Recent Studies," Public Services International Research Unit (PSIRU), University of Greenwich. July 2005. Available at: http://www.psiru.org/reports/2005-09-E-Nuclear.pdf.

Tolley, George S., and Donald W. Jones, Chairs (2004). "The Economic Future of Nuclear Power," University of Chicago, August.

Toronto Star (2009). "26B cost killed nuclear bid." July 14. Available at: http://www.thestar.com/article/665644.

Transparency International (2009). "Corruption Perceptions Index 2009." Available at: http://www.transparency.org/policy_research/surveys_indices/cpi/2009.

Tucker, William (2009) "There is No Such Thing as Nuclear Waste," *The Wall Street Journal*. March 13.

___ (2008). *Terrestrial Energy: How Nuclear Power will Lead the Green Revolution and End America's Energy Odyssey* Savage, M.D.: Bartleby Press.

UK Department of Trade and Industry (2007). Meeting the energy challenge: A White Paper on Energy, London, May. Available at: http://www.berr.gov.uk/files/file39387.pdf.

US Department of Energy (2009). "Program Activities for the Deployment of Nuclear Power," *Nuclear Power 2010*. Office of Nuclear Energy, US Department of Energy. Available at: http://nuclear.gov/np2010/activities.html.

___ (2006). *The U.S. Generation VI Fast Reactor Technology*, Office of Nuclear Energy, December. Available at: http://www.nuclear.gov/pdfFiles/genIvFastReactorRptToCongressDec2006.pdf.

US Government Printing Office (GPO) (2009a). "Foreign exchange rates, 1985-2008" (Table B-110), Economic Report of the President, Washington DC.

___ (2009b). "Gross Domestic Product and Deflators Used in the Historical Tables: 1940–2014" (Table 10.1), Budget of the United States Government (FY 2010), Washington DC.

US Presidential Committee of Advisors on Science and Technology (1995). *Fusion Review Panel*, US Program of Fusion Energy Research and Development, Washington DC.

Vandenbosch, Robert and Susanne E Vandenbosch (2007). *Nuclear Waste Stalemate: Political and Scientific Controversies*. Salt Lake City: University of Utah Press.

Van Hong, Le, and Hoang Anh Tuan (2004). "Preparation Studies for Introduction of Nuclear Power to Vietnam," Vietnam Atomic Energy Commission, Hanoi. Available at: http://www.vaec.gov.vn/Userfiles/file/NP-Vietnam.pdf.

von Hippel, Frank (2008). "Nuclear Fuel Recycling: More Trouble than it's Worth," *Scientific American.* Vol. 28. April.

Weil, Jenny (2009). "NEI's New President Sees Scaled-Down Expansion Goal," *Nucleonics Week*. March 12.

Weinberg, Alvin M., Irving Spiewak, Doan L. Phung and Robert S. Livingston (2000). "A Second Nuclear Era: A Nuclear Renaissance," *Energy*. Vol. 144, No. 3. May 1.

World Bank (2003). "Pages from World Bank History: Loan for Nuclear Power." August 22. Available at: http://web.worldbank.org/WBSITE/EXTERNAL/EXTABOUTUS/EXTARCHIVES/0,,contentMDK:20125474~pagePK:36726~piPK:36092~theSitePK:29506,00.html.

___ (2009). "Worldwide Governance Indicators: 1996-2008." Available at: http://info.worldbank.org/governance/wgi/index.asp.

World Bank Environment Department (1994). *Environmental Assessment Sourcebook*. Vol. III, World Bank Technical Paper No. 154. April.

World Business Council for Sustainable Development (2008). "Power to Change: A Business Contribution to a Low-Carbon Electricity Future," Geneva.

World Information Service on Energy (2010). "Jordan: Status of Uranium Mining." WISE Uranium Project. January 6. http://www.wise-uranium.org/upasi.html#JOGEN.

World Nuclear Association (WNA) (2009a). "Advanced Nuclear Power Reactors." Available at: http://www.world-nuclear.org/info/inf08.html.

___ (2009b). "Emerging Nuclear Energy Countries." December 29. Available at: http://www.world-nuclear.org/info/inf102.html.

___ (2009c). "Japanese Waste and MOX Shipments From Europe," March. Available at: http://www.world-nuclear.org/info/inf39.html.

___ (2009d). *Nuclear Century Outlook*. Available at: http://www.world-nuclear.org/outlook/clean_energy_need.html.

___ (2009e). "Structuring Nuclear Projects for Success: an Analytical Framework." London. Available at: http://www.world-nuclear.org/uploadedFiles/org/reference/pdf/EconomicsReport.pdf.

___ (2009f). "Nuclear Power in Ukraine," World Nuclear Association, December 2009. Available at: http://world-nuclear.org/info/inf46.html.

___ (2009g). "Thorium." August. Available at: http://www.world-nuclear.org/info/inf62.html.

___ (2008a)."Supply of Uranium." June 2008. Available at: http://www.world-nuclear.org/info/inf75.html.

___ (2008b). *Nuclear Century Outlook 2008 Data Table*, Available at: http://www.world-nuclear.org/outlook/nuclear_century_outlook.html.

___ (2008c). "The New Economics of Nuclear Power," WNA Report. November. Available at: http://www.world-nuclear.org/reference/pdf/economics.pdf.

World Nuclear News (WNN) (2009a). "UAE picks Korea as nuclear partner," December 29.

___ (2009b). "Full Power for Japan's First MOX burner." December 3.

___ (2009c). "Nuclear shutdown in Brazil blackout," November 12.

___ (2009d). "NEI Proposes Legislation for Nuclear Growth." October 28.

___ (2009e). "Olkiluoto 3 Gets its Dome." September 8.

___ (2009f). "China to Set Even Higher Nuclear Targets." June 1.

___ (2009g). "Construction at Sanmen within a Month." March 2.

___ (2009h). "Obama Dumps Yucca Mountain." February 27.

___ (2009i). "Olkiluoto 3 Losses to Reach €1.7 Billion." February 26.

___ (2008a). "Crossroads for Yucca Mountain." December 19.

___ (2008b). "IAEA: Nuclear Capacity Could Double by 2030." September 12.

___ (2008c). "New Date for Atucha 2." August 18.

___ (2008d). "Positive thinking in Italy, Canada, and Poland." August 7.

___ (2008e) "UAE Launches Nuclear Policy to Meet Energy Demand." July 14.

___ (2008f). "UK opinion swinging towards nuclear." June 25.

___ (2008g). "Poll: Two thirds of Americans back new nuclear." June 9.

___ (2008h). "Vietnam Passes Law on Nuclear Energy." June 4.

___ (2008i). "Opinion favors nuclear." April 29.

___ (2008j). "National Skills Academy Approved for UK Nuclear Industry." January 18.

___ (2008k). "Monju to Return in 2008 with New Plutonium Core." January 17.

___ (2008l). "Nuclear power is 'vital' to Britain." January 11.

___ (2007). "UK poll shows support for nuclear, but confusion on issues." 5 December.

World Nuclear University. (WNU) (2010). "What is the WNU?" Available at: http://www.world-nuclear-university.org/about.aspx?id=15036.

Xinhua (2008). "China, Jordan Sign Power Plant Deal." September 23. Available at: http://news.xinhuanet.com/english/2008-09/23/content_10099137.htm.

About the Author

Dr. Trevor Findlay is a CIGI senior fellow and holder of the William and Jeanie Barton Chair in International Affairs and a professor at the Norman Paterson School of International Affairs at Carleton University, Ottawa, where he is also director of the Canadian Centre for Treaty Compliance.

From 1998 to early 2005, Dr. Findlay was executive director of the Verification Research, Training and Information Centre in London, UK. As an Australian diplomat, Dr. Findlay was a member of the Australian delegation to the Conference on Disarmament, the UN General Assembly and the UN Disarmament Commission. He was a senior fellow and acting head of the Peace Research Centre at the Australian National University before establishing the program on peacekeeping and regional security at the Stockholm International Peace Research Institute in Sweden. He is the author of several books, including Nuclear Dynamite: The Peaceful Nuclear Explosions Fiasco (Brassey's Australia, 1990) and The Use of Force in UN Peace Operations (Oxford University Press, 2002). He holds a BA Honours in political science from the University of Melbourne and a master's degree and PhD in international relations from the Australian National University.

Nuclear Energy Futures Project Publications

GNEP Watch: Developments in the Global Nuclear Energy Partnership
Miles A. Pomper, *#1 - #11*
October 2007 - December 2008

The Economics of Nuclear Power: Current Debates and Issues for Future Consideration
David McLellan, *Nuclear Energy Futures Paper #1*
February 2008

A Guide to Global Nuclear Governance: Safety, Security and Nonproliferation
Justin Alger, *Nuclear Energy Futures Special Publication*
September 2008

The Global Nuclear Safety and Security Regimes
Aaron Shull, *Nuclear Energy Futures Paper #2*
November 2008

The Russian Nuclear Industry: Status and Prospects
Miles A. Pomper, *Nuclear Energy Futures Paper #3*
January 2009

The British Nuclear Industry: Status and Prospects
Ian Davis, *Nuclear Energy Futures Paper #4*
January 2009

Survey of Emerging Nuclear Energy States
Ray Froklage et al., *Nuclear Energy Futures web-based document*
May 2009

Uranium Enrichment in Canada
David Jackson and Kenneth Dormuth, *Nuclear Energy Futures Paper #5*
May 2009

From Nuclear Energy to the Bomb: The Proliferation Potential of New Nuclear Programs
Justin Alger, *Nuclear Energy Futures Paper #6*
September 2009

The US Nuclear Industry: Current Status and Prospects under the Obama Administration
Sharon Squassoni, *Nuclear Energy Futures Paper #7*
November 2009

The Canadian Nuclear Industry: Status and Prospects
John Cadham, *Nuclear Energy Futures Paper #8*
November 2009

The Indian Nuclear Industry: Status and Prospects
M. V. Ramana, *Nuclear Energy Futures Paper #9*
December 2009

US International Nuclear Energy Policy: Change and Continuity
Miles A. Pomper, *Nuclear Energy Futures Paper #10*
January 2010

Nigeria and Nuclear Energy: Plans and Prospects
Nathaniel Lowbeer-Lewis, *Nuclear Energy Futures Paper #11*
January 2010

The Future of Nuclear Energy to 2030 and Its Implications for Safety, Security and Nonproliferation
Trevor Findlay, *Nuclear Energy Futures Project Report*
February 2010
Overview
Part 1 – The Future of Nuclear Energy to 2030
Part 2 – Nuclear Safety
Part 3 – Nuclear Security
Part 4 – Nuclear Nonproliferation

Nuclear Energy and Global Governance to 2030: An Action Plan
Louise Fréchette (chair), Trevor Findlay (director), *Nuclear Energy Futures Project Report*
February 2010

Acronyms and Abbreviations

ABACC	Argentine-Brazilian Agency for Accounting and Control
ABWR	Advanced Boiling Water Reactor
ACR	Advanced CANDU Reactor
ADB	Asian Development Bank
AECL	Atomic Energy of Canada Limited
AFCI	Advanced Fuel Cycle Initiative (GNEP)
AFCONE	African Commission on Nuclear Energy
AFNI	L'Agence France Nucléaire International (France)
AIP	Advance Information Package (OSART)
ALARA	as low as reasonably achievable
ANDRA	Agence nationale pour la gestion des déchets radioactifs/ National Agency for the Management of Radioactive Waste (France)
ANWFZ	African Nuclear Weapon-Free Zone Treaty
AP	Additional Protocol (IAEA)
ASE	AtomsTroyExport (Russia)
ASME	American Society of Mechanical Engineers
ASN	Nuclear Safety Authority (France)
AU	African Union
BADEA	Arab Bank for Economic Development in Africa
BMWG	Border Monitoring Working Group (IAEA)
BNFL	British Nuclear Fuels Limited
BOG	Board of Governors (IAEA)
BSS	Basic Safety Standards (IAEA)
BWR	boiling water reactor
CACNARE	Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency
CANDU	Canada Deuterium Uranium reactor
CBO	Congressional Budget Office (US)
CCGT	combined cycle gas turbine
CCPNM	Convention on the Physical Protection of Nuclear Material
CCS	carbon capture and storage
CD	Conference on Disarmament (UN)
CDM	clean development mechanism
CEA	Commissariat à l'Énergie Atomique/ Atomic Energy Commission (France)
CEC	Commission of the European Communities (now EC)
CENNA	Convention on Early Notification of a Nuclear Accident
CFDT	Confédération Français Démocratique du Travail/ French Democratic Confederation of Workers
CHP	combined heat and power
CIA	Central Intelligence Agency (US)
CIRUS	Canada India Research US reactor
CISAC	Committee on International Security and Arms Control
CNRA	Committee on Nuclear Regulatory Activities (OECD/NEA)
CNS	Convention on Nuclear Safety
CNSC	Canadian Nuclear Safety Commission (Canada)
COGEMA	Compagnie Générale des Matières Nucléaires/ General Company for Nuclear Materials (France)
CORDEL	Working Group on Cooperation in Reactor Design Evaluation and Licensing (WNA)
CSA	Comprehensive Safeguards Agreement (IAEA)
CSS	Commission on Safety Standards (IAEA)
CTBT	Comprehensive Nuclear Test Ban Treaty
CTR	Cooperative Threat Reduction
DBT	design basis threat
DOE	Department of Energy (US)
DTI	Department of Trade and Industry (UK)
DUPIC	direct use of spent PWR fuel in CANDU
EC	European Commission
EDF	Electricité de France
EIA	Energy Information Agency (DOE)
ENAC	Early Notification and Assistance Conventions
ENATOM	Emergency Notification and Assistance Technical Operations Manual
ENEN	European Nuclear Education Network
ENSREG	European Nuclear Safety Regulators Group
EPAct	US Energy Policy Act (2005)
EPR	Evolutionary Power Reactor (formerly European Power Reactor)
EPREV	Emergency Preparedness Review Teams (IAEA)
EPRI	Electric Power Research Institute
ERBD	European Bank for Reconstruction and Development (EC)
ERNM	Emergency Response Network Manual
EUP	enriched uranium product
Euratom	European Atomic Energy Community (EC)
FAO	Food and Agricultural Organization of the United Nations
FBR	fast breeder reactor
FMCT	Fissile Material Cut-Off Treaty
FMT	Fissile Material Treaty
FOAK	first-of-a-kind
FP&L	Florida Power and Light
G8	Group of Eight
GAO	Government Accountability Office (US)
GCC	Gulf Cooperation Council
GCR	gas-cooled reactors
GDF	Gaz de France
GDP	gross domestic product
GHG	greenhouse gases
GIF	Generation IV International Forum
GNEP	Global Nuclear Energy Partnership
GPP	Global Partnership Program (G8)
GTCC	gas turbine combined cycle
HEU	highly enriched uranium
IACRNA	Inter-Agency Committee on Response to Nuclear Accidents
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICJ	International Court of Justice
ICNND	International Commission on Nuclear Nonproliferation and Disarmament
ICRP	International Commission on Radiological Protection
ICSANT	International Convention for the Suppression of Acts of Nuclear Terrorism
IDB	Inter-American Development Bank
IEA	International Energy Agency (OECD)
IEC	Incident and Emergency Centre
ILO	International Labor Organization
IMO	International Maritime Organization
INES	International Nuclear and Radiological Event Scale
INF	irradiated nuclear fuel
INFA	International Nuclear Fuel Agency
INIR	Integrated Nuclear Infrastructure Review (IAEA)
INLEX	International Expert Group on Nuclear Liability
INMM	Institute of Nuclear Materials Management
INPO	Institute of Nuclear Power Operations (US)
INPRO	International Project on Innovative Nuclear Reactors and Fuel Cycles
INRA	International Nuclear Regulators Association
INSAG	International Nuclear Safety Group (IAEA)
INSServ	International Nuclear Security Advisory Service (IAEA)
INSSP	Integrated Nuclear Security Support Plan (IAEA)
INTERPOL	International Criminal Police Organization

IPCC	Intergovernmental Panel on Climate Change
IPFM	International Panel on Fissile Materials
IPPAS	International Physical Protection Advisory Service (IAEA)
IRRS	Integrated Regulatory Review Service
IRS	Incident Reporting System (IAEA/NEA)
IsDB	Islamic Development Bank
ISIS	Institute for Science and International Security
ISSAS	International SSAC Advisory Service (IAEA)
ISSC	International Seismic Safety Centre
ITDB	Illicit Trafficking Database (IAEA)
ITE	International Team of Experts (IAEA)
ITER	International Thermonuclear Experimental Reactor
JREMPIO	Joint Radiation Emergency Management Plan of the International Organizations
JSW	Japan Steel Works
KEPCO	Korea Electric Power Corporation
KINS	Korea Institute of Nuclear Safety
LEU	low enriched uranium
LIS	laser-isotope separation
LNG	Liquid Natural Gas
LWGR	light water-cooled graphite-moderated reactor
LWR	light water reactor
MCIF	Major Capital Investment Fund (IAEA)
MDEP	Multinational Design Evaluation Program
MESP	Multilateral Enrichment Sanctuary Project
MIT	Massachusetts Institute of Technology
MOI	Ministry of Industry (Vietnam)
MOST	Ministry of Science and Technology (Vietnam)
MOX	Mixed Oxide Fuel
NAS	National Academy of Sciences (US)
NASA	National Aeronautics and Space Administration (US)
NATO	North Atlantic Treaty Organization
NCACG	National Competent Authorities' Coordinating Group
NEA	Nuclear Energy Agency (OECD)
NEF	Nuclear Energy Futures
NEI	Nuclear Energy Institute
NEPIO	Nuclear Energy Programme Implementing Organization
NERC	North American Electric Reliability Corporation
NERS	Network of Regulators of Countries with Small Nuclear Programmes
NESA	Nuclear Energy System Assessment
NEWS	Nuclear Events Web-based System
NGO	non-governmental organization
NGSI	Next Generation Safeguards Initiative
NIA	Nuclear Industry Association (UK)
NIF	National Ignition Facility (US)
NII	Nuclear Installations Inspectorate (UK)
NJFF	Nuclear Power Joint Fact Finding (Keystone Center)
NNWS	non-nuclear weapon state (NPT)
NPT	Nuclear Nonproliferation Treaty
NRC	Nuclear Regulatory Commission (US)
NRU	National Research Universal reactor (Canada)
NSEL	Nuclear Security Equipment Laboratory (IAEA)
NSF	Nuclear Security Fund (IAEA)
NSG	Nuclear Suppliers Group
NSSG	Nuclear Safety and Security Group (IAEA)
NTI	Nuclear Threat Initiative
NTM	National Technical Means
NUSS	Nuclear Safety Standards (IAEA)
NWFZ	nuclear-weapon-free zone
NWMO	Nuclear Waste Management Organization (Canada)
NWPA	US Nuclear Waste Policy Act (1982)
NWS	nuclear weapon state (NPT)
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OEF	operating experience feedback
OER	Operating Experience Reports
OSART	Operational Safety Review Teams (IAEA)
PBMR	Pebble Bed Modular Reactor
PHWR	pressurized heavy water reactor
PIU	Performance and Innovation Unit (UK Cabinet Office)
POC	Point of Contact
PRA	Probabilistic Risk Assessment
PRIS	Power Reactor Information System
PROSPER	Peer Review of the effectiveness of the Operational Safety Performance Experience Review
PSI	Proliferation Security Initiative
PSR	Periodic Safety Review
PUREX	Plutonium Uranium Extraction
PWR	pressurized water reactor
RADWASS	Radioactive Waste Safety Standards (IAEA)
RANET	Response Assistance Network
RBMK	Reaktor Bolshoy Moshchnosti Kanalniy (High Power Channel-Type Reactor) (Russia)
RDD	radiological dispersal device
REPLIE	Response Plan for Incidents and Emergencies (IAEA)
RWC	Radiological Weapons Convention
SAG	Senior Advisory Group (IAEA)
SAGSI	Standing Advisory Group on Safeguards Implementation (IAEA)
SAGSTRAM	Standing Advisory Group on the Safe Transport of Radioactive Materials (IAEA)
SAL	Safeguards Analytical Laboratory (IAEA)
SEDO	Safety Evaluation During Operation of Fuel Cycle Facilities (IAEA)
SENES	Survey of Emerging Nuclear Energy States
SILEX	separation of isotopes by laser excitation
SMR	small- and medium-sized reactor
SOARCA	State-of-the-Art Reactor Consequences Analysis
SOER	Significant Operating Experience Reports
SOLAS	International Convention for the Safety of Life at Sea
SQP	Small Quantities Protocol (IAEA)
SSAC	State System of Accounting and Control
STUK	Säteilyturvakeskus (Radiation and Nuclear Safety Authority, Finland)
SWU	separative work unit
TCP	Technical Cooperation Programme (IAEA)
TRC	Technical Review Committee (IAEA)
TTA	Nuclear Trade and Technology Analysis unit (IAEA)
TVO	Teollisuuden Voima Oyj (Finland)
UAE	United Arab Emirates
UNFCCC	United Nations Framework Convention on Climate Change
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
URENCO	Uranium Enrichment Company
USSPC	ultra-supercritical pulverized coal
VARANSAC	Vietnam Agency for Radiation Protection and Nuclear Safety Control
VERTIC	Verification Research, Training and Information Centre
VVER	Vodo-Vodyanoi Energetichesky Reactor (Russia)
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators Association
WGRNR	Working Group on Regulation of New Reactors (CNRA)
WHO	World Health Organization
WINS	World Institute of Nuclear Security
WMD	weapons of mass destruction
WMO	World Meteorological Organization
WNA	World Nuclear Association
WNTI	World Nuclear Transport Institute
WNU	World Nuclear University (WNA)

About CIGI

The Centre for International Governance Innovation is an independent, nonpartisan think tank that addresses international governance challenges. Led by a group of experienced practitioners and distinguished academics, CIGI supports research, forms networks, advances policy debate, builds capacity, and generates ideas for multilateral governance improvements. Conducting an active agenda of research, events, and publications, CIGI's interdisciplinary work includes collaboration with policy, business and academic communities around the world.

CIGI conducts in-depth research and engages experts and partners worldwide from its extensive networks to craft policy proposals and recommendations that promote change in international public policy. Current research interests focus on international economic and financial governance both for the long-term and in the wake of the 2008-2009 financial crisis; the role of the G20 and the newly emerging powers in the evolution of global diplomacy; Africa and climate change, and other issues related to food and human security.

CIGI was founded in 2002 by Jim Balsillie, co-CEO of RIM (Research In Motion) and collaborates with and gratefully acknowledges support from a number of strategic partners, in particular the Government of Canada and the Government of Ontario. CIGI gratefully acknowledges the contribution of the Government of Canada to its endowment fund. Support from the Government of Ontario includes a major financial contribution to the Nuclear Energy Futures project.

Le CIGI a été fondé en 2002 par Jim Balsillie, co-chef de la direction de RIM (Research In Motion). Il collabore avec de nombreux partenaires stratégiques et leur exprime toute sa reconnaissance pour leur soutien. Il remercie tout particulièrement le gouvernement du Canada pour sa contribution à son Fonds de dotation, de même que le gouvernement de l'Ontario, dont l'appui comprend une aide financière majeure au projet Perspectives de l'énergie nucléaire.

Publications Team

Senior Director for Publications: Max Brem
Publications Coordinator: Jessica Hanson
Media Designer: Steve Cross
Copyeditors: Matthew Bunch and Tammy McCausland

Media Contact

For media enquiries, please contact:
Mary-Lou Schagena
Communications Specialist
Tel: +1.519.885.2444 x238, mschagena@cigionline.org

CIGI
The Centre for International Governance Innovation
Centre pour l'innovation dans la gouvernance internationale

57 Erb Street West

Waterloo, Ontario N2L 6C2, Canada

tel +1 519 885 2444 fax +1 519 885 5450

www.cigionline.org