THE WORLD NUCLEAR INDUSTRY STATUS REPORT 2010–2011

# Nuclear Power in a Post-Fukushima World

## 25 YEARS AFTER THE CHERNOBYL ACCIDENT

Mycle Schneider
Antony Froggatt
Steve Thomas

Worldwatch Institute
Mycle Schneider Consulting
The Greens | EFA in the European Parliament

V2

**THE WORLD NUCLEAR INDUSTRY STATUS REPORT 2010–2011**

# Nuclear Power in a Post-Fukushima World

***25 Years After the Chernobyl Accident***

*By*

**Mycle Schneider**
Independent Consultant, Mycle Schneider Consulting, Paris (France)
*Project Coordinator and Lead Author*

**Antony Froggatt**
Independent Consultant, London, U.K.

**Steve Thomas**
Professor for Energy Policy, Greenwich University, U.K.

*Modeling and Graphic Design*
**Julie Hazemann**
Director of EnerWebWatch, Paris, France

*Editing*
**Lisa Mastny**
Worldwatch Institute, Washington, D.C., U.S.A.

**Paris, Berlin, Washington, April 2011**

**Commissioned by**
**Worldwatch Institute, Washington, D.C., U.S.A.**

with the support of
the Greens-EFA in the European Parliament

## About the Authors

**Mycle Schneider** is an independent international consultant on energy and nuclear policy based in Paris. He founded the Energy Information Agency WISE-Paris in 1983 and directed it until 2003. Since 1997, he has provided information and consulting services to the Belgian Energy Minister, the French and German Environment Ministries, USAID, the International Atomic Energy Agency, Greenpeace, the International Physicians for the Prevention of Nuclear War, the Worldwide Fund for Nature, the European Commission, the European Parliament's Scientific and Technological Option Assessment Panel and its General Directorate for Research, the Oxford Research Group, and the French Institute for Radiation Protection and Nuclear Safety. Since 2004, Mycle has been in charge of the Environment and Energy Strategies lecture series for the International MSc in Project Management for Environmental and Energy Engineering Program at the French Ecole des Mines in Nantes. In 1997, along with Japan's Jinzaburo Takagi, he received the Right Livelihood Award, also known as the "Alternative Nobel Prize."

**Antony Froggatt** works as independent European energy consultant based in London. Since 1997, he has worked as a freelance researcher and writer on energy and nuclear policy issues in the EU and neighboring states. He has worked extensively on EU energy issues for European governments, the European Commission and Parliament, environmental NGOs, commercial bodies, and media. He has given evidence to inquiries and hearings in the parliaments of Austria, Germany, and the EU. He is a part time senior research fellow at the Royal Institute of International Affairs – Chatham House in London. Antony works intensively with environmental groups across Europe, particularly on energy markets and policy and helped to establish a network on energy efficiency. He is a regular speaker at conferences, universities, and training programs across the region. Prior to working freelance, Antony served for nine years as a nuclear campaigner and co-coordinator for Greenpeace International.

**Steve Thomas** is a professor of energy policy at the Public Services International Research Unit (PSIRU) of the University of Greenwich, where he has been senior researcher since 2001. He holds a BSc (honors) degree in Chemistry from Bristol University and has been working in energy policy analysis since 1976. His main research interests are reforms of energy industries, economics, and policy toward nuclear power, and corporate policies of energy industry companies. Recent clients include Public Services International, the European Federation of Public Service Unions, the Nonproliferation Policy Education Center (USA), Energywatch (UK), and Greenpeace International.

---


## Acknowledgments

*The authors wish to thank Amory B. Lovins, Rebecca Harms, and Chris Flavin for their support for this project. The project coordinator wishes to express his sincere gratitude to his co-authors for their invaluable contributions, creative thinking, and impeccable reliability. Thank you also to M.V. Ramana and Walt Patterson for their useful comments on a draft version of the report. Special thanks to Julie Hazemann who has not only contributed the fundamental database work but who has been throughout a permanent, rock-solid support under insupportable conditions. Finally, a big thanks to Lisa Mastny for her editing efforts under impossible time constraints.*


### Contacts


**Publisher**
Worldwatch Institute
www.worldwatch.org





**Authors**

| Mycle Schneider | Antony Froggatt | Steve Thomas |
|---|---|---|
| Phone: +33-1-69 83 23 79 | Ph: +44-20-79 23 04 12 | Ph: +44-208 331 9056 |
| Email: mycle@orange.fr | E: a.froggatt@btinternet.com | E: stephen.thomas@greenwich.ac.uk |

# Table of Contents



## Figures and Tables

# Foreword

Mycle Schneider, Antony Froggatt, and Steve Thomas have again performed a vital public service by preparing this uniquely independent, thorough, and timely assessment of the global status of nuclear power, both before and after the Fukushima disaster began to unfold on March 11, 2011.

From Beijing and London to Tokyo and Washington, energy bureaucracies have for decades been pervaded by nuclear enthusiasm. The past few years, for the first time in history, also saw most major governments led by advocates of nuclear power. The media are saturated with a skilled, intensive, and effective advocacy campaign by the nuclear industry and its powerful allies. With disinformation increasingly prevalent and wholly counterfactual accounts of nuclear power's status and competitive landscape widely believed by otherwise sensible people, this report's objective assessment is vital to informed discourse and prudent choice.

The facts disclosed here, stated correctly and cited carefully to reputable sources, unravel the dense curtain of myths surrounding this deeply troubled industry. Readers may be surprised to learn, for example, that every nuclear power plant under construction in the world was chosen by central planners: not one was a free-market purchase fairly competed against or compared with alternatives.

By contrast, renewable electricity generators rule the marketplace, providing half the world's new generating capacity in 2008–09. But while wind and solar power boom, nuclear and coal-plant orders wither. Their cost and risk dissuade investors. Any new U.S. nuclear plants are 100-percent subsidized and more, but even in the three pre-crash years starting in August 2005, with the strongest capital markets, political support, and public acceptance in history, they couldn't raise a penny of private capital (nor have they since) because they have no business case. Moreover, they have four daunting risks:

First, an accident can swiftly transform a multi-billion dollar generating asset into a larger cleanup liability. The Fukushima accident has just vaporized the balance sheet of the world's #4 power company, TEPCO. A 2007 earthquake had cost the company perhaps $20 billion; this one could cost it $100-plus billion. TEPCO is now broke and is becoming, in whatever form, a ward of the state. And with such an unforgiving technology, accidents anywhere are accidents everywhere. This report documents how events at Fukushima, even if they don't get worse, are sending widening shockwaves through the energy and financial communities, and undermining the industry's credibility.

Second, efficient use of electricity, which is already flattening industrialized countries' demand and slackening global demand, is getting ever bigger and cheaper. Integrative design is even turning diminishing returns into expanding returns, making big savings cheaper than small ones. Efficiency is rapidly spreading to developing countries and indeed becoming a core element of national strategy: "Negawatts" are China's top development priority.

Third, atrophied skills, overstretched supply chains, and sheer complexity keep nuclear capital costs soaring. The threefold cost overruns of the previous U.S. nuclear binge devastated utilities' balance sheets: only 41 percent of ordered plants were built and survive. In the past five years, the estimated capital cost for new reactors rose three- to eightfold, mainly because initial "variable-cost" estimates gave way to firm- or fixed-cost commercial proposals that were many-fold higher because the vendor bore some or all of the price risk. No country has demonstrated a nuclear learning curve. Even France's last plant was 3.5 times costlier and nearly twofold slower than its first.

Finally, innovation and mass production, not giant units, are making nuclear power's renewable competitors inexorably cheaper—wind turbines by one-fifth since 2007 (they now beat new nuclear costs by two- to threefold) and solar by half. In spring 2009, a standard crystalline-silicon photovoltaic (PV) module cost $4.20 per peak watt, today it is $1.70; its forward pricing is $1.35 for the end of 2011 and $1.00 for mid-2012. (The other half of today's utility-scale PV installations, the non-module “balance of system” cost, is also in the process of being halved.) No wonder “micropower”—CHP (cogeneration) plus renewables minus large hydropower—generated about 91 percent of the world’s new electricity in 2008.

In 2010, all renewables excluding large hydro received $151 billion of global private investment (nuclear got none) and surpassed nuclear power’s total global installed capacity. Within a few years, they will exceed its output. Just new solar power that is buildable sooner than one new reactor would outproduce and outcompete all 64 reactors that are currently under construction. The renewable revolution already happened—yet the nuclear industry still doesn’t even acknowledge renewables as a realistic competitor, claiming that wind and solar power’s variability disqualify these burgeoning sources as unreliable. Just the opposite is true: they actually improve energy security and reliability more than nuclear power ever could.

All power plants fail. When nuclear or coal plants fail—6–7 percent of the time without warning and another 4–7 percent predictably—a billion watts vanish in milliseconds, often for weeks or months. Physics makes suddenly stopped nuclear plants particularly hard to restart: when nine plunged from 100 percent to 0 percent output in the U.S. Northeast’s blackout of 2003, they were idled for days and took two weeks to restore fully.

Fortunately, utility engineers have cleverly designed the grid so all these intermittent (unpredictably failing) power stations back each other up. Variable renewables can do the same but fail more gracefully. Achieving equal or better reliability even with 80–90 percent variable renewables takes five steps: Diversify wind and solar by location (seeing different weather) and by type (responding differently); forecast them; add other renewables that are dispatchable at need (small hydro, geothermal, biomass/waste, solar-thermal-electric, etc); and integrate them with flexible demand and supply. Four German states’ 2010 electricity was thus 43–52 percent powered by wind. Denmark is one-fifth wind powered and has Europe’s most reliable electricity at its lowest pretax prices.

Just as computing no longer needs mainframes, electricity no longer needs giant power plants. A diverse portfolio of mass-produced generators networked in microgrids can be as resilient as the Internet, so the Pentagon prefers them. Onsite and local generation even bypass the 98–99 percent of power failures that originate *in* the grid. As shown in detail in the Rocky Mountain Institute’s *Reinventing Fire* (Chelsea Green, autumn 2011), nuclear power is neither economic nor necessary to eliminate U.S. use of oil and coal (and reduce natural gas use) by 2050, led by business for profit, without carbon pricing or new national laws.

Yet it is now China, not America or Europe, that leads the global revolution in renewable energy. China is now #1 in five renewable technologies and aims to be in all. Thanks to private enterprise, China passed its 2020 wind power target in 2010, and India has more wind power than nuclear power. China’s 2006 renewables (excluding large hydro) had seven times nuclear’s capacity and were growing sevenfold faster; by 2010 that gap had widened despite the world’s most ambitious nuclear program.

The facts documented in this report make crystal clear that long before Fukushima, nuclear power was dying of an incurable attack of market forces. The industry had long ago created the mythology that only the 1979 Three Mile Island accident halted previous U.S. nuclear orders; in fact, they’d ceased more than a year earlier. No doubt the next myth will be that Fukushima halted nuclear power’s renaissance. Readers of this report will find that the renaissance itself had already fizzled over the several preceding years.

Nuclear power’s latest failure to thrive despite the most lavish and ever-increasing taxpayer support is actually an unequivocal blessing. For four decades we have known that modern energy systems could threaten civilization in two ways—climate change and nuclear proliferation—so we must reject both fates, not trade one for the other. Yet new nuclear build worsens both problems. It provides do-it-yourself bomb kits in civilian disguise. It reduces and retards climate protection by saving 2–10 times less carbon per dollar—and 20–40 times more slowly—than the superior low- and no-carbon competitors that are soundly beating it in the global marketplace. But taking economics seriously and buying those cheaper options instead can protect climate, peace, and profits.

Since new nuclear build is uneconomic and unnecessary, we needn't debate whether it's also proliferative and dangerous. In a world of fallible and malicious people and imperfect institutions, it's actually both. But even after 60 years of immense subsidies and devoted effort, nuclear power still can't clear the first two hurdles: competitiveness and need. End of story.

***Amory B. Lovins***
**Old Snowmass, Colorado, U.S.A.**
**April 17, 2011**

*Physicist Amory B. Lovins is Chairman and Chief Scientist of Rocky Mountain Institute (www.rmi.org) and an advisor to major firms and governments worldwide. This Foreword is adapted from an essay first published online by* The Economist *in April 2011.*

# Executive Summary

Four weeks after the beginning of the nuclear crisis on Japan's east coast, the situation at the country's Fukushima Daiichi power plant remains far from stabilized. The damaged reactors continue to leak radioactivity, and although it is impossible to predict the overall impact of the disaster, the consequences for the international nuclear industry will be devastating.

The present *World Nuclear Industry Status Report 2010–2011* was to be published at the occasion of the 25th anniversary of the Chernobyl disaster in Ukraine. The report provides the reader with the basic quantitative and qualitative facts about nuclear power plants in operation, under construction, and in planning phases throughout the world. It assesses the economic performance of past and current nuclear projects and compares their development to that of leading renewable energy sources. An extensive annex provides a country-by-country analysis of nuclear programs around the world.

The report also includes the first published overview of reactions to the catastrophe in Japan. But developments even prior to March 11, when the Fukushima crisis began, illustrate that the international nuclear industry has been unable to stop the slow decline of nuclear energy. Not enough new units are coming online, and the world's reactor fleet is aging quickly. Moreover, it is now evident that nuclear power development cannot keep up with the pace of its renewable energy competitors.

Annual renewables capacity additions have been outpacing nuclear start-ups for 15 years. In the United States, the share of renewables in new capacity additions skyrocketed from 2 percent in 2004 to 55 percent in 2009, with no new nuclear coming on line. In 2010, for the first time, worldwide cumulated installed capacity of wind turbines (193 gigawatts[a]), biomass and waste-to-energy plants (65 GW), and solar power (43 GW) reached 381 GW, outpacing the installed nuclear capacity of 375 GW prior to the Fukushima disaster. Total investment in renewable energy technologies has been estimated at $243 billion in 2010.

As of April 1, 2011, there were 437 nuclear reactors operating in the world—seven fewer than in 2002. The International Atomic Energy Agency (IAEA) currently lists 64 reactors as "under construction" in 14 countries. By comparison, at the peak of the industry's growth phase in 1979, there were 233 reactors being built concurrently. In 2008, for the first time since the beginning of the nuclear age, no new unit was started up, while two were added in 2009, five in 2010, and two in the first three months of 2011[b]. During the same time period, 11 reactors were shut down.[c]

In the European Union, as of April 1, 2011, there were 143 reactors officially operational[d], down from a historical maximum of 177 units in 1989.

In 2009[e], nuclear power plants generated 2,558 terawatt-hours (TWh) of electricity, about 2 percent less than the previous year. The industry's lobby organization the World Nuclear Association headlined "another drop in nuclear generation"—the fourth year in a row. The role of nuclear power is declining steadily and now accounts for about 13 percent of the world's electricity generation and 5.5 percent of the commercial primary energy.

---

[a] 1 gigawatt = 1,000 megawatts

[b] This figure includes the Chasnupp-2 reactor that was connected to the Pakistani grid on 14 March 2011, which did not receive any media coverage.

[c] Including six Fukushima reactors.

[d] Including seven units that the German government ordered to be shut down after the Fukushima crisis started and that are unlikely to come back on line after a three-month moratorium expires.

[e] The 2010 figure is not yet available.

In 2010, 16 of the 30 countries operating nuclear power plants (one fewer than in previous years due to the closure of the last reactor in Lithuania) maintained their nuclear share in electricity generation, while nine decreased their share and five increased their share.[a]

The average age of the world's operating nuclear power plants is 26 years. Some nuclear utilities envisage reactor lifetimes of 40 years or more. Considering that the average age of the 130 units that already have been closed is about 22 years, the projected doubling of the operational lifetime appears rather optimistic. One obvious effect of the Fukushima disaster is that operating age will be looked at in a quite different manner, as illustrated by the German government's decision to suspend operation of all reactors over 30 years old immediately following the start of the crisis.

One scenario in this report assumes an average lifetime of 40 years for all operating and in-construction reactors in order to estimate how many plants would be shut down year by year. This makes possible an evaluation of the minimum number of plants that would have to come on line over the coming decades to maintain the same number of operating plants. In addition to the units under construction, leading to a capacity increase of 5 GW (less than the seven German units currently off line), 18 additional reactors would have to be finished and started up prior to 2015. This corresponds to one new grid connection every three months, with an additional 191 units (175 GW) over the following decade—one every 19 days. This situation has changed little from previous years.

Achievement of this 2015 target is simply impossible given existing constraints on the manufacturing of key reactor components—aside from any post-Fukushima effect. As a result, even if the installed capacity level could be maintained, the number of operating reactors will decline over the coming years unless lifetime extensions beyond 40 years become the widespread standard. The scenario of generalized lifetime extensions is getting less likely after Fukushima, as many questions regarding safety upgrades, maintenance costs, and other issues would need to be more carefully addressed.

With extremely long lead times of 10 years and more, it will be practically impossible to maintain, let alone increase, the number of operating nuclear power plants over the next 20 years. The flagship EPR project at Olkiluoto in Finland, managed by the largest nuclear builder in the world, AREVA NP, has turned into a financial fiasco. The project is four years behind schedule and at least 90 percent over budget, reaching a total cost estimate of €5.7 billion ($8.3 billion) or close to €3,500 ($5,000) per kilowatt.[b]

The dramatic post-Fukushima situation adds to the international economic crisis and is exacerbating many of the problems that proponents of nuclear energy are facing. If there was no obvious sign that the international nuclear industry could eventually turn empirically evident downward trend into a promising future, the Fukushima disaster is likely to accelerate the decline.

[a] Based on the most recent figures available.

[b] In this report, conversions from Euros to U.S. Dollars were performed on 22 April 2011 using the exchange rate of 1 Euro = 1.5 U.S. Dollars.

# Introduction

*"We can't afford to have the Chinese have an accident,*
*something like Chernobyl, which would really set you way back."*

Charles Newstead
Senior Advisor, U.S. Department of State
Brookings Institution, 13 October 2010

The accident came where few expected it to happen. On 11 March 2011, triggered by the largest earthquake in the nation's history, a nuclear catastrophe of yet unknown proportions started unfolding in the world's preeminent high-tech country: Japan. "At [the Fukushima Daiichi plant], four reactors have been out of control for weeks—casting doubt on whether even an advanced economy can master nuclear safety.... We believe the Fukushima accident was the most serious ever for the credibility of nuclear power." This is how analysts at Swiss-based investment bank UBS summarized the likely global impact of the tragic developments on Japan's east coast in a report dated 4 April 2011.[1a]

Television viewers around the world witnessed massive hydrogen explosions that devastated reactor buildings and spent fuel pools. The result was large-scale fuel damage, partial meltdown in at least three reactors, and broken fuel elements in what remains of unit four's spent fuel pool. Helpless operators tried desperately to cool reactors and spent fuel with fire hoses and cement trucks, but short-term responses turned into long-term nightmares. The injection of large amounts of seawater into the reactor cores led to the accumulation of large volumes of salt at the bottom of the pressure vessels. The salt crystallizes on hot surfaces to form a hard, insulating layer that prevents the fuel from being cooled. Salt crystals will likely also hinder the operation of valves.

At the same time, the huge quantities of water that were injected and sprayed onto the reactors—an estimated 100 cubic meters per hour—became severely contaminated and must be collected somehow. The problem was so acute that the operator decided to discharge water with "lower" contamination levels into the sea to provide space for more highly affected water. In an unprecedented confrontation broadcasted by Japanese television, the Chairman of the National Fisheries Union told the chairman of Fukushima owner TEPCO: "You've trampled on the nation-wide efforts of fishery operators.... Despite our strong demand to cease the flow of contaminated water into the ocean as soon as possible, just a few hours later [more] water was dumped without consulting us—you pushed through. We were really ignored. We wonder if you had ever heard us. This is an affront to us and truly an unforgivable act."[2]

After four weeks of uncertainty and a constantly worsening outlook, the nerves of some of Japan's seemingly endlessly patient people are raw. Tens of thousands of evacuees are waiting for clear information about when—if ever—they can return home. Dogs and cows that were left behind wander along empty roads. Measurements in schools as far as 40 kilometers from the Fukushima plant show extremely high levels of radiation well outside the 20-kilometer (later 30-kilometer) evacuation zone. People don't know what they can safely eat or drink.

Although the accident scenario is different and the people speak a different language, much of the Japanese drama calls to minds an event that took place on the European continent exactly 25 years prior. On 26 April 1986, a hydrogen explosion followed by a power excursion (a massive liberation of energy)[b] entirely destroyed unit four of the nuclear power plant in Chernobyl, Ukraine, then part of the Soviet Union. For over a week, the burst-open reactor was burning, sending large amounts of radioactivity into the sky and across Europe.

---

[a] Endnotes are grouped by section and begin on page 75.

[b] It has been estimated that the reactor reached about 100 times its nominal capacity within four seconds.

Twenty-five years after what former Soviet President Mikhail Gorbachev now calls "one of the worst manmade disasters of the twentieth century," the consequences remain visible. The cost to human health, the environment, and the economies of the three former Soviet republics of Ukraine, Belarus, and Russia—the regions that experienced the greatest exposure from Chernobyl—has left deep scars.[3]

Chernobyl is still present in Western Europe, too. In October 2009, the Council of Ministers of the European Union decided to extend by at least 10 years the monitoring system for potentially contaminated food. In the United Kingdom, more than 150,000 sheep that were raised on contaminated pastures remain under slaughter restriction; they have to be moved to "clean" fields for a few months until the radioactivity levels in the meat drop below legal limits. In 2006, 18 Norwegian municipalities newly restricted the raising of sheep after the meat was found to be contaminated at seven times above EU limits. And in Germany, radioactive mushrooms still lead to the ban of contaminated game meat like wild boar.

Yet for the most part, Chernobyl and its horrific consequences appear to be forgotten, downplayed, and ignored. In December 2010, the oldest Ukrainian reactor, Rovno-1, was granted a 20-year lifetime extension, and by 2030 the country projects a doubling of the installed nuclear capacity. Belarus plans to enter into an agreement with Russia to build its first nuclear power plant.[4] And Russia has officially 11 reactors under construction, the second largest number in the world behind China.

Prior to the events in Japan, it appeared that the international nuclear industry had successfully overcome the "Chernobyl syndrome." According to the International Atomic Energy Agency (IAEA), "some 60 countries have turned to the IAEA for guidance" as they consider introducing nuclear power. One IAEA expert estimates that "probably 11 or 12 countries...are actively developing the infrastructure for a nuclear power program."[5]

Today, there are more units under construction worldwide now than in any year since 1988 (except for 2010), and 13 more than at the beginning of 2010. Fifteen new building sites were initiated in 2010—more than in any year since the pre-Chernobyl year of 1985, which saw 20 construction starts.

Is this, finally, what the industry has been calling for a decade the "nuclear renaissance"? Or is the phenomenon limited to only some countries, with China alone counting for 60 percent of the new projects?[6] How do new grid connections compare with plant life extensions? And what are the latest economic trends of the nuclear option? These are questions that the *World Nuclear Industry Status Report* analyzed in the previous (2009) edition published by the German government and analyzes in the present version.[7]

The first *World Nuclear Industry Status Report* was released in 1992—nearly 20 years ago—by the Worldwatch Institute, Greenpeace International, and WISE-Paris. Today—the year 2011—is a timely undertaking to assess where the industry is standing. The 25th anniversary of Chernobyl—"a horrible event" (in the words of Mikhail Gorbachev)[8] that disrupted the revival of an industry that had barely overcome the shock of the Three-Mile-Island meltdown in 1979—comes just one month after the start of Japan's Fukushima disaster. In addition to describing the state of the industry today, the report provides the first country-by-country assessment of the effects of Fukushima on the industry and an outlook that compares nuclear power to its main competitor: decentralized renewable energy.

# General Overview Worldwide

*"Another Drop in Nuclear Generation."*

World Nuclear News
Headline on 5 May 2010[9]

As of 2010, a total of 30 countries were operating nuclear fission reactors for energy purposes—one fewer than in previous years. Lithuania became the third country ever to revert to "non-nuclear energy" status, following Italy, which abandoned nuclear power after Chernobyl, and Kazakhstan, which shut down its only reactor in 1999.

Nuclear power plants generated 2,558 Terawatt-hours (TWh or billion kilowatt-hours) of electricity in 2009.[10a] World nuclear production fell for the third year in a row, generating 103 TWh (nearly 4 percent) less power than in 2006. This decline corresponds to more than the domestic annual nuclear generation in four-fifths of the nuclear power countries. The gap between the public's perception of an *increasing* role for nuclear power and reality seems to be widening.

The main reasons for nuclear's poor global performance are linked to technical problems with the reactor fleets of larger nuclear players, with the small producers remaining more or less stable. Between 2008 and 2009, nuclear generation declined in four of the "big six" countries—France, Germany, South Korea, and the United States. In Japan, the industry had been slowly recovering from the 2007 Kashiwasaki earthquake, and in Russia, production remained stable. These six countries generate nearly three-quarters (73 percent in 2009) of the world's nuclear electricity, a share that increased in 2009. In 2010, the nuclear role of four of the "big six" remained stable while two (Germany and South Korea) declined.

Many countries are now past their nuclear peak. The three phase-out countries (Italy, Kazakhstan, and Lithuania) and Armenia generated their historical maximum of nuclear electricity in the 1980s. Several other countries had their nuclear power generation peak in the 1990s, among them Belgium, Canada, Japan, and the UK). And seven additional countries peaked between 2001 and 2005: Bulgaria, France, Germany, India, South Africa, Spain, and Sweden.

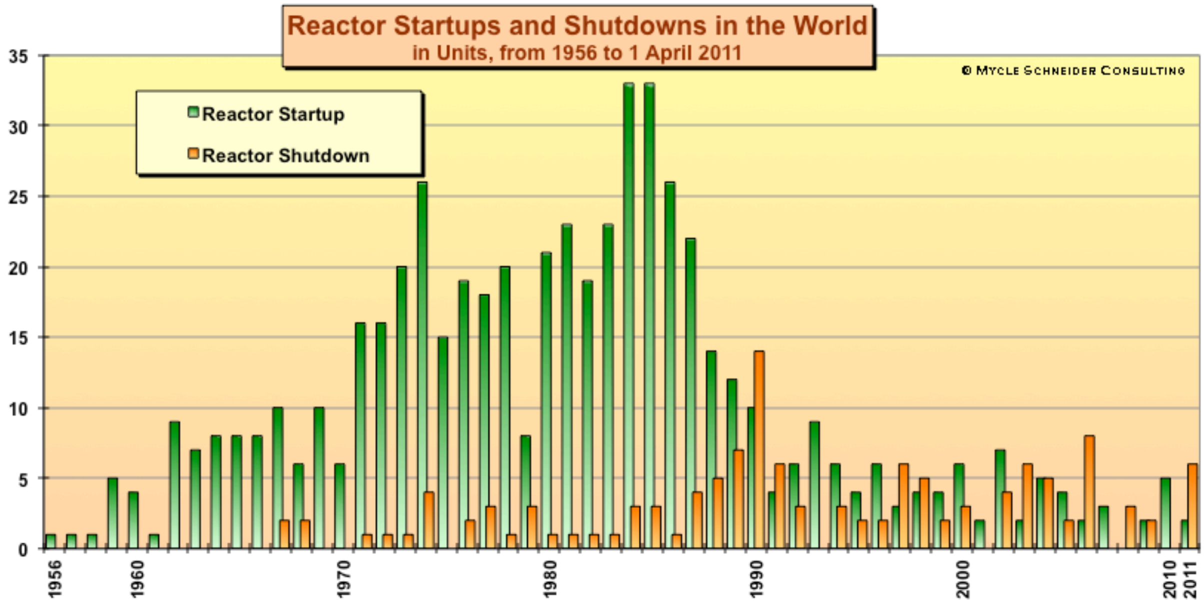
Among the countries with a remarkably steady increase in nuclear generation are China, the Czech Republic, Romania, Russia and the United States (except for 2009 when production dropped by almost 10 TWh). Considering the size of the U.S. program, the rather continuous improvement of the load factor is impressive (88 percent in 2009).[11] Russia is also generally on an upward trend (78.3 percent), and South Korea is fluctuating at a very high level (90.3 percent). France (at a 70.6 percent load factor), Japan (66.2 percent), and Germany (69.5 percent), which are already on the lower end of the performance indicator, for varying reasons, have exhibited a further downward trend over the past few years.[12]

## Overview of Operation, Power Generation, Age Distribution

There have been two major waves of grid connections since the beginning of the commercial nuclear age in the mid-1950s.[13] (See Figure 1.) A first wave peaked in 1974, with 26 reactor startups. The second wave occurred in 1984 and 1985, the years preceding the 1986 Chernobyl accident, reaching the historical record of 33 grid connections in each year. By the end of the 1980s, the uninterrupted net increase of operating units had ceased, and in 1990 for the first time the number of reactor shutdowns outweighed the number of startups.

[a] The 2010 figure is not available yet.

**Figure 1. Nuclear Power Reactor Grid Connections and Shutdowns, 1956–2011**

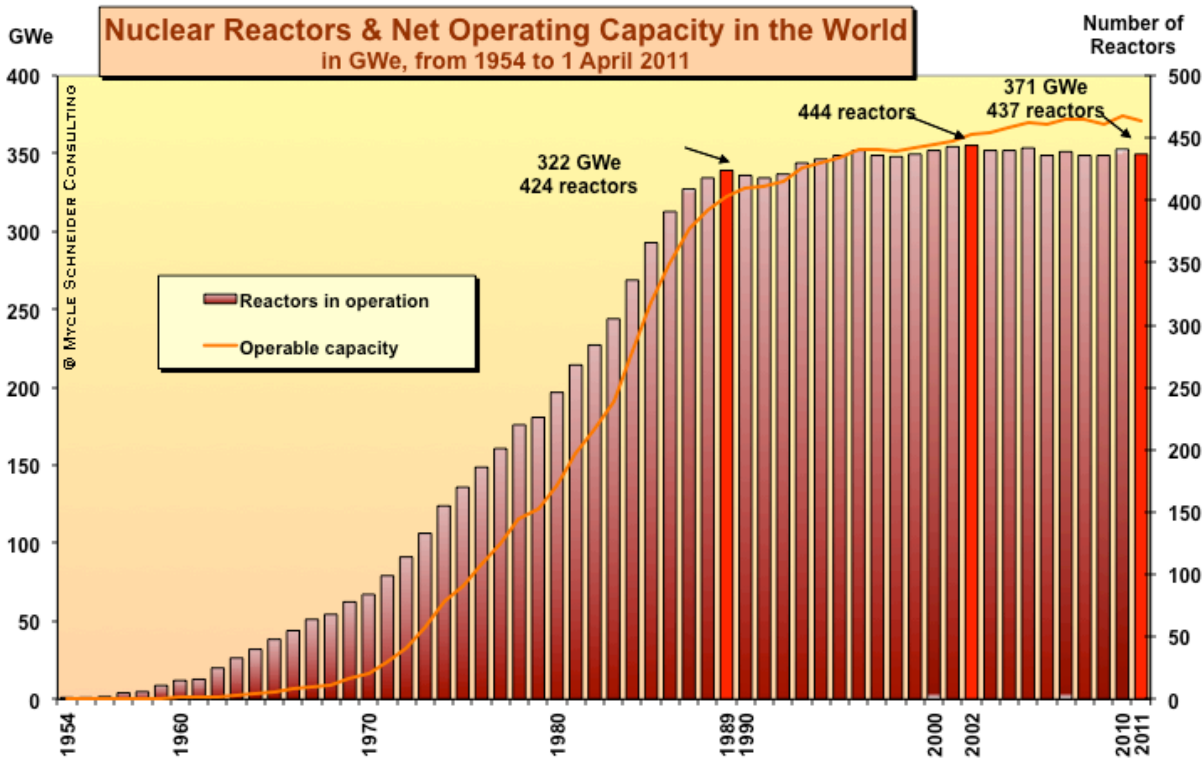



*Source: IAEA-PRIS, MSC, 2011*

As of April 1, 2011, a total of 437 nuclear reactors were operating in 30 countries, down seven from the historical maximum of 444 in 2002. Since then, 25 units were started up and 32 were disconnected from the grid, including six units at the Fukushima plant in Japan. These are very conservative numbers since it is unlikely that the seven units that have been "provisionally" shut down in Germany following the Fukushima events will ever start up again.

The current world reactor fleet has a total nominal capacity of about 370 gigawatts (GW or thousand megawatts).[14] (See Figure 2 and Annex 2 for details.)

**Figure 2. World Nuclear Reactor Fleet, 1954–2011**




*Source: IAEA-PRIS, MSC, 2011*

The world installed nuclear capacity has decreased three times since the beginning of the commercial application of nuclear fission—in 1998, 2008, and 2009; in 2010, it increased by 5.5 GW. Despite seven fewer units operating in 2011 compared to 2002, the capacity is still about 8 GW higher. This is a combined effect of larger units replacing smaller ones and, mainly, technical alterations at existing plants, a process known as "uprating." At least 1.8 GW of the capacity increase in 2010 is due to uprating.

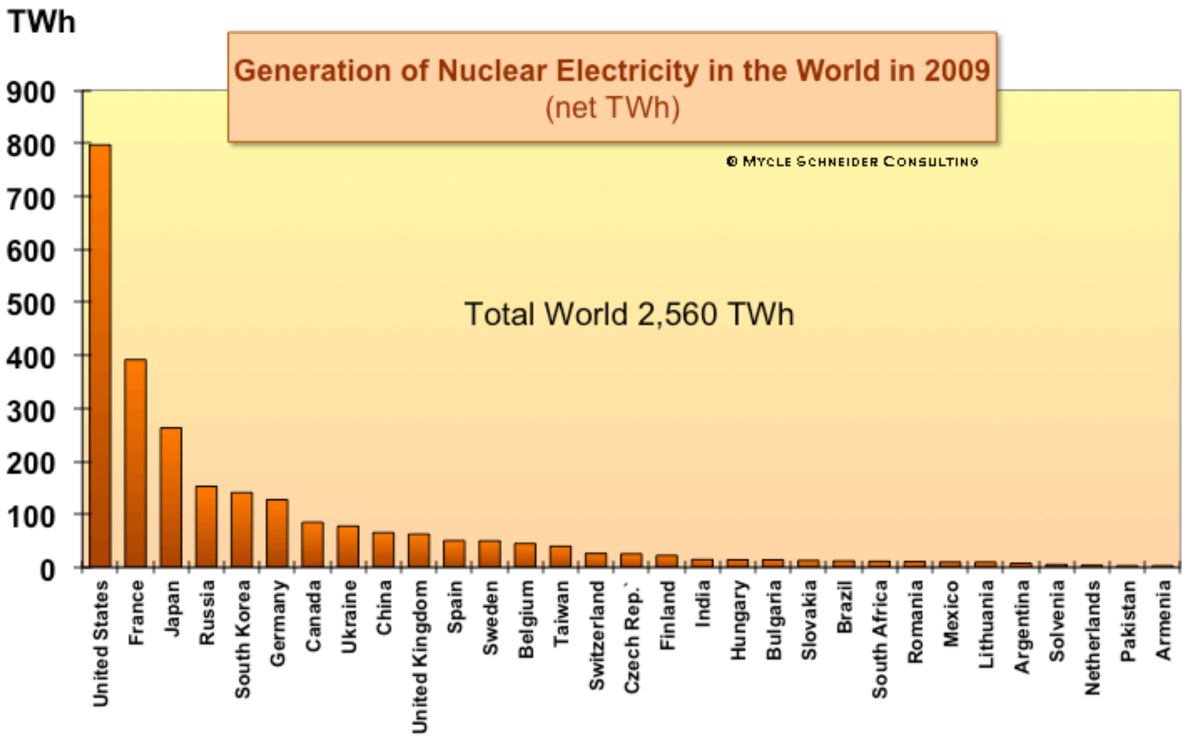
In the United States, the Nuclear Regulatory Commission (NRC) has approved 135 uprates since 1977. These included, in 2009–10, 10 minor uprates between 1.4 and 1.6 percent and five "extended uprates" of 15–20 percent. The cumulative additional approved uprates in the United States alone total 5.8 GW. Most of these already have been implemented, and applications for an additional 4.4 GW in increases at 13 units are pending.[15] A similar trend of uprates and lifetime extensions of existing reactors can be seen in Europe. It is obvious that the main incentive for lifetime extensions is their considerable economic advantage over new-build.

The capacity of the global nuclear fleet increased by about 3 GW annually between 2000 and 2004, much of it through uprating. Between 2004 and 2007, however, this dropped to 2 GW annually, and in 2008 and 2009 uprates were offset by plant closures, resulting in net declines in world nuclear capacity of about 650 MW and 860 MW, respectively.

The use of nuclear energy has been limited to a small number of countries, with only 31 countries, or 16 percent of the 192 members of the United Nations, operating nuclear power plants in 2009.[16] (See Figure 3.) One country, Lithuania, shut down its last reactor in 2009, so that currently only 30 countries operate nuclear power plants. Half of the world's nuclear countries are located in the European Union (EU), and they account for nearly half of the world's nuclear production. France alone generates close to half of the EU's nuclear production.

As previously noted, there was no growth in nuclear electricity generation in 2009. The 2,558 TWh of nuclear energy produced corresponded to about 13 percent of the world's commercial electricity.

**Figure 3. Nuclear Power Generation by Country, 2009**

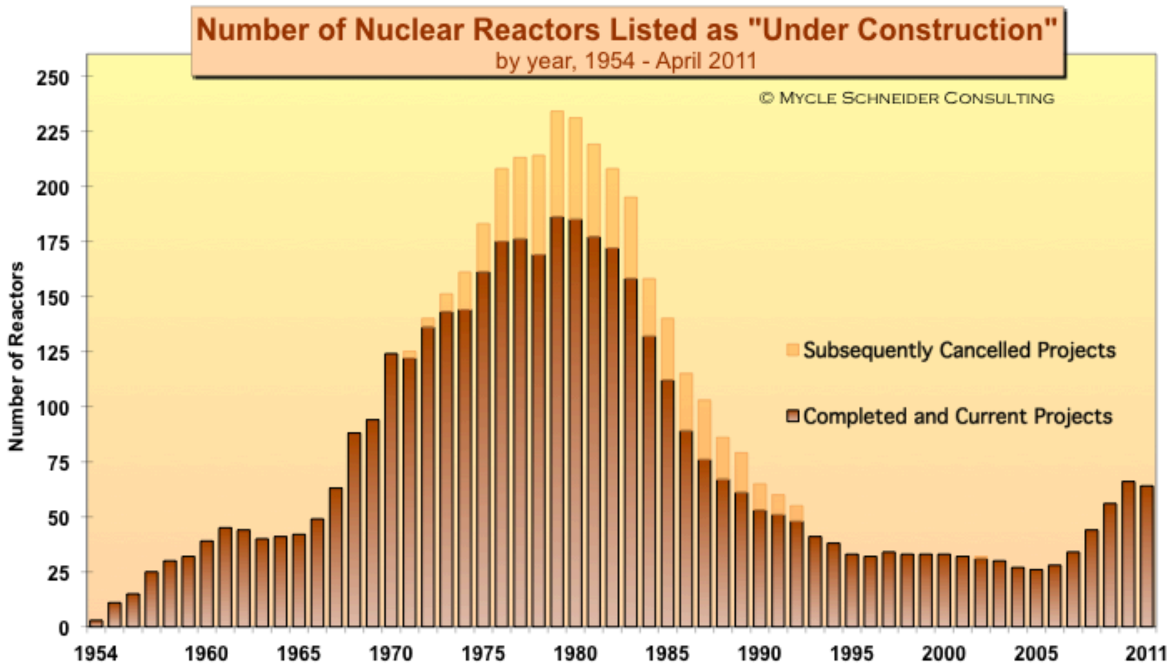



*Source: IAEA-PRIS, MSC, 2011*

## Overview of Current New Build

Currently, 14 countries are building nuclear power plants, and most of the sites are accumulating substantial and costly delays. As of April 1, 2011, the IAEA listed 64 reactors as "under construction," nine more than at the end of 2009. This compares with 120 units under construction at the end of 1987, and a peak of 233 such units—totaling more than 200 GW—in 1979.[17] (See Figure 4.) The year 2004, with 26 units under construction, marked a record low for construction since the beginning of the nuclear age in the 1950s.

**Figure 4. Number of Nuclear Reactors under Construction**




*Source: IAEA-PRIS, MSC 2011*

The total capacity of units now under construction is about 62.5 GW, with an average unit size of around 980 MW. (See Annex 3 for details.) A closer look at currently listed projects illustrates the level of uncertainty associated with reactor building:

- Twelve reactors have been listed as "under construction" for more than 20 years. The U.S. Watts Bar-2 project in Tennessee holds the record, with an original construction start in December 1972 (subsequently frozen), followed by the Iranian Bushehr plant, which was originally started by German company Siemens in May 1975 and is now slated to be finished by the Russian nuclear industry. Other long-term construction projects include three Russian units, the two Belene units in Bulgaria, two Mochovce units in Slovakia, and two Khmelnitski units in Ukraine. The construction of the Argentinian Atucha-2 reactor started 30 years ago. In addition, two Taiwanese units at Lungmen have been listed for 10 years.
- Thirty-five projects do not have an official (IAEA) planned start-up date, including six of the 11 Russian projects, the two Bulgarian reactors, and 24 of the 27 Chinese units under construction.
- Many of the units listed by the IAEA as "under construction" have encountered construction delays, most of them significant. The remaining units were started within the last five years and have not reached projected start-up dates yet. This makes it difficult or impossible to assess whether they are running on schedule.

- Nearly three-quarters (47) of the units under construction are located in just four countries: China, India, Russia, and South Korea. None of these countries has historically been very transparent or reliable about information on the status of their construction sites.

The geographical distribution of nuclear power plant projects is concentrated in Asia and Eastern Europe, extending a trend from earlier years. Between 2009 and April 1, 2011, a total of nine units were started up, all in these two regions.

Lead times for nuclear plants include not only construction times but also long-term planning, lengthy licensing procedures in most countries, complex financing negotiations, and site preparation. In most cases the grid system also has to be upgraded—often using new high-voltage power lines, which bring their own planning and licensing difficulties. In some cases, public opposition is significantly higher for the long-distance power lines that move the electricity than for the nuclear generating station itself. Projected completion times should be viewed skeptically, and past nuclear planning estimates have rarely turned out to be accurate.

Past experience shows that simply having an order for a reactor, or even having a nuclear plant at an advanced stage of construction, is no guarantee for grid connection and power supply. French Atomic Energy Commission (CEA) statistics on "cancelled orders" through 2002 indicate 253 cancelled orders in 31 countries, many of them at an advanced construction stage. (See also Figure 4.) The United States alone accounts for 138 of these cancellations.[18] Many U.S. utilities suffered grave financial harm because of reactor-building projects.

In the absence of any significant new build *and* grid connection over many years, the average age (since grid connection) of operating nuclear power plants has been increasing steadily and now stands at about 26 years.[a] Some nuclear utilities envisage average reactor lifetimes of beyond 40 years and even up to 60 years. The OECD's *World Energy Outlook 2010* recently gave a timeframe of 45–55 years, up five years from the 2008 edition of the report.

In the United States, reactors are usually licensed to operate for a period of 40 years. Nuclear operators can request a license renewal for an additional 20 years from the Nuclear Regulatory Commission. More than half of operating U.S. units have received this extension. Many other countries, however, have no time limitations to operating licenses. In France, where the country's first operating PWR started up in 1977, reactors must undergo an in-depth inspection and testing every decade. The French Nuclear Safety Authority (ASN) evaluates on a reactor-by-reactor basis whether a unit can operate for more than 30 years. At this point, ASN considers the issue of lifetimes beyond 40 years to be irrelevant, although the French utility EDF has clearly stated that, for economic reasons, it plans to prioritize lifetime extension over massive new build.

In assessing the likelihood of reactors being able to operate for up to 60 years, it is useful to compare the age distribution of reactors that are currently operating with those that have already shut down.[19] (See Figures 5 and 6.) At present, 12 of the world's operating reactors have exceeded the 40-year mark.[b] As the age pyramid illustrates, that number will rapidly increase over the next few years. Nine additional units have reached age 40 in 2011, while a total of 165 units have reached age 30 or more.

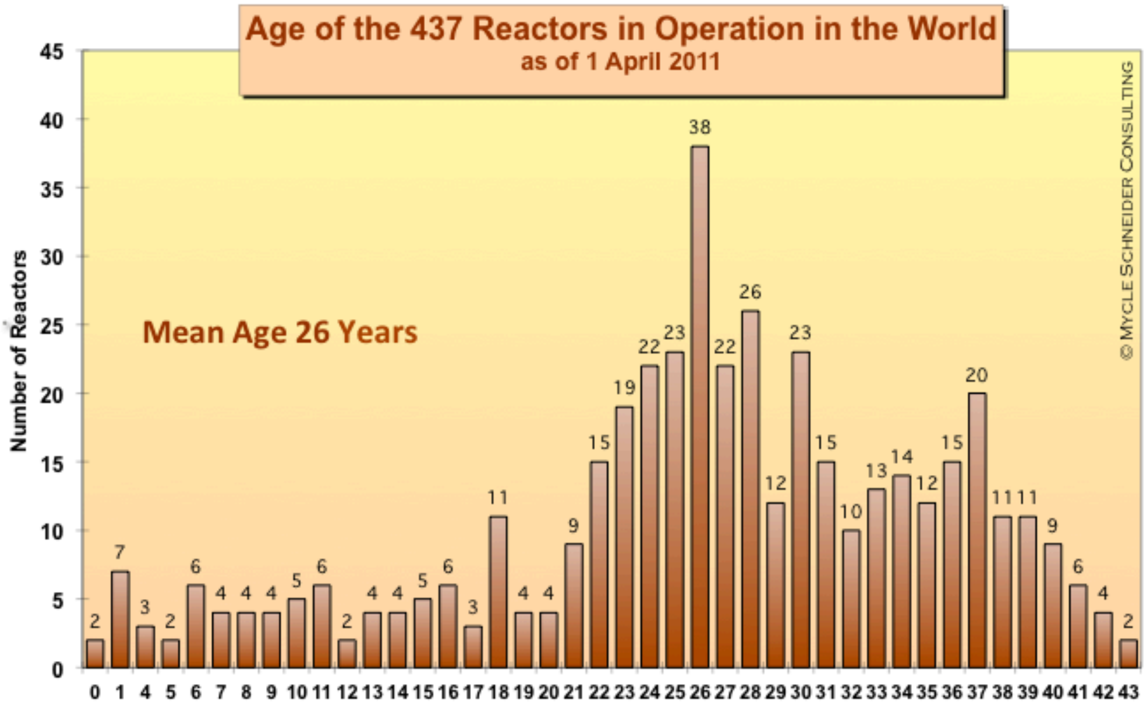
The age structure of the 130 units already shut down confirms the picture. In total, 32 of these units operated for 30 years or more; and within that subset, 16 reactors operated for 40 years or more. (See Figure 6.) The majority of these were Magnox reactors located in the U.K., most of which had been used to generate weapons-grade plutonium. These were all small reactors (50–225 MW) that had operated with very low burn-up fuel, and therefore are not comparable to large 900 MW or 1,300 MW commercial reactors that use high burn-up fuel that generates significantly more stress on materials.

[a] Here, reactor age is calculated from grid connection to final disconnection from the grid. In this report, "startup" is synonymous with grid connection and "shutdown" with withdrawal from the grid.

[b] We count the age starting with grid connection, and figures are rounded by half years.

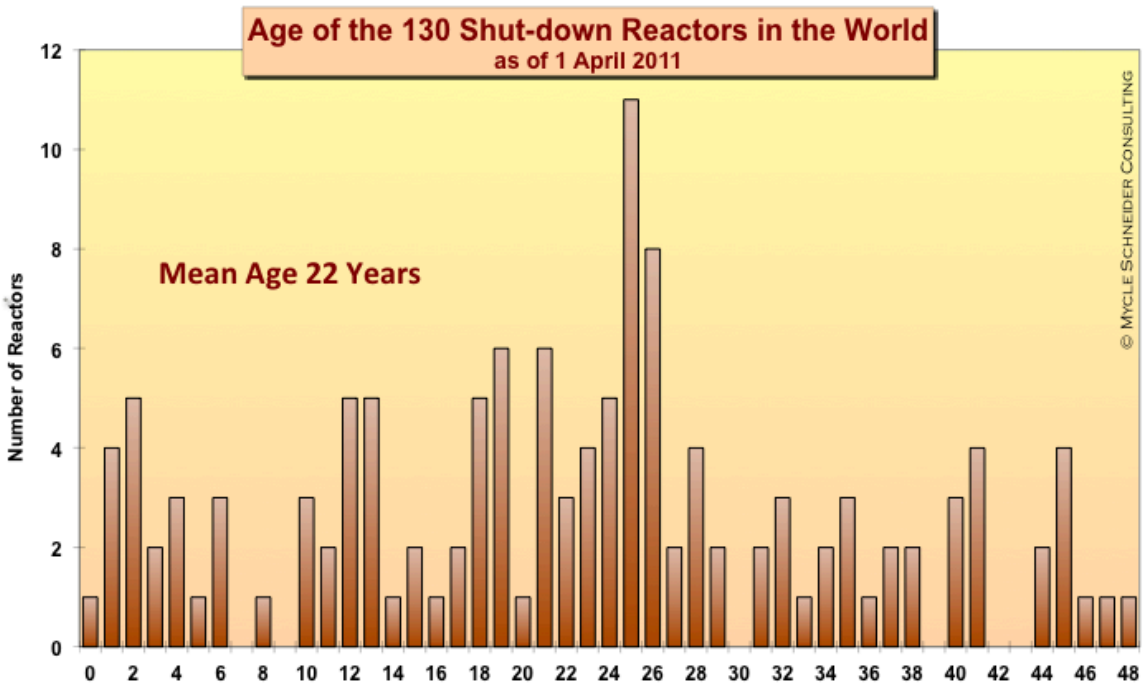
While many units of the first generation have operated for only a few years or less, even the operating experience beyond 30 years is very limited. And considering that the average age of the 130 units that have already shut down is about 22 years, plans to nearly double the operational lifetime of large numbers of units seem rather optimistic.

**Figure 5. Age Distribution of Operating Nuclear Reactors, 2011**




*Sources: IAEA-PRIS, MSC, 2011*

**Figure 6. Age Distribution of Shutdown Nuclear Reactors, 2011**

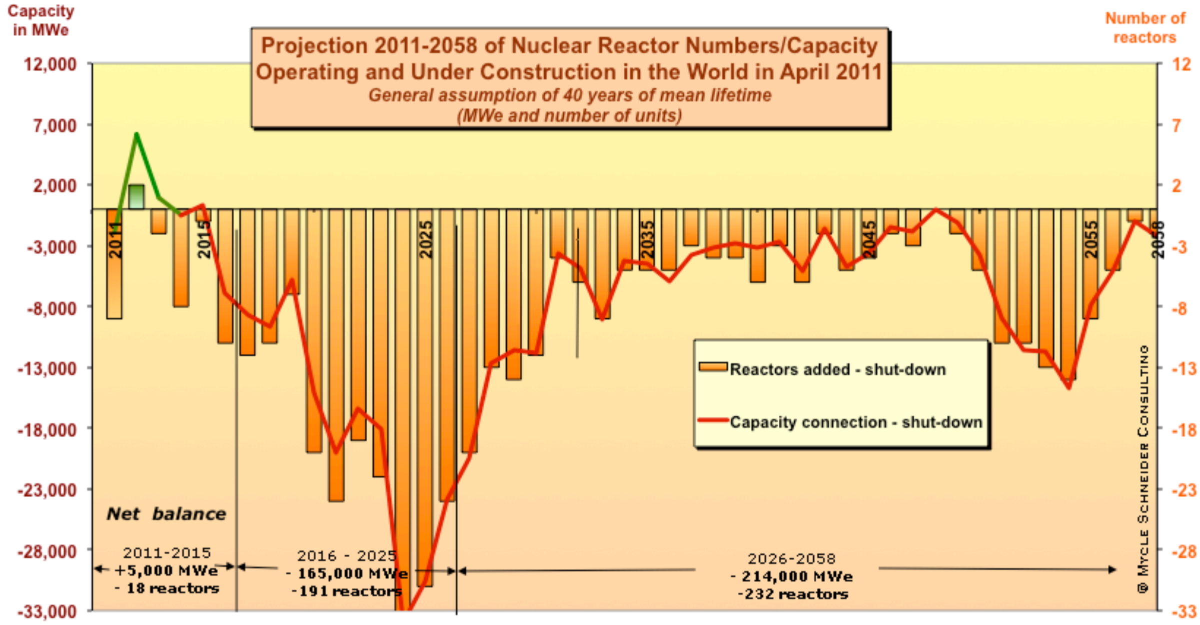



*Sources: IAEA-PRIS, MSC, 2011*

After the Fukushima disaster, it is obvious that operating age will get a second look. The troubled Fukushima-I units (1 to 4) were initially connected to the grid between 1971 and 1974. The license for unit 1 was extended for another 10 years only in February 2011. Four days after the beginning of the drama in Japan, the German government ordered the shutdown (for a three-month period) of seven reactors that had started up before 1981. It is increasingly clear that the political climate in Germany makes a restart of these reactors highly unlikely. Other countries might follow in a less dramatic manner, but it is obvious that recent events are having an impact on previously assumed extended lifetimes.

For the purposes of capacity projections, we have still assumed an average lifetime of 40 years for operating reactors, with a few adjustments. To remain conservative, we have considered, for example, that all 17 German units will be operated according to the current German legislation with remaining lifetimes between 8 and 14 years.[20] Similarly, there are several individual cases where earlier shutdowns have been officially decided.[21] (See Figure 7.)

**Figure 7. The 40-Year Lifetime Projection**




*Sources: IAEA-PRIS, WNA, MSC 2011*

The lifetime projections make possible an evaluation of the number of plants that would have to come on line over the next decades to offset closures and maintain the same number of operating plants. Besides 56 units under construction as of April 1, 2011[a], and while capacity would increase by 5 GW (less than the seven German units currently off line), 18 additional reactors would have to be finished and started up prior to 2015. This corresponds to one new grid connection every three months, with an additional 191 units (175 GW) over the following 10-year period—one every 19 days. This situation has hardly changed from previous years

Achievement of the 2015 target is simply impossible given existing constraints on the fabrication of key reactor components—aside from any post-Fukushima effect. As a result, the number of reactors in operation will decline over the years to come (even if the installed capacity level could be maintained) unless lifetime extensions beyond 40 years become a widespread standard. The scenario of generalized lifetime extensions is getting even less likely after Fukushima, as many questions regarding safety upgrades, maintenance costs, and other issues would need to be much more carefully

[a] Under the present scenario, 8 of the 64 units currently listed as under construction will enter operation after 2015. Respective start-up dates have been compiled by MSC.

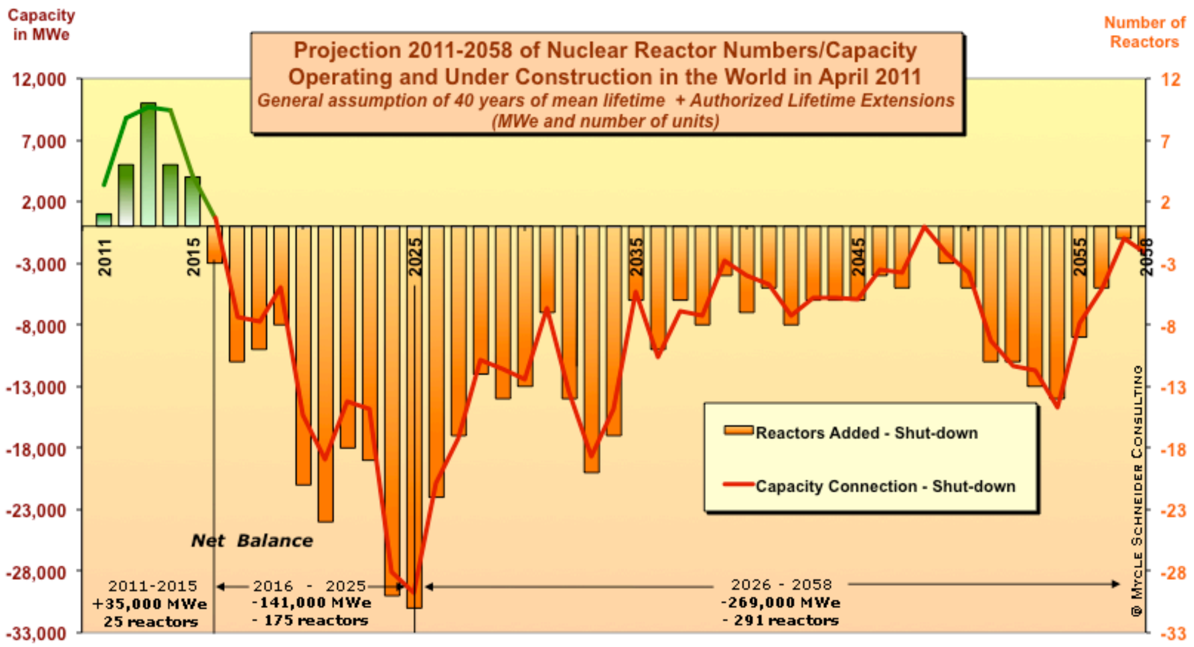
addressed.

Developments in Asia, and particularly in China, do not fundamentally change the global picture. Reported "official" figures for China's 2020 target for installed nuclear capacity have fluctuated between 40 GW and 120 GW.[22] However, the average construction time for the first 10 operating units was 6.3 years. At present, about 27 GW are under construction. While the acceleration of construction starts has been very impressive—with 18 new building sites initiated in 2009 and 2010—the prospects for significantly exceeding the original 2008 target of 40 GW for 2020 now seems unlikely.[a] China has reacted surprisingly rapidly and strongly to the Fukushima events by temporarily suspending approval of nuclear power projects, including those under development (see chapter on post-Fukushima developments). But even doubling the current capacity under construction would represent only half of the capacity of 145 units that reach age 40 around the world until 2020.

We have modeled a scenario in which all currently licensed lifetime extensions and license renewals (mainly in the United States) are maintained and all construction sites are completed. For all other units we have maintained a 40-year lifetime projection, unless a firm earlier shutdown date has been announced. The net number of operating reactors would increase by 25 units and installed capacity by 35 GW in 2015 before rapidly declining, starting the same year.[23] (See Figure 8.) The overall pattern of the decline would hardly be altered.[24] (See Figure 9.) The Japanese events are likely to accelerate the movement.

Renewal of the aging world nuclear fleet, or even extension of the operating power plants, encounters four major problems: a short-term manufacturing bottleneck, a dramatic shortage of skilled worker and managers, a skeptical financial sector, and public opinion. Other issues include widely fluctuating costs for raw materials, the aftermath of the Fukushima disaster, and the new dimension of the threat of nuclear terrorism. The world economic crisis has exacerbated these problems further, particularly in potential "newcomer" countries.

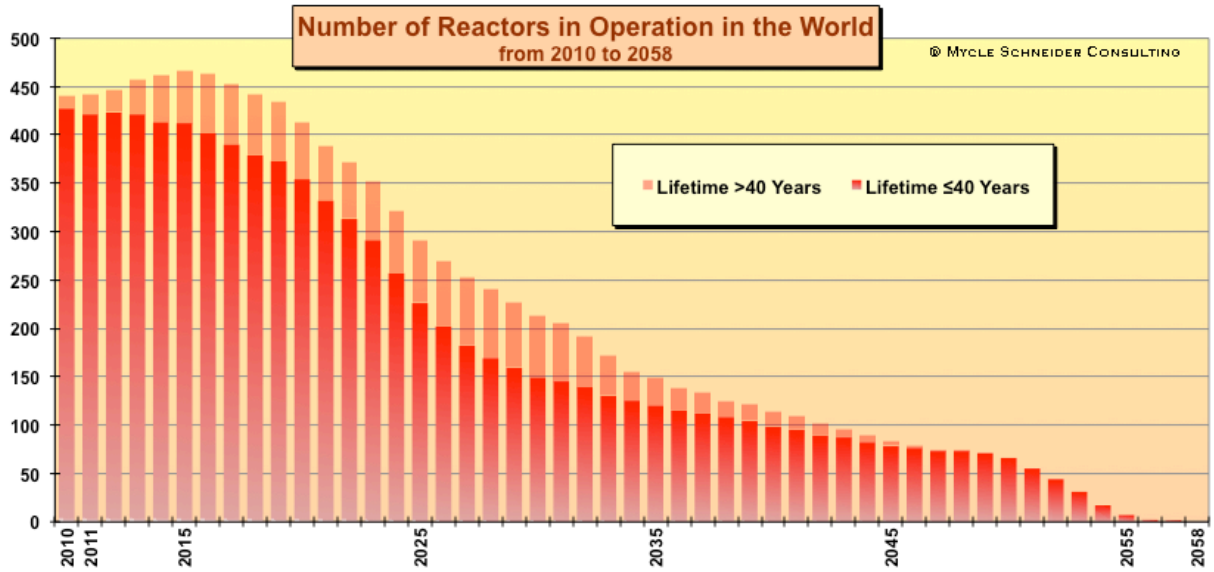
**Figure 8. The PLEX Projection**




*Sources: IAEA-PRIS, US-NRC, WNA, MSC 2011*

[a] A certain number of units that are currently in the planning or early construction phases are designs that have never been completed elsewhere, for example two EPRs and four AP1000s.

**Figure 9. Forty-Year Lifetime Projection versus PLEX Projection *(in numbers of reactors)***

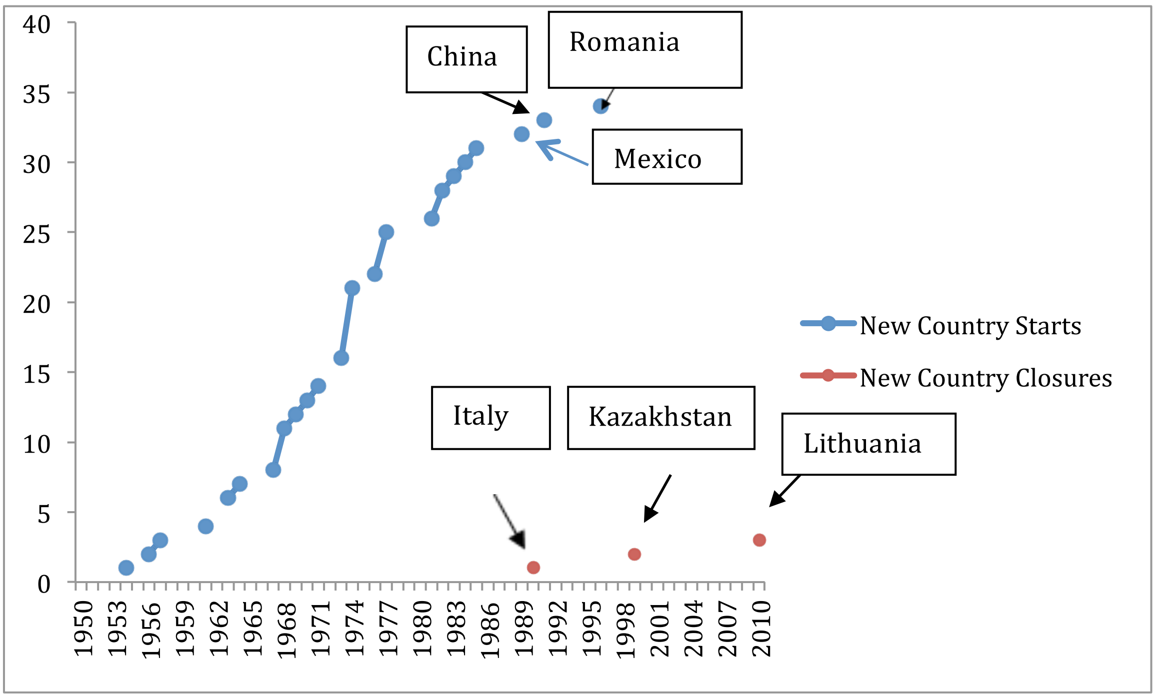



*Sources: IAEA-PRIS, US-NRC, MSC 2011*

## Potential Newcomer Countries

Not surprisingly, given the general slowdown in the growth of nuclear globally, the spread of nuclear power into new countries has all but stopped over the last 25 years. Since the accident at Chernobyl, only three countries—Mexico China, and Romania—have started new nuclear power programs, and three others—Italy, Kazakhstan, and Lithuania—have closed all their reactors.[a1] (See Figure 10.)

**Figure 10. Start-ups and Closures of National Nuclear Power Programs, 1950–2010**




*Sources: IAEA-PRIS 2011*

[a] Armenia closed its two reactors in 1989, following a referendum, but re-opened unit 2 in 1995.

In 2010, the IAEA announced that 65 countries had expressed an interest in, were considering, or were actively planning for nuclear power, up from an estimate of 51countries in 2008.[2] Twenty-one of these countries are in Asia and the Pacific, 21 in Africa, 12 in Europe (mostly Eastern Europe), and 11 in Latin America. A comparison of IAEA's assessments of potential newcomer countries in 2010 versus 2008 indicates that most of the rise in interest during this two-year period occurred in the least-certain category, where countries have made only supportive statements or participated in IAEA's technical cooperation programs, rather than expressing a specific plan to introduce nuclear power.[3] (See Table 1.)

**Table 1. Newcomer Countries in Nuclear Power, by Level of Interest, 2008 and 2010**

| Level of Interest | 2008 | 2010 | Probable Countries (2010) |
|---|---|---|---|
| | (number of countries) | | |
| Power plants under construction | 1 | 1 | Iran |
| Power plants ordered | — | 2 | Turkey, United Arab Emirates |
| Invitation to bid | 1 | — | |
| Declared intention to introduce nuclear power and preparing infrastructure | 4 | 10 | Belarus, Egypt, Indonesia, Italy, Kazakhstan, Jordan, Lithuania, Poland, Thailand, Vietnam |
| Active preparation, but no final decision | 7 | 7 | Bangladesh, Chile, Israel, Malaysia, Morocco, Nigeria, Saudi Arabia |
| Considering a nuclear power program | 14 | 14 | |
| Interested in nuclear issues | 16 | 31 | |
| **Total** | **43*** | **65** | |

* The IAEA uses two classifications, with 43 countries having expressed interest in the possible introduction of nuclear power through requests to the IAEA to participate in technical cooperation projects, while they also cite 51 countries having expressed an interest in the introduction of nuclear power.
*Source: See Endnote 3 for this section.*

Although several countries have in place relatively advanced plans to build nuclear reactors, numerous examples also exist of countries or companies that have planned, started, or even completed reactors that did not become operational, such as Baatan in the Philippines, Kalkar in Germany and Zwentendorf in Austria. The pace of nuclear development and construction varies greatly by country, but there are several fundamental reasons why building nuclear power plants is not as certain or as quick as building conventional or renewable power plants. The differences occur in the areas of scale of the construction, size of plant, investment costs, grid suitability, human capacity, political stability, and project lead times.

*Investment costs*. Although the costs of producing electricity from nuclear energy are often prohibitively high, the investment cost schedule for building a nuclear plant itself can be an even greater barrier. The size and complexities of nuclear reactors make both their cost per megawatt and the upfront investment requirements far higher than for conventional and renewable alternatives. This can disproportionally affect countries that have relatively small electricity grids. Consequently, the World Bank has noted that if nuclear power were a large part of the energy mix "the high costs would require large increases in tariffs and could threaten the financial viability of the systems."[4]

The economics of nuclear power are such that government subsidies are almost always required to support private sector construction of nuclear plants. Yet in many countries that wish to develop nuclear energy, limited government resources compete with pressing needs from health, education, and poverty reduction programs.[5] Finally, it must be noted that the investment required for nuclear energy is not restricted to the power stations, but also must support a fully functioning nuclear program, a safe and secure site, supporting power generators, a large water supply, roads and transportation and waste management facilities. An analysis from the Canadian Centre of International Governance Innovation (CIGI) suggests that "[r]eaching just a fraction of these milestones, requiring them to invest billions of dollars on infrastructure upgrades for several years, will be impossible for most SENES [emerging nuclear] states."[6]

The widespread needs for non-conventional sources and mechanisms of financing demonstrate the challenges faced in accessing large-scale financing for nuclear energy. Some governments are helping to finance the export of their technologies through the use of Export Credit Agencies (which again ties up public sector capital), and many projects—such as the build-own-operate proposal in Turkey—deploy delayed payment or leasing systems.

*Grid suitability.* Nuclear reactors tend to be large electricity generators that function most safely and efficiently when providing baseload demand (rather than following the fluctuating daily or seasonal demands). A modern reactor therefore needs to operate in a grid that has an installed capacity of at least 5 GW. According to the IAEA, as many as 17 of the 31 countries considering or planning nuclear power in 2010 did not have adequate grid size.[7] Even if countries have adequate grid capacity, the World Bank observes that a large nuclear investments strategy "lacks flexibility to adapt to changing circumstances."[8]

*Human capacity.* Building a new nuclear program requires adequately trained and experienced staff, both in the industry itself and in the regulatory infrastructure. While not easy in any industry, the human resource needs are further complicated by the hazardous and specialized nature of nuclear technology, in terms of its toxicity and longevity as well as its potential military applications. The CIGI notes that "many aspiring nuclear energy states struggle with poor governance, corruption, the threat of terrorism and civil unrest," suggesting that countries and companies that plan to export nuclear technologies will also need to help train qualified people.[9] This is likely to compound staffing issues in the existing technology-producing countries. Importantly, an aspiring nuclear power country needs to first set up an independent and adequate regulatory structure before establishing a nuclear construction program—an undertaking that can take many years.

*Political stability.* Globally, civil nuclear power production has often been accompanied by, and in some cases led to, the spread of nuclear weapons and the threat of nuclear proliferation. Further deployment of nuclear power raises genuine concerns about the proliferation of nuclear materials, especially in politically sensitive regions. Energy expert José Goldemberg notes that of the nine developing countries that have installed nuclear reactors for electricity production (Argentina, Brazil, China, India, Iran, Mexico, Pakistan, South Africa, and North Korea), five of them (China, India, Pakistan, South Africa, and North Korea) developed nuclear weapons, although South Africa later dismantled its stockpile.[10] And Argentina and Brazil both had weapons programs, even if they did not actually manufacture them. The current case of Iran provides an even more graphic example, given the considerable concern within the international community about Iran's nuclear program and the risk of direct or indirect leakage.

*Lead times.* Rising electricity demand around the world is a primary motivation for nuclear power. Yet creating a nuclear program from scratch is a lengthy business. The IAEA estimates that starting a new construction program in a country without experience can take between 11 and 20 years, and the French Safety Authorities assume a minimum of 15 years to set up an appropriate framework.[11] Given the uncertainty of electricity demand forecasts, matching these with the long lead times required for nuclear development is a potentially high-risk venture.

## Power Plants Under Construction

**Iran** is the only country that is currently building nuclear power plants that does not already produce nuclear energy. Yet Iran's nuclear development has hit numerous delays, and if the largely completed Bushehr reactor becomes operational in 2011, it would mark the end of a 36-year construction program. Although grid connection was expected in February 2011, new technical problems during commissioning make the final operational date again uncertain. The reactor builder, Russia's Rosatom, reportedly attributes the most recent delay to problems with one of the coolant pumps, which were originally supplied in the 1970s.[12] Fragments have entered the primary coolant, requiring removal of the fuel.

The plant's long construction history may have affected safety standards as well. The original reactors, ordered by the Shah in 1974, were designed and slated to be built by German electronics giant Siemens. Following the Islamic revolution, however, payments were halted and construction was suspended in 1979. At the time, two reactors were under construction, with unit 1 said to be around 85 percent complete and unit 2 to be 50 percent complete.

Further problems were inflicted during the Iran-Iraq War, when attacks from aircraft partially damaged both reactors. Iraqi warplanes first struck the Bushehr reactor on 24 March 1984, then two more air strikes took place in 1985, one in 1986, two in 1987, and a final raid in 1988. One reactor was severely damaged, with the structure sealed and the containment dome covered in sheet metal, with some reports suggesting that "the entire core area of both reactors" was destroyed.[13]

After the war, Iran attempted to complete the reactor using other Western suppliers. But pressure, particularly from the United States, blocked these developments, and Iran began negotiations with Russia in 1991. This led to a deal in 1994 for the completion of unit 1 as a VVER 1000 (a 1,000 MW light water reactor), and eventually to an agreement for the supply of fresh nuclear fuel and the return of spent fuel to Russia. Loading of the fuel started in October 2010.

Controversy and international concern regarding the reactor complex and especially Iran's uranium enrichment project remain, which has led to various speculations on the measures being used to restrict and halt the start up of the units. The most prominent of these was a reported attack on the facility's computer system using the computer worm Stuxnet, with a senior Iranian official saying that it had caused harm to the reactor.[14] Numerous Internet sites also report that unmanned aircraft (drones) crashed into the reactor in August 2010.

## Contracts Signed

Like Iran, **Turkey** has a long history of attempting to build a nuclear power program, starting in the early 1970s. In 1996, a call for tender was launched for the construction of 2 GW of nuclear capacity at the Akkuyu site along the eastern Mediterranean, and several international bids were received, including from Westinghouse, AECL, Framatome, and Siemens. In 2000, however, the bid was abandoned.[15] In 2006, the government revised the nuclear initiative and announced plans for up to 4.5 GW of capacity at Akkuyu and at the Black Sea site of Sinop. The plans met with massive local protests.

The following year, Turkey approved a bill introducing new laws on construction and operation of nuclear power plants, which led to a revised tender process in March 2008 for the Akkuyu plant. Only one bid was received jointly from Atomstroyexport and Inter RAO (both from Russia) and Park Teknik (Turkey) for an AES-2006 power plant with four 1200 MW reactors. In May 2010, Russian and Turkish heads of state signed an intergovernmental agreement for Rosatom to build, own, and operate the Akkuyu plant with four 1200 MW AES-2006 units—a $20 billion project.[16a] The reactors are expected to enter service at yearly intervals in the period 2018–21.[17]

In March 2010, Turkey also signed an agreement with Korea Electric Power Corporation (Kepco) to prepare a bid for the Sinop plant. However, the parties failed to reach an agreement because of "differences in issues including electricity sales price."[18] Negotiations switched to Toshiba, with support of the Japanese government, and in December 2010 the parties signed an agreement to prepare a bid for development.

[a] All dollar amounts are expressed in U.S. dollars unless indicated otherwise.

The **United Arab Emirates** (UAE) has the most advanced new nuclear development plans in the Middle East. In April 2008, the UAE published a nuclear energy policy that stated that nuclear power was a proven, environmentally promising and commercially competitive option that "could make a significant base-load contribution to the UAE's economy and future energy security."[19] The policy proposed installing up to 20 GW of nuclear energy capacity, including 5 GW by 2020. This would require the operation of four reactors, two between Abu Dhabi city and Ruwais, one at Al Fujayrah, and possibly one at As Sila.

A joint-venture approach, similar to that developed for the water and conventional power utilities, was proposed in which the government retains a 60 percent share and a private company a 40 percent share. A call for bids in 2009 resulted in nine expressions of interest and the short listing of three companies: AREVA (France) with GDF-SUEZ, EDF, and Total, proposing EPRs; GE-Hitachi (US-Japan), proposing ABWRs; and a South Korean consortium, proposing APR–1400 PWRs. In December 2009, the Korean consortium was awarded the $20 billion contract for the construction and first fuel loads of four reactors, reportedly because the consortium could demonstrate the highest capacity factors, lowest construction costs, and shortest construction times.

The public in the UAE has raised almost no objection to the nuclear energy policy, which has been sold as a way to relieve pressure on the country's fossil fuel resources, increase the security of electrical power supply, create employment and a high-tech industry, and reduce carbon emissions. In July 2010, a site-preparation license and a limited construction license were granted for four reactors at a single site at Braka, along the coast 53 kilometers from Ruwais.[20] The application is based substantially on the safety analysis done for South Korea's Shin–Kori units 3 and 4, the "reference plant" for the UAE's new build program. A tentative schedule published in late December 2010 projects that Braka-1 will start commercial operation in 2017 and unit 2 in 2018. In March 2011 a ground breaking ceremony was held to mark the start of construction.

## Decisions Announced by Industry and Governments

In mid-2006, the government of **Belarus** approved a plan for construction of a nuclear power plant in the Mogilev region in the country's east. Expressions of interest were sought from international companies, and, not surprisingly given economic and political ties, a bid from Russia's Atomstroyexport was taken forward. Under a financing agreement, Russia will provide a $9 billion loan. The two countries will reportedly sign an agreement on plant construction in spring 2011, with construction possibly starting that September.[21] Operation of the first unit is envisaged for 2016 and the second in 2018, a highly unlikely scenario. Meanwhile, the Implementation Committee of the Espoo Convention on Environmental Impact Assessments (EIA) in a Trans-boundary Context has notified Belarus about violations of its rules and major inconsistencies in the EIA documentation.[22]

In **Egypt**, the government's Nuclear Power Plants Authority was established in the mid-1970s, and plans were developed for 10 reactors by the end of the century. Despite discussions with Chinese, French, German, and Russian suppliers, little specific development occurred for several decades. In October 2006, the Minister for Energy announced that a 1,000 MW reactor would be built, but this was later expanded to four reactors by 2025, with the first one coming on line in 2019.[23] In early 2010, a legal framework was adopted to regulate and establish nuclear facilities; however, an international bidding process for the construction was postponed indefinitely in February 2011 due to the political situation.[24]

Since the mid-1970s, **Indonesia** has discussed and brought forward plans to develop nuclear power, releasing its first study on the introduction of nuclear power, supported by the Italian government, in 1976. The analysis was updated in the mid-1980s with help from the IAEA, the United States, France, and Italy. Numerous discussions took place over the following decade, and by 1997 a Nuclear Energy Law was adopted that gave guidance on commercial construction, operation, and decommissioning. A decade later, the 2007 Law on National Long-Term Development Planning for 2005–25 stipulated that between 2015 and 2019, four units should be completed with an installed capacity of 6 GW.[25] Discussions with nuclear vendors have included the possibility of using Russian floating reactors but appear to be dominated by Japanese and South Korean companies; however, neither financing nor detailed planning appear to be in place.

All of **Italy's** nuclear power plants were closed following a post-Chernobyl referendum in 1987, but this has not stopped the country's largest electricity utility, ENEL, from buying into nuclear power in other countries, including France, Slovakia, and Spain. In May 2008, the government introduced a package of nuclear legislation that included measures to set up a national nuclear research and development entity, to expedite licensing of new reactors at existing nuclear power plant sites, and to facilitate licensing of new reactor sites. ENEL and EDF have subsequently stated that they intend to build four EPR reactors by 2020. In January 2011, however, the Constitutional Court ruled that Italy could hold a referendum on the planned reintroduction of nuclear power, as proposed by an opposition party. The question to be posed in the referendum, scheduled for mid-2011, is whether voters want to cancel some of the legislative and regulatory measures that have been taken by the government over three years.[26] New-build projects would have to overcome significant popular opposition.

To date, **Jordan** has signed nuclear cooperation agreements with 12 countries. In February 2011, the country's energy minister announced that the Atomic Energy Commission had preselected designs from AECL of Canada, Atomstroyexport of Russia, and a joint venture between AREVA and Mitsubishi—called Atmea—for the country's first nuclear reactor, located at Majdal. According to the schedule, the preferred bidder would be chosen by September 2011 and the final decision made by the end of the year. Jordan is also seeking foreign corporations to both operate and invest in the nuclear project and has lined up four entities, GDFSUEZ, Rosatom, Datange International Power, and Kansai.[27] Building is expected to start on the 750-1100 MW plant in 2013 for operation by 2020, and a second for operation by 2025.

**Poland** planned the development of a series of nuclear power stations in the 1980s and started construction of two VVER 1000/320 reactors in Zarnowiec on the Baltic coast, but both construction and plans were halted following the Chernobyl accident. In 2008, however, Poland announced that it was going to re-enter the nuclear arena. In November 2010, the government adopted the Ministry of Economy's Nuclear Energy Program, which was submitted to a Strategic Environmental Assessment that is expected to take most of 2011.Poland wants to build 6 GW of nuclear power with the first bloc starting up by 2020, although the country has signaled previously that it may take until 2022.[28]

In its Power Development Plan for 2010–30, approved in 2010, **Thailand** proposes the construction of 5 GW of nuclear capacity. Currently, five locations are being considered as part of a feasibility study that was supposed to be completed by the end of 2010 but has now been delayed. This may be due in part to local opposition to proposed plant sitings, which reportedly have reduced the number of possible locations to two or three areas.[29] Consultancy firm Wood Mackenzie estimates that Thailand will not even be able to introduce a nuclear safety regulatory framework until 2026. Other key problems are the lack of finances and skilled personal.[30]

In October 2010, **Vietnam** signed an intergovernmental agreement with Russia's Atomstroyexport to build the Ninh Thuan 1 nuclear power plant, using 1200 MW reactors. Construction is slated to begin in 2014, and the turnkey project will be owned and operated by the state utility Electricity of Vietnam (EVN), with operations beginning in2020.[31] Rosatom has confirmed that Russia's Ministry of Finance is prepared to finance at least 85 percent of this first plant, and that Russia will supply the new fuel and take back used fuel for the life of the plant. The total cost is expected to near $10 billion.[32]

Vietnam has also signed an intergovernmental agreement with Japan for the construction of a second nuclear power plant in Ninh Thuan province, with its two reactors to come-on line in 2024–25. The agreement calls for assistance in conducting feasibility studies for the project, low-interest and preferential loans for the project, the use of the most advanced technology with the highest safety standards, technology transfer and training of human resources, and cooperation in the waste treatment and stable supply of materials for the whole life of the project. Both of Vietnam's proposed nuclear projects are likely to seriously slip because of a lack of finances and skilled staff.[33]

# Nuclear Economics

This chapter focuses on the key factors that determine the cost of power from a nuclear power plant, both from the corporate point of view and from the wider societal point. It identifies factors that carry little weight in conventional project appraisal but which from a societal point of view demand serious examination.

## Reactor Licensing and Economics

When the Gen III+ reactor designs began to emerge roughly a decade ago, they promised to be simpler and safer—but still cheaper—than previous designs. This is because they were being designed from scratch and could respond to all the regulatory requirements of the day, rather than being modifications of existing designs. The common assumption was that nuclear plants could be built for $1,000 per kW. Current estimates, however, are six times that.

Because of their claimed advantages, it was assumed that the new designs would quickly satisfy regulatory requirements. When U.S. President George W. Bush launched his Nuclear Power 2010 program in 2002, the government expected that at least one unit of a Gen III+ design would be on line by 2010. Yet as of late 2010, none of the five Gen III+ designs being evaluated in the United States had been fully certified by the safety regulator, much less built and brought into service.

One lesson that the nuclear industry learned from the construction cost and time overruns of the 1980s and 90s was that plant designs should be completed before the start of construction. This would allow for more accurate cost estimates because the only design issues left to be resolved at a given site would be site-specific, such as the cooling and foundations. In both the United States and United Kingdom, design certification is now generally a two-stage process: in the first stage (1–2 years), the regulator reviews the design in principle to ensure that there are no "fatal" flaws, and in the second stage (up to several years), the vendor produces the detailed design of all major systems.

But this two-stage process has not been adopted everywhere. At the Olkiluoto and Flamanville EPR plants, Finland and France carried out only the first stage of approval and allowed construction to start before the design was complete. This appears to be one reason for the extensive delays and extra costs, as regulators have not been happy with AREVA NP's detailed design that was proposed in mid-construction. As U.S. and U.K. regulators have reviewed the EPR, issues have arisen that the French and Finnish regulators have had to take up. As a result, the two plants will be, to some extent, one-offs, because design issues were raised too late in construction for the ideal solution to be implemented.

*United States*

The U.S. Nuclear Regulatory Commission, which has carried out generic design assessments since 1992, gave 15-year approval in 1997–98 for three reactor designs: the Westinghouse AP600, the General Electric (GE) ABWR, and the Combustion Engineering System 80+ PWR. None of these has been offered for sale in the United States. By the time the AP600 received certification, it was not competitive, although a scaled-up version, the AP1000, was developed. The GE ABWR was built in Japan and there is now renewed U.S. interest in it, although certification expires in 2012 and the process of renewal has just started. The System 80+ design was licensed to South Korea as the APR1400 and is now under construction there; Korea also won an order to build four units in the UAE. The NRC is currently reviewing five other reactor designs: the Westinghouse AP1000, the GE-Hitachi ESBWR, the updated ABWR, the EPR, and the Mitsubishi APWR.[1] (See Table 2.)

**Table 2. Reactor Designs Currently Under Review in the United States**

| Design | Description/Status |
|---|---|
| AP1000 | Received full regulatory approval in 2006, but roughly a year later Westinghouse (by then a subsidiary of Toshiba) submitted design revisions that are still undergoing NRC review. The most recent revision was in December 2010, and final approval was expected in late 2011, although the Fukushima accident could spell delays. Several U.S. projects are being actively pursued for AP1000s. |
| ESBWR | One of the first plants to begin consideration by the NRC, and generally seen as one of the most advanced of the Gen III+ designs. The NRC issued design approval in March 2011, and formal certification should take place in about a year, although the Fukushima accident may cause delay. Six U.S. utilities are interested in the ESBWR but none appear to be actively pursuing it, possibly because of cost. There is no interest outside the United States and it may be that, like the AP600, the design will achieve certification but will not be offered for sale. |
| EPR | In 2004, AREVA wrote the NRC requesting a review of the EPR that was expected to be completed in 2008. In 2010, the NRC pushed the review completion date to February 2013. A handful of U.S. utilities have expressed interest in building EPRs but only one project is being actively pursued, Calvert Cliffs (for one unit), which is now in serious doubt. Like the ESBWR and the AP600, the EPR may receive certification but not get any U.S. customers. |
| APWR | The APWR has been under development since around 1980, and for the past decade an order has been said to be imminent in Japan (Tsuruga), although it still has not been placed. An updated version of the design has been submitted to the NRC, but a completion date for review is unlikely before 2013. One U.S. APWR project is being pursued but is still at an early stage. |
| ABWR | Cost problems with the ESBWR led some utilities to return to the ABWR, which dates to 1980 and won its first order in 1989. It is the only design being reviewed that is actually in service, albeit with earlier versions. Both GE-Hitachi and Toshiba offer the design. Toshiba has one customer with a project that is well advanced, and it expects NRC approval in principle by the end of 2011, with design certification a year later. The GE-Hitachi version has no U.S. customers, and the company supplied the design details for NRC review only in February 2011, so there is no completion date yet. |

*Source: See Endnote 1 for this section.*

*United Kingdom*

The parallel process of generic review started in the United Kingdom in 2007. Of four designs originally submitted, two (the GE ESBWR and a Canadian heavy-water design) were quickly withdrawn, leaving the AP1000 and the EPR. The U.K. Nuclear Installations Inspectorate agreed to a completion date of July 2011 for their review and appear determined to keep to that. But not all issues are expected to be resolved by that date, and the conditional approval will not be a basis for placing orders, much less commencing construction. The extent of the remaining issues and how long it will take to resolve them is far from clear, especially given the additional safety reviews requested post-Fukushima

*The Fukushima Accident*

During the past 30 years, three major events have caused major rethinks to nuclear plant design: Three Mile Island (March 1979), Chernobyl (April 1986), and 9/11 (September 2001). It took more than a decade for new designs to respond to the first two events, and the consequences of 9/11 are still being incorporated. The March 2011 Fukushima accident will likely have a comparable impact on plant design. It is hard to see how a regulatory body could give generic approval to any new design until the problems at Fukushima have been thoroughly understood and designers find ways to prevent a repeat of events. As a result, completion of the U.S. and U.K. generic reviews will be delayed. The extent of additional design requirements remains to be seen, but it is very likely that additional costs, perhaps significant, will be imposed on any new designs.

*Impact on Costs*

In 2008 and 2009, tenders for nuclear power plants in Canada and South Africa were abandoned because the bids received (for AP1000 and EPR) were roughly double the expected level. The two reactor designs were also turned down in the UAE in 2009 in favor of a lower Korean bid for the APR1400. This led to a lot of soul-searching by the nuclear industry and appears to have exploded the myth that Gen III+ designs could be safer but simpler and cheaper. In 2010, AREVA CEO Anne Lauvergeon admitted that the cost of nuclear reactors has "always" gone up with each generation because the safety requirements are ever higher, stating that, "safety has a cost."[2]

One issue that arose after 9/11 was the need to ensure that a nuclear plant would survive a strike by a large civil airliner. European regulators also now require plant designs to include a "core catcher" that would catch the molten fuel (corium) if it breached the reactor's pressure vessel in the event of a failure of the emergency cooling system. When AREVA failed to win the UAE tender, Lauvergeon claimed that the reason that the proposed EPR was 15 percent more expensive than a Gen II PWR was because of costlier safety enhancements—such as the core catcher and the reinforced containment—that were designed to prevent offsite radiological impact. Buying the Korean APR1400, she said, was like buying "a car without air bags and safety belts."[3]

In light of these developments, some companies are revisiting earlier design generations, and EDF and AREVA (independently) have considered teaming up with China to offer the 1,000 MW PWR design that comprises most orders in China. This PWR is based on a design supplied to China by Framatome (predecessor of AREVA NP) in the 1980s, which itself was licensed from Westinghouse in the 1970s. Senior politicians in South Africa have discussed with Chinese and Korean politicians the possibility of importing the Chinese PWR or the Korean APR1400, respectively.

China has only ever exported one small reactor unit (to Pakistan), and it is unclear whether it has the capacity for further exports given that it has been ordering roughly six units a year for its own market. It also remains unclear whether Chinese-supplied plants would be much cheaper than their Western counterparts. Moreover, there are indications that the Korean bid for the UAE plant—Korea's first nuclear export order—is in fact not economic but simply reflects the country's effort to get a foothold in the world nuclear market, even at a loss.

The UAE project also raises serious safety issues. In 2010, AREVA's Lauvergeon told a French National Assembly Committee that "the outcome of the UAE bid poses fundamental questions about the nature of the world nuclear market and the level of safety requirements for reactors that will still be operating in 2050 or 2070." She raised the specter of "a nuclear [market] at two speeds": a high-tech, high-safety mode for developed countries and a lower-safety mode for emerging countries. "The most stringent safety standards are in the U.S. and Europe," Lauvergeon said. "In Europe we couldn't construct the Korean reactor. Are American and European safety standards going to become international standards, or not?"[4]

The negotiating of nuclear orders at a political level is also troubling. The UAE order was placed before the country had a functioning safety regulator, meaning that politicians effectively have decided that the Korean design will be licensable. Meanwhile, if South Africa decides to buy a Chinese or Korean reactor, what will the South African regulatory body do if it is not comfortable with licensing reactors that fall well below the standards required in Europe? If the Fukushima accident does reveal significant inadequacies in earlier designs, however, the renewed interest in older designs may well prove short-lived.

## Implementation Costs of Nuclear Power Plants

For a company investing in new nuclear power, a leading concern is the ability to repay the costs associated with building the plant. AREVA NP, the largest nuclear builder in the world, estimates that plant construction alone accounts for about two-thirds of the cost of a kilowatt-hour of nuclear electricity.[5] Operating costs are relatively small compared to construction but are not insignificant. Other costs, such as plant decommissioning and waste disposal, are huge but are incurred so far in the future that they have little weight in conventional project appraisals for new nuclear plants.

From a corporate point of view, the main cost elements associated with nuclear power are:

- *Fixed costs*, which are primarily associated with construction of the plant and are determined by the construction cost, the construction time, and the cost of capital. The costs of decommissioning the plant and of radioactive waste disposal also can be considered fixed costs, although they increase somewhat the longer a plant operates. The more electricity a plant produces per year, the thinner the fixed costs can be spread, so good reliability is a key requirement in keeping the cost of nuclear electricity down.
- *Variable costs*, which include the cost of fuel, the cost of maintenance, and the non-fuel operating costs. Although these vary somewhat according to plant output, they are not generally "avoidable" costs and are typically incurred even if the plant is not operating.
- *Accident insurance*, should the owner of the plant choose to insure it against damage (large companies may opt to self-insure to save the insurance premium). International treaties, such as the Brussels and Vienna conventions, cap the cost of "third-party" damage caused by a plant accident to a specified sum, which varies by country but is generally around $1 billion.

*Construction Cost*

The estimated cost of building new nuclear plants of the latest design generation, the Gen III+, has escalated dramatically.[6] A decade ago, when these plants were first being touted, the nuclear industry forecast confidently that they could be built for an "overnight" cost (including the cost of the first fuel charge but excluding finance charges) of $1,000 per kilowatt, such that a 1,000 MW unit would cost $1 billion. But these were just indicative estimates, and the representatives making them had little to lose if they proved to be wrong.

The historic record, however, shows that indicative estimates are not accurate predictors of actual costs. In general, cost estimates made by vendors (other than in actual tenders), utilities (unless they face penalties if the estimates are wrong), governments, nuclear industry bodies, and consultants and academics have had little credibility. The only numbers that have had any value in predicting cost are outturn costs at completed plants, vendor tenders, and utility cost estimates. Estimates made before the start of construction have generally underestimated actual costs, sometimes by a large margin.

In theory, a vendor could be responsible for taking on the risk of a cost overrun if the plant is contracted on a "turnkey" basis, under which the vendor agrees to pay any costs over and above the cap of the contract price. Finland's Olkiluoto contract of 2003 was issued on a turnkey basis, but when the costs overran substantially, the vendor, AREVA NP, refused to meet the extra costs—an issue that is now being deliberated in arbitration courts.

The Olkiluoto example illustrates that signing a turnkey contract is a very high risk to a vendor, possibly too high to justify to shareholders and credit rating agencies.[a] It also suggests that financiers will regard turnkey contracts as having little value. Although it may be possible to buy individual components on turnkey contracts with some credibility, historically the problem of controlling costs has arisen not from the cost of individual components, but from the cost of design changes and on-site engineering. Fixing the price of the major components does not reduce this risk.

*Cost of Capital*

The cost of capital is perhaps the most important—and most variable—element in the economics of nuclear energy. The capital cost depends in part on the credit ratings of both the country and the power utility in question; countries with more stable economies tend to get lower interest rates, as do utilities

[a] Off the record, AREVA top officials admit they "won't do it again."

that have sounder finances. But the structure of the electricity industry is a factor as well. In countries that have traditional monopoly utilities, consumers effectively bear the project risk because any incurred costs are passed on—allowing for full-cost recovery. For financiers, this is the ideal situation, as consumers always pay. Some markets, such as those in most developing countries and some U.S. states, still assume full-cost recovery, making the financing of new nuclear build possible.

If a nuclear plant's electricity is sold into a competitive market, however, the risk falls on the utility. And if the cost of nuclear power is higher than the market price for electricity, the utility will be quickly bankrupted, as occurred with British Energy in 2002. The U.K. government chose to save the nuclear generation company at a cost to taxpayers of more than £10 billion ($16.5 billion).[a] When a utility goes bankrupt, its creditors and shareholders, including banks that lend money for nuclear projects, are likely to lose most of their money.

In the United States, where energy markets in some states are still regulated monopolies, the degree of risk depends on the attitude of the state regulatory body. If the regulator is indulgent toward nuclear power and is expected to allow full-cost recovery, the risk is low and finance is easy to obtain. The poor record of nuclear power in meeting cost estimates, however, means that the public might not tolerate regulators signing a "blank check" on its behalf.

If costs do overrun, the cost of borrowing the additional money could be significantly higher than the cost of finance for the original loan, especially if the overrun has to be met from utility profits.

*Loan Guarantees*

One way to reduce the cost of capital is for governments to offer credit guarantees on the loans, essentially transferring the risk to taxpayers. If the utility building the nuclear plant defaults, the government will make up the loss to the financiers. Effectively, this means that the financiers are lending to the government at an interest rate close to the government's base rate, resulting in a very low-risk loan for the utility.

Loans for the Olkiluoto plant were covered in part by loan guarantees offered by the French and Swedish governments, resulting in a very low interest rate (reportedly at 2.6 percent). Critics challenged this as an "unfair state aid," but the European Commission ruled in favor of the support because the borrowers had paid a fee for the loan guarantees. The EC did not specify the level of the fee, making it difficult to determine whether the fee was "economic" in the sense that it reflected the risk of default.

Loan guarantees are a central element of efforts to restart nuclear ordering in the United States. Guarantees are available for 100 percent of the borrowing required for a plant, for up to 80 percent of the total cost. However, the fees charged for loan guarantees must be economic (i.e., they must reflect the risk of default). So far, loan guarantees have been offered for two U.S. plants: Georgia Power's Vogtle project for two Westinghouse AP1000s in the state of Georgia, and Constellation Energy's Calvert Cliffs project for an AREVA EPRs in Maryland.

For the Vogtle project, Georgia remains a fully regulated state and the Georgia Public Service Commission accepted early-on Georgia Power's request to start recovering the construction cost from its monopoly consumers. As a result, any bank lending money to the project had double protection: from the federal government (taxpayers) via loan guarantees, and from consumers via guaranteed cost recovery. As a result, the fee for the loan guarantees was reportedly only 1–1.5 percent, and Georgia Power claimed that the support of the regulator meant that the project would have been viable even without the guarantees.

[a] In this report, conversions from British Pounds to U.S. Dollars were performed on 22 April 2011 using the exchange rate of 1 Pound = 1.65 U.S. Dollars.

Maryland, in contrast, is part of the competitive PJM (Pennsylvania-Jersey-Maryland) wholesale market and will have to compete to survive in the nuclear arena. In October 2010, Constellation Energy unilaterally withdrew from negotiations with the U.S. Department of Energy (DOE) for loan guarantees for the Calvert Cliffs project. The fee to provide loan guarantees for 80 percent of the forecast cost of the plant ($9.6 billion) was reportedly proposed at $880 million, or 11.6 percent.[7] When Constellation rejected that offer, DOE proposed a 5 percent fee, but on condition that Constellation fully guarantee construction and commit to sell 75 percent of the power through a power purchase agreement (presumably through its subsidiary Baltimore Gas & Electric) that would have to be approved by the Maryland Public Service Commission. As of March 2011, Electricité de France (EDF), originally an equal partner with Constellation through the Unistar joint venture in Calvert Cliffs, was still trying to salvage the project by striking a deal with the commission.[8].

Rising estimated construction costs for nuclear plants have meant that the public liability associated with loan guarantees has escalated dramatically as well. When attempts to restart ordering in the United States began nearly a decade ago, it was expected that loan guarantees would be provided for no more than 50 percent of the cost of building five nuclear units at $1,000 per kW—totaling some $3.75 billion in guarantees, if the average unit size is 1,500 MW. Now, the plan is to provide guarantees for up to 15 units covering 80 percent of the cost—meaning guarantees worth more than $100 billion at an average cost of $6,000 per kW. The U.S. Congress has been very reluctant to commit guarantees on this scale, and in March 2011 the government was still trying to triple the amount available for loan guarantees from $18 billion (enough for 3–4 units) to $54 billion.[9] In general, governments will be very reluctant to take on these huge liabilities, especially at a time of large budgetary cuts.

*Construction Time*

Overruns in construction time are likely to correlate with higher construction costs. Plants that are completed late will impose additional costs on the plant owner as well, including interest charges as well as market costs if the utility is forced to buy outside power to substitute for what the nuclear plant should have been producing. If the market is tight, these "replacement power" costs could be very high and perhaps crippling to the utility (or its consumers). In the case of the still-incomplete Olkiluoto plant, owner TVO had contracted to start selling nuclear power at the end of April 2009. For the next four years or more before plant completion, TVO will have to buy the contracted power from the Nordic electricity market.[10] If that market becomes tight (for example, if low snowfall leads to low water levels in hydropower dams), the cost of this replacement power could cripple TVO and its customers, including energy-intensive industries that cannot afford higher energy costs.

*Reliability*

In the early decades of nuclear energy, the reliability of nuclear plants frequently fell far below the levels forecast by utilities. During the past 20 years, however, reliability has improved substantially, and the world average load factor (the annual power output of the plant as a share of the maximum possible output) is now about 85 percent, compared to about 60 percent in the mid-1980s. This is probably near the maximum it can reach, as most plants have to be shutdown annually for maintenance and refueling that generally takes at least a month.

France is among the notable exceptions to this improvement in reliability. A commission set up by the French government under former EDF CEO François Roussely found that, "while the average capacity of nuclear power worldwide...has increased significantly over the past fifteen years, the French nuclear plant capacity has sharply declined in recent years."[11] Thus, although poor reliability is a lesser risk today than in the past, good reliability cannot be assumed, particularly for new, unproven designs.

*Operations & Maintenance Cost*

As with reliability, the cost of operating and maintaining a nuclear plant was a serious concern 20 years ago, and some plants were closed because these high costs made them uneconomic even on a marginal-cost basis (i.e., not including the fixed costs). With improved reliability, however, maintenance and repair can be spread out over time, resulting in lower operations and maintenance costs per kilowatt-hour.

*Fuel Cost*

Fuel cost—including the cost of the uranium, the cost of processing (including enrichment), and the cost of spent-fuel disposal (or reprocessing)—represents only around 5 percent of the per-kilowatt-hour cost of nuclear electricity. Although uranium costs are going up, the quality of ore being discovered is getting lower, and many previously subsidized enrichment facilities will have to be replaced in the coming years at higher cost, the impact of these trends on the overall economics of nuclear power will be low.

The costs associated with spent-fuel disposal can only be guessed, since countries are still decades away from operating an actual disposal facility. As with plant decommissioning, spent-fuel disposal is likely to occur as much as 50–100 years from the time the fuel is removed from the reactor, meaning that the associated liability is discounted away. If disposal occurs 100 years after the fuel is unloaded and the discount rate is 3 percent, the cost impact is reduced by a factor of nearly 20.

*Decommissioning*

So far, there is little worldwide experience with full decommissioning of nuclear plants. No plant that has operated for several decades has been decommissioned and subsequently dismantled, including the final disposal of the radioactive waste. The costs of decommissioning are therefore highly uncertain, but are projected to approach those associated with construction: several billion dollars for a large plant. The long time periods and low discount rates associated with nuclear plants, however, can reduce the liability dramatically. Decommissioning may well be completed 150 years or more after plant commissioning, and if the expected cost is $1 billion and the interest rate is only 3 percent, the discounted liability would be only $12 million.

It is important to note that the economics of nuclear energy are very different when considered from a societal point of view, rather than from a strictly corporate perspective. Most governments advocate the "polluter pays principle," meaning that those who consume the energy from a nuclear plant should also pay for the wider impacts on society and the environment—including impacts associated with decommissioning and waste disposal. This assumes, however, that future generations will have the funds to carry out these hazardous tasks. The timescales for investment and return are so long that even the most conservative financing scheme will have a significant risk of failure. The mechanism to provide cash to pay for decommissioning nuclear facilities in the United Kingdom already has failed comprehensively, leaving undiscounted liabilities of some £100 billion ($165 billion) but few funds available, putting the burden on future taxpayers.

Uranium mining is a highly damaging process that leaves hazardous wastes that must be dealt with extremely carefully to avoid permanent damage to the local environment. As the quality of ore deteriorates, the amount of waste per kilogram of uranium will increase and the amount of energy (much of it fossil fuel) used to extract the uranium is likely to increase. Moreover, since many civil nuclear facilities can be dual purpose (civil and military) or can be a cover for military activities, exploiting nuclear energy inevitably raises the risk of weapons proliferation. There is also the risk of accidents, with massive consequences to health, and the costs of which would be met by taxpayers.

## Developments in 2010

*Construction Costs*

The main developments in 2010 were further cost escalations at two AREVA projects: Olkiluoto in Finland and Flamanville in France. In March 2011, AREVA announced a further €367 million ($534 million) in provisions against losses on the Olkiluoto plant in addition to the €2.3 billion ($3.3 billion) already announced.[12] With completion again delayed, commercial operation is now expected in mid-2013, four years longer than the original four-year schedule.[13] Flamanville is similarly lagging: in August 2010, EDF acknowledged that the project was running two years behind schedule after 2.5 years of construction, and that costs were at least €1 billion ($1.5 billion) over budget.[14]

No major calls for tender were announced in 2010 for which reliable costs were published. Vietnam reportedly ordered two 1,200 MW reactors from Russia with construction start scheduled for 2014, but no costs have been published and it is not clear whether the order is a firm one or simply an option.[15] Vietnam signed a similar accord with Japan.[16] There were also no major updates to U.S. utility cost estimates, although John Rowe, CEO of Exelon, the largest U.S. nuclear utility, estimated that a carbon price of $100 per ton would be needed to make new nuclear energy break even.[17]

In the United Kingdom, the cost estimates on which that country's nuclear policy was based have increased dramatically. When the government published its white paper on nuclear power in 2008, it assumed a plant construction cost of £1,250 per kW ($2,000 per kW).[18] For a 1,600 MW EPR, this would equate to a cost of £2 billion ($3.3 billion) for a single EPR, or £1.5 billion ($2.5 billion) for a single AP1000. At this level, the study concluded that new nuclear power stations would not be economic unless the carbon price in the European Union Emissions Trading Scheme was higher than €36 per ton ($59 per ton). In the five years since this carbon market was introduced, the price has seldom exceeded this level and has generally been below €10/ton.

In June 2010, the U.K. government published new cost estimates, prepared by consulting firm Mott Macdonald, forecasting the overnight cost of a "First of a Kind" (FOAK) nuclear plant as $6,000 per kW.[19] Costs would then fall with experience, with the "Nth of a Kind" plant costing only $4,500 per kW, but likely not for orders placed before 2025. For a FOAK EPR, the cost estimate would equate to £6 billion ($9.9 billion) for an EPR and £4.5 billion ($7.4 billion) for an AP1000—costs in line with those from construction projects, tenders, and U.S. utility estimates.

In 2010, the Nuclear Energy Agency (NEA) updated its cost estimates for new generating technologies, which range between $1,600 and $5,900 per kW.[20] The lower end of the range reflects the highly optimistic view of nuclear costs that still exists in some countries. These estimates should be treated with some skepticism, however, as the NEA is required to use data supplied by member states.

Financial institutions produced some influential studies on nuclear costs as well. Ernst & Young examined the construction risk and stated in a 2010 report: "It is hoped that the nuclear industry has learned its lessons from the extensive cost overruns and schedule delays that characterized the 1970s and 1980s, and cost the US industry alone billions of dollars in failed rate recoveries and losses. However, current data suggests that many new projects are not faring much better."[21] And Standard & Poor's, in a review of the economics of U.S. nuclear power, concluded that, "We expect unregulated companies, which are sponsoring new nuclear projects and which do not receive loan guarantees, will defer or abandon them altogether because it's too expensive, or uneconomic, to build them without such guarantees."[22]

Some of the most important new research in 2009-10 analyzed past costs, especially in France. Nuclear advocates generally consider France to be the example for building and operating nuclear plants efficiently, due in large part to the country's use of standardization, large-scale and predictable ordering that brought economies of scale, minimization of the scope for public intervention, and state backing for the program. But several recent reports question this thinking.

Former EDF chair François Roussely's report, released in June 2010, confirmed that the French utility was not operating its nuclear plants as reliably as its peers in Europe.[23] And in 2009, researcher Arnulf Grübler found that the real cost of construction, rather than falling over time as might be expected because of economies of scale, learning, and technical progress, had in fact increased more than three-fold over the 20-year period to 1998, covering most nuclear orders in France.[24] Building on this work, Mark Cooper with Vermont Law School concluded that "the claim that standardization, learning, or large increases in the number of reactors under construction will lower costs is not supported in the data."[25]

*The U.S. Program*

The U.S. announcement in 2010 of a shortlist of five nuclear power projects (soon reduced to four) for loan guarantees suggested that the country's nuclear program was finally getting under way. But the process of obtaining regulatory approval has been continually delayed, and none of the designs will receive full approval before 2012. The shortlisted projects are: Vogtle in Georgia (two AP1000 reactors), Calvert Cliffs in Maryland (one EPR), South Texas (two ABWRs), and Summer in South Carolina (two AP1000s). Like the Calvert Cliffs project, South Texas will be a "merchant plant" feeding into a competitive market and will require loan guarantees, the fee for which may be prohibitively high.[26] (See also the chapter on post-Fukushima developments, page 41.) And like the Vogtle plant, the Summer project is planned in a fully regulated state where regulators are sympathetic to nuclear power. The lead utility, South Carolina Electricity and Gas, is state-owned, and loan guarantees are not seen as critical because of the high probability of cost-recovery.[27]

*The Need for Subsidies*[28]

As the estimated cost of nuclear plants continues to escalate, it has become very hard to argue that nuclear power is economic even against renewable options, much less against fossil fuels. Exelon CEO John Rowe observed in May 2010 that, "[p]icking our favorite technologies in 2008 would have led to some good decisions, like energy efficiency and uprates, and some very large, very expensive ones, like new nuclear plants and clean coal."[29] Nevertheless, many governments continue to support subsidies for nuclear power.

In the United Kingdom, the Conservative-Liberal Democrat coalition government has effectively abandoned its and the previous Labor government's pledge to not offer public subsidies to new nuclear projects. In a statement to the House of Commons in October 2010, Chris Huhne, Secretary of State for Energy and Climate Change, first "reconfirm[ed] the Government's policy that there will be no public subsidy for new nuclear power," then contradicted this statement in several ways, noting that: "New nuclear power will...benefit from any general measures that are in place or may be introduced as part of wider reform of the electricity market to encourage investment in low-carbon generation," and that "we are not ruling out action by the Government to take on financial risks or liabilities for which it is appropriately compensated or for which there are corresponding benefits."[30]

The U.K. government followed up this statement with a consultation paper on electricity market reform that suggested several mechanisms for subsidizing new nuclear plants, including long-term power purchase agreements, setting a floor on the carbon price, and offering capacity payments to generators.[31] It remains to be seen which of these mechanisms will be chosen and to what extent they will be adapted to suit nuclear power, but the Secretary of State's statement leaves the way open for almost any form of subsidy for nuclear power.

*What Do Financiers Need?*

As attempts to finance new nuclear power plants continue, it is clear that one of the major barriers developers face is obtaining finance. Increasingly, it will be banks and credit rating agencies, not utilities and governments, that determine whether nuclear plants are built. The ideal solution for financiers remains guaranteed cost-recovery, and it is no surprise that the orders placed in the past three years have been in markets where utilities are mostly publicly owned. Similarly, China accounts for 26 of the 43 construction starts in the past four years, Russia for six, and Korea for five. All of these countries have publicly owned utilities that operate in monopoly markets.

The U.K. proposals to offer long-term contracts for new nuclear projects may well amount to full cost-recovery, depending on the terms of the contract. Due to claims of commercial confidentiality, however the terms will not be made public.

Loan guarantees are becoming problematic. Although they would allow for a low cost of capital, the main obstacle is the fee, particularly if it is determined based on the risk associated with the project. The perception of risk will be the same whether the assessor determining the fee is a bank or a government agency. If there already is cost recovery for a project, loan guarantees are irrelevant—as appears to be the case with the U.S. Vogtle and Summer projects. If there is not, the fee for the loan guarantee may well be prohibitively high.

Turnkey contracts for the whole plant represent another financing option. But after the experience with Finland's Olkiluoto project, vendors are unlikely to offer such contracts. And if they do, financial institutions may well view the credibility of such approaches as dubious.

### Conclusion on Economics

The so-called "nuclear renaissance" was based on the claim that a new design of reactors would be offered that was both safer and cheaper than existing designs. Whether this was a delusion on the part of the nuclear industry or a desperate attempt to get one more chance at the promise of cheap power is hard to say, but it was clearly a fallacy. There is no clear understanding of why cost estimates have escalated so dramatically—sixfold—in the past decade, but it may well be that the process of taking a design from concept to full specification and licensing leads to many more costs than anticipated. The Fukushima accident will likely only ratchet up costs further.

## Nuclear Power vs. Renewable Energy Development

There could hardly be a more symbolic picture for the tête-a-tête of renewables and nuclear power than the March 2011 earthquake and tsunami in Japan. The disaster shut down 11 of the country's nuclear reactors, at least six of which are now condemned, but the Japanese Wind Power Association stated, "there has been no wind facility damage reported by any association member, from either the earthquake or the tsunami."[1] Within three weeks of the disaster, Fukushima operator TEPCO, one of the five largest electricity utilities in the world, lost more than three-quarters of its share value, while the Japan Wind Development Company nearly doubled its stock price.

The Fukushima crisis only exacerbates the major changes that the energy sector is facing due to a combination of environmental, resource, and demand factors. At the United Nations climate change conference in Cancún, Mexico, in December 2010, delegates agreed that "climate change is one of the greatest challenges of our time and that all Parties share a vision for long-term cooperative action." For the first time under the U.N. climate framework, participants acknowledged that "deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2°C above pre-industrial levels."[2]

This statement not only confirms the scientific framework by which global emissions should be measured, but it enables calculations to be made about the volume of greenhouse gases that can be safely released to the atmosphere to avoid serious climatic disruption. Estimates indicate that global emissions must be cut roughly 80 percent by 2050, requiring the effective "decarbonization" of the energy sector. Given that the expected lifetime of investments in energy infrastructure, grids, and power stations typically exceeds 50 years, all new projects built today should fulfill these sustainability criteria or face premature retirement. Although a large number of "low-carbon" technologies are both being deployed and under development, particularly in the renewable energy arena, the key factor is how (and if) these fit together into a zero-emissions energy sector.

Traditional energy forecasts anticipate rapid increases in energy demand, driven primarily by the need to fuel Asia's growing economies, particularly in China and to a lesser extent in India. The International Energy Agency assumes that, if current policies continue, global energy demand will increase 47 percent by 2035. Based on this scenario, energy consumption in China will effectively triple, whereas in the European Union and the United States it will increase about 4 percent.[3]

Over the medium term, a pressing concern is the availability of suitable energy resources—particularly liquid fuels—and the associated impact on both supply and consumer prices. The U.K. Energy Research Centre estimated in 2009 that the average annual rate of decline from oil fields that are past their peak of production is at least 6.5 percent, while the decline from currently producing fields is at least 4 percent.[4] Just maintaining the current level of output would require 3 million barrels a day of new capacity each year, equivalent to the production of Saudi Arabia over three years.[5] And this does not take into account the growing demand from developing countries. The situation for oil is particularly acute, but concerns about the availability of other fossil fuels, such as natural gas, in some countries and regions is affecting their price significantly.

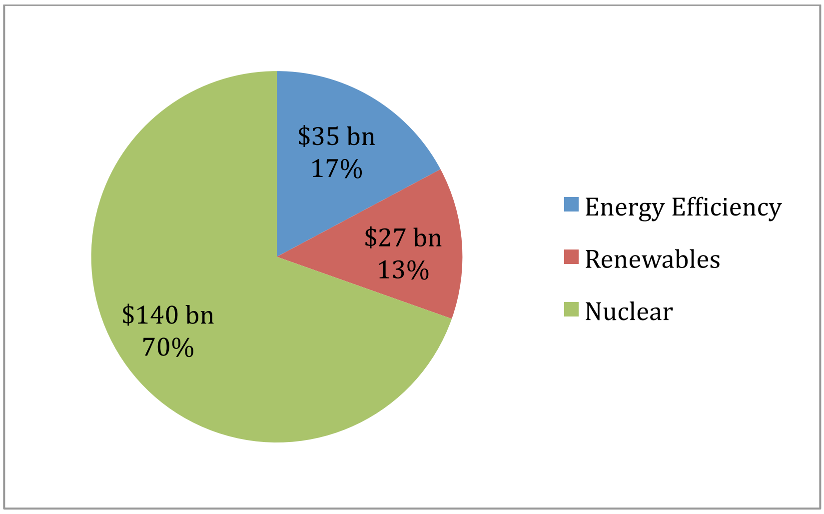
From the perspective of both climate security and traditional supply security, the current energy system and the policies that shape it are highly unsustainable. The new energy system must be based on two pillars. Firstly, energy efficiency must be at the heart of any new energy system, because meeting the anticipated increase in energy demand at current efficiency levels is not an option given the growth in population and changing consumption patterns. As the European Commission points out, "energy savings is one of the most cost effective ways" to address concerns about climate change and the security of energy supplies.[6]

The second pillar of the new energy system is no (or extremely low) carbon dioxide emissions. This decarbonization could come from three sources: nuclear power, fossil fuels (using emissions capture and storage), and renewable energy. Supporters of nuclear power believe that nuclear should play an increasingly important role in this new, highly efficient, zero-emissions energy sector, since in their view all low-carbon technologies will be needed.[7] But this claim must be addressed from multiple perspectives.

## An Economic Comparison

When evaluating the role of nuclear power in the global energy mix, it is important to consider the types of support that nuclear receives compared with other technologies. Proponents of new energy technologies argue that direct government support is needed to enable these to compete with established technologies. Nuclear power has been in commercial operation for more than 50 years, yet it continues to receive large direct and indirect subsidies, in part because electricity prices fail to reflect the full environmental costs, and because of government guarantees for the final storage or disposal of radioactive waste.[8] In the United States, even though nuclear and wind technologies produced a comparable amount of energy during their first 15 years (2.6 billion kWh for nuclear versus 1.9 billion kWh for wind), the subsidy to nuclear outweighed that to wind by a factor of over 40 ($39.4 billion versus $900 million).[9]

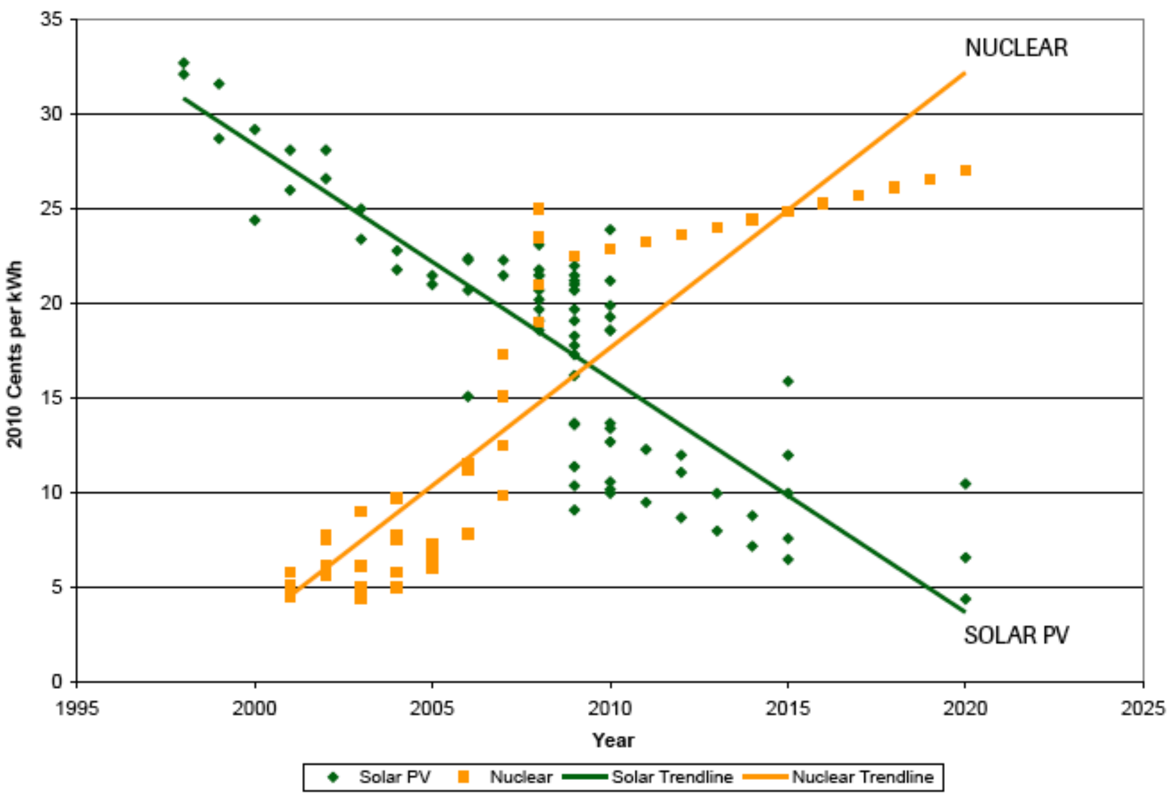
**Figure 11. Government Research and Development Budgets across IEA countries 1986–2008 *(billion $2008)***




*Source: IEA 2011*

Even with the demise of new orders for nuclear power and the rise of other energy technologies, nuclear continues to enjoy unparalleled access to government research and development (R&D) funding. Analysis from the IEA shows the dominance of nuclear power, both fission and fusion, within R&D budgets—commanding nearly two-thirds of total expenditures in recent decades.[10] (See Figure 11 above.) Compared with renewables, nuclear power has received roughly five times as much government R&D finance since 1986 across the countries of the IEA.

**Figure 12. Solar and Nuclear Costs: The Historic Crossover**




*Source: Blackburn and Cunningham 2010*

Moreover, the building of new nuclear power plants, which is being proposed for the first time in decades in some developed countries, will require further government subsidies or support schemes, such as production tax credits, insurance for cost overruns, and more. With increasing constraints on public-sector spending, state support for one technology will mean less support available for others.

Despite the disproportionately lower support historically, some analysts consider solar photovoltaic (PV) energy to be competitive with nuclear new-build projects under current real-term prices. The late John O. Blackburn of Duke University calculated a "historic crossover" of solar and nuclear costs in 2010 in the U.S. state of North Carolina. Whereas "commercial-scale solar developers are already offering utilities electricity at 14 cents or less per kWh," Blackburn estimated that a new nuclear plant (none of which is even under construction) would deliver power for 14–18 cents per kWh.[11] (See Figure 12 above.) Solar electricity is currently supported through tax benefits but is "fully expected to be cost-competitive *without subsidies* within a decade," he noted.[12]

## Rapid and Widespread Deployment

Because the transition from fossil fuels to low-carbon energy sources needs to be rapid and global, technologies that are widely available today and that can be implemented in the short term have a clear advantage. Given the need for immediate reductions in greenhouse gas emissions, the time needed to introduce new technologies on a mass scale is a crucial parameter. The commissioning of new energy-generating facilities involves two major phases, pre-development and construction, and both must be considered when comparing the benefits of technologies to emissions reduction.

The pre-development phase can include wide-ranging activities such as conducting extensive consultations, obtaining the necessary construction and operating licenses, getting consent both locally and nationally, and raising the financing package. In some cases, technology deployment may be sped up through the use of generic safety assessments. Alternatively, pre-development may take longer than expected because of local site conditions or new issues coming to light.

The IEA has estimated a pre-development phase of approximately eight years for nuclear power.[13] This includes the time it takes to gain political approval but assumes an existing industrial infrastructure, workforce, and regulatory regime. In the case of the United Kingdom, then-Prime Minister Tony Blair announced that nuclear power was "back with vengeance"[14] in May 2006, but it was some years before nuclear pre-development even began.

With regard to construction, nuclear power has a history of delays.[15] (See Table 3.) According to the World Energy Council, the significant increase in construction times for nuclear reactors between the late 1980s and 2000 was due in part to changes in political and public views of nuclear energy following the Chernobyl accident, which contributed to alterations in the regulatory requirements.

**Table 3. Construction Time of Nuclear Power Plants Worldwide, 1965–2010**

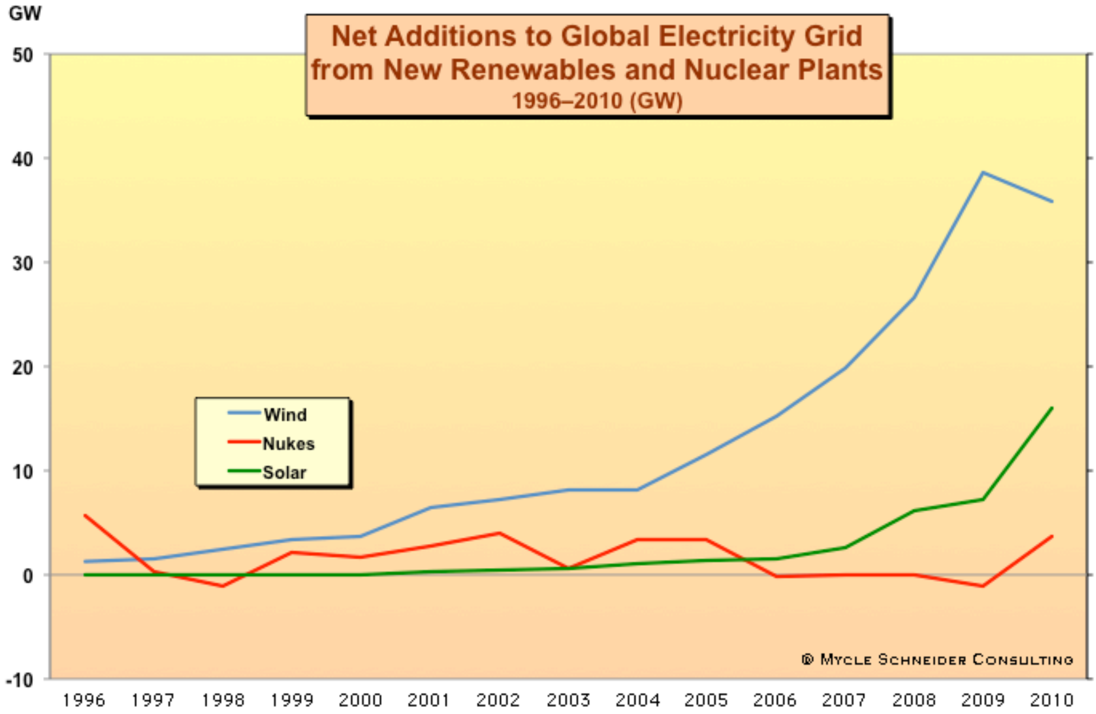
| Years | Number of Reactors | Average Construction Time (months) |
|---|---|---|
| 1965–1970 | 48 | 60 |
| 1971–1976 | 112 | 66 |
| 1977–1982 | 109 | 80 |
| 1983–1988 | 151 | 98 |
| 1995–2000 | 28 | 116 |
| 2001–2005 | 18 | 82 |
| 2005–2010 | 10 | 71 |

Note: The 2005–10 range does not include completion of Romania's Cernavoda 2 unit, which took 279 months, and Russia's Rostov unit, which took 322 months, due to an extended break in construction.
*Source: See Endnote 15 for this section.*

It is important to note the differences in construction of a wind farm (and many other renewable energy schemes) compared to conventional power stations. The European Wind Energy Association (EWEA) likens building a wind farm to the purchase of a fleet of trucks: the turbines are bought at an agreed fixed cost and on an established delivery schedule, and the electrical infrastructure can be specified well in advance. Although some variable costs are associated with the civil works, these are very small compared to the overall project cost.[16] The construction time for onshore wind turbines is relatively quick, with smaller farms being completed in a few months, and most well within a year.

The contrast with nuclear power, and even conventional fossil fuel power plants, is significant.
Looking at the net additions to the global electricity grid over the last two decades, nuclear power added some 2 GW annually on average during the beginning of this period, compared with a global installed capacity of some 370 GW today.[17] (See Figure 13.)

**Figure 13. Net Additions to Global Electricity Grid from New Renewables and Nuclear, 1990–2010 (in GW)**




*Sources: See Endnote 17 for this section.*

However, this trend has stagnated or decreased since 2005. Over the same period, global installed wind power capacity increased more than 10 GW annually on average, rising steadily to more than 37 GW in 2009 and 35 GW in 2010. Solar PV has accelerated rapidly in recent years as well.

In 2010, for the first time, the cumulative installed capacity of wind power (193 GW), small hydropower (80 GW), biomass and waste-to-energy (65 GW), and solar power (43 GW) reached 381 GW, outpacing the installed nuclear capacity of 375 GW prior to the Fukushima disaster.[18] Although renewable electricity generation (excluding large hydro) will remain lower than nuclear output for a while, it is catching up fast.

Total investment in clean energy technologies increased 30 percent in 2010 to $243 billion globally, a nearly fivefold increase over 2004.[19] China is the world leader, investing $54.4 billion in renewables in 2010 (up 39 percent over the previous year), followed by Germany at $41.2 billion (up 100 percent) and the United States at $34 billion (up 66 percent).[20] (See Table 4.) Italy more than doubled its renewable energy investments in 2010, to $13.9 billion, jumping in rank from 8th to 4th. Extension of a favorable feed-in tariff is expected to more than double Italy's installed PV capacity in 2011 to around 8 GW—the government's target for 2020.[21]

**Table 4. Renewable Energy Investment, Top 10 Countries, 2009 versus 2010**

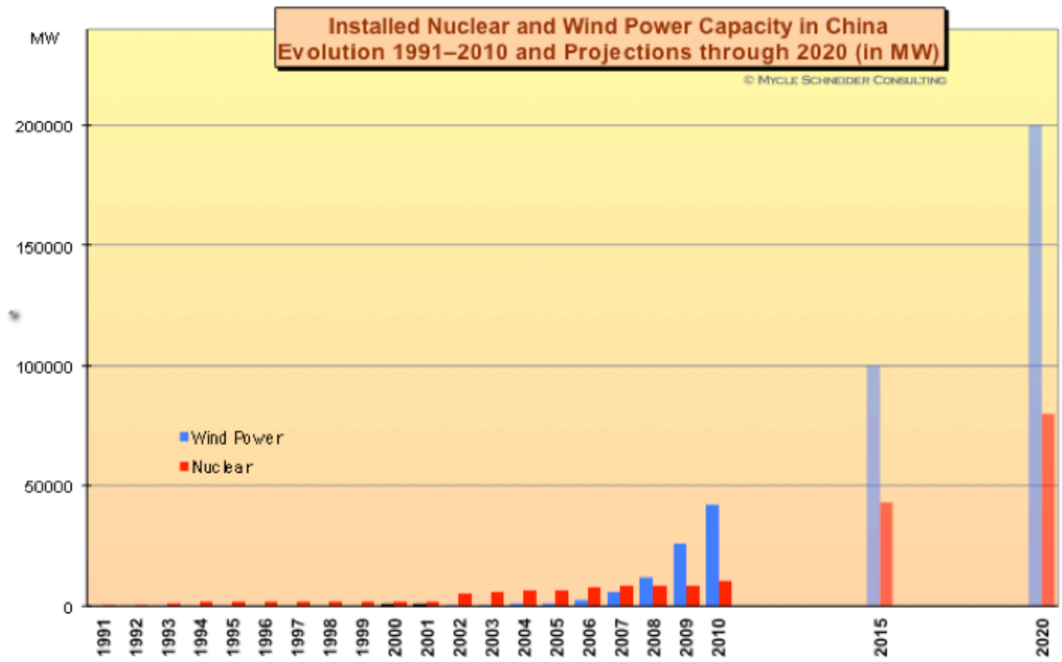
| 2010 Rank | Country | 2010 Investment (billion dollars) | 2009 Investment (billion dollars) | 2009 Rank |
|---|---|---|---|---|
| 1 | China | 54.4 | 39.1 | 1 |
| 2 | Germany | 41.2 | 20.6 | 3 |
| 3 | United States | 34.0 | 22.5 | 2 |
| 4 | Italy | 13.9 | 6.2 | 8 |
| 5 | Rest of EU-27 | 13.4 | 13.3 | 4 |
| 6 | Brazil | 7.6 | 7.7 | 7 |
| 7 | Canada | 5.6 | 3.5 | 9 |
| 8 | Spain | 4.9 | 10.5 | 6 |
| 9 | France | 4.0 | 3.2 | 12 |
| 10 | India | 4.0 | 3.2 | 11 |

*Source: See Endnote 20 for this section.*

Part of this rapid scale-up is due to the geographical diversity of renewable energy deployment. According to the Global Wind Energy Council, some 50 countries are home to more than 10 MW of installed wind power capacity, compared to 30 countries operating commercial nuclear reactors. Although the majority of renewable energy countries are in Europe, there is widespread deployment of wind power in Egypt (550 MW), New Zealand (500 MW), Morocco (286 MW), and the Caribbean (99 MW). Markets in emerging and developing countries now determine growth in wind power, and in 2010 for the first time, more than half of newly added wind power was installed outside of Europe and North America.[22]

China in particular has become the global leader for new capacity in both nuclear and wind power. Forty percent of all reactors under construction are in China. The extent to which both technologies are expected to grow is unparalleled, although the installed capacity for wind power, at roughly 45 GW, is currently more than four times that for nuclear (roughly 10 GW).[23] (See Figure 14.)

**Figure 14. Installed Nuclear and Wind Power Capacity in China, 1991–2010 and Projections to 2020 *(MW)***



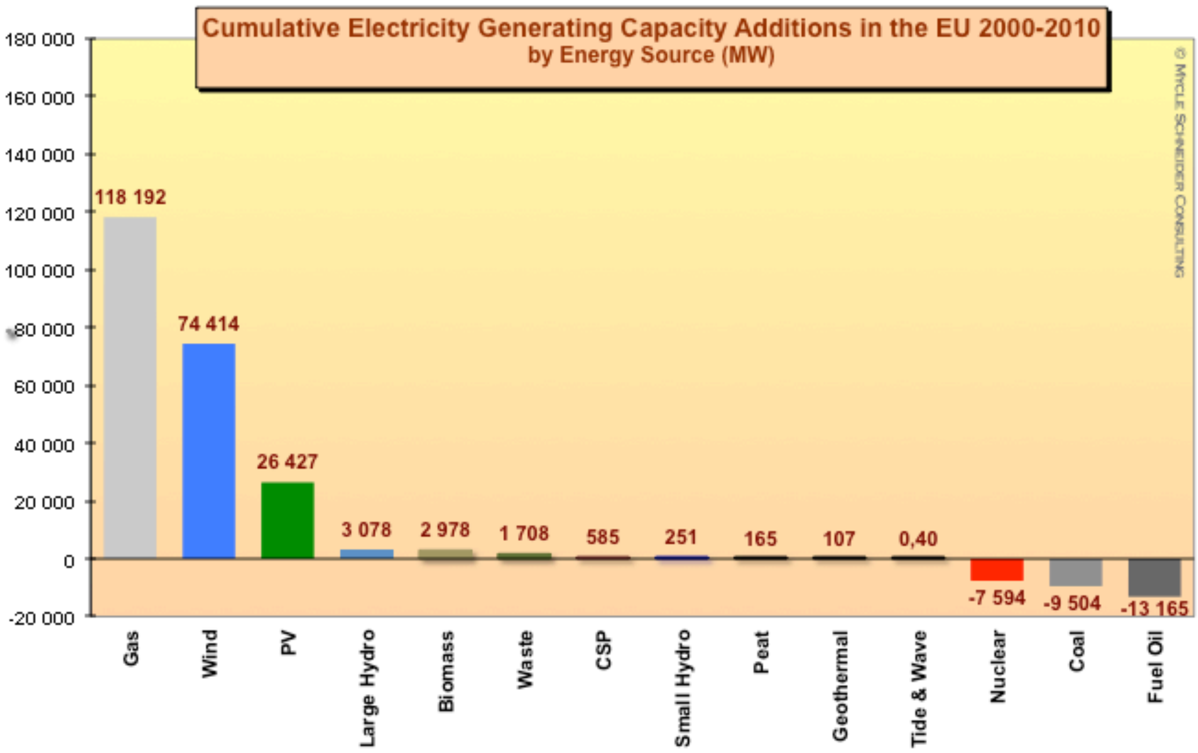

*Source: See Endnote 23 for this section.*

Even with a 3–4 times lower load factor, wind is likely to produce more electricity in China in 2011 than nuclear. China's wind power growth is so dramatic that the country must continually raise its production targets, as they are repeatedly being met prematurely.[24] China is not only a major implementer of wind technologies, but a global player in related manufacturing. In India, meanwhile, wind generation outpaced nuclear power already in 2009, according to data from the U.S. Department of Energy.[25]

In the United States, no new nuclear capacity has been added since the Watts Bar-2 reactor in Tennessee was commissioned in 1996, after 23 years of construction. Meanwhile, the share of renewables in newly added U.S. electricity capacity jumped from 2 percent in 2004 to 55 percent in 2009.[26] And although Germany provisionally shut down seven of its reactors after the Fukushima disaster, if the remaining 10 units generate a similar amount of electricity as they did in 2010, then in 2011 for the first time ever renewable energy will produce more of the country's power than nuclear. Four German states generated more than 40 percent of their electricity from wind turbines alone already in 2010.[27]

An analysis by the European Wind Energy Association (EWEA) shows that while more than 100 GW of wind and solar were added to the EU power grid between 2000 and 2010, nuclear generation declined by 7.6 GW, joining the rapidly declining trend of coal- and oil-fired power plants. (See Figure 15.)

**Figure 15. Cumulative Electricity Additions in the European Union, by Energy Source, 2000–10**




*Source: EWEA*

## Are Nuclear and Renewables Compatible?

*"If someone declares publicly that nuclear power would be needed in the baseload because of fluctuating energy from wind or sun in the grid, he has either not understood how an electricity grid or a nuclear power plant operates, or he consciously lies to the public. Nuclear energy and renewable energies cannot be combined."*
—Siegmar Gabriel, then-Federal Environment Minister of Germany[28]

From a systemic perspective, the key question is whether nuclear energy is in fact compatible with a power system that is dominated by energy efficiency and, in particular, by renewable energy. Experience in places where renewables account for a rapidly growing share of electricity generation, such as Germany and Spain, suggests that efficient "co-dominant" systems are not possible. The main reasons are as follows:

*Overcapacity kills efficiency incentives.* Large, centralized power-generation units tend to lead to structural overcapacities. Overcapacities usually lead to lower prices, which discourages energy efficiency. Lower prices also stimulate consumption or inefficient uses, often leading to higher electricity bills.

*Renewables need flexible complementary capacity.* Increasing levels of renewable electricity will require flexible, medium-load complementary facilities rather than inflexible, large, baseload power plants. Johannes Lambertz, CEO of RWE Power, one of Germany's largest electricity utilities, observed in 2010 that, "what is most important for the energy industry is the wise integration of renewable energies into the power generation market."[29] In Germany, the injection of renewable electricity has legal priority over nuclear and fossil power. But in October 2008, wind energy generation was so high that some non-renewable electricity had to be offered for "negative" prices on the power market because utilities could not reduce the output from nuclear and coal plants quickly enough—even though some 8 GW of nuclear capacity was off line for maintenance.[30] Since then, negative electricity prices, legal in Germany since September 2008, have become a more frequent phenomenon: in the six months between September 2009 and February 2010, power prices in Germany dropped into the red on 29 days. Negative prices, a sort of financial penalty for inflexibility, reached stunning levels: on October 4, 2009, one power producer had to pay up to €1,500 per megawatt-hour (15 cents per kilowatt-hour) to get rid of its electricity.

*Future grids go both ways.* Smart metering, smart appliances, and smart grids are on their way, and received considerable emphasis in the economic stimulus packages of many countries in 2008. Under this entirely redesigned grid system, which is radically different from the top-down centralized approach, the user also generates and stores power. The consumer becomes producer and vice-versa, giving rise to the "prosumer."

In many developing countries, where key decisions about grid infrastructure have yet to be made, it is critical to assess the implications of these basic system choices. Industrial countries illustrate the outcome of past strategic choices. Unfortunately, although there are numerous successful local and regional cases, there is no "good" example of a successful national energy policy that provides affordable, sustainable energy services. All countries have implemented policies that have serious drawbacks, and major "repair jobs" are necessary to address the defaults.

# Post-3/11 Developments in Selected Countries
## (as of April 2011)

The nuclear crisis in Japan that commenced with the devastating 3/11 earthquake and tsunami is far from over as we are writing this report. Nevertheless, it is already obvious that the implications for the international nuclear industry will be unprecedented. The following chapter merely attempts to give a first snapshot on reactions by key players in a selected number of countries. The financial sector also has reacted to the disaster events, issuing preliminary reports and statements. (See Box, page 48.)

## Asia

*China*

The Fukushima accident may become a factor in the drafting of China's future energy plans. On March 14, Xie Zhenhua, vice chairman of the National Development and Reform Commission, stated that "[e]valuation of nuclear safety and the monitoring of plants will be definitely strengthened."[1] But some observers are more skeptical. Dave Dai, a Hong Kong-based analyst at Daiwa Securities Capital Markets Co., noted that although the accident "may trigger increased public concerns" about nuclear plants and China "will become more cautious" while developing these plants, the country "is unlikely to alter its long-term nuclear development plans."[2]

Tian Jiashu, director of two nuclear safety centers under the Ministry of Environmental Protection, similarly observed that, "The safety of China's nuclear power facilities is guaranteed and China will not abandon its nuclear power plan for fear of slight risks."[3] Nevertheless, the write-up of a mid-March State Council meeting chaired by Premier Wen Jiabao states unequivocally: "We will temporarily suspend approval of nuclear power projects, including those in the preliminary stages of development.... We must fully grasp the importance and urgency of nuclear safety, and development of nuclear power must make safety the top priority."[4]

*India*

The Fukushima crisis may be "a big dampener" on India's program, according to Shreyans Kumar Jain, chairman of the Nuclear Power Corp. of India (NPCIL), who stated: "We and the Department of Atomic Energy will definitely revisit the entire thing, including our new reactor plans, after we receive more information from Japan."[5] But Sudhinder Thakur, NPCIL executive director, has sought to minimize the impact: "The accident in Japan is quite serious and we are in touch with international organizations, but there is no need for a knee-jerk reaction on our program."[6] Key outside observers are more pessimistic: "The Japan accident has created a very, very tough situation for India; actual implementation of nuclear power projects will now certainly take a backseat," said Debasish Mishra, Mumbai-based senior director at Deloitte Touche Tohmatsu. "It will be very difficult to sell the idea of nuclear power to people for any political party after the Japan disaster."[7] In fact, following Fukushima, public protests have intensified at all sites earmarked for new nuclear reactor projects.

*Indonesia*

Hudi Hastowo, head of Indonesia's National Atomic Energy Agency (Batan), told the Jakarta Post that using nuclear energy was one of the best solutions to address the country's power shortage issue. He played down safety issues that critics have been voicing, saying that it would be safe to operate a nuclear plant.[8] Chalid Muhammad from the environmental NGO Indonesia Green Institute, however, has argued that the government should stop the plan to build a reactor because 83 percent of Indonesia's area is prone to disasters such as earthquakes and tsunamis. "The government should focus on building decentralized power plants that use renewable energy sources, such as micro-hydro and geothermal plants," Muhammad said, stating that these small-scale plants can meet the needed electricity demand and are much safer compared to larger plants.[9]

Environment Minister Gusti Muhammad Hatta observed in mid-March that Indonesia is not ready to build nuclear plants due to human resource issues and public opposition. He argued that nuclear power plants should be the last resort because the country has several other energy options. But Gusti's statement comes even as Batan insists on going ahead with its nuclear program despite mounting opposition.[10]

*Japan*

In total, 14 of 54 reactors in Japan remain off line as a consequence of the Fukushima disaster. Units 1–4 of the Fukushima-I plant are condemned, and the likelihood for units 5 and 6 to be restarted is virtually zero. Japanese Chief Cabinet Secretary Yukio Edano said the government will review its nuclear power policy once the situation at the crippled plant is under control. "Once this is resolved, we need to carry out a thorough review and examination of this major policy decision."[11] In a late-

March 2011 survey by Kyodo news agency, more than 58 percent of Japanese respondents disapproved of how the government was dealing with the crisis.[12]

Tokyo Electric Power Co. (TEPCO), the operator of the Fukushima plant, is suffering badly, and there are suggestions that the company will have to be nationalized to avoid bankruptcy. Toward the end of March 2011, TEPCO was forced to secure $25 billion from three of Japan's largest banks for emergency funding; even so, it will likely need to ask the government for further financial support.[13] The company's share value has fallen dramatically and had lost more than half of its pre-Fukushima value as of late March 2011.[14]

TEPCO halted construction at its Higashidori plant and suspended plans for three more units. Two other Japanese utilities have also taken action: Electric Power Development Co. halted construction of the Oma plant, and Chubu Electric postponed a new-build project. On April 6, 2011, Ikuhiro Hattori, chairman of the National Federation of Fisheries Cooperative Associations, met with TEPCO Chairman Tsunehisa Katsumata and declared: "You've trampled on the nationwide efforts of fishery operators We want your company to make clear your responsibility in and countermeasures for bringing about such a serious accident as this, and that is why I have come."[15] The fisheries union chairman announced that his organization will request the closure of all nuclear power plants in Japan.

*Malaysia*

Two of Malaysia's three Barisan Nasional (National Front) government coalition parties—the Malaysian Chinese Association (MCA) and Gerakan—have joined together in urging the government to reconsider its proposed nuclear plant program in light of the inherent danger to the general public. But Energy, Green Technology, and Water Minister Datuk Seri Peter Chin Fah Kui has indicated that the government will proceed with its plan to build two nuclear power plants despite the tragedy in Japan. He added that all aspects will be considered before a final decision is made, saying that the "government will not do it secretly without informing the public." The Democratic Action Party (DAP), Malaysia's largest opposition party, urged the government to abandon the idea of setting up nuclear plants to generate electricity.[16]

Deputy Prime Minister Muhyiddin Yassin believes that Malaysia is capable of handling its nuclear ambitions. While acknowledging the concerns in view of radiation leaks from Japan's affected plants, he asserted that his government's plan to build two plants is safe. "I think every country in the world is taking note of what is happening in Japan," Yassin said at a press conference. "There are many things that we can learn, but what is important is the safety of the country and the public. In this matter, we have an agency that is responsible and we are confident that they will implement what is best."[17]

*Thailand*

An opinion poll in late March 2011 found that 83 percent of respondents disagreed with the plan to build nuclear plants in Thailand, and only 16.6 percent backed the move. When asked about construction of a nuclear plant in their respective provinces, 89.5 percent of respondents objected while only 10.5 percent agreed.[18] Thailand's study on nuclear plant construction will be thoroughly reviewed in light of the crisis in Japan, which will serve as a study case for Thailand, Energy Minister Wannarat Channukul said.[19]

*Taiwan*

On March 28, 2011, the *United Evening News* quoted Minister of Economic Affairs Shih Yen-shiang as saying that nuclear power will remain a necessary choice for Taiwan in the coming decades to ensure a stable and affordable energy supply.[20] Lawmakers with the Democratic Progressive Party (DPP) called on the legislature to approve a referendum on nuclear power, the latest in an effort to scrap the Fourth Nuclear Power Plant in New Taipei City.[21]

*Vietnam*

The Ministry of Foreign Affairs stated in a press release on its website: "Viet Nam puts nuclear safety-related issues [as] a top priority. This is particularly important in the context of climate change and natural disasters, particularly the earthquake and tsunami [that] just happened in Japan."[22] Deputy Minister Le Dinh Tien stated: "Vietnam is planning to build nuclear power plants. Information and assessments of the blasts at the Fukushima No. I plant will act as a foundation to help Vietnam's relevant authorities appropriate nuclear power programs in the country."[23]

## Middle East

*United Arab Emirates*

South Korean president Lee Myung-bak dismissed concerns about the safety of nuclear plants that the South Korean industry plans to build in the UAE. Safety concerns have been rising since the Fukushima crisis began. Lee said that South Korea will make all-out efforts to ensure the safety of reactors. "The construction of the nuclear power plants reflects growing economic ties between Korea and the UAE. We will take all possible measures to ensure their safety," Lee said three days after the Fukushima crisis started, at a groundbreaking ceremony for initial work at the proposed nuclear site in Braka, some 300 kilometers west of Abu Dhabi. The Crown Prince of Abu Dhabi, Sheikh Mohammed bin Zayed al Nahyan, was also present.[24]

## Europe

*European Union*

On March 15, 2011, EU Energy Commissioner Günther Oettinger stated: "We must also raise the question of if we, in Europe, in the foreseeable future, can secure our energy needs without nuclear energy."[25] At a meeting on March 24–25, the European Council (EC) released a statement calling for the following priorities (as paraphrased):

- The safety of all EU nuclear plants should be reviewed on the basis of comprehensive and transparent risk and safety assessments (i.e., "stress tests") developed in light of the lessons learned from Japan and with the full involvement of European member states. The assessments will be conducted by independent national authorities, making use of all available expertise and peer review, and the results and any necessary subsequent measures will be made public. The EC will assess initial findings by the end of 2011.
- The EU will request that similar "stress tests" be carried out in neighboring countries and worldwide, for both existing and planned plants and with full use of relevant international organizations;
- The highest standards for nuclear safety should be implemented and continuously improved in the EU and promoted internationally;
- The EC will review the existing legal and regulatory framework for the safety of nuclear installations and will propose by the end of 2011 any improvements that may be necessary. Member states should ensure full implementation of the directive on the safety of nuclear installations and adopt as soon as possible the proposed directive on the management of spent fuel and radioactive waste. The EC is invited to reflect on how to promote nuclear safety in neighboring countries.[26]

*Bulgaria*

EU Energy Commissioner Günther Oettinger has said that Bulgaria's project to build a second nuclear plant in the Danube town of Belene must be re-examined.[27] Bulgaria announced that it will seek additional safety guarantees on two Russian nuclear reactors planned for the Belene plant, with Energy and Economy Minister Traicho Traikov stating that Bulgaria will "request additional information and guarantees from the manufacturer."[28]

*Czech Republic*

On March 14, 2011, Dana Drabova, chief of the Czech state office for nuclear safety, said that the country has no immediate plans to review its nuclear expansion plans, but that the Fukushima crisis could potentially raise serious questions for her country's nuclear future. "It will depend a lot on how it finally ends in Japan," Drabova said. "If they can handle it, as they are so far, it might not have serious consequences, but if the situation there worsens significantly, it will mean serious questions and serious discussions."[29]

*Finland*

Minister of Economic Affairs Mauri Pekkarinen, responsible for energy issues, has said that Finland will review the safety of its nuclear reactors in light of the Japanese crisis. "We have agreed with STUK [the Finnish nuclear authority] that we will again go through safety risks and electricity supply functionality in all situations," he said.[30]

*France*

French President Nicolas Sarkozy has stated that it would be "obviously out of the question to phase out nuclear [power]."[31] Prime Minister François Fillon has requested the Nuclear Safety Authority (ASN) to carry out a safety assessment of all 58 French operating reactors. ASN has said the audit will be consistent with the EU initiative for "stress tests" and that implementation of lessons learned from Fukushima will be "a long process that will stretch over several years."[32]

For the first time, a leader of a major French political party has asked openly for a phase-out of nuclear power. Martine Aubry with the French Socialist Party said she was "personally in favor of phasing out nuclear power," although her party was still debating the question.[33] François Bayrou, president of the MODEM party, has said that "the rethink must put into question [France's] 100-percent-nuclear option."[34] And the Green Party has requested a national referendum on nuclear energy. In an opinion survey commissioned by the party and carried out by the French Institute of Public Opinion (IFOP), 70 percent of respondents supported a nuclear phase-out in France, of which 51 percent favor a gradual phase-out (25–30 years) while 19 percent favor a "rapid" end to reactor operation.[35]

The Fukushima crisis is causing considerable financial uncertainty for the French national utility EDF, which has said it would wait for details of the new electricity law before presenting its strategy to investors. This is due to uncertainty about technical upgrade requirements. One analyst from Citigroup noted that, "If the regulator releases an upgrade plan for the nuclear plants by the end of June, we are skeptical on whether EDF will be able to present a credible mid-term plan before it knows and assesses these details."[36] A colleague from the Société Générale confirms that, "Investors could put into question the validity of EDF's strategy."[37]

*Germany*

On March 15, 2011, Chancellor Angela Merkel abruptly put plans to extend the life of Germany's reactors on hold for at least three months, noting that the seven reactors started up before 1980 will be shuttered during a three-month review of plant safety and the country's broader energy strategy.[38] Hermann Groehe, general secretary of Merkel's Christian Democratic Union (CDU), later stated that most of the seven plants will probably never restart.[39] Jürgen Grossmann, CEO of RWE, one of the four large nuclear operators in Germany, conceded that "it can be excluded that all seven will continue to operate."[40]

Junior government ministers have even been quoted as calling for the closure of Germany's reactors within 10 years. Jürgen Becker, the deputy environment minister, stated: "A decision has been taken to shut down eight plants before the end of this year and they definitely won't be reactivated. And the remaining nine will be shut down by the end of the decade." He gave as justification for this rapid phase-out: "Japan has shown that even if there is a miniscule occurrence, the residual risk is too high to justify the continuation of nuclear power.... It is better to go for other energy services in a civilized country."[41]

Germany's political landscape has been profoundly marked by the Fukushima events. Equity research company NOMURA concluded that, "[w]e are now less likely to get nuclear life extensions and there could be a greater need to spend additional amounts on safety. This is likely to be the near-term focus, and the impact on regional elections in Germany could determine the future for life extensions."[42] In a historic election in Bade-Wurtemberg, the Green Party doubled its votes to reach 24.2 percent and trailed only the formerly governing CDU. For the first time, a Green Prime Minister of the third largest German state, with a population of over 10 million, will lead a coalition with the Social Democrats. The state recently bought back EDF's participation in the utility EnBW and co-owns four nuclear reactors, two of which are among the seven that are "provisionally" shut down. In Germany, state governments have primary administrative responsibility for nuclear safety.

*Italy*

Italian utility ENEL still counts on moving ahead with the relaunch of nuclear power in Italy as part of a €31 billion ($45 billion) spending budget in the next five years. Presenting its 2011–15 business blueprint in London, ENEL said it would improve its energy mix in Italy by developing nuclear power along with clean coal and liquefied natural gas. The center-right government of Prime Minister Silvio Berlusconi vowed to re-launch nuclear power in Italy after it was banned in 1987.[43] On March 23, 2011, however, the Italian cabinet approved a one-year moratorium on the relaunch. Energy Minister Paolo Romani stated that, "The government won't proceed with the realization [of a nuclear program] if the initiatives at European Union level don't provide full guarantees on safety."[44]

Although a referendum on nuclear plant construction planned for later in 2011 could have derailed any potential further plans, the Italian government decided to pull the plug even earlier, on April 20. The cabinet tabled a bill that abrogates previous legislation that would have set the scene for a restart of the nuclear program.[45] The latest opinion polls show that three-quarters of Italians surveyed favor dropping the country's nuclear plans.

*The Netherlands*

The Netherlands is following the Fukushima crisis very closely and will take the Japanese experience into account when deciding on the Dutch nuclear power program, economic affairs minister Maxime Verhagen said.[46]

*Poland*

The early official reaction in Poland was that the country would press on with plans to build its first nuclear power plants despite renewed safety concerns in the wake of the Fukushima crisis.[47] A week later, however, on 23 March 2011, Polish Premier Donald Tusk did not rule out a referendum on the issue, stating that, "this kind of undertaking doesn't make sense without social approval."[48]

*Sweden*

Swedish Prime Minister Fredrik Reinfeldt said the decision "still holds" to allow for replacement of any of the country's 10 operating units that will be shut down in the future, and that safety reviews are not foreseen.[49] But public opinion differs. A poll in the leading Swedish daily *Dagens Nyheter* (DN) showed that 36 percent of Swedes now support a phase-out of nuclear power, up from 15 percent in

2008 and up sharply since the Japan crisis started. The poll also showed that only 21 percent of Swedes now favor further development of the country's nuclear power capacity, a spectacular drop from 47 percent in 2008.[50] On March 30, 2011, the Swedish Radiation Authority agreed with the nuclear operators to review nuclear safety and to carry out "stress tests," following the EU line.[51]

*United Kingdom*

Chris Huhne, Secretary of State for Energy and Climate Change, called for a thorough report on the implications of the situation in Japan and the lessons to be learned. The report will be prepared in close cooperation with other nuclear regulators internationally. "It is essential that we understand the full facts and their implications, both for existing nuclear reactors and any new program, as safety is always our number one concern," Huhne said.[52] Meanwhile, a poll commissioned by Friends of the Earth found that fewer than 10 percent of respondents now believe that nuclear power should be an investment priority in coming years, while more than 75 percent think that the focus should be on renewables or energy efficiency in homes, business, and industry.[53] The CEO of French utility EDF's U.K. subsidiary, Vincent de Rivaz, has nevertheless stated that the U.K.'s plans for nuclear power plants "have to go ahead."[54]

## Non-EU Europe

*Russia*

Just after the start of the Fukushima crisis, Prime Minister Vladimir Putin commissioned a review of the future of Russia's nuclear power energy sector, requesting "that the energy ministry, nuclear agency and environment ministry carry out an analysis of the current condition of the atomic sector and an analysis of the plans for future development." Putin ordered that the results of the investigation be delivered to the government "within one month."[55]

*Switzerland*

Switzerland was one of the first countries to take domestic action in response to the Fukushima crisis. On March 14, 2011, Energy Minister Doris Leuthard suspended the approval process for three new nuclear power stations so safety standards could be revisited.[56] Support for nuclear plants fell sharply in Switzerland following the crisis, with a poll published on March 20 showing that 87 percent of the population wants the country's reactors phased out.[57]

## The Americas

*Brazil*

In the early days of the Fukushima crisis, Brazilian Mines and Energy Minister Edison Lobao stated that no changes would be made to Brazil's nuclear energy program, which foresees construction of four new nuclear reactors in the coming years.[58] Ten days later, however, Science and Technology Minister Aloizio Mercadante said that Brazil "isn't in a hurry" to build more plants and would comply with any new international standards, because "with nuclear energy, safety comes before any other issue."[59]

*United States*

Senator Joe Lieberman of Connecticut stated on CBS's *Face the Nation*: "I don't want to stop the building of nuclear power plants, but I think we've got to kind of quietly, quickly put the brakes on until we can absorb what has happened in Japan...and then see what more, if anything, we can demand of the new power plants that are coming on line."[60] Deputy Energy Secretary Daniel Poneman said nuclear power must be considered as part of any energy strategy, stating that, "We do see nuclear power as continuing to play an important role in building a low-carbon future. But be assured that we will take the safety aspect of that as our paramount concern."[61]

U.S. Republican lawmakers who back nuclear power do not appear to be about to give up the struggle because of events in Japan. Even though his state is a known earthquake-prone region, Congressman Devin Nunes of California has proposed a comprehensive energy bill that calls for 200 new nuclear power plants nationwide by 2040 and thinks the events at Fukushima will "make the case for nuclear power in the long run."[62] Christine Tezak, an energy analyst with Robert W. Baird and Co. is skeptical, noting that there will be a "further re-examination of future nuclear construction plans in the United States" and that "inexpensive natural gas in the United States has made it difficult to move forward with nuclear projects."[63] John Rowe, CEO of Exelon, the largest U.S. nuclear plant operator, agrees that "new nuclear plants are not economic investments with today's natural gas forecasts."[64]

Nuclear utility NRG, the majority shareholder of the South Texas Project (STP), announced in April 2011 that it is withdrawing from the project, writing down $481 million investment and excluding any further investment. NRG CEO David Crane said: "The tragic nuclear incident in Japan has introduced multiple uncertainties around new nuclear development in the United States which have had the effect of dramatically reducing the probability that STP 3 and 4 can be successfully developed in a timely fashion."[65]

**Box 1. Reactions by the Financial Sector to the Fukushima Crisis[66]**

With the crisis at Fukushima still unfolding as of early April 2011, the long-term impact of the disaster remains highly uncertain. In mid-March, however, London-based bank HSBC undertook a first analysis of some of the areas where the nuclear sector has been and might be affected. These include:

- Safety reviews of reactors in several countries (e.g., Germany, Spain, Switzerland, the U.K., and the United States);
- Immediate shutdown of older reactors (e.g., Germany);
- Limited or no further lifetime extensions for aging reactors (e.g., Germany, the U.K., the United States);
- Suspension of new plant approvals (including in China, which was expected to account for 40 percent of new installations over the next decade);
- Review of reactors under construction in seismically active zones;
- Higher safety and other costs (as yet hard to quantify) for new and existing nuclear facilities that would render nuclear power less economic or uneconomic; and
- Re-evaluation of planned energy policy in all nuclear countries, with a greater focus on energy efficiency measures and natural gas and renewables installations.

The HSBC report concluded that, "[o]verall, we expect a number of impacts from the public and political backlash against nuclear, which could mean the focus switches to renewables."

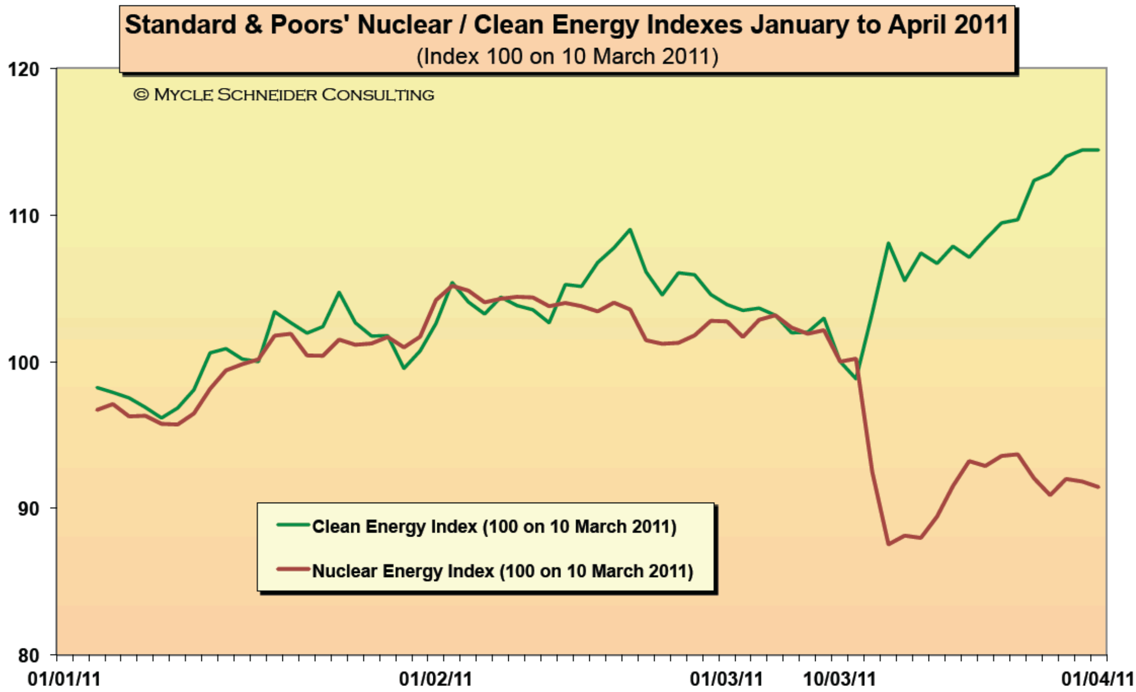
Trends in Standard and Poor's nuclear and clean energy indexes also clearly illustrate the changing fortunes of these two sectors during the first quarter of 2011. (See Figure 16.) Although the two indexes had been tracking closely early in the year, after the Fukushima crisis in early March the valuation of clean energy companies rose 17 percent on average, while that of nuclear companies fell 8.7 percent.

Analysts anticipate more specific implications for Japanese companies, and not just for TEPCO, the utility that owns the troubled Fukushima reactors. In April, credit rating agency Moody's suggested that the nuclear crisis could significantly impact Japan's electric utility sector, resulting in "a fundamental reassessment of the use of nuclear power in Japan, perhaps resulting in earlier than anticipated decommissioning of some nuclear plants and the potential cancellation or indefinite postponement of some new nuclear generation." These developments, according to Moody's, "are likely to result in accelerated decommissioning costs, increased capital expenditures for higher cost replacement generation, lower reserve margins, and higher operating costs at existing nuclear plants as a result of increased scrutiny, more stringent safety procedures, and longer required maintenance outages."

Japan's nuclear builders will be affected severely as well. In early April, Deutsche Bank's Takeo Miyamoto stated that "any plans to export all-Japan nuclear reactor projects will be delayed," and Yuichi Ishida with Mizuho Investors Securities Co. in Tokyo commented that "the myth of Japan's nuclear safety is dying." Such fears have led to a dramatic decline in the share prices of reactor manufacturers Hitachi and Toshiba.

Analysts at Swiss-based investment bank UBS summarized the likely global impact of Fukushima in a report dated April 4, 2011: "At Fukushima, four reactors have been out of control for weeks—casting doubt on whether even an advanced economy can master nuclear safety.... We believe the Fukushima accident was the most serious ever for the credibility of nuclear power."

**Figure 16. Fortunes of Nuclear and Clean Energy Companies, January–March 2011**



# Annex 1. Overview by Region and Country

This annex provides an overview of nuclear energy worldwide by region and country. Unless otherwise noted, data on the numbers of reactors operating and under construction (as of March 2011) and nuclear's share in electricity generation are from the International Atomic Energy Agency's Power Reactor Information System (PRIS) online database. Historical maximum figures, provided in parentheses, indicate the year that the nuclear share in the power generation of a given country was the highest since 1986, the year of the Chernobyl disaster.

## Africa

**South Africa** has two French (Framatome) built reactors. They are both located at the Koeberg site east of Cape Town, which supplied 4.8 percent of the country's electricity in 2009 (the historical maximum was 7.4 percent in 1989). The reactors are the only operating nuclear power plants on the African continent.

The state-owned South African utility Eskom launched an effort in 1998 to develop the Pebble Bed Modular Reactor (PBMR), a helium-cooled graphite moderated reactor based on earlier German designs. Initially, it was forecast that a demonstration plant would be built and that commercial orders would be possible from 2004 onward. However, projected costs escalated dramatically and timescales slipped, leaving Eskom and the South African government to pick up the development costs. In 2008, operation of the demonstration plant was not expected before 2016. Costs had increased almost 10-fold from the early estimates, and commercial orders were not expected before 2026. In September 2010, the government "[dropped the] final curtain on PBMR," a few months after having terminated all public support.[1] Some $1.3 billion had been invested in the project, with more than 80 percent coming from the South African government.[2]

The failure of the PBMR led Eskom to consider buying additional large Pressurized Water Reactors (PWR). In the longer term, it planned to build 20 gigawatts (GW) of nuclear plants by 2025. In addition to escalating cost projections, Eskom faced an additional challenge of a falling credit rating, reduced by Moody's in August 2008 to Baa2, the second worst investment grade. In November 2008, Eskom scrapped an international tender because the scale of investment was too high.

In October 2010, facing power shortages in the medium term, the South African government decided to open investment in power generation to private companies. "Eskom does not have the money, the government doesn't have the money" to invest in nuclear plants, Chris Forlee, deputy director general of the Department of Public Enterprises stated.[3] While nuclear power is "likely" to be the preferred option, according to Forlee, within two weeks in late 2010, the Department of Energy received 384 applications combining 20 GW, of which 70 percent were wind, 15 percent photovoltaic solar, 10 percent concentrated solar, and the remainder biomass projects. In addition, the department received 20 applications totaling 4 GW of combined heat and power (CHP) projects.[4]

## The Americas

**Argentina** operates two nuclear reactors that provided less than 6 percent of the country's electricity in 2010 (down from a maximum of 19.8 percent in 1990). Argentina was one of the countries that embarked on an ambiguous nuclear program, officially for civil purposes but backed by a strong military lobby. Nevertheless, the two nuclear plants were supplied by foreign reactor builders: Atucha-1, which started operation in 1974, was supplied by Siemens, and the Candu type reactor at Embalse was supplied by the Canadian AECL. After 28 years of operation, the Embalse plant is supposed to get a major overhaul, including the replacement of hundreds of pressure tubes, to operate for a potential 25 more years.[5]

Atucha-2 is officially listed as "under construction" since 1981. In 2004, the International Atomic Energy Agency (IAEA) estimated that the start-up of Atucha-2 would occur in 2005. By the end of 2007, the IAEA's projected start-up date had turned into a question mark that was later replaced by 1 October 2010 as a new projected date for grid connection, which was not met. As of February 2011, according to the IAEA, grid connection has been delayed to the admirably precise date of 6 July 2012, exactly 31 years after construction start.

The presidents of Argentina and Brazil, Fernandez de Kirchner and Lula, met in February 2008 and agreed to "develop a program of peaceful nuclear cooperation that will serve as example in this world."[6] In early May 2009, Julio de Vido, Argentina's Minister of Planning and Public Works, stated that planning for a fourth nuclear reactor would be under way and that construction could start as early as within one year.[7] It did not. Neither a siting decision, nor a call for tender, has been reported to date. Fernandez and Lula's successor Dilma Rousseff met in January 2011 and signed an agreement for the joint construction of two research reactors.[8] Nothing has been reported on potential cooperation on the construction of power reactors.

**Brazil** operates two nuclear reactors that provide the country with 3.1 percent of its electricity in 2010 (down from a maximum of 4.3 percent in 2001). As early as 1970, the first contract for the construction of a nuclear power plant, Angra-1, was awarded to Westinghouse. The reactor went critical in 1981. In 1975, Brazil signed with Germany what remains probably the largest single contract in the history of the world nuclear industry for the construction of eight 1.3 GW reactors over a 15-year period. Due to an ever-increasing debt burden and obvious interest in nuclear weapons by the Brazilian military, practically the entire program was abandoned. Only the first reactor covered by the program, Angra-2, was finally connected to the grid in July 2000, 24 years after construction started.

The construction of Angra-3 was started in 1984 and abandoned in June 1991. Any hopes of Eletronuclear, the plant's owner, to relaunch construction received a severe damper in July 2008 when Environment Minister Carlos Minc announced 60 stiff "pre-license" conditions for completion of the unit. The most difficult challenge will be to provide a "definite" solution for final disposal of high-level radioactive waste. In 2008, the completion of Angra-3 looked "more doubtful."[9] However, in May 2010, Brazil's Nuclear Energy Commission issued a license for the building of Angra-3, and the IAEA indicates that a "new" construction start occurred on 1 June 2010. In early 2011, the Brazilian national development bank BNDES approved 6.1 billion reals ($3.6 billion) for work on the reactor. While some sources indicate a targeted completion date by 2015, the IAEA envisages commercial operation for 30 December 2018.[10] It is unclear how and to what extent the "pre-license" conditions have been met.

In January 2011, Brazil's Energy Minister Edison Lobao stated that the government plans to approve the construction of four additional reactors "this year."[11] However, neither the capacity of the plants nor sites have been indicated so far.

**Canada** operates 18 reactors, all of which are Candus (CANadian Deuterium Uranium), providing 15.1 percent of the country's electricity in 2010 (down from a maximum of 19.1 percent in 1994). Four additional units are listed by the IAEA as in "long-term shutdown." There have been significant delays in restarting the reactors, and as of February 2011 only four of the eight reactors had returned to operation. The two 40-year old Pickering A2 and A3 reactors were scheduled to come back online in 2009 or early 2010, but they did not. In January 2010, operator Ontario Power Generation (OPG, Ex-Ontario Hydro) requested a five-year license renewal for the four Pickering A reactors, but in July 2010 the Canadian Nuclear Safety Commission (CNSC) decided to limit the license to three years. For both Pickering A and B, the licenses will expire on 30 June 2013.[12] The two other remaining units in long-term shutdown, Bruce A3 and A4—"one of North America's most complex engineering projects," according to owner/operator Bruce Power—are slated to be back online by 2013.[13]

On 16 June 2008, the Canadian government announced Darlington in Ontario as the site for a two-unit new-build project. But in early July 2009, the Ontario government shelved the plan and the province's premier, Dalton McGuinty, observed that, "We didn't factor in the single greatest global economic recession in the past 80 years."[14] Ontario's power needs were actually declining rather than increasing as had been forecasted, leaving the province with more time to make a decision on new build.

The Darlington project resurfaced in 2010 in connection with the Canadian government's attempt to privatize the loss-making nuclear crown company, Atomic Energy of Canada Ltd. (AECL), and with a C$87 billion ($91 billion) Ontario power equipment plan to 2030 that also includes C$27 billion ($28 billion) for major refurbishment of 10 units. The Canadian government is pressing Ontario to firmly commit to the order of new reactors to give AECL's privatization a slim chance. But Premier McGuinty has stated that, "We don't feel any need to rush into anything."[15] The development of an Advanced Candu Reactor line, so far entirely financed by public funds, seems compromised today.

The province of New Brunswick has abandoned the option of adding a second nuclear reactor at its Point Lepreau site; meanwhile, a massive refurbishment project on the first unit is way over budget and running years late. The unit has been down since April 2008, and restart is currently scheduled for fall 2012.[16]

AECL has, with the support of the Canadian Export Credit Agency, undertaken an aggressive marketing campaign to sell reactors abroad, and to date a total of 12 units has been exported to South Korea (4), Romania (2), India (2), China (2), Pakistan (1), and Argentina (1). The export market, until recently a crucial component of the AECL's reactors development program, will likely not change the fate of AECL.

In 2009, Kazakhstan overtook Canada as the world's largest producer of uranium, but Canada retained a world market share of about 20 percent.

In **Mexico,** two General Electric reactors operate at the Laguna Verde power plant, located in Alto Lucero, Veracruz. The first unit went into commercial operation in 1990 and the second in April 1995. In 2010, nuclear power produced 3.6 percent of the country's electricity (down from a maximum of 6.5 percent in 1995). An uprating project carried out by Iberdrola between 2007 and early 2011 boosted the nameplate capacity of both units by 20 percent, from 682 megawatts (MW) to 820 MW (gross). The power plant is operated by Iberdrola Ingenieria of Spain (97 percent) and Alstom Mexicana of France (3 percent).[17] There are currently no concrete plans to build new reactors.

The **United States** has more operating nuclear power plants than any other country in the world, with 104 commercial reactors providing 20.2 percent of U.S. electricity in 2009 (down from a maximum of 22.5 percent in 1995). Although the country is home to a large number of operating reactors, the number of cancelled projects—138 units—is even larger. It now has been 38 years (since October 1973) since a new order has been placed that has not subsequently been cancelled.

The last reactor to be completed—in 1996—was Watts Bar 1, near Spring City, Tennessee, and in October 2007 the Tennessee Valley Authority (TVA) announced that it had chosen to complete the two-thirds-built 1.2 GW Watts Bar 2 reactor for $2.5 billion. Construction had originally started in 1972 but was frozen in 1985 and abandoned in 1994. Construction has restarted and is now expected to take until 2012 to finish the reactor. Watts Bar 1 was one of the most expensive units of the U.S. nuclear program and took 23 years to complete.

Despite the failure so far to build more reactors, the U.S. nuclear power industry remains highly successful in two main areas: increased output from existing reactors and plant life extensions. Due to changes in the operating regimes and increased attention to reactor performance, the energy availability of U.S. reactors has increased significantly from 56 percent in the 1980s to 90 percent in 2009. As a result, along with new capacity coming on line and reactor uprates, the output from U.S. reactors has tripled over this period.

The lack of new reactor orders means that over 40 percent of U.S. reactors will have operated for at least 40 years by 2015. Originally it was envisaged that these reactors would operate for a maximum of 40 years; however, projects are being developed and implemented to allow reactors to operate for up to 60 years. As of February 2011, 61 U.S. nuclear reactors had been granted a life-extension license by the Nuclear Regulatory Commission (NRC); another 21 applications are under review and some 14 have submitted letters of intent covering a period up to 2017.[18]

The election of President George W. Bush in 2000 was expected to herald a new era of support for nuclear power. The administration's National Energy Policy set a target of two new reactors to be built by 2010, but this objective was not met. To reduce uncertainties regarding new construction, a two-stage license process has been developed. This enables designs of reactors to receive generic approval, and utilities will then only have to apply for a combined Construction and Operation License (COL), which does not involve questioning of the reactors' designs.

As of February 2011, the NRC had received 18 licensing applications for a total of 28 reactors. No application was submitted in 2010/11, and only one in 2009. Of the 28 reactor projects, three were subsequently cancelled, three were suspended, and 16 were delayed.[19] The U.S. Department of Energy (DOE) attributes the delays to such factors as "rising costs, adverse regulatory decisions, difficulties in negotiations for new reactors, and last-minute reactor design changes," in addition to low costs of competing fuels.[20]

License applications cover five different reactor designs: GE-Hitachi's Advanced Boiling Water Reactor (ABWR) and Economic Simplified Boiling Water Reactor (ESBWR), Mitsubishi's Advanced Pressurized Water Reactor (APWR), AREVA NP's Evolutionary Pressurized Water Reactor (EPR), and Westinghouse's AP-1000. Only one design—the ABWR, which is referenced only in the application for South Texas units 3 and 4—has been certified by the NRC, but this certification runs out in 2012 and major modifications are likely to be needed for it to be re-certified.

Delays to the generic approval process have meant that the sequence of approval has been inverted. As a result, utilities are likely to be granted COLs before generic approval of the reactor design to be built has been granted.

As of February 2011, the NRC had granted four Early Site Permits (ESP) and received two additional applications that are under review.[21] ESPs are independent of the construction/operating license.[22] None of the applicants has received an ESP *and* a certified design at this stage.

The July 2005 U.S. Energy Policy Act was aimed at stimulating investment in new nuclear power plants. Measures include a tax credit on electricity generation, a loan guarantee of up to 80 percent of debt (not including equity) or $18.5 billion for the first 6 GW, additional support in case of significant construction delays for up to six reactors, and the extension of limited liability (the Price Anderson Act) until 2025.

By the end of 2008, nuclear utilities had applied for $122 billion in loan guarantees, and in May 2009 the DOE short-listed four companies for the first group of loan guarantees: Southern Nuclear Operating Co. for two AP1000s at the Vogtle nuclear power plant site in Georgia; South Carolina Electric & Gas for two AP1000s at the Summer site in South Carolina; NRG Energy for two ABWRs at the South Texas Project site in Texas; and Constellation for one EPR at the Calvert Cliffs site in Maryland. By then, the limit for coverage of loan guarantees had been increased from 80 percent of the debt to 80 percent of the total cost.

In February 2010, Southern's Vogtle project was the first to have been awarded a conditional loan guarantee ($8.3 billion) for a nuclear power plant project worth an estimated $14 billion. Final approval of the guarantee is dependent on a number of conditions, including the issuance of a COL, expected in late 2011. At the same time, Westinghouse hopes to receive the final design approval for the AP1000. The reactors are supposed to start operating by 2016 and 2017.

In December 2010, the U.S. House of Representatives, in a narrow vote (212/206), approved a bill that would award $7 billion in new loan guarantees, far short of the $36 billion requested by the Obama administration, in addition to the original $18.5 billion. The bill had not passed the Senate as of February 2011. While these are large sums of money, they are relatively small considering the overall cost of a single nuclear reactor and the challenge of launching a large series of units. Carol Browner, director of the Office of Energy and Climate Change Policy, stated in December 2010 that, "Ultimately, the government continuing to provide loan guarantees is probably not going to be a practical solution."[23]

The U.S. nuclear industry has been shaken again by delays and setbacks in 2010 and early 2011, including:

- Constellation Energy abandoned the application for a loan guaranty for the Calvert Cliffs-3 project after discovering a "shockingly high estimate of the credit subsidy cost" (11.6 percent or $880).[24] French utility EDF, which acquired Constellation Energy's nuclear activities, is currently trying to find a new U.S.-based partner.
- Following the withdrawal of project partner CPS, the head of NRG, David Crane, told investors in the summer of 2010 that the company would slash monthly spending on its South Texas Project by 95 percent while waiting for a loan guarantee for the project. The Japan Bank for International Cooperation made a $4 billion loan depending on the U.S. government's loan guarantee.[25]
- New York State's Environmental Conservation Department refused to grant the Indian Point nuclear power plant the water quality certification it needs for extending operating licenses that expire in 2013 (unit 1) and 2015 (unit 2). To avoid massive fish kill, operator Entergy would likely need to invest hundreds of millions of dollars in the construction of cooling towers. Exelon decided to shut down the 41-year-old Oyster Creek reactor at least 10 years early, by 2019, to avoid building costly cooling towers following a similar decision by the New Jersey Department of Environmental Protection.
- Progress Energy delayed major work on the Levy project in Florida after the utility's credit ratings were downgraded. Additional reasons given were delays in licensing, uncertainty about future federal policies, and a large increase in the cost projection for the two planned AP1000, now estimated at up to $22.5 billion.[26]

In its provisional *Annual Energy Outlook 2011*, the DOE projects an increase in installed nuclear capacity of about 10 GW to 2035—just 10 percent—of which 6.3 GW is new capacity (five reactors) and the rest comes from uprating. The nuclear share would shrink from 20 percent to 17 percent.[27] In other words: according to the DOE, the "nuclear renaissance" will not take place in the United States over the next 25 years.

## Asia

China came relatively late to the civil nuclear industry, starting construction of its first commercial reactor only in 1985. As of February 2011, China had 13 reactors in operation, which in 2009 provided 1.9 percent of the country's electricity, the lowest nuclear share of any country. This compares to a historical maximum of 2.2 percent.

Despite, or maybe because of, its late arrival to the nuclear field, China now has an impressive recent history of construction starts. In 2010, it completed two new units (out of five globally) and started nine (out of 14 globally). It plans to continue the pace of new construction, and the 12th Five-Year Plan (2011–16) reportedly anticipates 43 GW of reactors in operation by the end of 2015.[28] Meeting this target would require the completion of all the reactors currently under construction, plus a handful more—presumably those ordered in the first half of 2011. In all other countries, it would be hard to believe such a timetable, but recent construction times of 4.5 years in China make the target tough but possible.

Concerns have been raised, however, about the availability of qualified staff and about the impact of such rapid construction on supply chains, leading a research unit of the State Council (China's parliament) to suggest that the rate of growth be limited.[29] Moreover, public acceptance of new reactors cannot be taken for granted, although so far this has not been a major obstacle to nuclear deployment in China. Historically, protests have occurred in Hong Kong against the Daya Bay facility (both before and after the transfer of sovereignty) as well as in other parts of China, where they have reportedly delayed at least one new project. With new reactors proposed in up to 16 provinces, wider public engagement is likely.

Meeting the Five-Year Plan's target for 2015 would increase the nuclear contribution to China's electricity supply to around 5 percent, or 3 percent of primary energy. Moving forward, China plans to continue this rapid growth, with proposed installed capacities of around 80 GW by 2020. If achieved, this would give China the world's second largest installed capacity behind the United States.

While these potential deployment rates are impressive, China's importance in the global nuclear sector is not just construction numbers but the types of reactors now being built. Currently, the world's major reactor vendors, including AREVA and Westinghouse, are building their most advanced designs in China. In the case of Westinghouse, the AP1000 is the company's flagship Generation III design, and China is its only sale under contract—worth around $5.3 billion, well below the commercial rate for four units.[30] A key factor in the contract was that it contained technology transfer not only for the reactor but also for the back-end services, particularly waste management.[31]

Not to be outdone, in November 2007 AREVA announced the signing of a €8 billion ($11.6 billion) contract with the China Guangdong Nuclear Power Corp. (CGNPC) for two European Pressurized Water Reactors (EPR) in Taishan in Guangdong Province and will provide "all the materials and services required to operate them."[32] Interestingly, at the signing of the deal, AREVA stated that this would result in the deployment of the world's third and fourth EPRs, after those being built in Finland and France. However, construction problems at both European sites (described later) may lead to China hosting the world's first operating EPR.

At roughly the same time, China and France signed an agreement opening the way to industrial cooperation at the back end of the nuclear fuel cycle, committing to undertake feasibility studies related to the construction of an 800 ton-per-year spent fuel reprocessing plant in Jiayuguan, Gansu Province. Design, construction, and commissioning were expected to take a decade starting from 2010. In November 2010, an industrial agreement was signed that AREVA called "the final step towards a commercial contract" for the project, though this view may be too optimistic.[33]

In addition to the AREVA project, China is building reprocessing plants using domestic technology, and in January 2011 Chinese state television ran a news item "announcing" a breakthrough in reprocessing at the small pilot plant in Lanzhou in Gansu Province. It is unclear what the breakthrough was, given that the plant was completed some six years ago, but speculation has linked it either to ongoing uranium supply negotiations or to the announcement a week later that India had completed another reprocessing plant at Tarapur. What is clear, however, is that China is actively obtaining the technology for the full range of nuclear technologies, including plutonium-fueled reactors, as options for the future.

To fuel the country's growing reactor fleet, various Chinese enterprises have been active in purchasing options for the supply of uranium. In November 2010, CGNPC signed a 10-year deal for the supply of 24,200 tons (heavy metal) of uranium from Kazakhstan's Kazatomprom, as well as a similar deal with AREVA for 20,000 tons at a price of $3.5 billion.[34] In addition, CGNPC and Chinese equity funds each have a 24.5 percent share in AREVA's mines in Namibia, South Africa, and the Central African Republic, which should provide an additional 40,000 tons of uranium by 2022. CGNPC signed a third deal in November 2010 with Cameco of Canada for the supply of 13,000 tons of uranium through 2025.[35] This flurry in activity is probably the major cause of the rapid, 30-percent increase in the global spot price of uranium during the last quarter of 2010. These deals likely are not the last, with uranium demand set to increase from around 3,600 tons per year in 2010 to some 10,000 tons in 2020.[36]

**India** operates 20 reactors with a total capacity of 4.4 GW and a (small) average size of 220 MW per unit. Three units were commissioned between December 2009 and January 2011 that added only 612 MW. Nuclear power provides just 2 percent of India's electricity, down from a maximum of 3.7 percent in 2001/02.

India lists five units as under construction with a total of 3.6 GW. Most currently operating reactors experienced construction delays, and operational targets were seldom achieved. With a lifetime load factor of only 52 percent India holds a negative world record. The annual load factor slipped even to less than 42 percent in 2009.[37]

India's 1974 nuclear weapons test triggered the end of most official foreign nuclear cooperation, including invaluable Canadian assistance. The test series in 1998 came as a shock to the international community and triggered a new phase of instability in the region, including a subsequent test series by Pakistan.

The IAEA "safeguards agreement" with India was nevertheless approved in August 2008, and on 6 September 2008 the Nuclear Suppliers Group (NSG), a 45-country group regulating international commerce to prevent the proliferation of nuclear weapons, granted an exception to its own rules. Thus, although India is a non-signatory of the Non-Proliferation Treaty, has developed and maintains a nuclear weapons program, and refuses full-scope safeguards on all of its nuclear facilities, it is still permitted to receive nuclear assistance and to carry out nuclear commerce with other nations.

In 2009, *World Nuclear News* reported that, "[n]uclear trade restrictions on India were lifted last year [2008] and delegation after delegation of foreign firms has visited since then."[38] In December 2010, Nuclear Power Corporation of India Ltd. (NPCIL) and AREVA signed an agreement—though not yet a commercial contract—for the construction of two EPRs (and potentially four more) for a site in Jaitapur and a fuel supply for 25 years.[39] The contract reportedly would be worth some €7 billion ($10 billion), a surprisingly low figure considering that the cost-estimate range for the French and Finnish EPRs is €5–6 billion ($7.3–8.7 billion).[40]

Even before the agreement was signed, opposition against the Jaitapur project was massive, including from unexpected origin. In a stinging December 2010 op-ed, A. Gopalakrishnan, former Chairman of the Indian Atomic Energy Regulatory Board, identified "serious design deficiencies" of the EPR and "much higher toxicity of the radioactive waste," and accused NPCIL of "hiding the enormous cost of the EPR from the public." Gopalakrishnan concluded: "On the false premise of ensuring energy security for the nation, the PM is leading India to purchase six unproven French EPRs at an enormous cost to the exchequer."[41]

Other builders including GE Hitachi, AECL, and the Russian nuclear industry are also in negotiations over the potential supply of nuclear power plants at various sites in India.

Considering its poor past industrial record, it remains to be seen whether the Indian nuclear sector will meet its own expectations of 20 GW installed by 2020. Foreign assistance could make a difference to some extent. The Indian government, however, slashed the fund allocation for nuclear power in the 2010/11 budget by over 10 percent to RS1,848 crore ($400 million), a move that raised eyebrows among industry observers.[42]

AREVA is awaiting approval from the Japanese government for the purchase of Japan Steel Work's EPR pressure vessels for the Jaitapur project. In principle, Japan does not export nuclear equipment to non-NPT signatory countries.[43] And in January 2011, the Australian government reiterated its embargo over uranium sales, despite the Nuclear Suppliers Group (NSG) waiver, stating that it "will only supply uranium to countries that are signatories to the Nuclear Non-Proliferation Treaty (NPT) and have signed a bilateral agreement with Australia."[44]

**Japan** operates 54 reactors that produce 29.2 percent of the country's electricity (down from a maximum of 35.9 percent in 1998). In 1998, nuclear energy had produced almost 36 percent of Japan's electricity but was subsequently hit by various quality-control scandals and a major earthquake. The Japanese reactors are with 71 percent on the lower end of the lifetime load factors in the world and reached only 66 percent in 2009.[45] Besides serious exceptional events, Japanese nuclear plants operate on much shorter operating cycles compared to other countries—13 months versus over 18 months in the United States, for example—and have much longer outage times—98 days versus less than 44 days in the United States or South Korea.[46]

On 16 July 2007, a 6.8 magnitude earthquake hit the region that houses TEPCO's Kashiwasaki-kariwa nuclear plant. With seven units, this plant is the largest single nuclear power station in the world. The reactors were shut down and only four units (1, 5, 6, and 7) had restarted as of March 2011, with the remaining three units still closed.

On 6 May 2010, the controversial 250 MW Monju fast-breeder reactor was restarted after more than 14 years of shutdown following a sodium leak and subsequent fire. On 26 August 2010, a three-ton relay device used for fuel loading dropped into the reactor vessel. So far, all attempts to recover the device have failed. The situation is complex because the fuel in the vessel is cooled by sodium, which has to be kept at a certain temperature and away from contact with air that would ignite the sodium. Full restart is now scheduled for 2014 or later.[47]

Officially, two reactors are listed as under construction in Japan. After several years of delays, the Ohma building finally started in May 2010. The planned beginning of commercial operation for the Shimane-3 reactor has been delayed by three months to March 2012 following the discovery of significant faults in control-rod drive mechanisms.[48] Shimane-1 and -2 made headlines in 2010 when it was revealed that inspections were not properly implemented. The operator acknowledged 123 cases where checks were missed, including when parts were not replaced as scheduled. In a stinging editorial, Japan's leading newspaper *Asahi Shimbun* commented: "If nuclear power plants are not run safely, they cannot be considered part of the solution for global warming. Instead, they will become yet another, serious environmental hazard."[49] Further construction plans are vague and have been scaled back several times.[50]

The plutonium separation plant in Rokkasho-mura started active testing in March 2006. As of early 2011 and after the 18th postponement due to countless technical problems (in particular with the vitrification facility), the reprocessing facility with a nominal annual throughput of 800 tons is intended to "start-up" by 2012. The project is now 15 years behind schedule.[51]

Past accidents and scandals in Japan's nuclear industry have also delayed the use of MOX (uranium-plutonium mixed oxide) fuel by a decade. MOX fuel was introduced into a Japanese reactor (Genkai-3) for the first time in 2009. The country has a significant stock of plutonium, about 46 tons, of which more than 36 tons are stored in France and the United Kingdom. The construction of Japan's own MOX fuel fabrication facility, currently at least 10 years behind schedule, officially began in October 2010.[52]

**Pakistan** operates two reactors that provided 2.7 percent of the country's electricity in 2010. One additional unit, supplied by China, came on line in early 2011. During Chinese Prime Minister Wen Jibao's visit to Pakistan in December 2010, it was reported that China might build another two 650 MW reactors in the country.[53] The Pakistan Atomic Energy Commission (PAEC) indicated a target capacity of 8.8 GW with 10 installed units by 2030.[54]

In the 1980s, Pakistan developed a complex system to illegally access components for its weapons program on the international black market, including from various European sources.[55] Immediately following India's nuclear weapons tests in 1998, Pakistan also exploded several nuclear devices. International nuclear assistance has been practically impossible, given that Pakistan, like India, has not signed the Non-Proliferation Treaty (NPT) and does not accept full-scope safeguards, and is currently unlikely to be granted the same exception as India to the Nuclear Suppliers Group's export rules. The Pakistani nuclear program will therefore most likely maintain its predominantly military character.

On the Korean Peninsula, the **Republic of South Korea** operates 21 reactors that provided 32.2 percent of the country's electricity in 2010 (down from a maximum of 53.3 percent in 1987). In addition, five reactors are listed as under construction, two of which are scheduled to come on line in 2011. For a long time, South Korea (alongside China) had been considered the main future market for nuclear power expansion. While the early program was implemented without much public debate, a major controversy over the future of the nuclear program—and in particular about the destiny of the radioactive waste—hit expansion plans in the 1990s, bringing them virtually to a halt. The government has since reinvigorated nuclear projects, and in December 2008 it announced its plan to complete 14 more units by 2024 and thus raise the nuclear share to 48.5 percent of total installed capacity.[56]

In December 2009, South Korea stunned international observers when, in its first major overseas nuclear deal, it succeeded in "snatching" a reported $20 billion contract with the United Arab Emirates (UAE) from the world's largest builder AREVA, backed by French state utility EDF ("Team France"), for the building of four 1.4 GW reactors. The first unit is scheduled to come on line on 1 May 2017.[57] In the meantime, however, the groundbreaking ceremony, originally scheduled for the end of 2010, has been postponed as the South Korean government experienced difficulties in coming up with the promised $10 billion loan. Opposition parties have picked up the issue, and pressure is increasing into a parliamentary inquiry into the circumstances of the deal.[58]

In January 2010, South Korea's Ministry of Knowledge Economy announced the country's ambitious aim, by 2030, to become the third largest nuclear plant exporter, to secure 20 percent of the world market share, and to build 80 reactors for an estimated contract value of $400 billion.[59]

**Taiwan** operates six reactors that provided 19.3 percent of the country's electricity in 2010 (down from a maximum of 41 percent in 1988). Two 1.3 GW Advanced Boiling Water Reactors (ABWR) are listed under construction at Lungmen, near Taipei, since 1998 and 1999 respectively. Their startup has been delayed many times and is at least six years behind schedule. In January 2011, state utility Taipower stated that the first unit will not start up until "late 2012" because there are "still problems with its instrumentation and control system" that have not yet been fixed. According to the Minister of Economic Affairs, the project costs Taipower an estimated NT$400–600 million ($10–15 million) per month of delay.[60]

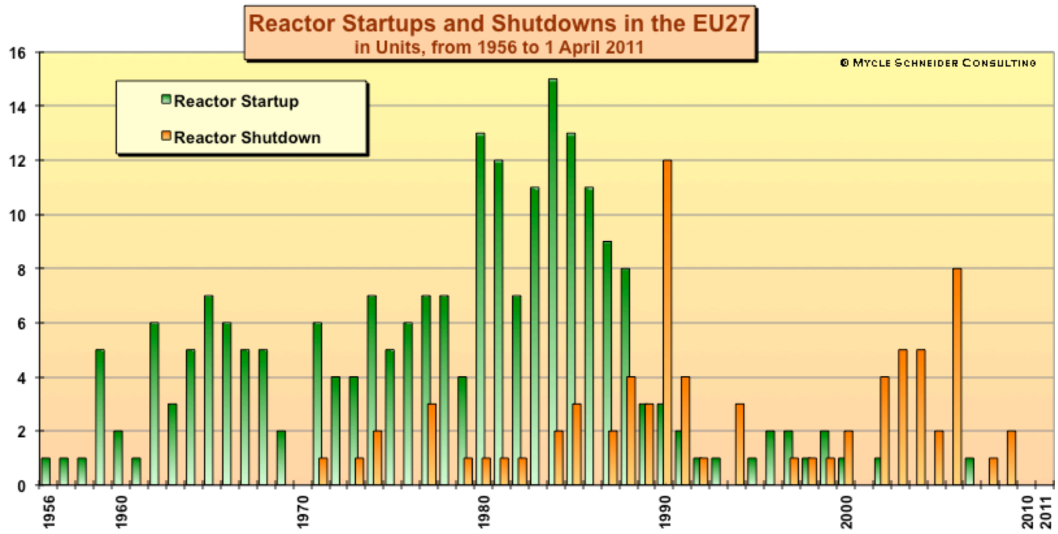
## Europe

The EU27 has gone through three nuclear construction waves, two small ones in the 1960s and the 1970s plus a big one in the 1980s (mainly in France). The region saw hardly any construction starts in the 1990s and since the turn of the 21st century.[61] (See Figure 17.)

In early 2011, 14 of the 27 countries in the enlarged European Union (EU27) operated 143 reactors—about one-third of the world total—down from 177 units in 1989.[62] (See Figure 18.) The vast majority of the facilities, 124, are located in eight of the western EU15 countries, and only 19 are in the six new member states with nuclear power. By the end of 2009, Lithuania had to shut down its last Chernobyl-type reactor, under a condition included in the EU accession agreement. During its final year of nuclear generation, Lithuania had the highest nuclear share in the world (76 percent), 1 percent higher than France.

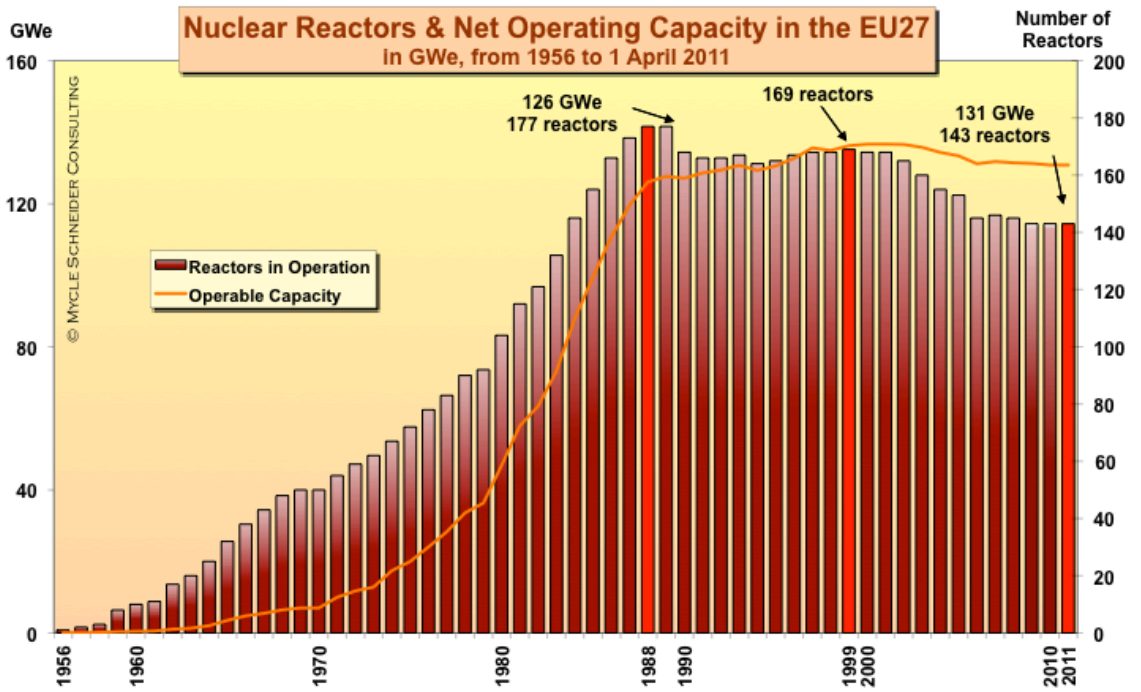
In 2009, nuclear power produced 28 percent of the commercial electricity in the EU, down from 31 percent in 2003. Nearly half (46 percent) of the nuclear electricity in the EU27 was generated by one country, France.

**Figure 17. Nuclear Reactors Startups and Shutdowns in the EU27, 1956–2011**




*Source: IAEA-PRIS, MSC, April 2011*

**Figure 18. Nuclear Reactors and Net Operating Capacity in the EU27, 1956–2011**




*Source: IAEA-PRIS, MSC, April 2011*

## Western Europe

In Western Europe, as in many places, the public generally overestimates the significance of electricity in the overall energy picture, as well as the role of nuclear power. Electricity currently accounts for only about one-fifth of the EU15's commercial primary energy consumption.

As of early 2011, the EU15 was home to 124 operating nuclear power reactors, or 33 units less than in the peak years of 1988/89. In 2008, nuclear energy provided roughly 29 percent of gross commercial electricity production, 14 percent of commercial primary energy consumption, and 6 percent of final energy consumption.[63]

Two reactors are currently under construction in the older member states EU15, one in Finland and one in France. These are the first building sites in the region since construction began on the French Civaux-2 unit in 1991. Apart from the French exception, until the reactor project in Finland, no new reactor order had been placed in Western Europe since 1980.

The following provides a short overview by country (in alphabetical order).

**Belgium** operates seven reactors and has the world's fourth highest share of nuclear in its power mix, at 51.2 percent in 2010 (down from a maximum of 67.2 percent in 1986). In 2002, the country passed nuclear phase-out legislation that required the shutdown of nuclear plants after 40 years of operation, meaning that (based on their start-up dates) plants would be shut down between 2014 and 2025. On 13 October 2009, the government issued a 10-page general policy statement that included one reference to nuclear power: "The government has decided to postpone by 10 years the first sequence of the phase-out of nuclear power."[64] However, that government was voted out in June 2010, and Belgium has been without a new government ever since. To be effective, the decision of the previous government must be voted into law, meaning that prospects for postponing the phase-out remain uncertain.

**Finland** currently operates four units that supplied 28.4 percent of its electricity in 2010 (down from a maximum of 38.4 percent in 1986). In December 2003, Finland became the first country to order a new nuclear reactor in Western Europe in 15 years. AREVA NP, comprising 66 percent AREVA and 34 percent Siemens, is building a 1.6 GW EPR under a fixed-price turn-key contract with the utility TVO—an arrangement that AREVA top managers have admitted in private talks they would "never do again"). Construction started in August 2005 at Olkiluoto on the Finnish west coast. Five and a half years later, the project is about four years behind schedule and at least 97 percent over budget, with the loss for the provider estimated at €2.7 billion ($3.9 billion) (see the economics chapter starting on page 25 for further economic analysis). It remains unclear who will cover the additional cost.

From the beginning, the Olkiluoto-3 (OL3) project was plagued with countless management and quality-control issues. Not only did it prove difficult to carry out concreting and welding to technical specifications, but the use of sub-contractors and workers from several dozen nationalities made communication and oversight extremely complex. By May 2009, the Finnish safety authority STUK was getting increasingly nervous, and section head Martti Vilpas commented that, "Things cannot continue like this."[65]

In an unprecedented move, the three nuclear safety regulators from Finland, France, and the United Kingdom issued a joint statement on 2 November 2009 raising concern about the EPR's Control and Instrumentation (C&I) system, noting that AREVA's design "doesn't comply with the independence principle, as there is a very high degree of complex interconnectivity between the control and safety systems."[66] Full system independence is fundamental to guarantee plant safety in case the control system fails. In January 2011, Petteri Tiippana, STUK's director of nuclear reactor regulation, was quoted as saying: "The automation system has not yet been approved in every aspect."[67]

The repeated construction delays of OL3 are a blow not only to power planning by the utility and to the some 60 large customers involved in the project consortium, but also for the Finnish government. OL3 was part of the government's strategy to achieve its target of a zero-percent increase of 1990 emissions under the Kyoto Protocol. The lack of an operational OL3 will force Finland to use expensive flexible Kyoto mechanisms to compensate for emissions in the country.

The obstacles faced by the OL3 project have not prevented TVO from filing an application, in April 2008, for a decision-in-principle, ratified by the Finnish Parliament on 1 July 2010, to develop "OL4", a 1–1.8 GW reactor to start construction in 2012 and enter operation "in the late 2010s" (currently planned for "around 2020").[68] In parallel, Fortum Power is planning a similar project, known as Loviisa-3. In January 2009, the company Fennovoima Oy submitted an application to the Ministry of Employment and the Economy for a decision-in-principle on a new plant at one of three locations—Ruotsinpyhtää, Pyhäjoki, or Simo—which has since been narrowed down to the latter two sites and to being either an EPR or ABWR. Startup is planned for 2020. None of these projects, however, has a construction license or has been developed to the level of a call for tender.

Finland is planning a final spent fuel repository at the Olkiluoto site as well. Drilling of the access tunnel of the ONKALO "rock characterization facility," slated to become a final repository, started in 2004 and has advanced practically to the target depth of just over 400 meters. The project, based heavily on the Swedish approach of disposing of spent fuel in copper canisters, is often presented as exemplary; however, geological aspects in particular have received severe criticism. Matti Saarnisto, a professor of geology, former research director of the Geological Survey of Finland, and former secretary general of the Finnish Academy of Science and Letters, has commented of the location: "It is insane to believe you can store nuclear waste for 100,000 years… You can see traces in the landscape of major earthquakes that have occurred about every 2,500 years."[69] In March 2009, the operator Posiva Oy submitted an application for a decision-in-principle to license an increase in the final disposal capacity from 6,000 tons to 12,000 tons to accommodate not only fuel from OL4 but also from Loviisa-3.[70]

**France** is the worldwide exception in the nuclear sector. Thirty-seven years ago, the government launched the world's largest public nuclear power program as a response to the so-called oil crisis in 1973. However, less than 12 percent of France's oil consumption that year was used for power generation. More than three decades later, France has reduced overall fossil fuel consumption (oil, gas, coal) by less than 10 percent and the oil consumption in the transport sector has increased far more than the annual consumption substituted by nuclear energy in the electricity sector. Per capita oil consumption in France is higher than in Germany, Italy, the United Kingdom, or the EU27 on average.[71]

In 2010, France's 58 reactors[a] produced 74.1 percent of the country's electricity, even though only about half of the country's installed electricity-generating capacity is nuclear. Nuclear's share in France's power mix reached its maximum in 2005, at 78.5 percent, and has been decreasing steadily since.

France has a huge overcapacity that led to dumping of electricity on neighboring countries and stimulated the development of highly inefficient thermal-applications electricity. A historical winter peak-load of 96.7 GW (in December 2010) is to be compared with an installed capacity of 123.5 GW. Even a comfortable 20 percent reserve leaves a theoretical overcapacity, which is the equivalent of 20 of the 34 units of 900 MW. It is no wonder that the equivalent of about 10 reactors operate for export, and that France remains the only country in the world that operates over 40 units on load-following mode.

Meanwhile, France's seasonal peak electricity load has exploded since the mid-1980s, due mainly to the widespread introduction of electric space and water heating. About 30 percent of French households heat with electricity, the most wasteful form of heat generation because it results in the loss of most of the primary energy during transformation, transport, and distribution. The difference between the lowest load day in summer and the highest load day in winter is now over 60 GW. Short-term peak load is covered not by nuclear power but by either fossil fuel plants or expensive peak-load power imports. Globally, France remains a net power exporter, but in 2010 it imported 16.1 TWh of

[a] All pressurized water reactors, 34 x 900 MW, 20 x 1300 MW. and 4 x 1400 MW. One 35-year-old 250 MW fast breeder reactor (Phénix, Marcoule) was taken off the grid in 2009.

peak power from Germany for an undoubtedly high price. Having exported only 9.4 TWh, France remains a net importer of German coal-based power.[72]

Considering its existing nuclear overcapacities and the average age of its reactors (roughly 26 years), France would not need to build any new units for a long time. Other factors equally play in that direction: the nuclear share in the power mix is too high; lifetimes of operating units shall be extended; the shutdown of the gaseous diffusion uranium enrichment plant will save huge amounts of electricity, and several plants should be made redundant through efficiency.[73]

It therefore will be years, if not decades, before capacity constraints require new baseload power plants in France. If the French government and EDF opt to proceed with construction of a new unit, then this is because the nuclear industry faces a serious problem of maintaining competence in the field. The decision to go ahead with the authorization of an additional EPR at Penly, expected at the end of March 2011 (for commissioning in 2017), was meant as a follow-up project in the same logic.[74]

Considering the debacle with Finland's Olkiluoto EPR, as well as France's Flamanville EPR, the reality of the Penly-3 project remains to be seen. In December 2007, EDF started construction of Flamanville-3. The FL3 site encountered quality-control problems with basic concrete and welding similar to those at the OL3 project, which started two-and-a-half years earlier. As in Finland, the extensive employment of foreign workers exacerbates communication and social problems.[75] The project is now reportedly three years late, more than 50 percent over budget, and not expected to start commercial operation before 2015.[76]

Massive advertising campaigns cannot hide the fact that the French nuclear industry must confront severe difficulties in many areas. Beyond the EPR building problems, the two state-owned companies EDF and AREVA are fighting over several strategic issues: follow-up agreements on uranium enrichment, reprocessing and fuel fabrication, as well as the entire industrial strategy (AREVA's integrated company model versus EDF-controlled transversal sector policy).[77] On 21 February 2011, President Nicolas Sarkozy convened the Nuclear Policy Council, which determined that EDF and AREVA sign a commercial and technical agreement "before summer" on the optimization of the EPR, increased performance of the operating reactor fleet, and fuel and radioactive waste management.[78]

Time is of the essence. Already, major difficulties with large investment projects—especially in Italy, the United Kingdom, and United States—are taking the toll on the credit rating of France's major nuclear companies. In December 2010, Standard & Poor's gave AREVA's long-term rating on CreditWatch a negative outlook, reflecting "the likelihood that we will downgrade by one notch AREVA's 'BBB+' rating as well as its stand-alone credit profile of 'bbb-'."[79] AREVA's capital increase of €900 million ($1.3 billion) had fallen far short of the expected €2–2.5 billion ($2.9–3.6 billion). As of February 2011, AREVA's share price was less than half of its 2008 value, and EDF shares had lost over 60 percent of their value since 2007.[80]

France also operates many other nuclear facilities, including uranium conversion and enrichment, fuel fabrication, and plutonium facilities. France and the United Kingdom are the only countries in the EU that engage in reprocessing, or separating plutonium from spent fuel. France's two La Hague facilities are licensed to process 1,700 tons of fuel per year; however, all significant foreign clients have finished their contracts and turned away from plutonium separation. The La Hague operator AREVA NC therefore depends entirely on the domestic client EDF for future business.

**Germany** operates 17 reactors that generated 140.5 TWh in 2010 and, according to the IAEA, provided 27.3 percent of the electricity in the country (down from a maximum of 34.3 percent in 1989). The IAEA apparently takes into account only public electricity generation, however, and German official sources indicate a nuclear share in gross national power generation of only 23 percent in 2010.[81]

In 2002, the German Parliament adopted a nuclear phase-out law that stipulates shutdown of the country's nuclear power plants after an average lifetime of about 32 years. Two units, Stade and Obrigheim, have been shut down under the law. A third unit, Mülheim-Kärlich, had been under long-term shutdown since 1988 and is now closed for good. The last unit would have been shut down around 2022.

The current coalition government (Christian Democrats and Liberal Democrats) has significantly amended the phase-out legislation.[a] Social Democrats, Green Party members, environmental organizations like Greenpeace, and ordinary citizens have announced they will bring the new law to the Constitutional Court. Under the modified legislation, older nuclear units can be operated eight years longer that planned and more recent units up to about 12 years longer. Life-extended units will have to undergo additional safety analysis and upgrading, and new build remains explicitly prohibited. As under the previous legislation, a generation "credit" can be transferred from an older to a more recent plant. The overall generation credit has been increased from 2,623.31 TWh to 4,427.59 TWh, an increase of more than 40 percent.[82] Operators will have to pay a substantial nuclear fuel tax[b] that feeds an energy and climate fund to boost energy efficiency and renewable energy measures.[83]

After a significant crisis in the nuclear utility sector following incidents at the Brunsbüttel and Krümmel plants in June 2007, three top managers of the Swedish state-owned operator Vattenfall were sacked and the units underwent extensive reviews and upgrading.[84] However, both units are still off-line as of February 2011. Additional upgrading costs of old units according to the new legislation are estimated at about €500 million ($727 million) per unit. Faced with these substantial costs, operators are envisaging shutting down the oldest units much earlier than planned and transferring the production credit to the newer units.[85]

In a generally hostile public environment, nuclear power has virtually no future in Germany. Even before the lifetime extension decision had passed parliament, massive demonstrations (including a Berlin crowd of 100,000 in September 2010) illustrated the broad opposition to the policy change. The new focus on nuclear energy will likely make it a prime topic in the 2012 federal elections.

The **Netherlands** operates a single, 38-year-old 480 MW plant that provided 3.4 percent of the country's power in 2010 (down from a maximum of 6.2 percent in 1986). The operator succeeded in overturning in court the original political decision to shut down the Borssele reactor by 2004. In June 2006, the operator and the government reached an agreement to allow operation of the reactor until 2033.[86] In 2009, the German utility RWE bought up Essent, which owns half of the reactor, but in January 2011 the Dutch Supreme Court put a freeze on the planned ownership transfer after the other co-owner, Delta, argued that the unit should remain in public ownership.[87]

In February 2011 the Dutch government presented the parliament with a 17-page document outlining the conditions for new nuclear construction, including safety requirements and financial guarantees. The government wishes to accelerate the decision making process to provide a construction license before the end of its term in 2015, and to see plant commissioning by 2019.[88] This schedule seems very optimistic considering that planning is in its early stages.

In early 2004, Borssele operator EPZ extended a reprocessing contract with AREVA NC. This is a curious decision considering that there are no possibilities in the Netherlands of using separated plutonium. Instead, EPZ pays the French utility EDF to get rid of the plutonium.

**Spain** operates eight reactors that provided 20.1 percent of the country's electricity in 2010 (down from a maximum of 38.4 percent in 1989). Beyond the de-facto moratorium that has been in place for

[a] It should be stressed that this still is a phase-out legislation, it only has been delayed in time.

[b] The tax is €145 ($200) per gram of plutonium-239, plutonium-241, uranium-233, or uranium-235. It is due with the introduction of the nuclear materials into a reactor.

many years, Premier Jose Luis Zapatero announced at his swearing-in ceremony in April 2004 that his government would "gradually abandon" nuclear energy while increasing funding for renewable energy in an effort to reduce greenhouse gas emissions, in accordance with the Kyoto Protocol. The first unit (José Cabrera) was shut down at the end of 2006. Zapatero confirmed the nuclear phase-out goal following his reelection in 2008, and Industry Minister Miguel Sebastian has stated, "There will be no new nuclear plants."[89]

Spain is, however, implementing both uprating and lifetime extensions for existing facilities. Licenses for the operating units would have run out between 2010 and 2018; however, in 2009 the government extended the operating license of the 40-year old Garoña plant to 2013, and in 2010 it granted the 30-year old Almaraz-1 plant a 10-year extension and a capacity increase of 7 percent. The 28-year old Almaraz-2 plant also will be uprated.[90] In February 2011, the Spanish parliament amended the Sustainable Energy Law, deleting from the text a reference to a 40-year lifetime limitation and leaving nuclear share and lifetime to be determined by the government.[91]

The added capacity from Spain's nuclear uprating (64 MW at Almaraz so far) remains negligible compared to the country's surge in renewables. Spain added 1.5 GW of wind power in 2010 alone (more than Germany)—for a total installed capacity of more than 20 GW—and now accounts for a quarter of the installed capacity in the EU, second only to Germany at 32 percent.[92]

**Sweden** operates 10 reactors that provided 38.1 percent of the country's electricity in 2010 (down from a maximum of 52.4 percent in 1996). Sweden's per capita power consumption is among the highest in the world, due primarily to the widespread and very inefficient thermal use of electricity. Electric space heating and domestic hot water represent about a quarter of the country's power consumption.

Sweden decided in a 1980 referendum to phase out nuclear power by 2010. Oddly, the referendum took place at a time when only six out of a planned 12 reactors were operating; the other six were still under construction. It was effectively a "program limitation" rather than a "phase-out" referendum. Sweden retained the 2010 phase-out date until the middle of the 1990s, but an active debate on the country's nuclear future continued and led to a new inter-party deal to start the phase-out earlier but abandon the 2010 deadline. The first reactor (Barsebäck-1) was shut down in 1999 and the second one (Barsebäck-2) went off line in 2005.

On 5 February 2009, the parties of Sweden's conservative coalition government signed an agreement on energy and climate policy that defines ambitious renewable energy and energy efficiency targets and calls for the scrapping of the Nuclear Phase-Out Act. In June 2010, the parliament voted by a tight margin (174/172) to abandon the phase-out legislation.[93] As a result, new plants can again be built—but only if an existing plant is shut down, meaning that the maximum number of operating units will not exceed the current 10. This puts Sweden many years away from potential new construction. In the meantime, operators have pushed uprating projects to over 30 percent: at Oskarshamn-2 a 38 percent capacity increase is under way while a 33 percent uprate has already been implemented at Oskarshamn-3.

The **United Kingdom** operates 19 reactors that provided 15.7 percent of the country's electricity in 2010 (down from a maximum of 26.9 percent in 1997). The first-generation Magnox reactors, with 11 stations, have been mostly retired. After lifetime extensions, the two 43-year old Oldbury units are to shut down in June 2011 and the last two Magnox, at Wylfa, by the end of 2012.[94] The seven second-generation stations, the Advanced Gas-cooled Reactors (AGR), are also at or near the end of their design life, although the owners now hope to extend their life to 40 years, with retirement only in 2016–29. It remains to be seen whether this plan is feasible. The AGRs have always had reliability problems, and their operating costs are now so high that it may be uneconomic to keep them in service even if the safety case can be made. The newest plant, Sizewell-B, is the United Kingdom's only PWR and was completed in 1995.

The U.K. nuclear industry has gone through troublesome decades, including the last one. In September 2004, the government issued a $13.5 billion restructuring package (which included taking over the decommissioning liability) to stop privately owned nuclear generator British Energy from going into liquidation. The state-owned nuclear fuel and technology company BNFL was also effectively bankrupt because it could not meet its liabilities. The government split the company up, passing the physical assets to a new agency, the Nuclear Decommissioning Authority (NDA), while the capabilities were privatized. The reactor design and fuel manufacture division (based mainly on the Westinghouse nuclear division acquired in 1998) was re-privatized as Westinghouse and sold to Toshiba.

The NDA is now responsible for decommissioning all Britain's civil nuclear facilities except those owned by British Energy, a liability estimated in 2007/08 to be in excess of £63 billion ($104 billion), up from £51 billion ($84 billion) a year earlier.[95] The NDA inherited negligible funds for this task, relying partly (and increasingly) on grants from the Treasury and partly on income from the facilities still in operation, including the two Magnox stations, the THORP reprocessing plant, and the SMP plutonium fuel manufacturing plant. Both of the latter facilities, however, have been plagued by very serious technical problems that have kept their operation significantly below expectations.[96]

In 2004, the nuclear lobby in the U.K. launched a major initiative, widely reflected in the media, to keep the nuclear option open. But key government ministers rebutted the claims in an unusually clear manner, with then-Environment Secretary Margaret Beckett stating that "[b]uilding nuclear power stations would risk landing future generations with 'difficult' legacies."[97] In March 2006, the government's Sustainable Development Commission concluded that "[t]he relatively small contribution that a new nuclear power program would make to addressing these challenges (even if we were to double our existing nuclear capacity, this would give an 8 percent cut on total emissions from 1990 levels by 2035, and would contribute next to nothing before 2020) simply doesn't justify the substantial disbenefits and costs that would be entailed in such a program." [98]

Two years later, the Brown government started to organize the new-build program. In April 2009, the NDA auctioned off the first pieces of land earmarked for the construction of new reactors. French utility EDF[a] and German companies E.ON and RWE were among the buyers. By May 2009, EDF had issued prequalification questionnaires to a number of firms for preparatory and civil works contracts.[99] While EDF would propose the EPR model, RWE is in negotiations with Westinghouse over the construction of up to three AP1000 in North Wales starting in 2013.[100] Considering the dramatic situation of nuclear and general engineering education in the U.K., this seems very optimistic.

Between November 2009 and February 2010, a first consultation on the Draft National Policy Statement (NPS) for energy infrastructure took place. The opposition to the draft strategy was massive, and over 3,000 comments were submitted. In October 2010, the government released a Revised Draft NPS for Nuclear Power Generation. The first paragraph states that new nuclear power stations "will play a vitally important role" for reliable electricity supplies in the U.K. [101] The eight[b] "potentially suitable sites" considered for deployment "before the end of 2025" are exclusively current or past nuclear power plant sites in England or Wales. Northern Ireland and Scotland[102] are not included. The U.K. House of Common's Energy Committee is "skeptical" that the government's target of commissioning two nuclear reactors per year between 2020 and 2025 is feasible. Committee chairman Tim Yeo was quoted as saying: "Hooking up this amount of nuclear and other generation to the national grid poses an unprecedented challenge."[103] The government plans to adopt the final energy NPS and pass it through parliament during 2011.

The only non-EU Western European country that operates nuclear power plants is **Switzerland**. It operates five reactors that accounted for 38 percent of the country's electricity consumption in 2010

[a] As early as 2006, EDF hired a powerful ally, Andrew Brown, the then-Prime Minister's younger brother, who, as of May 2009, acted as press officer for EDF Energy. By February 2011, someone else was responding to his extension number.
[b] Bradwell, Hartlepool, Heysham, Hinkley Point, Oldbury, Sizewell, Sellfield, and Wylfa.

(down from a maximum of 44.4 percent in 1996). In 2001, resentment against nuclear power was at an all-time high, with 75 percent of the Swiss people responding "no" to the question "is nuclear power acceptable." While the phase-out option never gained a sufficient majority, the "Swiss-style" referenda have maintained an effective moratorium on any new project over long periods of time. Currently, the nuclear operators have initiated a debate over potential replacement of the country's aging nuclear plants. The utilities Axpo, BKW, and Alpiq are jointly planning the rebuild of two replacement units for the aging Beznau and Mühleberg reactors. A local referendum on 13 February 2011 saw a slim 51/49 percent majority for future replacement of the 40-year old Mühleberg reactor that is expected to shut down by 2022. With such a short margin, the vote can tip either way any time. That same day, a cantonal referendum on a proposed geological repository in Nidwalden turned into a fiasco for its proponents, with 80 percent of voters refusing the nuclear waste disposal project.[104]

**Central and Eastern Europe**

In **Bulgaria,** nuclear power provided 33 percent of the country's electricity in 2010 (down from a maximum of 47.3 percent in 2002), with generation occurring at the remaining two units of the Kozloduy plant. As part of the deal to join the EU, the Bulgarian government agreed to close the oldest, and most dangerous, reactors at Kozloduy, four VVER 440-230 designed units, two of which were closed in 2002 and two in 2006. Bulgaria has received €550 million ($800 million) from the EU as compensation for the closure, with up to €300 million ($437 million) more possible in the coming years.[105]

In 2003, the government announced its intention to restart construction at the Belene site in northern Bulgaria. Construction of a reactor began in 1985 but was suspended following the political changes in 1989 and formally stopped in 1992, due in part to concerns about the geological stability of the site. In 2004, a call for tender for completion of the 2 GW of nuclear capacity was made and seven firms initially expressed an interest. In October 2006, Russia's ASE consortium, which involves the French nuclear constructor AREVA, Germany's Siemens, and Bulgarian firms, was awarded the contract, valued at the time at €4 billion ($5.8 billion).

A Belene construction consortium has been established in which the state utility Natsionalna Elektricheska Kompania (NEK) was to retain overall control, at 51 percent, with the remaining shares being put to tender. In late 2008, German utility RWE was announced as the strategic investor.[106] This led to formation of the Belene Power Company in December 2008 as a joint venture. In April 2009, ASE and AREVA NP signed a contract to develop documentation on the instrumentation and control (I&C) systems.

In October 2009, RWE, which had been set to take a 49 percent stake in the project, pulled out, prompting the Bulgarian government to search for new partners. In November 2010, NEK signed a memorandum of understanding (MoU) with the Russian state energy company Rosatom to re-establish the Belene Power Company—again with 51 percent initially being held by NEK. For its part, Rosatom is endeavoring to arrange financing for the project, to attract other investors, and to facilitate ASE's commissioning of the reactors by 2016 and 2017 at a fixed price of €6.3 billion ($9.2 billion). The ownership structure is shared between NEK (51 percent stake), Rosatom (47 percent), and Fortum and Altran (1 percent each). This will likely change when the joint venture is set up, however, as Fortum's share could rise to 25 percent. Serbia is also expected to join and Bulgaria reportedly is negotiating with several other investors.[107]

In February 2011, French media reported that Rosatom may drop its project to build at the Belene site.[108] Meanwhile, that same day, Rosatom announced that the first concrete at the site could be poured as early as September 2011.

The **Czech Republic** has six Russian-designed reactors in operation at two sites, Dukovany and Temelín. The former houses four VVER 440-213 reactors, and the latter two VVER 1000-320 units. Between them, they produced 33.2 percent of the country's electricity in 2010 (the second highest level on record after the 33.8 percent in 2009), with the Temelín plant covering slightly less than the country's annual net electricity export. Temelín was the focus of considerable controversy since a decision was taken to restart construction in the mid-1990s after being halted in 1989. The two reactors were eventually started in 2000 and 2002, with financial assistance from the U.S. Export-Import Bank and I&C technology supplied by Westinghouse.

The involvement of Westinghouse at a relatively late stage of construction caused additional technical problems, leading to delays and cost over-runs. The IEA has suggested that "despite low operating costs, amortising Temelín's costs (total cost: CZK99 billion [$6 billion], plus CZK10 billion [$603 million] of unamortized interest) will create a significant financial burden for CEZ," the Czech nuclear utility.[109] Even after the reactors began operating, the controversy has continued as technical problems, especially with the plant's uniquely large turbines, have caused unplanned outages.

In July 2008, CEZ announced a plan to build two more reactors at Temelín, with construction to start in 2013 and commissioning of the first unit in 2020. In March 2010, CEZ announced that discussions had begun with three vendor groups prior to the bid submission: a consortium led by Westinghouse; a consortium of Škoda JS, Atomstroyexport, and OKB Gidropress; and France's AREVA.[110] In February 2011, the final delivery date was shifted to 2025.[111]

The Dukovany plants have operated since the first half of the 1980s and have been the subject of engineering changes to extend the life of the reactors while simultaneously expanding their output by about 15 percent. The operators envisage that the units will continue operating until 2025.

**Hungary** is home to one nuclear power plant at Paks, which houses four VVER 440-213 reactors that provided 42.1 percent of the country's electricity in 2010 (down from a maximum of 51.4 percent in 1990). The reactors started commercial operation in the early 1980s and have been the subject to engineering works to enable their operation for up to 50 years accompanied by a 20 percent increase in capacity. In April 2003, the site's second reactor experienced the country's worst ever nuclear accident, rated on the international scale as a "serious incident" (INES Level 3), which resulted in evacuation of the main reactor hall and the venting of radioactivity to the outside environment. It later transpired that the accident was caused by inadequate cooling of the fuel rods during cleaning, leading to their overheating and to damage of the majority of the 30 rods. The reactor was out of operation for 18 months.

In March 2009, the Hungarian parliament approved a government decision-in-principle to build additional reactors at Paks.[112] In January 2011, national media reported that the operation of existing units, after plant life extension, would cease between 2030 and 2040. The proposed additional units (5 and 6) "will not generate extra power but make up for the output of the phased-out blocks."[113] Russian assistance seems to be the preferred option, and Hungary's foreign minister has indicated that expansion of the Paks plant would be part of a "package deal" on outstanding economic issues with Russia.[114]

**Lithuania's** Ignalina nuclear power plant, which was shut down in 2009, was an RBMK design similar to that used at Ukraine's Chernobyl site. Given the impact of the Chernobyl accident across Western Europe, it is remarkable that a similar design of reactor was allowed to operate within the EU for so long. As part of the accession agreement, the remaining Ignalina unit was closed on 31 December 2009, several years after the first unit was shut down in 2004. The justification for the long phase-out was the country's dependency on the stations.

Before the 2009 shutdown, Lithuania's remaining unit generated 76.2 percent of the country's electricity, the largest share worldwide. Lithuania also holds the absolute world record of all times, with nuclear achieving a staggering 88 percent share in 1993. Although the country has more-than-sufficient other installed generation capacity to make up for the loss of Ignalina, it now imports a considerable amount of (cheaper) electricity from Russia following the 2009 closure.

In February 2007, the governments of the three Baltic States and Poland agreed to build a new nuclear power plant at Ignalina.[115] Lithuania passed a parliamentary bill that July calling for construction and completion by 2015. During the following two years, various permutations of ownership structures and sizes of the proposed reactor(s) were put forward, and in April 2010 formal proposals from five selected strategic investors were submitted to the government, with bids subsequently sought. The Lithuanian government then announced that it would instead conduct direct negotiations with potential investors and that it hoped to begin operation of the new plant in 2020.[116] This led to exclusive negotiations with Korean utility Kepco, which turned down cooperation in early December 2010, two weeks after submitting a bid. In reaction, the prime ministers of Lithuania, Latvia, Estonia, and Poland confirmed their support for the Baltic power plant project during a meeting in Warsaw, though none of them made any concrete commitments.[117]

**Romania's** Cernavoda nuclear power plant hosts Europe's only CANDU (Canadian-designed) reactors. The plant project was initiated under the regime of Nicolae Ceausescu in the 1970s and was initially proposed to house five units. Construction began in 1980 on all the reactors, in part using funding from the Canadian Export Development Corporation, but this was scaled back in the early 1990s to focus on unit 1. The unit was completed in 1996 at an estimated cost of around $2.2 billion, nearly a decade late. The second unit, also completed with foreign financial assistance (a C$140 million [$146 million] Canadian loan and a €223 million [$324 million] Euratom loan) was connected to the grid in August 2007. The two reactors generated 20.6 percent of Romania's electricity in 2009, more than ever before.

Plans are being actively developed to complete two additional units at the power plant. Bids have been solicited to create an independent power producer between the utility Nuclearelectrica, which will complete and provide operation and maintenance, and private investors. In 2008, following protracted negotiations, the government decided that Nuclearelectrica would take 51 percent equity and provide funding of €1.02 billion ($1.5 billion) in loans and loan guarantees. Other funds would be internal and from partial privatizing of Nuclearelectrica in 2011.

In November 2008, an investment agreement was signed between SNN and ENEL of Italy, CEZ of the Czech Republic, GDF Suez of France, and RWE Power of Germany (with each having 9.15 percent) as well as Iberdrola of Spain and ArcelorMittal Galati of Romania (with both having 6.2 percent). Commissioning of unit 3 was due initially in October 2014 and unit 4 in mid 2015; however, this has since been revised, with the first unit not expected to be completed until 2016 at the earliest. In January 2011, CEZ sold its shares to Nuclearelectrica, and GDF Suez, RWE, and Iberdrola also withdrew from the project, explaining that, "Economic and market uncertainties surrounding this project, related for the most part to the present financial crisis, are not reconcilable now with the capital requirements of a new nuclear power project."[118]

Nuclearelectrica announced nevertheless that its tender for construction of Cernavoda 3 and 4 had received three bids: from U.S./Canadian engineering giant Bechtel, from a consortium led by Canada's SNC Lavalin and including Italy's Ansaldo and Romania's Elcomex, and from a full Russian consortium led by Atomtechnoprom.[119]

In **Slovakia**, the state utility Slovak Electric (SE) operates all nuclear power plants at two sites: Bohunice, which houses two VVER 440 units, and Mochovce, which has two similar reactors. In 2010, these provided 51.8 percent of the country's electricity production (down slightly from a maximum of 57.4 percent in 2003). Of the three other reactors that once existed at Bohunice, the first, A1, was closed after two meltdown accidents in the late 1970s. Two older VVER 440-230 reactors were closed in 2006 and 2008 as part of the EU-accession partnership agreement. The two remaining operational units were the subject of both uprating (from 440 MW to 505 MW each) and upgrading (extending their operating lives to 40 years), which would enable the station to operate until 2025.[120]

In October 2004, the Italian national utility ENEL acquired a 66 percent stake in SE and, as part of its bid, proposed to invest nearly €2 billion ($2.9 billion) in new nuclear generating capacity, including completion of the third and fourth blocks of Mochovce. In February 2007, SE announced that it was proceeding with this initiative and that ENEL had agreed to invest the lower amount of €1.8 billion ($2.6 billion). In July 2008, the European Commission gave a conditioned opinion on the Mochovce 3 and 4 project, noting that the reactor did not have the "full containment" structure used in the most recent nuclear power plants planned or under way in Europe and requesting that the investor and national authorities implement additional features to withstand a potential impact from a small aircraft.[121]

Construction at Mochovce restarted on 3 December 2008. In 2009, an Environmental Impact Assessment (EIA) was carried out, and three permits were given for major changes in the safety setup of the project. This led to formal complaints by a group of NGOs to the Aarhus Convention Compliance Committee, which resulted in December 2010 in a verdict that the three permits had been issued in breach of the convention over access to information, public participation, and access to justice in environmental matters.[122] Slovakia still needs to implement this decision, which would mean a halt to construction and a new EIA.

Plans for a new reactor at Bohunice (V3) were announced in April 2008.[123] In December 2008, Czech utility CEZ was presented as the 49-percent joint venture partner, with state-owned Javys holding 51 percent. Plans indicate that financing is to be finalized in 2011 and construction to start in 2013, at an expected cost of €3.3 billion ($4.8 billion). The reactor choice is supposed to be part of a larger tender for five reactors in total, which also includes units at the Czech sites of Temelín and Dukovany.

In **Slovenia**, the Krsko nuclear power plant was the world's first reactor to be owned jointly by two countries, **Croatia** and Slovenia. The reactor, a 696 MW Westinghouse PWR, was connected to the grid in 1981 and is due to operate until 2021. The output is shared between the two countries and covered 38.3 percent of Slovenia's power consumption in 2010 (down from a maximum of 57.4 percent in 2003). Discussions remain ongoing for the construction of a second reactor at the site; a decision has been delayed several times in Slovenia and has been pushed back to 2012 in Croatia.[124]

## Former Soviet Union

**Armenia** has one remaining reactor at the Medzamor (Armenia-2) nuclear power plant, which is situated within 30 kilometers of the capital Yerevan. The reactor is of early Soviet design, a VVER 440-230, and has raised considerable concerns. In 1995, a U.S. Department of Energy document stated: "In the event of a serious accident…the reactor's lack of a containment and proximity to Yerevan could wreak havoc with the lives of millions."[125] Due to this proximity, a 1998 referendum resulted in an agreement to close the then-two operating VVER 440-230 reactors.

In December 1988, Armenia suffered a major earthquake that killed some 25,000 people and led to the rapid closure of the reactors in March 1989. During the early 1990s and following the collapse of the former Soviet Union, a territorial dispute between Armenia and Azerbaijan resulted in an energy blockade against Armenia that led to significant power shortages, resulting in the government's decision in 1993 to re-open unit 2, the younger of the two units. The reactor provided 39.4 percent of the country's electricity in 2010 (down from a maximum of 45 percent in 2009). It was due to close in 2016, but Armenia's Minister of Energy stated in February 2011 that it will be closed only when a new plant is operational, "probably" in 2017 or 2018.[126]

In September 2007, the Minister of Energy called for a new reactor with an anticipated construction cost of $2 billion and a construction time of four-and-a-half years. In December 2009, the government approved setting up JV Metzamorenergoatom, a 50-50 Russian-Armenian joint stock company set up by the Ministry of Energy and Natural Resources with Atomstroyexport, with shares offered to other investors.[127] In August 2010, an intergovernmental agreement determined that the Russian party will build at least one VVER-1000 reactor, supply nuclear fuel for it, and decommission it. Construction should commence in 2012 and is now expected to cost $5 billion.[128]

**Kazakhstan** had just one fast breeder reactor in operation at Aktau, the BN 350, which went on line in 1973 as the world's first commercial fast breeder reactor. Used to generate power (never more than 0.6 percent of national consumption) and heat, and for desalination, it was closed down in 1999. A wide range of proposals for new nuclear power exist, ranging from further FBRs, to larger light water reactors, to as many as 20 smaller reactors deployed in towns across the country. The plans mainly involve Russian or Japanese technology. In September 2010, Japan Atomic Power Co, Toshiba and Marubeni signed a technical cooperation agreement with the National Nuclear Centre (NNC) to study the feasibility of building nuclear power capacity in the country.[129]

Kazakhstan's main contribution to the global nuclear industry is its uranium production, as it has 15 percent of the world's reserves. Uranium production has increased rapidly in the last decade, from 795 tons in 1997 to 17,803 tons in 2010, with plans for 30,000 tons by 2018.[130] At the end of 2010, Kazatomprom's portfolio of orders was worth about $17 billion, and the company expects the year's net income to be around 53 billion Tenge ($360 million), up 24 percent from 2009.[131] To meet these objectives, the company has established cooperation agreements with companies and government agencies from Canada, China, France, Japan, and Russia, among others. These agreements are not restricted to uranium supply but also involve enrichment and fuel fabrication.

**Russia** is home to 32 operating reactors with a total installed capacity of 22.6 GW.[132] In 2010, this nuclear fleet generated 155 TWh, or 17.1 percent of the country's electricity, second only to the historical maximum of 17.8 percent in 2009. Of the reactors in operation, 15 reflect early designs (four first-generation VVER 440-230s and 11 RBMKs), four are small (11 MW) BWRs used for cogeneration in Siberia, one is a fast breeder (BN-600), and 12 are second-generation light water reactors (two VVER 440-213s and 10 VVER 1000s). The average age of the reactors is 27 years, and only two have been completed in the last 10 years: one in 2004 after nearly 20 years of construction, and one in 2010 at Rostov after 27 years of construction. Eleven additional reactors are officially under construction, two of which were started more than 20 years ago: Kursk 5, started in 1985, and Kalinin, started in 1986.

In May 2010, Russia announced that over the period 2010–16, it would commission a total of 9.87 GW of new nuclear capacity, including starting up partially built reactors of older light water and fast breeder designs as well as building new units of the most recent design, the VVER 1150 MW.[133] As of 2009, the country's longer-term target for 2020 anticipated that an additional 16 GW of capacity will come on line between 2016 and 2020.[134] Russia is also constructing reactors for export, with sales of the latest design of the VVER 1000, the AES 91 and AES 92, in Bulgaria, China, and India. Other reactor designs also are being developed, including smaller 300 MW BWRs. In November 2010, Russian nuclear manufacturer Atomenergomash stunned analysts with its ambition to become "a global player in wind energy" by 2020.[135]

Russia has developed the whole nuclear fuel chain. According to the OECD's Nuclear Energy Agency, the country is home to around 10 percent of the world's reasonably assured uranium resources and also has inferred resources, with the largest mines close to the Chinese/Mongolian border.[136] For many decades, Russia was involved in the supply of fresh fuel to Central and Eastern Europe, and the take-back of spent fuel, practices that have now largely ceased. Despite intending to expand its reprocessing efforts, Russia currently reprocesses only VVER 440 fuel, with the VVER 1000 and RBMK fuel stored. Construction of the RT-2 plant at Krasnoyarsk, proposed for reprocessing of VVER 1000 fuel, was stopped.

**Ukraine** has 15 reactors in operation, which provided 48.1 percent of the country's electricity in 2010 (down from a maximum of 51.1 percent in 2004). The accident at Chernobyl in 1986 not only did huge damage to the country's economy, environment, and public health, but also stopped the domestic development of nuclear power. A later accident at Chernobyl's unit 2 in 1991 further exacerbated the situation. The two remaining units at Chernobyl have since been closed and the station is undergoing decommissioning.

Since 1986, three reactors have been completed: Zaporozhe 6, Khmelnitsky 2, and Rovno 4. In December 2010, the operating license of Rovno-1, Ukraine's oldest operating reactor at 30 years, was extended for another 20 years. After an accident at the turbine in January 2011, reactor power had to be reduced by 50 percent, even though the reactor had recently undergone major upgrading work. Ukrainian environmental organizations have severely criticized the 20-year lifetime extension.[137]

In 2006, the government approved a strategy that would lead to a doubling of nuclear installed capacity by 2030, requiring the replacement of 9 to 11 existing reactors and the addition of 11 new reactors. In February 2011, Russia and Ukraine signed an intergovernmental agreement to resume work on the third and fourth units at Khmelnitsky. Russia is to finance the design, construction, and commissioning of the two reactors, as well as any services and goods the country supplies.[138] The project's estimated cost has increased by a factor of 2.5 within half a year and stands now at some UAH40 billion ($5 billion).[139] Identification of the other projects in the expansion plan and the ordering of new construction were expected to start in 2010 but have not been reported to date.

Ukraine has uranium reserves and is undertaking mining activities, in particular at Zholtye Vody in the Dnepropetrovsk region, which provide about one-third of the country's uranium needs. Further sites are under active exploration and development using domestic resources, although plans exist to invite foreign investment to help meet a goal of doubling production to some 1,500 tons annually by 2013.

# Annex 2. Status of Nuclear Power in the World (1 April 2011)

| Countries | Nuclear Reactors[1] | | | | Power[2] | Energy[3] |
|---|---|---|---|---|---|---|
| | Operate (Reactors) | Capacity (MWe) | Average Age (Years) | Under Construction[4] (Reactors) | Share of Electricity[5] | Share of Commercial Primary Energy |
| **Argentina** | 2 | 935 | 31 | 1 | 6%(=) | 2% |
| **Armenia** | 1 | 376 | 30 | | 39%(=) | ?% |
| **Belgium** | 7 | 5 926 | 29 | | 51%(-) | 15% |
| **Brazil** | 2 | 1 884 | 18 | 1 | 3%(=) | 1% |
| **Bulgaria** | 2 | 1 906 | 20 | 2 | 33%(–) | 20% |
| **Canada** | 18 | 12 569 | 26 | | 15%(=) | 6% |
| **China** | 13 | 10 048 | 8 | 27 | 2%(=) | <1% |
| **Czech Republic** | 6 | 3 634 | 18 | | 34%(+)[6] | 15% |
| **Finland** | 4 | 2 696 | 30 | 1 | 28%(–) | 21% |
| **France** | 58 | 63 130 | 24 | 1 | 74%(–) | 38% |
| **Germany** | 17 | 20 470 | 28 | | 27%(–)[7] | 11% |
| **Hungary** | 4 | 1 849 | 24 | | 42%(=) | 16% |
| **India** | 20 | 4 388 | 18 | 5 | 3%(=) | <1% |
| **Iran** | | | | 1 | | |
| **Japan** | 48 | 42 277 | 24 | 2 | 29%(=) | 13% |
| **Mexico** | 2 | 1 300 | 18 | | 4%(–) | 1% |
| **Netherlands** | 1 | 515 | 36 | | 3%(=) | 1% |
| **Pakistan** | 3 | 737 | 24 | | 3%(=) | <1% |
| **Romania** | 2 | 1 300 | 8 | | 21%(+)[6] | 8% |
| **Russia** | 32 | 22 693 | 27 | 11 | 17%(=) | 6% |
| **Slovakia** | 4 | 1 816 | 19 | 2 | 52%(+) | 19% |
| **Slovenia** | 1 | 666 | 28 | | 37%(=) | ?% |
| **South Africa** | 2 | 1 800 | 25 | | 5%(=) | 2% |
| **South Korea** | 21 | 18 657 | 17 | 5 | 32%(–) | 14% |
| **Spain** | 8 | 7 514 | 26 | | 20%(+) | 9% |
| **Sweden** | 10 | 9 304 | 31 | | 38%(=) | 28% |
| **Switzerland** | 5 | 3 220 | 34 | | 38%(–) | 21% |
| **Taiwan** | 6 | 4 949 | 28 | 2 | 19%(–) | 9% |
| **Ukraine** | 19 | 10 097 | 21 | 2 | 48%(=) | 17% |
| **United Kingdom** | 15 | 13 107 | 28 | | 18%(+)[6] | 8% |
| **USA** | 104 | 100 683 | 30 | 1 | 20%(=) | 9% |
| **EU27** | **143** | **130 823** | **27** | **6** | **28% (=)**[6] | |
| **Total** | **437** | **370 446** | **26** | **64** | **ca. 13%** | **5.5%** |



Notes:
[1] According to IAEA, PRIS database, www.iaea.org/programmes/a2/index.html, April 2011, unless noted otherwise.
[2] In 2010, based on IAEA, PRIS database, April 2010.
[3] In 2009, according to BP, *Statistical Review of World Energy* (London: June 2010).
[4] As of 1 April 2010.
[5] A +/-/= in brackets refer to change in 2010 versus the level in 2009; a change of less than 1% is considered =.
[6] Figure for 2009 (change compared to 2008).
[7] German official statistics give the share in the gross national power generation as only 23 percent, per Annex to BDEW, "Breiter Erzeugungsmix sichert Stromversorgung," press release, 21 February 2011.

## Annex 3. Nuclear Reactors in the World Listed as "Under Construction" (1 April 2011)

| Country | Units | MWe (net) | Construction Start | Planned Grid Connection |
|---|---|---|---|---|
| **Argentina** | 1 | 692 | 1981/07/14 | 2012/07/06[1] |
| **Brazil** | 1 | 1 245 | 2010/06/01 | 2018/12/30[4] |
| **Bulgaria** | 2 | 1 906 | | |
| *…Belene-1* | | *953* | 1987/01/01 | 2016[2] |
| *…Belene-2* | | *953* | 1987/03/31 | 2017[2] |
| **China** | 27 | 27 230 | | |
| *…Changjiang-1* | | *1000* | 2010/04/25 | 2014/12/31[3] |
| *…Changjiang-2* | | *1000* | 2010/11/21 | 2015/12/31[4] |
| *…Fangchenggang-1* | | *1000* | 2010/07/30 | 2015/12/31[3] |
| *…Fangjiashan-1* | | *1000* | 2008/12/26 | 2013/12/31[5] |
| *…Fangjiashan-2* | | *1000* | 2009/07/17 | 2014/12/31[5] |
| *…Fuqing-1* | | *1000* | 2008/11/21 | 2013/10/31[3] |
| *…Fuqing-2* | | *1000* | 2009/06/17 | 2014/12/31[6] |
| *…Fuqing-3* | | *1000* | 2010/12/31 | 2015/07/31[4] |
| *…Haiyang-1* | | *1000* | 2009/09/24 | 2014/05/31[3] |
| *…Haiyang-2* | | *1000* | 2010/06/21 | 2015/03/31[3] |
| *…Hongyanhe-1* | | *1000* | 2007/08/18 | 2012/10[3] |
| *…Hongyanhe-2* | | *1000* | 2008/03/28 | 2013[7] |
| *…Hongyanhe-3* | | *1000* | 2009/03/07 | 2014[7] |
| *…Hongyanhe-4* | | *1000* | 2009/08/15 | ? |
| *…Lingao-4* | | *1000* | 2006/06/15 | 2011/08[3] |
| *…Ningde-1* | | *1000* | 2008/02/18 | 2012/12[7] |
| *…Ningde-2* | | *1000* | 2008/11/12 | 2013[7] |
| *…Ningde-3* | | *1000* | 2010/01/08 | 2014[7] |
| *…Ningde-4* | | *1000* | 2010/09/29 | 2015 |
| *…Qinshan-II-4* | | *610* | 2007/01/28 | 2012/03/28[8] |
| *…Sanmen-1* | | *1000* | 2009/04/19 | 2013/11[7] |
| *…Sanmen-2* | | *1000* | 2009/12/17 | 2014/09[7] |
| *…Taishan-1* | | *1700* | 2009/10/28 | 2013/12[7] |
| *…Taishan-1* | | *1700* | 2010/04/15 | 2014/11[7] |
| *…Yangjiang-1* | | *1000* | 2008/12/16 | 2013/08[5] |
| *…Yangjiang-2* | | *1000* | 2009/06/04 | 2014[7] |
| *…Yangjiang-3* | | *1000* | 2010/11/15 | 2015[7] |
| **Finland** | 1 | 1 600 | 2005/08/12 | 2013[9] |
| **France** | 1 | 1 600 | 2007/12/03 | 2014[10] |
| **India** | 5 | 3 564 | | |
| *…Kakrapar-3* | | *630* | 2010/11/10 | 2015/03/31 |
| *…Kakrapar-4* | | *630* | 2010/11/10 | 2015/09/30 |
| *…Kudankulam-1* | | *917* | 2002/03/31 | 2011/02/28[11] |
| *…Kudankulam-2* | | *917* | 2002/07/04 | 2011/08/31[12] |
| *…PFBR* | | *470* | 2004/10/23 | 2012[13] |
| **Iran** | 1 | 915 | 1975/05/01 | 2011/05/15[16] |
| **Japan** | 2 | 2 650 | | |
| *…Ohma* | | *1325* | 2010/05/07 | 2014/11/01 (commercial operation) |
| *…Shimane-3* | | *1325* | 2007/10/12[17] | 2011/12/15 |
| **Russia** | 11 | 9 051 | | |
| *…BN-800* | | *750* | 1985[18] | 2014 (commercial operation)[19] |
| *…Kalinin-4* | | *950* | 1986/08/01 | 2011/10[20] |
| *…Kursk-5* | | *925* | 1985/12/01 | ?[21] |
| *…Leningrad-2-1* | | *1085* | 2008/10/25 | 2013/10/31[22] |
| *…Leningrad-2-2* | | *1085* | 2010/04/15 | 2016 (commercial operation)[22] |
| *…Novovoronezh-2-1* | | *1085* | 2008/06/24 | 2012/12/31 (commercial operation)[23] |
| *…Novovoronezh-2-2* | | *1085* | 2008/07/12 | 2016 (commercial operation)[24] |
| *…Lomonosov-1* | | *32* | 2007/04/15 | 2012/12/31 (commercial operation)[25] |
| *…Lomonosov-2* | | *32* | 2007/04/15 | 2012/12/31 (commercial operation)[25] |
| *…Rostov-3* | | *1011* | 2009/09/15 | 2014 (commercial operation)[22] |
| *…Rostov-4* | | *1011* | 2010/06/16 | 2016 (commercial operation)[22] |

| | | | | |
|---|---|---|---|---|
| **Slovakia** | 2 | 810 | | |
| *...Mochovce-3* | | *405* | 1985/01/01[26] | 2012/12/30[12] |
| *...Mochovce-4* | | *405* | 1985/01/01[26] | 2013/09/01[12] |
| **South-Korea** | 5 | 5 560 | | |
| *...Shin-Kori-2* | | *960* | 2007/06/05 | 2011/08/01 |
| *...Shin-Kori-3* | | *1340* | 2008/10/31 | 2013/09/30 (commercial operation) |
| *...Shin-Kori-4* | | *1340* | 2009/09/15 | 2014/09/30 (commercial operation) |
| *...Shin-Wolsong-1* | | *960* | 2007/11/20 | 2012/03[27] |
| *...Shin-Wolsong-2* | | *960* | 2008/09/23 | 2013/01[28] |
| **Taiwan** | 2 | 2 600 | | |
| *...Lungmen-1* | | *1300* | 1999/03/31 | 2011/02/01[29] |
| *...Lungmen-2* | | *1300* | 1999/08/30 | 2012/02/01[30] |
| **Ukraine** | 2 | 1 900 | | |
| *...Khmelnitski-3* | | *950* | 1986/03/01 | 2015/01/01[12] |
| *...Khmelnitski-4* | | *950* | 1987/02/01 | 2016/01/01[12] |
| **USA** | 1 | 1 165 | 1972/12/01 | 2012/08/01 |
| **Total** | 64 | 62 488 | | |

 *Sources: IAEA-PRIS, April 2011, unless otherwise noted.*

Notes:

[1] Delayed multiple times. Most recent date published after August 2009.
[2] Delayed multiple times; no IAEA start-up date. This estimate from: http://world-nuclear.org/info/inf87.html.
[3] No IAEA startup date. This estimate from www.world-nuclear.com/info/inf63.html.
[4] Commercial operation.
[5] No IAEA start-up date. This estimate for commercial operation from www.world-nuclear.com/info/inf63.html.
[6] Delayed from August 2014; no IAEA start-up date. This estimate from www.world-nuclear.com/info/inf63.html.
[7] No IAEA start-up date. This estimate derived from www.world-nuclear.com/info/inf63.html.
[8] Delayed by six months.
[9] After numerous revisions of the original planned commissioning in 2009, the date refers to the grid connection of the plant, according to AREVA. TVO stated that, "regular operation will start during the latter half of 2013." Sources: TVO, press release, 26 November 2010; AREVA, press release, 29 November 2010.
[10] Delayed by at least two years, according to credible press reports; "Les retards de l'EPR à Flamanville inquiètent l'Etat," Le Monde, 30 July 2010.
[11] Date passed. Delayed numerous times.
[12] Delayed numerous times.
[13] Delayed numerous times; no IAEA start-up date. This estimate for commercial operation from www.world-nuclear.org/info/inf53.html.
[14] Delayed again from planned start-up at 2007/12/31; new date 2009/09/30 withdrawn in July 2009. No new IAEA date; retained date for modeling purposes only.
[15] Delayed again from planned start-up at 2007/06/30. June 2009 date still on IAEA list on 5 August 2009. Retained 2009 as start-up date for modeling purposes.
[16] Delayed countless times.
[17] This unit was added to the IAEA list only in October 2008.
[18] The IAEA Power Reactor Information System (PRIS) database curiously provides a new construction start date as 2006/07/18. Until 2003, the French Atomic Energy Commission (CEA) listed the BN-800 as "under construction" with a construction start-up date of "1985." In subsequent editions of the CEA's annual publication ELECNUC, Nuclear Power Plants in the World, the BN-800 had disappeared.
[19] Delayed numerous times; no IAEA start-up date. This estimate from www.world-nuclear.com/info/inf29.html.
[20] Delayed from planned start-up at 2010/12/31 as of end of 2007, no new IAEA date. This estimate from www.world-nuclear.org/info/inf45.html.
[21] Delayed from planned start-up at 2010/12/31 as of end of 2007; no new IAEA date and deleted from WNA construction list. Kursk-5 is based on an upgraded RBMK design and its completion seems highly uncertain. We have arbitrarily envisaged, for modeling purposes only, that it starts in 2018.
[22] No IAEA start-up date; this estimate for commercial operation from www.world-nuclear.org/info/inf45.html.
[23] Commercial operation date introduced in early 2009.
[24] Delayed by two years; no IAEA start-up date. This estimate for commercial operation from www.world-nuclear.org/info/inf45.html.
[25] Commercial operation originally planned for 2010 at Severod. Since moved to Lomonosov and delayed by two years.
[26] On 11 June 2009 construction officially resumed.
[27] Delayed. Startup date of 2011/05/28 withdrawn from IAEA-PRIS. This date from www.world-nuclear.org/info/inf81.html.
[28] Delayed. Startup date of 2012/05/28 withdrawn from IAEA-PRIS. This date from www.world-nuclear.org/info/inf81.html.
[29] Delayed many times from original start-up date of mid-2006. IAEA startup date passed.
[30] Delayed many times from original start-up date of mid-2007.

# Endnotes

## Introduction

[1] James Paton, "Fukushima Crisis Worse for Atomic Power Than Chernobyl, UBS Says," Bloomberg.com, 4 April 2011.
[2] National Federation of Fisheries Cooperative Associations (JF Zengyoren) Protests to TEPCO, Nikkei Domestic TV News (Japanese version), unofficial translation by Aileen Smith, Green Action; see www.nikkei.com/video/?bclid=67421386001&bctid=888329135001.
[3] Mikhail Gorbachev, "Chernobyl 25 Years Later: Many Lessons Learned," http://bos.sagepub.com/content/67/2/77.full, viewed 1 March 2011.
[4] "Belarus Nuclear Deal to Be Signed on March 15," Voice of Russia, 16 February 2010, see http://english.ruvr.ru/2011/02/16/44704708.html.
[5] "Powering Development," Voice of Russia, 8 February 2011, see http://english.ruvr.ru/2011/02/16/44704708.html.
[6] As the Brookings Institution's John Banks puts it, "one man's nuclear renaissance could be another man's burst bubble," per Brookings Institution, *Streamlining the Nuclear Energy Regulatory Process* (Washington, DC: 13 October 2010).
[7] Mycle Schneider et al., *The World Nuclear Industry Status Report 2009 – With Particular Emphasis on Economic Issues*, commissioned by the German Ministry for the Environment, Nature Conservation and Reactor Safety (Berlin: August 2009). English and German editions at www.bmu.de/english/nuclear_safety/downloads/doc/44832.php; Spanish edition at www.tanquemlesnuclears.org/materials/WNISR2009CAST.pdf. Earlier editions include: Mycle Schneider with Antony Froggatt, *The World Nuclear Industry Status Report 2007*, commissioned by the Greens-EFA in the European Parliament (Brussels-Paris-London: January 2008); French version February 2008; Italian, Spanish versions April 2008, available at www.greens-efa.org/cms/topics/rubrik/6/6659.energy@en.htm.
Earlier versions were released in 2004 by the Greens-EFA Group in the European Parliament and in 1992 jointly by Worldwatch Institute, Greenpeace International, and WISE-Paris.
[8] Gorbachev, op. cit. note 3.
[9] "Another Drop in Nuclear Generation," *World Nuclear News* (WNN), 5 May 2010.
[10] If not otherwise noted, all nuclear capacity and electricity generation figures based on International Atomic Energy Agency (IAEA), Power Reactor Information System (PRIS) online database, www.iaea.org/programmes/a2/index.html.
[11] "Load Factors to End December 2009 – Updated June 2010," *Nuclear Engineering International* (NEI), May 2010. According to NEI, "Annual load factors are calculated by dividing the gross generation of a reactor in a one-year period by the gross capacity of the reactor (sometimes called output), as originally designed, multiplied by the number of hours in the calendar year. The figures are expressed as percentages. Where a plant is uprated, the revised capacity is used from the date of the uprating."
[12] Ibid.
[13] Figure 1 from IAEA-PRIS, op. cit. note 10, and from Mycle Schneider Consulting.
[14] Figure 2 from ibid.
[15] Nuclear Regulatory Commission (NRC), "Approved Applications for Power Uprates," 3 November 2010, at www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html; NRC, "Pending Applications for Power Uprates," 3 November 2010, at www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/pending-applications.html.
[16] Figure 3 from IAEA-PRIS, op. cit. note 10, and from Mycle Schneider Consulting.
[17] Figure 4 from ibid.
[18] CEA, *Elecnuc – Nuclear Power Plants in the World* (Gif-sur-Yvette Cedex, France: 2002).
[19] Figures 5 and 6 from IAEA-PRIS, op. cit. note 10, and from Mycle Schneider Consulting.
[20] Calculation uses a projection from the Öko-Institut for individual reactor shutdown dates.
[21] Figure 7 from IAEA-PRIS, op. cit. note 10, from World Nuclear Association, various documents, and from Mycle Schneider Consulting.
[22] See, for example, "Maintain Nuclear Perspective, China Told," *WNN*, 11 January 2011.
[23] Figure 8 from the following sources: IAEA-PRIS, op. cit. note 10; U.S. Nuclear Regulatory Commission; World Nuclear Association, various documents; Mycle Schneider Consulting.
[24] Figure 9 from IAEA-PRIS, op. cite note 10, from NRC, op. cit. note 15, and from Mycle Schneider Consulting.

## Potential Newcomer Countries

[1] Figure 10 from International Atomic Energy Agency (IAEA), Power Reactor Information System (PRIS) database, www.iaea.org/programmes/a2/index.html, viewed February 2011.
[2] IAEA, "International Status and Prospects of Nuclear Power," Report by the Director General, Board of Governors General Conference (Vienna: 2 September 2010); IAEA, "International Status and Prospects of Nuclear Power," Report by the Director General, Board of Governors General Conference (Vienna: 12 August 2008).
[3] Table 1 from the following sources: IAEA, op. cit. note 2, both references; World Nuclear Association (WNA), "Emerging Nuclear Countries," www.world-nuclear.org/info/inf102.html, February 2011; Centre of International Governance Innovation (CIGI), "Survey of Emerging Nuclear Energy States," www.cigionline.org/senes, viewed 2 March 2011.
[4] World Bank, *Environmental Assessment Sourcebook: Volume III. Guidelines for Environmental Assessment of Energy and Industrial Projects* (Washington, DC: Environment Department, 1991).
[5] José Goldemberg, "Nuclear Energy in Developing Countries," *Journal of the American Academy of Arts and Science*, vol. 138, no. 4 (2009).
[6] Trevor Findlay, *The Future of Nuclear Energy to 2030 and Its Implications for Safety, Security and Nonproliferation. Overview* (Waterloo, ON: CIGI, 2010).
[7] IAEA, "International Status and Prospects of Nuclear Power," op. cit. note 2, 2 September 2010.
[8] World Bank, op. cit. note 4.
[9] Findlay, op. cit. note 6.
[10] Goldemberg, op. cit. note 5.
[11] WNA, op. cit. note 3.
[12] "Setback in Bushehr Commissioning," *World Nuclear News (WNN),* 28 February 2011.
[13] Federation of American Scientists, ""Bushehr," www.fas.org/nuke/guide/iran/facility/bushehr.htm, viewed 4 March 2011; Mohammad Sahimi, "Iran's Nuclear Program. Part 1: Its History," *Payvand Iran News*, 10 February 2003.
[14] "Iran Says Fuel Not Removed at Bushehr Nuclear Site," *Reuters*, 1 March 2011.
[15] WNA, op. cit. note 3.
[16] "Russia's Plans for Akkuyu," *WNN*, 13 May 2010.
[17] "Site Work to Start for Turkish Plants," *WNN*, 25 February 2011.
[18] Tsuyoshi Inajima, "Turkey Holds Nuclear Talks With Japan After South Korean Discussions Fail," Bloomberg.com, 23 December 2010.
[19] "Abdullah Al Mutawa Explains How the UAE is Preparing to Meet Future Power Demands," ArabianOilandGas.com, 10 June 2008.
[20] "ENEC Welcomes Regulator's Licence Approval," *ArabianBusinesss.com*, 11 July 2010.
[21] "Belarus Nuclear Deal to be Signed on March 15," *Voice of Russia*, 16 February 2011.
[22] Bellona, "Belarus to Break Ground on Its New Nuclear Plant, Despite Criticism from the Espoo Convention," 10 February 2011, at www.bellona.org/articles/articles_2011/belarus_espoo.
[23] CIGI, op. cit. note 3.
[24] "International Bidding for Egypt's First Nuclear Power Plant Is Postponed," *Ahram Online*, 20 February 2011.
[25] Hanan Nugroho, "Development of Nuclear Power in Indonesia: Stop or Go?" *Jakarta Post*, 5 May 2010.
[26] "Italy's Nuclear Power Comeback, Facing Strong Opposition and Referendum," GreenOptimistic.com, 13 January 2011.
[27] "Jordan to Seek Bids for Reactor Operator Next Week," Bloomberg.com, 17 February 2011.
[28] "Polish Government Approves Nuclear Regulations," *Reuters*, 22 February 2011.
[29] WNA, "Emerging Nuclear Energy Countries," www.world-nuclear.org/info/inf102.html, updated 25 February 2011.
[30] "Thai, Vietnamese Nuclear Plans Face Delays on Labor, Wood Mackenzie Says," Bloomberg.com, 18 November 2010.
[31] "Japan and Russia to Build Ninhthuan Nuclear Power Plants for Vietnam," Global Energy Magazine, 3 November 2010.
[32] WNA, op. cit. note 3.
[33] Ibid.

## Nuclear Economics

[1] Table 2 from the following sources: "NRC Issues Final Safety Evaluation Report and Final Design Approval for GE-Hitachi ESBWR Advanced Reactor," *Targeted News Service*, 9 March 2011; "GE Hitachi Nuclear Energy's ABWR Renewal Application Formally Accepted by the NRC," *ENP Newswire*, 24 February 2011.

[2] "Lauvergeon: French Lost UAE Bid Because of Expensive EPR Safety Features," *Nucleonics Week*, 14 January 2010.
[3] Ibid.
[4] Ibid.
[5] Obtained from AREVA Web site, www.areva.com, dated June 2009.
[6] See the 2009 edition of the *World Nuclear Industry Status Report* for a detailed discussion about the rising costs of nuclear plant design.
[7] "EDF Partner Sees Impasse in Plan for U.S. Reactor: Cost of Loan Guarantee Dooms Joint Project, Maryland Utility Says," *International Herald Tribune*, 11 October 2010, p. 15.
[8] "EDF Seeks Maryland's Help for Unprofitable New Nuclear Reactor," Bloomberg.com, 1 March 2011.
[9] "Nuclear Energy: Loan Guarantee Program Survives GOP Cuts," *Environment and Energy Daily*, 17 February 2011.
[10] "Teollisuuden Voima Oyj's Report of the Board of Directors and Financial Statement 2010," *ENP Newswire*, 3 March 2011.
[11] François Roussely, *Future of the French Civilian Nuclear Industry* (Paris:16 June 2010), translated by the Institute for Energy and Environmental Research, Takoma Park, Maryland, http://www.psr.org/nuclear-bailout/resources/roussely-report-france-nuclear-epr.pdf
[12] AREVA, "2010 Annual Results," press release (Paris: 3 March 2011).
[13] "Olkiluoto-3 Operation Again Delayed, But Progress Made on I&C Issue," *Nucleonics Week*, 10 June 2010, p. 1.
[14] "Flamanville-3 Two Years Behind Schedule, EDF Says in Targeting 2014 for Startup," *Nucleonics Week*, 5 August 2010, p. 1.
[15] "Russian Industry to Build Vietnam's First Nuclear Plant," *Nucleonics Week*, 29 April 2010, p. 6.
[16] "Vietnam Signs Reactor Construction Accords with Russia, Japan," *Nucleonics Week*, 11 November 2010, p. 1.
[17] John Rowe, CEO, Exelon, presentation to National Association of Home-builders, Washington, DC, 12 May 2010.
[18] U.K. Department for Business, Enterprise and Regulatory Reform, *Meeting the Energy Challenge: A White Paper on Nuclear Power* (London: January 2008), p. 61.
[19] Mott MacDonald, *UK Electricity Generation Costs Update* (London: June 2010).
[20] Nuclear Energy Agency, *Projected Costs of Generating Electricity: 2010 Edition* (Paris: 2010).
[21] Ernst & Young, *Passing the Starting Line: Nuclear Construction Risk* (Düsseldorf, Germany: 2010).
[22] Standard & Poors, *The Economics of U.S. Nuclear Power: Natural Gas Prices and Loan Guarantees Are Key to Viability* (San Francisco: 2010).
[23] Roussely, op. cit. note 11.
[24] Arnulf Grubler, *An Assessment of the Costs of the French Nuclear PWR Program: 1970–2000* (Laxenburg, Austria: International Institute for Applied Systems Analysis, 6 October 2009).
[25] Mark Cooper, *Policy Challenges of Nuclear Power Construction: Cost Escalation and Crowding Out Alternatives* (South Royalton, VT: Institute for Energy and the Environment, Vermont Law School, 2010).
[26] "Constellation Move Casts Doubt About Nuclear Merchant Plants' Future," *Nucleonics Week*, 14 October 2010, p. 1.
[27] "DOE, OMB Consider Changes in Loan Guarantees," *Nucleonics Week*, 18 November 2010, p. 1.
[28] For a comprehensive review of the use of subsidies to promote nuclear power, see Doug Koplow, *Nuclear Power: Still Not Viable Without Subsidies* (Cambridge, MA: Union of Concerned Scientists, 2011).
[29] Rowe, op. cit. note X.
[30] U.K. Department of Energy and Climate Change, "Statement on Energy Policy by Chris Huhne (Written Ministerial Statement), Secretary of State for Energy and Climate Change," 18 October 2010, www.decc.gov.uk/en/content/cms/news/en_statement/en_statement.aspx.
[31] The Stationary Office, *Electricity Market Reform* (London: December 2010).

### Nuclear Power vs. Renewable Energy Development

[1] Kelly Rigg, "Battle-proof Wind Farms Survive Japan's Trial by Fire," *Huffpost Green*, 17 March 2011.
[2] United Nations Framework Convention on Climate Change, "Outcome of the Work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention," Draft decision, COP 16 (Cancún, Mexico: 2010), at http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_lca.pdf.
[3] International Energy Agency (IEA), *World Energy Outlook 2010* (Paris: 2010).
[4] U.K. Energy Research Centre, *"Global Oil Depletion: An Assessment of the Evidence for a Near-term Peak in Global Oil Production"* (London: August 2009).
[5] Ibid.

[6] European Commission, "The Commission's New Energy Efficiency Plan," press release (Brussels: 8 March 2011).
[7] International Atomic Energy Agency (IAEA), "Climate Change and Nuclear Power 2008" (Vienna: 2008).
[8] For an in-depth discussion of historic government subsidies to nuclear energy in Germany, see Green Budget Germany, *Staatliche Förderungen der Atomenergie im Zeitraum 1950 bis 2008* (Berlin: 2009).
[9] Marshall Goldberg, "Federal Energy Subsidies: Not All Technologies Are Created Equal", Renewable Energy Policy Project Research Report No. 11 (Washington, DC: July 2000).
[10] Figure 11 from IEA, R&D Statistics Database, Government Energy Technology R&D Budgets, www.iea.org/stats/rd.asp, viewed March 2011.
[11] Figure 12 from John O. Blackburn and Sam Cunningham, "Solar and Nuclear Costs – The Historic Crossover," prepared for NC WARN Waste Awareness & Reduction Network (Durham, NC: 2010).
[12] Ibid.
[13] IEA, *Nuclear Power in the OECD* (Paris: 2001).
[14] "Blair Backs New Power Plans," *BBC News*, May 2007.
[15] Table 3 from the following sources: World Energy Council, Alessandro Clerici, and ABB Italy, European Regional Study Group, "The Future Role of Nuclear Energy in Europe" (June 2006); post-2000 figures based on IAEA, PRIS database, www.iaea.org/programmes/a2/index.html.
[16] European Wind Energy Association (EWEA), "Wind Energy, The Facts: Volume 1, Technology*"* (Brussels: 2003).
[17] Figure 13 from the following sources: Amory Lovins, 2010; Global Wind Energy Council (GWEC), *Global Wind Energy Report 2010* (Brussels: 2001); IAEA, PRIS database; European Photovoltaic Industry Association, "Global Market Outlook for Photovoltaics until 2014" (Brussels: May 2010).
[18] Pew Charitable Trusts, "Who's Winning the Clean Energy Race – Edition 2010" (Philadelphia: 2011).
[19] Bloomberg New Energy Finance, "Global Trends in Clean Energy Investment: Clean Energy Investment Storms to New Record in 2010," fact sheet, 11 January 2011.
[20] Table 4 from Pew Charitable Trusts, op. cit. note 18.
[21] The Italian government set the 2020 solar PV target in its National Action Plan of July 2010, per "Italy Prepares to Squeeze PV," *Power in Europe*, 7 March 2011.
[22] GWEC, "Global Wind Capacity Increases by 22% in 2010 – Asia Leads Growth" (Brussels: 2 February 2011).
[23] Figure 14 from the following sources: IAEA, PRIS database; GWEC, op. cit. note 17; Chinese 12th Five-Year Plan; media reports.
[24] Kevin Mo, "Go With Wind: China to Dramatically Boost Its Wind Power Capacity, Again," *Switchboard* (Natural Resources Defense Council blog), 21 July 2009.
[25] M.V. Ramana, personal communication, 16 April 2011
[26] U.S. National Renewable Energy Laboratory, "2009 Renewable Energy Data Book" (Golden, CO: August 2010).
[27] J.P. Molly, "Status der Windenergienutzung in Deutschland – Stand 31.12.2010" (Berlin: DEWI, 2011).
[28] Siegmar Gabriel, Deutscher Bundestag, 16. Wahlperiode, 211. Sitzung, Berlin: 19 March 2009.
[29] Johannes Lambertz, "Utility Power Plant Investment: Why Europe Needs Smart Megawatts," PowerGenWorldwide.com, 6 March 2011.
[30] Manfred Fischedick et al., *Hindernis Atomkraft – Die Auswirkungen einer Laufzeitverlängerung der Atomkraftwerke auf erneuerbare Energien* (Berlin: German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, April 2009).

### Post-3/11 Developments in Selected Countries

[1] Archana Chaudhary, "Nuclear Accident Forces China Policy Review as India Sees Safety Backlash," Bloomberg.com, 14 March 2011.
[2] Heather Timmons and Vikas Bajaj, "India, China to Move on With Nuclear Plans," *New York Times*, 15 March 2011.
[3] "China's Nuclear Safety Assured," china.org.cn, 28 March 2011.
[4] "China Suspends Approval for Nuclear Power Plants," *The Guardian* (U.K.), 16 March 2011.
[5] Chaudhary, op. cit. note 1.
[6] Navin Singh Khadka, "South Asia Nuclear Policy Not Shaken by Japan Crisis," *BBC News*, 27 March 2011.
[7] Ibid.
[8] Tifa Asrianti, "RI Unfazed by Japan Nuclear Crisis," *Jakarta Post*, 15 March 2011.
[9] Ibid.
[10] Adianto P. Simamora, "Indonesia Not Ready for Nuclear Plant: Minister," *Jakarta Post*, 19 March 2011.
[11] "Edano Says Japan Nuclear Policy Must Be Reviewed After Crisis," Bloomberg.com, 28 March 2011.
[12] "Japan Cabinet Rating Up, Low Marks for Nuclear Crisis—Poll," *Reuters*, 27 March 2011.

[13] Mure Dickie, "No Plans to Nationalise Tepco, Says Kan," *Financial Times*, 1 April 2011.
[14] Shigeru Sato, James Paton, and Yuriy Humbe, "Tepco Chief Pressured to Quit After Costing Holders $29 Billion," Bloomberg.com, 28th March 2011.
[15] Nikkei video (Japanese version), 6 April 2011, www.nikkei.com/video/?bclid=67421386001&bctid=888329135001; informal translation by Aileen Smith, Green Action, Kyoto.
[16] Hemananthani Sivanandam and Azril Annuar, "Reconsider Nuclear Plans, Urges MCA, DAP," *The Sun*, 14 March 2011.
[17] Syed Jaymal Zahiid, "Muhyiddin Sees No Issues with Nuclear Plans," FreeMalaysiaToday.com, 15 March 2011.
[18] "80% of Thai People Oppose Nuclear Power," *The Nation/Asia News Network*, 27 March 2011.
[19] "Thailand to Review Nuclear Power Plan: Minister," *Thai News Agency*, 17 March 2011.
[20] "Taiwan Says Nuclear Power Is Necessary Choice, Evening News Says," Bloomberg.com, 28 March 2011.
[21] "DPP Urges Nuclear Power Poll," *Taipei Times*, 29 March 2011.
[22] Helen Clark, "Vietnam to Go Ahead with Nuclear Plans," GlobalPost.com, 20 March 2011.
[23] "Vietnam to Proceed with Nuclear Power Plants," ThanhNienNews.com, 17 March 2011.
[24] "Lee Pledges to Ensure Safety at UAE Nuclear Plants," *Korean Times*, 14 March 2011.
[25] "EU Must Consider Nuclear-free Future—Oettinger," *Reuters*, 15 March 2011.
[26] General Secretariat of the Council Delegations, "European Council 24–25 March 2011 Conclusions" (Brussels: 25 March 2011).
[27] "EC 'Reexamines' Bulgaria's Belene Nuclear Project," *Sofia News Agency*, 15 March 2011.
[28] Elizabeth Konstantinova, "Bulgaria to Seek Nuclear Safety Guarantees on Russian Reactors," Bloomberg.com, 14 March 2011.
[29] "Czechs Say No Nuclear Review Yet on Expansion Plans," *Reuters*, 14 March 2011.
[30] "Finland Reviews Nuclear Safety, Sweden No Review," *Reuters*, 14 March 2011.
[31] "Sarkozy: 'pas question de sortir du nucléaire,'" *Agence France Presse*, 14 March 2011
[32] André-Claude Lacoste, letter to French Prime Minister Nicolas Sarkozy, 25 March 2011.
[33] "Martine Aubry 'personellement' favorable à une sortie du nucléaire," nouvelobs.com, 5 April 2011.
[34] "Bayrou compare crise au Japon et 11/9," *Agence France Presse*, 16 March 2011.
[35] French Institute of Public Opinion (IFOP), "Les Français et le nucléaire" (Paris: 17 March 2011).
[36] Nina Sovich, "Japan Crisis May Raise French Nuclear Upgrade Cost," *Reuters*, 18 March 2011.
[37] Jean-Michel Bezat, "La catastrophe de Fukushima hypotèque lourdement le renouveau de la filière française de l'atome civil," *Le Monde*, 16 March 2011.
[38] Nicholas Comfort and Kari Lundgren, "Merkel Review Shows Fukushima Put EU Energy Targets at Risk," Bloomberg.com, 15 March 2011; Patrick McGroarty, "Germany to Shut Seven Reactors," *Wall Street Journal*, 15 March 2011.
[39] "Most of Germany's Idled Nuclear Plants Will Never Open, CDU's Groehe Says," Bloomberg.com, 28 March 2011.
[40] Author interview with Deutschlandfunk, 3 April 2011.
[41] "Germany to Phase Out Nuclear Power: Deputy Minister," *Reuters,* 4 April 2011.
[42] Nomura, "Nuclear Contamination – We Consider the Risks to New Build, Safety Costs and Fossil Fuel Prices," 14 March 2011.
[43] "Italy's Enel to Press Ahead with Nuclear Plans," *Reuters*, 15 March 2011.
[44] "Italy Approves Nuclear Pause," *Wall Street Journal*, 23 March 2011.
[45] "Italy Freezes Return to Nuclear Power," *Financial Times,* 20 April 2011.
[46] "Japanese Nuclear Problems Will Be Taken into Account Here," dutchnews.nl, 15 March 2011.
[47] "Poland to Keep N-power on Track," thenews.com.pk, 15 March 2011.
[48] "Polish Premier: Nuclear Energy Referendum Possible," Deutsche Presse-Agentur, 23 March 2011.
[49] Terhi Kinnunen and Simon Johnson, "Finland Reviews Nuclear Safety, Sweden No Review," *Reuters*, 14 March 2011.
[50] "More Swedes Favour Nuclear Phase-out: Poll," TheLocal.se, 22 March 2011.
[51] "Review of Nuclear Safety," Radio Sweden, 30 March 2011.
[52] Chris Huhne, "Statement on Nuclear Situation in Japan" (London: 14 March 2011).
[53] "Public Opposition to Nuclear Power Grows in UK," EnergyEfficiencyNews.com, 24 March 2011.
[54] "EDF's De Rivaz Says U.K. Nuclear Power Plans Will Proceed," Bloomberg.com, 20 March 2011.
[55] "Putin Orders Review of Russian Nuclear Sector," *Deccan Chronicle*, 15 March 2011.
[56] "Swiss Suspend Approvals for New Nuclear Plants," *Reuters*, 14 March 2011.
[57] "Most Swiss Want Nuclear Energy Phase Out: Poll," *Agence France Presse*, 20 March 2011.
[58] "Brazil's Nuclear Energy Program Won't Be Changed on Japan - Minister Lobao," *Wall Street Journal*, 14 March 2011.

[59] Zhong Yuan Wei, "Brazil to Adopt New Safety Guidelines for Future Nuclear Plants," YTWHW.com, 24 March 2011.
[60] Jeff Mason and Will Dunham, "Japan Nuclear Woes Cast Shadow over U.S. Energy Policy," *Reuters*, 13 March 2011.
[61] Michael A. Memoli, "Japan's Nuclear Problems Pose Little Danger to U.S., Nuclear Regulatory Commission Chief Says," *Los Angeles Times*, 14 March 2011.
[62] Jim Acosta and Evan Glass, "Fears Mounting over U.S. Nuclear Plants," CNN.com, 15 March 2011; "Japan Nuclear Crisis and Tsunami - Tuesday 15 March," *The Guardian* (U.K.), 15 March 2011.
[63] Peter Behr, "A Bullet Aimed at the Nuclear Energy 'Renaissance,'" *New York Times*, 14 March 2011.
[64] Irwin Stelzer, "Japan's Crisis and the Future of Nuclear Power in the US," *San Francisco Examiner*, 3 March 2011.
[65] "NRG Withdraws From Texan Project", *WNN,* 20 April 2011.
[66] Box is based on the following sources: HSBC, *Climate Investment Update: Japan's Nuclear Crisis and the Case for Clean Energy* (London: 18 March 2010); Standard and Poors, "S&P Global Nuclear Energy," www.standardandpoors.com/indices/sp-global-nuclear-energy/en/eu/?indexId=SPGBTHENNEUSDW---P-RGL---, viewed April 2011 (the S&P Global Clean Energy Index comprises a diversified mix of 30 "production" and "equipment & technology" companies, including First Solar, Gamesa, Iberdrola, and Vestas; the S&P Nuclear Index comprises 24 of the largest publicly traded companies in nuclear energy and is equally distributed between "nuclear materials, equipment, and services" and "nuclear energy generation" companies, including Mitsubishi, AMEC, E.ON, and The Shaw Group); Osha Gray Davidson, "Japan's Nuclear Crisis: Moody's Reviews Eight Utilities for Possible Downgrades," Forbes.com, 28 March 2011; Lee Jay Walker, "Toshiba and Hitachi Need to Overcome the Nuclear Reactor Crisis in Fukushima," *Modern Tokyo Times*, 1 April 2011; James Paton, "Fukushima Crisis Worse for Atomic Power Than Chernobyl, UBS Says," Bloomberg.com, 4 April 2011.

### Annex 1. Overview by Region and Country

[1] "Government Drops Final Curtain on PBMR," *World Nuclear News* (WNN), 20 September 2010. The company PBMR, which in September 2010 still claimed on its website that "the South-African project is on schedule to be the first commercial scale HTR in the power generation field," later fired all but nine staff, went into "care and maintenance" mode to safeguard intellectual property, and shut down its website for good.
[2] For an independent historical account of the PBMR, see David Fig, *Nuclear Energy Rethink? The Rise and Demise of South-Africa's Pebble Bed Modular Reactor*, ISS Paper 210 (Pretoria: Institute for Security Studies, April 2010).
[3] "South Africa to Develop a Policy for Private Investment in Nuclear Plants," Bloomberg.com, 26 October 2010.
[4] Department of Energy, Republic of South Africa, "Media Briefing" (Pretoria: 6 December 2010), at www.energy.gov.za/files/media/presentations/RFI%20Results%20%20Media%20presentation%20%201%20December%202010%20(2).pdf.
[5] "Argentina's Embalse Nuclear Plant to Get 25-year Extension," PowerGenWorldwide.com, 5 August 2010.
[6] "Argentina and Brazil Team Up for Nuclear," *WNN*, 25 February 2008. Both countries have a long way to go to make their programs exemplary. Their industrial as well as their non-proliferation record has been far from convincing.
[7] "Argentina to Reinforce Nuclear Energy by Adding 700 MW and Building Fourth Nuclear Plant," Marketwire.com, 7 May 2009.
[8] "Brazil, Argentina Extend Cooperation," *WNN*, 1 February 2011.
[9] "The Completion of Brazil's Angra-3 Reactor Looks More Doubtful after the Country's Environment Minister Set 60 Tough Conditions for the Project," *WNN*, 24 July 2008.
[10] See, for example, "Brazil Commission Gives Go-Ahead for Angra-3 Nuclear Plant," *Dow Jones Newswire*, 31 May 2010.
[11] "Brazil to Approve Construction of Four Nuclear Power Plants in 2011," www.neimagazine.com, 10 January 2011.
[12] "Pickering A Gets 3-year Licence Extension," www.neimagazine.com, 2 July 2010.
[13] Bruce Power, "Bruce A Restart & Refurbishment Project Expanded," press release (Tiverton, ON: 29 August 2007).
[14] "Economy Let Us Delay Nuclear Plan, Premier Says," *The Star* (Toronto), 7 July 2009.
[15] "Ottawa Seeks Nuclear Commitment from Ontario," *Globe and Mail* (Toronto), 20 January 2011.
[16] NB Power, "Point Lepreau Generating Station Refurbishment Project Update," press release (Fredericton, NB: 3 February 2011).
[17] "Iberdrola Completes Modernization Work on Mexican Nuclear Plant," *European Business Review*, 7 February 2011.

[18] U.S. Nuclear Regulatory Commission (NRC), "Status of License Renewal Applications and Industry Activities," www.nrc.gov/reactors/operating/licensing/renewal/applications.html, viewed 11 February 2011.
[19] NRC, "Combined License Applications for New Reactors," www.nrc.gov/reactors/new-reactors/col.html, viewed 11 February 2011.
[20] U.S. Department of Energy (DOE), Energy Information Administration (EIA), "Status of Potential New Commercial Nuclear Reactors in the United States," www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/reactorcom.html, updated 1 July 2010.
[21] ESP granted: Clinton (Exelon), Grand Gulf (SERI), North Anna (Dominion), Vogtle (Southern). ESP under review Victoria County Station (Exelon), PSEG Site (PSEG).
[22] NRC, "Early Site Permit Applications for New Reactors," www.nrc.gov/reactors/new-reactors/esp.html, viewed 12 February 2011.
[23] "More Funds for Loan Guarantees," *WNN*, 10 December 2010.
[24] Michael J. Wallace, Chairman of Constellation Energy Nuclear Group, letter to Dan Poneman, DOE, 8 October 2010.
[25] Abby Gruen, "Princeton-based NRG Cuts Nuclear Spending Pending DOE Loan Guarantee," 2 August 2010, see www.nj.com/business/index.ssf/2010/08/princeton-based_nrg_cuts_nucle.html.
[26] "Construction Work Delayed at Levy as Costs Rise," *WNN*, 7 May 2010.
[27] DOE, EIA, *AEO2011 Early Release Overview* (Washington, DC: February 2011).
[28] Dr. Shin Wei Ng and Nick Mabey, *Chinese Challenge or Low Carbon Opportunities: The Implications of China's 12th Five-Year-Plan for Europe* (London: E3G, February 2011).
[29] "China's Nuclear Power Build-up Moving Too Fast," *Straits Times*, 11 January 2011.
[30] "Westinghouse Wins $5.3 Billion China Nuclear Contract (Update5)," Bloomberg.com, 16 December 2006.
[31] Westinghouse, "Westinghouse, Shaw Group Sign Landmark Contracts to Provide Four AP1000 Nuclear Power Plants in China," press release (Beijing: July 2007).
[32] AREVA, "China: AREVA and CGNPC Sign the Biggest Contract Ever in the History of Nuclear Power and Enter into a Long-term Commitment. AREVA and CNNC Strengthen Their Links," press release (Paris: 26 November 2007).
[33] World Nuclear Association (WNA), "China's Nuclear Fuel Cycle," www.world-nuclear.org/info/inf63b_china_nuclearfuelcycle.html, updated January 2011.
[34] Trend, "Kazakhstan, China Sign Long-term Contract on Uranium Supply," 11 November 2010, at http://en.trend.az/capital/business/1780770.html.
[35] WNA, "China's Nuclear Fuel Cycle," op. cit. note 99.
[36] Nuclear Energy Agency, *Uranium 2009: Resources, Production and Demand*, A joint report of the Organisation for Economic Co-Operation and Development (OECD) and International Atomic Energy Agency (IAEA) (Paris: OECD Publishing, 2010).
[37] Caroline Peachey, "Power Plant Performance: Load Factors to End December 2009," *Nuclear Engineering International*, May 2010 [updated June 2010].
[38] "Money No Object for Indian Reactor Plans," *WNN*, 25 March 2009.
[39] AREVA, "India: Agreements Between Areva and NPCIL for the Supply of Two EPR Reactors and Fuel for 25 Years," press release (Paris: 6 December 2010).
[40] "India Signs $9.3 Billion Deal for Areva to Build Two Nuclear Power Plants," Bloomberg.com, 6 December 2010.
[41] A. Gopalakrishnan, "Reject French Reactors for Jaitapur," *Indian Express News Service*, 2 December 2010.
[42] Ernst & Young representative Kuljit Singh is quoted as saying: "It is unusual that the government has cut down the expenditure for something it wants to encourage," per "Budget Support for Nuclear Power Down 10 Percent," *Business Standard*, 1 March 2010.
[43] "Le futur EPR en Inde est suspendu à un accord du Japon," *Les Echos*, 31 January 2011.
[44] "Australia Refuses to Lift Ban on Selling Uranium to India," *RTT News*, 19 January 2011.
[45] Peachey, op. cit. note 103.
[46] "Inside Japanese Outages," www.neimagazine.com, 21 December 2010.
[47] "Accident Delays Monju Startup Till '14," *Japan Times*, 17 December 2010.
[48] "Start-up of New Shimane Unit Delayed," *WNN*, 15 February 2011.
[49] "Nuclear Power Safety," *Asahi Shimbun*, 5 April 2010.
[50] Construction for Tsuruga-3 and -4, for example, was originally planned to commence in 2006. After multiple delays, work is now supposed to start in March 2012, per "Construction of Tsuruga 3 and 4 to Start in 2012", *WNN*, 2 February 2011.
[51] "Delayed Nuclear Reprocessing Project," *Asahi Shimbun*, 12 October 2010.
[52] AREVA reported in April 2009: "The technology transferred by AREVA to the Rokkasho Mura plant is now in operation. Commercial production is scheduled for 2009. The JMOX plant, also located at the Rokkasho Mura

site, will be started up in 2012." This is just one example of the remarkable lack of overview even in the short term of the technology provider and largest nuclear builder in the world. See AREVA, *2008 Reference Document* (Paris: April 2009).

[53] "Nuclear Energy on Agenda as Chinese Premier Visits Pakistan," *Spero News*, 17 December 2010.

[54] "Ten Nuclear Power Plants Planned," Dawn.com, 12 January 2011.

[55] See Mycle Schneider, "Nucléaire: Paris, plaque tournante du trafic pakistanais," *Politis* (Paris), 1989.

[56] "Korea to Build 14 More Nuclear Power Plants by 2024," *The Chosunilbo*, 19 February 2011.

[57] "UAE's First Nuclear Power Station to Start in 2017," *Energy Tribune*, 22 December 2010.

[58] "S. Korea Found to Loan $10B for UAE Power Plant," *The Hankyoreh*, 1 February 2011.

[59] "South Korea Targets $400 Billion Nuclear Plant Orders," Bloomberg.com, 13 January 2010.

[60] Focus Taiwan News Channel, "Start Date for Commercial Operation of Nuclear Power Plant Postponed," 6 January 2011, at http://focustaiwan.tw/ShowNews/WebNews_Detail.aspx?ID=201101060017&Type=aECO.

[61] Figure 17 from IAEA, Power Reactor Information System (PRIS) database, accessed April 2011, and from Mycle Schneider Consulting.

[62] Figure 18 from ibid.

[63] European Commission, Eurostat, online database, http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database, accessed 19 February 2011.

[64] Prime Minister of Belgium, "Déclaration du gouvernement relative à sa politique générale," 13 October 2009, at http://archive.vanrompuy.belgium.be/files/Statepremier.pdf.

[65] "TVO: Welding Problems Will Not Cause Further Delays to Completion of Olkiluoto III," *Helsingin Sanomat*, 13 May 2009. Even the French daily *Le Monde* published a full-page article about this (on page 3): "Unrealistic Schedule, Lack of Local Context Knowledge: Delays and Cost Increases Accumulate, in Finland, on the Building Site of the EPR, the French Reactor – AREVA, the Finnish Mishap," *Le Monde*, 2 July 2010.

[66] ASN/HSE/STUK, "Joint Regulatory Position Statement on the EPR Pressurised Water Reactor," press release, 2 November 2009.

[67] For an excellent overview piece, see Angela Oker-Blom, "Finland – Land of Uranium," *Baltic Worlds*, 10 January 2011.

[68] TVO, "Construction of a Nuclear Power Plant Unit at Olkiluoto – General Description – OL4," www.tvo.fi/www/page/2840/, August 2008.

[69] Oker-Blom, op. cit. note 133.

[70] Ministry of Employment and the Economy, "Application to the MEE for a Decision-in-principle on Expanding the Spent Nuclear Fuel Final Disposal Facility," press release (Helsinki: 13 March 2009).

[71] For a detailed analysis of the French nuclear and energy sector, see Mycle Schneider, "Nuclear Power Made in France – A Model?" in Henry D. Sokolski, ed., *Nuclear Power's Global Expansion: Weighing Its Costs and Risks* (Carlisle, PA: Strategic Studies Institute, U.S. Army War College, December 2010), pp. 189–277.

[72] RTE, "Le bilan électrique français 2010," 20 January 2011, at www.rte-france.com/fr/nous-connaitre/espace-presse/dossiers-de-presse/le-bilan-electrique-francais-2010.

[73] The EURODIF plant at Tricastin consumed the production of up to three reactors.

[74] "L'Etat devrait signer fin mars le décret du projet d'EPR à Penly," *Le Monde*, 22 February 2011.

[75] The French Nuclear Safety Authority (ASN) notes in an inspection report that a translator, one of only two French speaking individuals in a team of steel workers, "had difficulties to understand the questions" the inspectors asked, per ASN, "Letter to the Director of the FL3 Construction Project," 29 December 2010. A worker's lethal fall on 24 January 2011 was only the latest signal of the working and living conditions that trade unions claim have been criticized for the past three years; see CGT, "Chantier EPR de Flamanville – Les conditions de vie et de travail des salaries doivent s'améliorer!" press release (Montreuil: 3 February 2011). The Human Rights League got involved considering that "its intervention became indispensable since questions of freedom and dignity were firmly raised"; see "LDH: Grand chantier EPR de Flamanville: le point," *l'Humanité*, 6 February 2011. Even the Bulgarian media have picked up the issue; see "Bulgarians, Romanians Building Nuclear Reactor in France Face Ruthless Exploitation," novinite.com, 12 January 2011.

[76] "Nouveau retard pour l'EPR d'EDF," *Le Figaro*, 27 October 2010.

[77] François Roussely, "Avenir de la filière française du nucléaire civil," Synthèse du Rapport, 16 June 2010.

[78] Présidence de la République, "Compte rendu du Conseil de Politique Nucléaire du 21 février 2011," 21 February 2011.

[79] According to Standard & Poor's (S&P) credit rating categories, BBB+ is "Lower Medium Grade". S&P points out that AREVA's current rating "incorporates two notches of uplift above the company's SACP [Stand-Alone Credit Profile] for extraordinary state support," per Standard & Poor's, "France-Based AREVA 'BBB+' Long-Term Rating Placed on CreditWatch Negative on Lower Than Projected Capital Increase,"15 December 2010. Note: BBB- is the lowest S&P investment grade. If S&P did downgrade AREVA by one notch, its SACP would slip into the junk bond category.

[80] AREVA, www.areva.com/EN/finance-424/, viewed 20 February 2011; EDF, "Graphique interactif," http://finance.edf.com/action-edf/cours-de-l-action/graphique-interactif-40659.html, viewed 20 February 2011. This performance is to be compared with a value reduction of about a third of the national indicator CAC40 since 2007; see Boursorama, www.boursorama.com, viewed 21 February 2011.
[81] Bundesverband der Energie- und Wasserwirtschaft (BDEW), "Breiter Erzeugungsmix sichert Stromversorgung," Annex to press release (Berlin: 21 February 2011).
[82] "Elftes Gesetz zur Änderung des Atomgesetzes," 8 December 2010, in *Bundesgesetzblatt* No. 62, 13 December 2010.
[83] "Gesetz zur Errichtung eines Sondervermögens 'Energie- und Klimafonds' (EKFG)," 8 December 2010, in *Bundesgesetzblatt* No. 62, 13 December 2010.
[84] Lars G. Josefsson, Vattenfall's CEO at the time, admitted later that "Vattenfall has offended the safety culture both in Sweden and in Germany – and we were rightly criticised," per "Vattenfall's Crisis of Confidence," *European Energy Review*, 15 January 2010.
[85] "Ältere Atomkraftwerke stehen vor dem vorzeitigen Aus," *Handelsblatt*, 6 February 2011.
[86] WNA, "Nuclear Power in the Netherlands," www.world-nuclear.org/info/inf107.html, updated January 2011.
[87] "Court Halts Transfer of Stake in Dutch Nuclear Plant," Expatica.com, 21 January 2011.
[88] "Conditions Laid Out for Netherlands Nuclear," *WNN*, 18 February 2011.
[89] "Spain Insists on Energy Saving, Not Nuclear Plants," *Reuters*, 21 January 2009.
[90] "Spain Approves Increase in Nuclear Power Output, *Expansion* Says," Bloomberg.com, 4 January 2011.
[91] "No Limits for Spanish Reactors," *WNN*, 17 February 2011.
[92] European Wind Energy Association, "Wind in Power – 2010 European Statistics" (Brussels: February 2011).
[93] "Swedish Government Overturns Nuclear Ban," www.neimagazine.com, 21 June 2010.
[94] "Oldbury 2 Licence Extended Until June 2011," *WNN*, 10 February 2011.
[95] Nuclear Decommissioning Authority, *Annual Report & Accounts 2007/08* (London: 2008).
[96] Cumbrians Opposed to a Radioactive Environment (CORE), *Sellafield – Breaching International Treaty Targets on Radioactive Marine Pollution* (Broughton-in-Furness, Cumbria: February 2011).
[97] "Beckett Rejects Nuclear Option, *The Observer*, 19 September 2004, see www.guardian.co.uk/uk/2004/sep/19/nuclear.greenpolitics?INTCMP=ILCNETTXT3487.
[98] Sustainable Development Commission, "Is Nuclear the Answer?" (London: March 2006).
[99] Platts' David Stellfox, in a February 2009 presentation in Washington, D.C., put it this way: "How to resurrect a flagging nuclear industry quickly – give it to the French!"; "Ten Firms in Race for £700m Nuclear Civils Packages," *Contract Journal*, 20 May 2009.
[100] "Westinghouse Gets Set for UK Construction," *WNN*, 5 September 2008.
[101] U.K. Department of Energy and Climate Change (DECC), *Revised Draft National Policy Statement for Nuclear Power Generation,* Vols. I&11 (London: October 2010). At the same time, several hundred pages of documents were published, including DECC, "The Government Response to the Consultation on the Draft National Policy Statements for Energy Infrastructure" (London: October 2010), 300 pp.
[102] The Scottish government is opposed to new build and said it would not allow replacement of the Torness and Hunterston plants once they will be shut down (likely in 2016 and 2023, respectively). Only 18 percent of the Scottish people supported new build in a recent poll, per "Only 18% of Scots Say 'Yes' to New Nuclear Power Stations," *The Scotsman*, 27 September 2010.
[103] "MPs 'Sceptical' that Nuclear Power Stations Will Be Built on Time," *The Telegraph*, 26 January 2011.
[104] "Bern Says Yes to Nuclear Power Plant," swissinfo.ch, 13 February 2011.
[105] "Bulgaria Might Get More Compensation for Shutting Down Reactors at Kozloduy NPP Media Reports Say," SofiaEcho.com, 27 October 2009.
[106] "Bulgaria Reviews Belene Project, Energy in East Europe," *Platts*, 14 August 2009.
[107] "Belene Deal Signed by Bulgaria, Investors," SETimes.com, 1 December 2010.
[108] "French Areva Could Take Part in Nuclear Power Projects in Bulgaria," SofiaEcho.com, 15 February 2011.
[109] International Energy Agency, "Energy Policies in IEA Countries, Country Review - Czech Republic" (Paris: 2001).
[110] WNA, "Nuclear Power in Czech Republic," www.world-nuclear.org/info/inf90.html, updated February 2011.
[111] "Czech CEZ Puts off Temelin Expansion Deadline to 2025," *Reuters*, 18 February 2011.
[112] John Shepherd, "Hungary's Parliament Paves Way to Build New Reactor Unit," NucNet, 31 March 2009.
[113] "Hungary Mulls Plans to Build New Nuclear Blocks." caboodle.hu, 14 January 2011.
[114] "Hungary, Russia Seek to Resolve All Outstanding Issues in One Package, Says FM," realdeal.hu, 21 January 2011.
[115] Foratom, "New Member States Take the Nuclear Lead," May 2007, at www.foratom.org/e-bulletin-tout-1378/new-member-states-tout-1387/419-new-member-states-take-the-nuclear-lead.html.
[116] WNA, "Nuclear Power in Lithuania," www.world-nuclear.org/info/inf109.html, updated December 2010.
[117] "Tender for New Lithuanian Plant Investor Stalls," *WNN*, 6 December 2010.

[118] GDF-Suez, RWE, and Iberdrola, "GDF-Suez, RWE and Iberdrola Have Decided Not to Continue to Participate in the Cernavoda Nuclear Project in Romania," press release, 20 January 2011.
[119] "Foreign Investors Ditch Cernavoda 3&4 Project," www.neimagazine.com, 24 January 2011.
[120] "SE Switches on Two Upgraded Nuclear Power Units," TheDaily.sk, 11 October 2010.
[121] European Commission, "Commission Issues Its Opinion on Units 3 and 4 of the Slovak Nuclear Power Plant of Mochovce," IP/08/1143 (Brussels: 5 July 2008).
[122] "Mochovce Public Participation Insufficient," *Nuclear Monitor* (NIRS/WISE), 21 January 2011.
[123] " Slovakian Nuclear JV Gets Government Blessing," *WNN*, 10 December 2009.
[124] "East Europe Nuclear Plants Struggle to Find Investors," novinite.com, 27 January 2011.
[125] DOE, Office on Energy Intelligence, *Most Dangerous Reactors: A Worldwide Compendium of Reactor Risk* (Washington, DC: May 1995).
[126] "Armenian NPP to Operate Until 2016," NEWS.am, 15 February 2011.
[127] "New Company Being Established to Build New Reactor in Armenia," Nuclear.ru, 25 December 2009.
[128] WNA, "Nuclear Power in Armenia," www.world-nuclear.org/info/inf113.html, updated August 2010.
[129] Marubeni, "Memorandum of Understanding with National Nuclear Center of the Republic of Kazakhstan," press release (Tokyo: 29 September 2010).
[130] Nuclear Energy Agency (NEA), *Uranium 2009* (Issy-les-Moulineaux, France: 2010).
[131] "Record Year for Kazakh Uranium," *WNN*, 1 February 2011.
[132] IAEA, op. cit. note 127.
[133] "Russia Releases Near-term Nuclear Plans," www.neimagazine.com, May 2010.
[134] WNA, "Nuclear Power in Russia," www.world-nuclear.org/info/inf45.html, updated February 2011.
[135] "Russian Nuclear Manufacturer Moves into Wind," *WNN*, 12 November 2010.
[136] NEA, *Uranium 2009…*, op. cit. note 198.
[137] National Ecological Center of Ukraine, "The Operation of the Old Reactor, Lifetime of Which Was Extended for 20 Years, Is Unstable," press release, 18 January 2011.
[138] "Contract Agreement for Khmelnitsky 3 and 4," *WNN*, 10 February 2011.
[139] National Ecological Center of Ukraine, "Construction of Unit-3 and Unit-4 at Khmelnytska NPP Has Not Yet Started But the Cost Has Already Increased 2.5 Times," press release, 15 February 2011.