4/15/2009

DRAFT

RESOURCE LETTER

THE FUTURE OF NUCLEAR POWER

General Outline

I. Introduction

II. Nuclear Power in the World Today

III. The Need for Nuclear Power

IV. Forecasts and Planning for Nuclear Power

V. U.S. Status, Planning, and Forecasts for Nuclear Power Additions

VI. Economics of Nuclear Power

VII. Safety and Regulation of Nuclear Power

VIII. Spent-Fuel/High-Level-Waste Status and Plans

IX. Nuclear Power and Proliferation of Nuclear Weapons

X. Public Attitudes toward Nuclear Power

XI. General Resources for New Nuclear Power in United States

Resource Letter: ?????: The Future of Nuclear Power

George Flanagan, George Kulynych, Cecil Parks
Nuclear Science and Technology Division, Oak Ridge National Laboratory[*]*, Oak Ridge, TN 37831*

This Resource Letter is intended to summarize the status of nuclear power in the world today, the need for significant expansion of nuclear power over the next several decades, the planning of and forecasts for the addition of new power reactors, and issues surrounding the addition of these new reactors. Due to the breadth of this subject, an extensive list of references that includes journal articles, web pages, reports, etc., is presented to provide the reader further guidance on the subject. The subject of nuclear power and its related issues are dynamic. So the most current information is likely to be found on reputable web sites.

I. INTRODUCTION

Nuclear power uses energy released by splitting atomic nuclei, primarily of uranium and plutonium, and converting that energy into heat used for electricity generation, propulsion, or other uses.

Two typical fission reactions are shown with the average values of energy released and the number of neutrons ejected.

^{235}U + neutron → fission fragments + 2.4 neutrons + 192.9 MeV

^{239}Pu + neutron → fission fragments + 2.9 neutrons + 198.5 MeV

Since more than one neutron is ejected per fission, some of the free neutrons will interact with the surrounding medium or leak from the system; if fissile material (^{235}U or ^{239}Pu) is present, some of the ejected neutrons may be absorbed and result in more fissions; thus, the cycle repeats to give a reaction that is self-sustaining. Nuclear reactors are designed in such a manner as to balance the number of ejected neutrons to ensure that one is available to sustain a chain reaction.

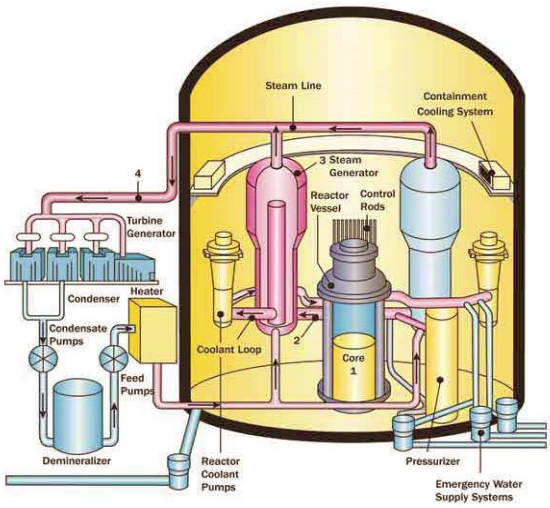
Two types of commercial power reactors are in use today in the United States—the pressurized-water reactor (PWR) and the boiling-water reactor (BWR). A brief description of each is provided below courtesy of the Nuclear Regulatory Commission (NRC) web site.

Pressurized-Water Reactors

In a typical commercial pressurized light-water reactor (LWR), (1) the core inside the reactor vessel creates heat, (2) pressurized water in the primary coolant loop carries the heat to the steam generator, (3) inside the steam generator, heat is converted to steam, and (4) the steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity. The unused steam is exhausted into the condenser where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the reactor vessel. The reactor's core contains fuel assemblies that are cooled by

[*]*Notice: This manuscript has been authored by UT-Battelle, LLC, under Contract No. DE-AC05-00OR22725 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.*

water circulated using electrically powered pumps. These pumps and other operating systems in the plant receive their power from the electrical grid. If offsite power is lost, emergency cooling water is supplied by other pumps, which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need power. Pressurized-water reactors contain between 150 to 200 fuel assemblies

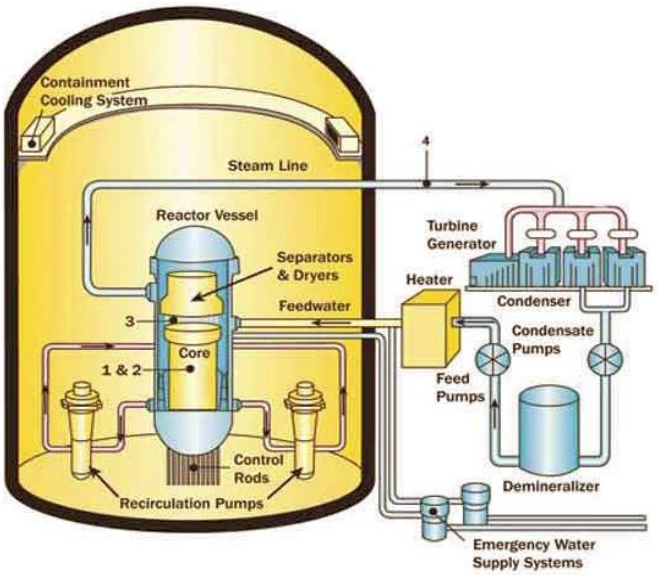


Typical Pressurized-Water Reactor

Boiling-Water Reactors

In a typical commercial boiling-water reactor, (1) the core inside the reactor vessel creates heat, (2) a steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core, absorbing heat, (3) the steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line, and (4) the steam line directs the steam to the main turbine, causing it to turn the turbine generator, which produces electricity. The unused steam is exhausted into the condenser where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the reactor vessel. The reactor's core contains fuel assemblies that are cooled by water circulated using electrically powered pumps. These pumps and other operating systems in the plant receive their power from the electrical grid. If offsite power is lost, emergency cooling water is supplied by other pumps, which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need electric power.

Boiling-water reactors contain between 370–800 fuel assemblies.



Typical Boiling-Water Reactor

The world will need to increase its energy supply in the next 30 years, especially cleanly generated electricity. Electricity demand is increasing more rapidly than overall energy use and is likely to double from 2004 to 2030. Nuclear power is the most environmentally benign way of producing electricity on a large scale. Without nuclear power, the world would have to rely primarily on fossil fuels for a continuous, reliable supply of electricity. Renewable energy sources other than hydro have high generating costs and must have backup generating capability, but they are helpful at the margin in providing clean power.

Nuclear power has many advantages. In particular, it currently can provide a near-term large source of carbon-free electrical generation, and its long-term refueling requirements reduce the rapid cost fluctuations associated with most forms of base-load electrical production. Currently nuclear power plants are and have been achieving >90% capacity factors for several years, and the overall lifetime costs are competitive with coal and natural gas. However, four major obstacles are keeping nuclear power from rapid growth, especially in the United States. These obstacles are (1) high capital cost, (2) uncertainty in the licensing process, (3) proliferation concerns, and (4) lack of a consistent policy regarding disposal of high-level waste or spent fuel. It appears that, although important, safety and reliability issues have been generally addressed by the experience base of the current reactor fleet. The Nuclear Regulatory Commission has revised the licensing process to encourage standardization of designs and combined the construction and operational licensing reviews into a single review in order to reduce uncertainty and speed up the licensing process. The plants being planned in the United States have taken advantage of this new single-review approach; however, the design certification of new designs is still a long process, and only four generation III+ designs have been certified by the NRC to date.

For generation III^+ plants, the estimated capital costs have doubled or tripled from values estimated in the early part of this decade, and before construction on these plants has even begun. Thus, many U.S. utilities are seeing capital investment requirements equal to the company assets, and the uncertainty in the licensing process makes investments in new plants rather high risk.

The worldwide increase in plant orders—40 new plants under construction and 90 planned—are primarily from government-owned utilities and therefore not subject to private investment concerns.

Proliferation issues, particularly in areas of the world where nuclear power has not been established, are of concern and are being addressed on an international scale with oversight being provided by the International Atomic Energy Agency (IAEA) and the Nuclear Suppliers Group. Lowering the potential for proliferation is also included in the design and operation of the proposed new reactors.

Treatment of high-level waste or spent fuel has two aspects: short term, <100 years, and long term, >100 years. Short-term approaches include on-site storage of spent fuel either in pools or in aboveground licensed dry cask storage. In some countries, the fuel is reprocessed and much of the fissile material (^{235}U and ^{239}Pu) converted to mixed oxide (MOX) and reused and the high-level waste is stored on the site of the reprocessing plant. The long-term disposal option being considered in most countries is geological disposal. This was the plan in the United States until 2009, when it was decided to reexamine options for long-term storage. The results of this reexamination of options in the United States are not yet available.

Many of these issues will be discussed in detail in later chapters of this report.

II. Nuclear Power in the World Today

A. Journals

Annuals of Nuclear Energy
Bulletin of the Atomic Scientists
Nuclear Engineering and Design
Nuclear Engineering International
Nuclear News—Annual Listing of Nuclear Power Plants Worldwide
Nuclear Plant Journal
Nuclear Science and Engineering
Nuclear Technology
Progress in Nuclear Energy

B. Books and Major Compilations

1. **Megawatts and Megatons A Turning Point in the Nuclear Age?** R. L. Garwin and G. A. Charpak (Alfred A. Knopf, New York, 2001). This book provides a summary of the progress of nuclear energy from its use in weapons to nuclear reactors. (E)
2. **The Second Nuclear Era,** A. M. Weinberg (Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee 37830, 1984). This book provides insight into the potential future of nuclear power following the first nuclear era, which was principally focused on weapons production and research. (E)
3. **Nuclear Energy Data 2009** (Nuclear Energy Agency, Paris, France). This publication is an annual summary of information on nuclear energy production. (E)

C. Conference Proceedings

The International Atomic Energy Agency (IAEA) is a UN agency set up to promote peaceful use of nuclear energy and to monitor and aid in controlling military uses. The agency regularly sponsors conferences and issues reports on the use of nuclear energy worldwide.

4. International Ministerial Conference on Nuclear Energy in the 21st Century, April, Beijing, China (IAEA, Vienna, 2009). (E)

D. Web Sites

The issues influencing the future of nuclear energy are dynamic and can change rapidly. There are many organizations and associations that maintain up-to-date web sites that contain both summary and detailed information on nuclear power plants. Some of these sites are listed as follows.

5.	Nuclear Energy Institute	http://www.nei.org/
6.	Department of Energy (NE)	http://www.ne.doe.gov/
7.	Energy Information Administration (EIA)	http://eia.gov/
8.	Nuclear Regulatory Commission	http://www.nrc.gov/
9.	Electric Power Research Institute	http://my.epri.com/portal/server.pt
10.	Institute of Nuclear Power Operations (INPO)	http://www.inpo.info/AboutUs.htm
11.	World Nuclear Association (WNA)	http://www.worldnuclear.org/
12.	International Atomic Energy Agency (IAEA)	http://www.iaea.org/
13.	Nuclear Energy Agency	http://www.nea.fr/index.html

Based on information provided in these web sites, the following summary can be drawn.

Today, the world produces as much electricity from nuclear energy as it did from all sources combined in 1960. Civilian nuclear power has accumulated over 13,000 reactor years (March 2009) of experience and provides almost 16% of global electricity needs in 30 countries. There are about 436 civil nuclear power reactors operating in 30 countries, with 372,000 Megawatts-electric [MW(e)] of total capacity. An additional 40 power reactors are under construction (equivalent to 8% of the existing capacity), while over 90 are planned (equivalent to 27% of existing capacity). In addition, 56 countries operate a total of about 280 research reactors and another 220 reactors power nuclear ships and submarines.

Sixteen countries depend on nuclear power for at least 25% of their electricity needs. France gets over 75% of its electric power from nuclear energy, while other industrialized countries such as Japan, Germany, South Korea, and Belgium get over 25% of their power from nuclear energy. The United States gets almost 20% of its electricity from nuclear.

14. http://en.wikipedia.org/wiki/Nuclear_power_by_country#Table The table shows the current nuclear generation capacity, percentage of the total generating capacity, number of operating plants, and number of plants under construction, planned, or proposed by country.

The United States has the largest number of power reactors in the world, with 104 operating nuclear power reactors at a capacity of over 100 MW(e) generating electricity in 31 states and operated by 32 utilities. Four more are partly built and have valid construction licenses. All the

U.S. plants are either PWRs or BWRs. Six states get more than 46% of their electricity from nuclear energy.

Although no nuclear plants have been placed into service in the United States since 1996, most of the nuclear plants have completed or are planning power upgrades and/or license renewals for the nuclear plants. Fifty-one plants have been approved for 20-year license renewal, and there has been a cumulative power upgrade since 1977 of 5640 MW(e) with projections of an additional 3478 MW(e) power upgrades by 2013.

15. http://www.world-nuclear.org/info/inf08.html

In addition to the current reactors (generation II and III), several new designs (generation III^+) are currently under way or are in the process of being licensed in the United States and in other countries. These reactors are generally large [>1000 MW(e)] base-load systems that are expected to be more efficient and have a greater degree of inherent safety built into their designs. They consist of both standard LWRs (PWR and BWR) and high-temperature gas-cooled reactors. International studies are under way on several unique designs for future reactors (Generation IV) that account for sustainability, nonproliferation, further improvements in safety, and address not only electricity production but process heat applications as well.

16. **Deliberately Small Reactors and the Second Nuclear Era,** D. T. Ingersoll, *Progress in Nuclear Energy*, Vol. 51, Issues 4–5, May–July 2009. This article discusses designs being undertaken for a new type of small/medium reactor which ranges from 10 to 500 MW(e) in size and is generally modular, factory constructed, and inherently safe. Some of these reactors may have the ability to produce process heat as well as electricity. The advantages of their smaller design are that they may require less upfront capital investment than the large base-load reactors and may be able to accommodate a less developed electrical transmission infrastructure or provide power to remote sites with the ability to add capacity as needed. Most of the components would be factory produced to reduce onsite construction. Most increase the refueling interval or do not need to be refueled over their lifetime, thus reducing the proliferation potential. (E).

17. **World Nuclear Industry Handbook 2009**, Nuclear Engineering International, Global Trades Media, London England, 2009. This handbook describes the industries that are involved in the production of nuclear energy. Over the last decades, the number of nuclear reactor vendors has been reduced by a process of consolidation. Of the operating reactors in the world, most have been designed and/or supplied by companies that are now part of the current major vendors of power reactors. These companies include Westinghouse (Toshiba), General Electric (Hitachi), AREVA-NP, ROSATOM (Russia), Mitsubishi (Japan), and Korea Heavy Industries & Construction. In addition there are numerous engineering, manufacturing and technical support firms that support reactor operators in the licensing, operations, maintenance, and refueling of operating nuclear power plants. Nuclear Engineering International prepares an excellent annual compilation of companies that provide this support. (E)

III. The Need for Nuclear Power

18. http://www.eia.gov/ This web site provides forecasts of U.S. and world energy needs and as well as access to several scholarly articles on the needs for various energy sources based on current economic and political conditions. It stresses that energy is vital to human

civilization and underpins national security, economic prosperity, and global security. Worldwide demand for energy is increasing and could double by 2050 due to population increase and the increase in per capita use of energy by developing nations. At the same time, there is an increasing concern that CO_2 emissions are contributing to global warming and must be reduced globally.

Today, nuclear energy provides 16% of the world's electricity and offers unique benefits. It is the only existing energy technology with the capability for major expansion that can provide stability for base-load electricity, security through reliable fuel supply, and environmental stewardship by avoiding emissions of greenhouse gases and other pollutants. It has demonstrated reliability, exemplary safety, and operational economy through improved performance.

Nuclear energy is expected to play a significant role in the U.S. and world's electricity portfolio for the next 100+ years. Nuclear energy also has the potential to contribute to broader energy needs. For example, nuclear energy can supply the electricity for electric-powered vehicles, or it could be used to generate hydrogen for vehicles that utilize hydrogen fuel cells. Nuclear energy can also generate high-temperature process heat, providing a valuable role in preparing feedstock to chemical production and aid in the production of freshwater from seawater and contaminated surface and groundwater.

The following web sites also contain information relating to the need for nuclear power for sustaining development of energy resources and in reducing greenhouse gases.

19. http://www.iea.org/

20. http://www.eia.gov/

21. http://www.ne.doe.gov/pdfFiles/rpt_KeystoneReportNuclearPowerJointFactFinding_2007.pdf

22. http://www.worldenergyoutlook.org/

23. http://www.ne.doe.gov/pdfFiles/rpt_SustainableEnergyFuture_Aug2008.pdf

24. http://www.worldenergy.org/documents/stat2007.pdf

25. http://www.world-nuclear.org/info/inf16.html

26. **Alternative Energy Resources, the Quest for Sustainable Energy,** Paul Kruger (John Wiley and Sons Inc., Hoboken, New Jersey, 2006). This book provides a summary of the current energy resources and prospective needs in the future, as well as a description of the means by which to meet the projected demand while reducing dependency on carbon-based fuels. (I)

27. **The Political Economy of World Energy, an Introductory Textbook,** Ferdinand E. Banks (World Scientific Publishing, New Jersey, 2007). (I)

28. **Some Aspects of Nuclear Energy and the Kyoto Protocol,** Ferdinand E. Banks (Geopolitics of Energy, July/August, 2002). These books discuss the relationship of nuclear energy to world economics and climate change. (I)

IV. Forecasts and Planning for Nuclear Power

In March 2009, there were about 436 civil nuclear power reactors operating in 30 countries plus Taiwan, with over 370,000 MW(e) of total capacity. An additional 40 power reactors are under construction in 11 countries, notably China, South Korea, Japan, and Russia.

29. http://www.iaea.org/NewsCenter/News/2009/npprojections.html The IAEA has significantly increased its projection of world nuclear generating capacity. It now anticipates at least 70 new plants within the next 15 years, increasing the total world nuclear capacity to 470–750 GW(e) in 2030.

30. http://www.oecd.org/home/0,2987,en_2649_201185_1_1_1_1_1,00.html The Organisation for Economic Co-operation and Development (OECD) estimates range up to 680 GW(e) in 2030. These forecasts are based on specific plans and actions in a number of countries including China, India, Russia, Finland, France, and the United States, coupled with a different outlook due to the desire to reduce CO_2 emissions.

31. http://www.ipcc.ch/ The Intergovernmental Panel on Climate Change (IPCC) reports that on a global scale, nuclear power currently reduces CO_2 emissions by some 2.5 billion tonnes per year (relative to the main alternative of coal-fired generation, about 2 billion tonnes relative to the present fuel mix). Carbon dioxide accounts for half of the human-contributed portion of the global warming effect of the atmosphere. The 2007 IPCC report on mitigation of climate change says that the most cost-effective option for restricting the temperature rise to under 3°C will require an increase in non-carbon electricity generation from 34% (nuclear plus hydro) now to 48 to 53% by 2030, along with other measures. With a doubling of overall electricity demand by then, and a carbon emission cost of U.S. $50 per tonne of CO_2, nuclear's share of electricity generation is projected by IPCC to grow from 16% now to 18% of the increased demand (i.e., 2650 TWh to some 6000 TWh/year), representing more than a doubling of the current nuclear output by 2030. The report projects other noncarbon sources apart from hydro contributing some 12 to17% of global electricity generation by 2030. These projected figures are estimates, and it is evident that if renewables fail to grow as much as hoped, it means that other non-carbon sources will need to play a larger role. Thus nuclear power's contribution could triple or perhaps quadruple to more than 30% of the global generation mix in 2030—around 10,000 TWh. Nuclear power has a key role to play in reducing greenhouse gases. Every 22 tonnes of uranium (26 t U_3O_8) used saves 1 million tonnes of CO_2 relative to coal.

The following web sites have information and data on specific plans for worldwide nuclear plant additions. Although projections vary by assumptions made, the trend is a steep rise in nuclear power production.

32. http://www.eia.doe.gov/oiaf/ieo/negen.html
33. http://www.world-nuclear.org/info/inf17.html
34. http://www.world-nuclear.org/info/inf16.html
35. http://www.ne.doe.gov/pdfFiles/rpt_SustainableEnergyFuture_Aug2008.pdf
36. http://www.world-nuclear.org/info/inf45.html#Extending_nuclear_capacity_
37. http://www.world-nuclear.org/info/inf40.html
38. http://www.world-nuclear.org/info/inf63.html
39. http://www.world-nuclear.org/info/inf102.html
40. http://www.world-nuclear.org/info/inf53.html

V. U.S. Status, Planning and Forecasts for Nuclear Plant Additions

41. http://www.nrc.gov/reactors/new-reactors.html

Over the last 20 years, the U.S. nuclear industry has been working with the NRC on certification of advanced generation III reactor designs. There are now four designs which have final design certification and can be built in the United States and require only site-specific licensing procedures. However, only two of these designs are being considered by U.S. utilities—the Advanced Boiling Water Reactor and the AP-1000.

- The GE-Hitachi (formerly Combustion Engineering) Advanced Boiling Water Reactor — 1300–1500 MW(e) ABWR
- Westinghouse System 80+ — 1400 MW(e) PWR
- Westinghouse AP-600 — 600 MW(e) PWR
- Westinghouse AP-1000 — 1100 MW(e) PWR

Several other reactor designs are undergoing design certification or at the preapplication stage.

- GE-Hitachi Economic and Simplified BWR (ESBWR) — 1550 MW(e)
- AREVA-U.S. Evolutionary Pressurized Reactor (EPR) — 1600 MW(e)
- Mitsubishi-U.S. Advanced Pressurized Reactor (US-APWR) — 1700 MW(e)

Seventeen companies or groups of companies have submitted or plan to submit applications to the NRC for combined construction and operating licenses (COL). These applications encompass 34 new reactors.

The following web pages have information on the status of U.S. new plant program.

42. http://www.nei.org/resourcesandstats/documentlibrary/newplants/graphicsandcharts/newnuclearplantstatus/

43. http://www.ne.doe.gov/np2010/neScorecard/pdfFiles/scorecard_2009_04_09.pdf

Several studies have provided forecasts of the number of nuclear plants needed to meet the U.S. electricity and energy needs in the 21st century.

44. http://www.ne.doe.gov/pdfFiles/rpt_KeystoneReportNuclearPowerJointFactFinding_2007.pdf

45. http://web.mit.edu/nuclearpower/

46. http://www.ne.doe.gov/neac/neacPDFs/NEAC_Final_Report_Web%20Version.pdf

47. http://www.eia.doe.gov/conf_pdfs/Tuesday/Grecheck.pdf This article predicts the number of nuclear power plants needed in this country, which varies over a wide range.

Below are summaries from the U.S. Energy Information Agency 2009 Annual Report showing the projected electrical generating capacity by fuel type and the additional growth in capacity needed in 2030.

Figure 55. Electricity generation by fuel in three cases, 2007 and 2030 (billion kilowatthours)

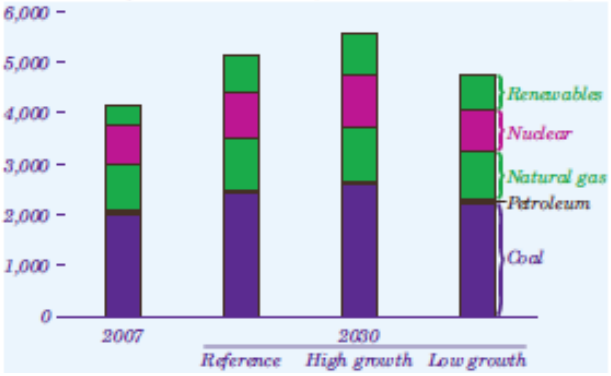
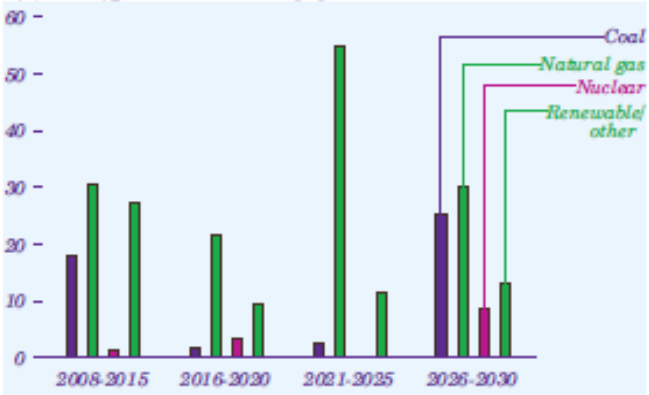


Figure 56. Electricity generation capacity additions by fuel type, 2008-2030 (gigawatts)



VI. Economics of Nuclear Power

48. http://www.eia.gov/ In the energy information agency analysis and projection reports for 2009, the relative costs of generating electricity from nuclear, coal, and gas plants vary depending on the specific resource situation in the various countries. Coal is, and is likely to remain, economically attractive in countries such as China, the United States, and Australia that have abundant and accessible domestic coal resources, as long as carbon emissions are cost-free. Gas is also competitive for base-load plants in many places, particularly using high-efficiency combined-cycle plants, though rising and cyclic gas prices have raised questions regarding the use of gas for base-load plants. Nuclear energy is, in many places, competitive with fossil fuels for electricity generation, despite high capital costs and the need to internalize all waste disposal and decommissioning costs. If the social and environmental costs of fossil fuels are also taken into account, nuclear plants are clearly less costly. The fuel cost for nuclear plants is a small portion of the total generating cost, though capital costs are high and increasing.

For most existing U.S. nuclear plants, the capital costs have already been amortized leaving only fuel and operations and maintenance (O&M) costs. In addition, improvements in maintenance and operation have resulted in high capacity factors (>90%).

In addition to capital, fuel, and O&M costs, nuclear plant costs normally include spent fuel management, plant decommissioning, and final waste disposal cost. These costs, while usually external for other technologies, are internal for nuclear power (they have to be paid or set aside by the utility and the cost passed on to the customers).

The front end steps of the fuel cycle for today's LWRs include mining and milling of uranium ore, conversion of ore concentrate ("yellowcake") to uranium hexafluoride, enrichment of the ^{235}U to the level needed to sustain a nuclear reaction, and fabrication of the enriched uranium oxide into fuel assemblies to be inserted in the reactor. Back end steps in today's "once-through" cycle include pool and cask storage of irradiated fuel, and eventual emplacement and disposal in a geologic repository. Given that the Yucca Mountain (NV) site may no longer be the repository site, other back-end options such as longer-term storage and/or fuel recycle may be examined.

49. http://www.inl.gov/technicalpublications/documents/3915965.pdf The report "Advanced Fuel Cycle Cost Basis" (INL/EXT-07-12107) describes the steps of both "once-through" and "closed" (recycle) options and their costs (includes several hundred cost-related references).

50. http://www.nei.org/filefolder/The_Cost_of_New_Generating_Capacity_in_Perspective.pdf (I) This report indicates that for new nuclear generating capacity, there is considerable uncertainty about the capital cost. Credible estimates of overnight capital cost range from about $2400/kW(e) to $4540/kW(e) and in a few cases run as high as $7000/kW(e). This wide variation can be attributed to several factors:

- Uncertainty about cost escalation of commodities, equipment, and labor
- Status of detailed plant design completion
- Amount of project planning and regulatory cost included in the estimate

The cost of financing new plants and contingencies tends to be higher for nuclear plants because of the extended construction periods and uncertainties related to licensing.

The following web pages provide in-depth evaluations of the economics of new plant construction and operation.

51. http://www.world-nuclear.org/info/inf02.html

52. http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/uselectricityproductioncostsandcomponents/

53. http://www.nei.org/resourcesandstats/nuclear_statistics/costs/

54. http://www.nei.org/resourcesandstats/documentlibrary/newplants/reports/univchicagoeconomicstudy804

55. http://www.nei.org/resourcesandstats/documentlibrary/newplants/reports/wnaeconomicsnuclearpowerreport12105

56. http://web.mit.edu/ceepr/www/publications/workingpapers/2006-019.pdf

57. **Nuclear Energy Balancing Benefits and Risks**, Charles D. Ferguson (Council on Foreign Relations, CSR No. 28, New York, April 2007). This report illustrates that the uncertainty in the economic analysis indicates that nuclear power, even with its carbon-free generation capability, may still not play a major role unless accompanied by a carbon tax. (I)

VII. Safety and Regulation of Nuclear Plants

58. http://www.nrc.gov/reading-rm/doc-collections This site describes the licensing process in the United States. To build and operate a commercial nuclear power plant in the United States, a utility has to obtain a license from the U.S. Nuclear Regulatory Commission (NRC). The NRC is responsible for licensing and regulating the operation of nuclear power plants. Over the past five decades, the NRC (formed in 1975) and its predecessor, the Atomic Energy Commission, have issued 126 operating licenses for nuclear power plants. Of these, 103 are currently operating, one is temporarily closed, and 22 have been shut down after operating and are in various stages of decommissioning. In addition, four plants have NRC-issued permits that would allow them to complete construction. About 100 additional plants began the licensing process but did not complete it for various reasons. In the past, nuclear power plants were licensed under a two-step licensing process. This process required both a construction permit and an operating license. In 1989, the NRC established an alternative licensing process that essentially combines a construction permit and an operating license (COL), with certain conditions, into a single license. Under either process, before an applicant can build and operate a nuclear power plant, approval from the NRC must be obtained. Other licensing alternatives established in 1989 are early site permits (ESP), which allow an applicant to obtain approval for a reactor site and "bank" it for future use, and certified standard plant designs, which can be used as preapproved "off-the-shelf" designs. Public involvement is a key element in all of the NRC's reactor licensing processes. Consequently, the agency holds numerous public meetings during the course of the licensing process, and the law requires that the NRC must hold a public hearing before issuing a construction permit, early site permit, or combined license for a nuclear plant. In addition, all documents and correspondence related to an application are placed in the NRC's Public Document Room (PDR) in Rockville, Maryland, which can be accessed through the Public Electronic Reading Room.

59. http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0298/br0298r2.pdf

60. http://www.nrc.gov/reactors/new-reactors/col.html

61. http://www.nrc.gov/reactors/new-reactors/design-cert.html

62. http://www.nrc.gov/reactors/new-reactors/esp.html

63. http://www.nrc.gov/reactors/new-reactors/regs-guides-comm.html

64. http://www.nei.org/keyissues/newnuclearplants/newnuclearplantlicensing/

65. http://www.nei.org/keyissues/newnuclearplants/factsheets/licensingnewnuclearpowerplants

66. http://www.ne.doe.gov/pdfFiles/DESIGNPL.PDF

VIII. Spent-Fuel/High-Level-Waste Status and Plans

67. http://www.ocrwm.doe.gov/ This DOE web site describes the U.S. nuclear fuel waste management strategy and history. All parts of the nuclear fuel cycle produce some radioactive waste, and the cost of managing and disposing of this part of the electricity cost is internalized and paid for by consumers.

At each stage of the fuel cycle, there are proven technologies to safely dispose of the radioactive waste. For low and intermediate waste, these technologies are being implemented. Some countries await the accumulation of enough high-level waste, including spent nuclear fuel,

to warrant building geological repositories while others, such as the United States, have been developing a repository at Yucca Mountain (YM) but have experienced licensing and political delays.

In 1982, the U.S. Congress passed the Nuclear Waste Policy Act, which made the DOE responsible for finding a site, building, and operating an underground disposal facility called a geologic repository. DOE started studying Yucca Mountain (YM) in 1978 to determine if it would be suitable as the nation's first long-term repository for the spent fuel and high-level waste currently being stored in 121 sites around the nation. In 1987, Congress amended the Nuclear Waste Policy Act and directed DOE to study only the YM site, which is located within a former nuclear test site.

On February 12, 2002, the U.S. DOE Secretary made the decision that the YM was a suitable site as the nation's nuclear repository. The governor of Nevada had 90 days to object and did so; however, the Congress overrode the objection and directed DOE to prepare the formal NRC application.

The YM project is opposed in Nevada and is being debated at the national level. It became a topic of discussion during the 2008 national election, and current Congressional leadership and the President have stated the desire to terminate the YM project. The Secretary of Energy has ordered a reexamination of the U.S. spent fuel policy, but the results of this reexamination of options are not yet available.

Because of the delays in opening YM, utilities in the United States have resorted to dry cask storage of spent nuclear fuel in onsite casks. The high-level waste from the reprocessing of defense-production spent fuel is being vitrified, placed in sealed stainless containers, and stored in shielded high-level-waste storage facilities near the shutdown DOE reprocessing facilities. To date, the U.S. utilities have contributed over $16 billion to the Nuclear Waste Fund and nearly 60,000 MTU of nuclear spent fuel has been discharged from the U.S. reactors.

The following web sites provide detailed information on the spent fuel and high-level waste issues in the United States.

68. http://www.world-nuclear.org/info/inf69.html

69. http://www.world-nuclear.org/info/inf04.html

70. http://www.ocrwm.doe.gov/info_library/index.shtml

71. http://www.ocrwm.doe.gov/info_library/program_docs/06237PD_The_National_Repository_at_Yucca_Mountain.pdf

72. http://www.world-nuclear.org/info/inf69.html Issues regarding spent fuel continue to be addressed at the international level, including reprocessing to remove the highly radioactive fission products.

73. http://www.world-nuclear.org/info/inf04.html

IX. Nuclear Power and Proliferation of Nuclear Weapons

Increased use of nuclear power worldwide, particularly in the Third World nations, inevitably increases the risk of proliferation. The United States and other coutries using nuclear power need to mitigate those risks by examining a range of potential approaches including new international

treaties, new requirements on current signatories to the Nuclear Non-Proliferation Treaty (NPT), and other lesser measures such as strengthening proliferation protection.

74. http://www.ne.doe.gov/pdfFiles/rpt_ISAB_GlobalExpansionofCivilNuclearPower_Apr2008.pdf The April 2008 report prepared by the U.S. International Security Advisory Board (ISAB) reviews the nonproliferation challenges facing the world with the expansion of nuclear power capabilities and use of nuclear fuel and presents recommendations for U.S. actions.

75. http://www.world-nuclear.org/info/inf12.html

76. http://www.world-nuclear.org/info/inf73.html

77. http://www.world-nuclear.org/info/inf80.html The World Nuclear Association has prepared three recent "information papers" related to nuclear proliferation covering key elements of the issue and specific case studies.

78. http://nnsa.energy.gov/982.htm The U.S. Department of Energy–National Nuclear Security Administration (NNSA) has significant responsibility for promoting both national and international nuclear security and nonproliferation of nuclear weapons.

79. http://www.iaea.org/Publications/Booklets/Safeguards3/safeguards0408.pdf The International Atomic Energy Agency (IAEA) is one of the worlds leading agency's working on nonproliferation and safeguards of nuclear materials. This web site describes some of this agency's activities and plans.

80. **The Politics and Technology of Nuclear Proliferation,** Robert Fred Mozley (The University of Washington, University of Washington Press, Seattle, Washington 98195-9570, 1998). (I)

X. Public Attitudes toward Nuclear Power

Uranium mining and the use of nuclear power continue to be contentious issues involving both facts and ideology. Public ignorance regarding basic standards of technology and performance can cause trivial incidents to become high profile subjects in the media. In many areas, the debate involves site specific (not in my backyard—NIMBY) rather than opposition to nuclear power.

81. http://www.world-nuclear.org/info/inf50.html The World Nuclear Association has prepared an information paper entitled "The Nuclear Debate" that presents a summary of common anti-nuclear assertions and includes main points of response and sources of further information.

82. http://.nei.org/resourcesandstats/documentlibrary/publications/perspectiveonpublicopinion/november2008/ The Nuclear Energy Institute periodically commissions a poll on the U.S. public attitude toward nuclear power.

XI. General Resources for New Nuclear Power in United States

The following is a summary of some of the comprehensive reports prepared by various agencies and groups relating to the future of nuclear power.

83. http://www.ne.doe.gov/pdfFiles/rpt_KeystoneReportNuclearPowerJointFactFinding_2007.pdf The Keystone Center report, *Nuclear Power Joint Fact-Finding*, issued June

2007 reviews a range of nuclear power issues and uses a fact-finding process to answer often debatable questions relating to nuclear power.

84. http://www.ne.doe.gov/neac/neacPDFs/NEAC_Final_Report_Web%20Version.pdf The DOE-NE Nuclear Energy Advisory Committee issued a November 2008 report entitled *Nuclear Energy: Policies and Technology for the 21st Century* that explored the critical choices and implications in U.S. nuclear energy technology and policy, including framing options for the country to consider.

85. http://www.ostp.gov/galleries/PCAST/PCAST%20Energy%20update-final.pdf The President's Council of Advisors on Science and Technology (PCAST) report, *The Energy Imperative: Report Update*, issued November 2008 is an update to the November 2006 report, which discussed the potential for advanced energy technology to enhance U.S. energy security while protecting the environment.

86. http://www.ne.doe.gov/pdfFiles/rpt_TheFutureofNuclearPowerMITStudy2003.pdf The Massachusetts Institute of Technology report entitled *The Future of Nuclear Power*, issued in 2003, is a broad interdisciplinary study that analyzes what would be required to retain nuclear power as a significant option for reducing greenhouse gases and meet the growing needs for electricity supply.