Chapter 8
Nuclear Energy

Introduction

An enormous amount of energy exists in the bonds that hold atoms together. This energy can be released through nuclear fission, the splitting of one atom into two or more lighter atoms; or nuclear fusion, the joining of two atoms. At present, only fission can be used to generate electricity.

Energy is released when the nuclei of certain atoms absorb a free neutron, become unstable and split apart, releasing one or more free neutrons. The process is repeated, creating a self-sustained chain reaction. In commercial nuclear power plants, the resulting heat is used to create steam that turns a turbine and generates electricity, without producing greenhouse gas emissions.

Texas has two operating nuclear power facilities, Comanche Peak in Glen Rose and the South Texas Project located near Bay City. Together, the two facilities employ more than 2,000 people with a combined payroll of nearly $200 million annually.[1]

And more facilities are on the horizon. Owners of the South Texas Project have submitted an application to the U.S. Nuclear Regulatory Commission (NRC) to expand their facility. And over the next two years, the NRC expects to receive applications for six more new nuclear reactors in Texas, two more at Comanche Peak and four at two new sites. Once complete, these new reactors will require several thousand employees.

History

Ancient Greek philosophers first developed the idea that all matter is made of atoms. During the 18th and 19th centuries, scientists conducted experiments to unlock the secrets of the atom. In 1904, British physicist Ernest Rutherford wrote, "If it were ever possible to control at will the rate of disintegration of the radio elements, an enormous amount of energy could be obtained from a small amount of matter."[2]

One year later, Albert Einstein developed his theory of the relationship between mass and energy. Einstein's mathematical representation of his theory, $E=mc^2$, related the amount of energy that could be derived from a mass if it were transformed to energy. In 1938, Lise Meitner and Otto Hahn first provided the first experimental evidence of the release of energy from fission.

The world's first self-sustained nuclear fission chain reaction occurred on December 2, 1942, in a squash court under the University of Chicago's Stagg Field.[3] Enrico Fermi's reactor, Chicago Pile 1, was built of six tons of uranium metal, 34 tons of uranium oxide, nearly 400 tons of graphite bricks (to moderate the reaction) and cadmium rods to absorb free neutrons.[4] After World War II, following the success of the Manhattan Project that developed the atomic bomb, the U.S. began to use nuclear energy for non-military purposes.

The first reactor to generate electricity was an experimental breeder reactor run by the U.S. government in Arco, Idaho, beginning on December 20, 1951.[5] Breeder reactors differ from commercial light-water reactors by using a fast neutron process that produces, or breeds, more fuel than it consumes. Civilian commercial nuclear reactors in the U.S. are all light-water reactors, which use ordinary water to cool the reactor cores.

The first civilian nuclear power plant began generating electricity at Santa Susana, California on July 12, 1957. The first large-scale commercial nuclear power plant in the U.S. began operating on December 2, 1957, in Shippingport, Pennsylvania and continued to operate until it was shut down in 1982.[6]

Uses

The military uses nuclear energy for explosive warheads and naval propulsion, which was pioneered by the U.S. Navy. The first nuclear-powered submarine, the USS Nautilus, was launched in 1954.

Texas has two operating nuclear power facilities, Comanche Peak in Glen Rose and the South Texas Project located near Bay City.

The eight new reactors anticipated in Texas will need several thousand workers.

Commercial nuclear energy is used primarily to generate electricity. Today, the U.S. has 104 licensed commercial nuclear reactors that provide approximately 20 percent of the nation's electricity.[7] In 2006, total generating nameplate capacity for the nation's nuclear power plants was about 106,000 megawatts (MW), or 9.8 percent of the total nameplate capacity of all electricity generation in the U.S.[8] Nameplate capacity is the maximum rated output of a generator as designated by the manufacturer. It is called such because this capacity is typically written on a nameplate that is physically attached to the generator.

Nuclear Power in Texas

In 2006, Luminant's Comanche Peak near Glen Rose and the South Texas Project (STP) in Matagorda County together produced 10.3 percent of the state's electricity.[9] Electricity generated at these sites goes to the state's electric grid for purchase by commercial, industrial and retail consumers.

Economic Impact

Comanche Peak has two reactors with a net generating capacity of 2,300 megawatts, enough to power almost 1.3 million homes, based on average electric use in 2006. Luminant has about 1,050 employees at Comanche Peak, 800 company employees and 250 contractors who work on outsourced projects.The Comanche Peak operation paid $24.4 million in property taxes and $100 million in payroll in 2006.[10]

The South Texas Project has two reactors with a net generating capacity of 2,700 megawatts, enough to power more than 1.5 million homes, based on average electric use in 2006. STP is operated by the South Texas Project Nuclear Operating Company (STPNOC), which is owned by NRG Texas LLC (44 percent), CPS Energy (40 percent) and Austin Energy (16 percent). STPNOC has an annual payroll of $96 million for 1,150 employees. Hourly wages at South Texas average $31; hourly employees earn an average of $64,000 annually without overtime.[11] The average annual salary for other employees is $94,000.[12] By comparison, the average annual salary for Texans in 2006 was $36,373.[13]

However, there are concerns about meeting the demand for a growing nuclear workforce.

Workforce Issues

New nuclear power plants obviously will need trained employees — but finding them may be a challenge. The nuclear industry already foresees difficulties with an aging work force; a large percentage of the nation's nuclear employees will be eligible for retirement in five to ten years. In addition, new "Generation III" and "Generation III+" plant designs feature updated technologies, such as digital instrumentation and control systems, which are not present in the operating plants.

Problems involving the energy industry work force have caught the attention of the nation's leaders. At an August 2007 meeting of the Southern Governors Association, an "Energy Summit" was convened in conjunction with the U.S. Department of Labor Employment and Training Administration. Assistant Secretary of Labor Emily Stover DeRocco led the conference.[14] Each state was asked to develop a strategy to respond to the challenge of producing the work force needed by the energy industry. Nuclear energy was a major part of this discussion.

The eight new reactors anticipated in Texas will need several thousand workers. Many of these positions will involve technically sophisticated tasks requiring qualified and well-trained individuals.

For operational and technician positions, nuclear utilities provide training lasting up to three years. The curriculum for such training is established by the National Academy for Nuclear Training (NANT) and the Institute of Nuclear Power Operations (INPO).

The utilities with plans to build new plants in Texas have identified additional workers as part of the "critical path" to successful operations. The Texas Workforce Commission is working with these utilities to create the Texas Nuclear Workforce Development Initiative, a grant program to encourage universities, community colleges and the Texas State Technical College to recruit young people into two-year and four-year programs to prepare them for jobs in the new plants. These programs will give students the background in nuclear systems and operations they will need to enter into accelerated training programs upon hiring.[15]

The initiative will offer attractive opportunities for young Texans to find high-paying jobs that allow them to remain in the state and contribute to the growth of the Texas economy.

Production

All U.S. commercial nuclear power plants use enriched uranium fuel pellets in their reactor cores. The three naturally occurring varieties, or isotopes, of uranium are U-234, U-235 and U-238. Uranium-235, which makes up only 0.72 percent of all available uranium, is the only naturally occurring uranium isotope capable of undergoing fission and sustaining a chain reaction under typical civilian power generation conditions.

Uranium Mining and Enrichment

Uranium is found in the earth's crust and in seawater. All uranium used in the nuclear fuel cycle comes from deposits found on land.

In its natural state, uranium is an ore that must be mined. Once mined, uranium is processed into uranium oxide, sometimes called "yellowcake." To be enriched for use in a nuclear power plant — that is, to increase its amount of U-235 — uranium oxide must be converted to uranium hexafluoride and then transformed to a gas.

After being enriched to a level of between 3 percent and 5 percent U-235, uranium hexafluoride is converted to uranium dioxide and fabricated into cylindrical fuel pellets. These pellets are loaded into fuel rods that are in turn grouped in fuel assemblies, built to the specifications of each individual reactor. In theory, one pellet weighing only 0.24 ounces can generate as much energy as 1,780 pounds of coal or 19,200 cubic feet of natural gas.[16]

Commercial nuclear reactors have a core composed of fuel assemblies and control rods made of neutron-absorbing materials such as boron or hafnium that can be used to dampen and thus control the nuclear reaction.

Transportation

Fuel assemblies are transported by truck, rail, air or water to their specific nuclear reactor. Both the U.S. Department of Transportation and the U.S. Nuclear Regulatory Commission (NRC) oversee the security of the transport of nuclear materials.[17]

Power Generation

The number of fuel assemblies in the reactor core depends on the reactor's size and design. Reactor power output can vary significantly depending on the number of assemblies as well as other factors.

Inside the reactor core, U-235 atoms absorb a neutron and become U-236, which has an unstable nucleus. About 84 percent of the time, the U-236 atoms spontaneously split apart. This fission releases a number of products including gamma rays, beta particles, neutrons, neutrinos and, usually, two fission fragments of the original atom.

These fission fragments carry a large amount of kinetic energy. They collide with the fuel, converting their kinetic energy into increased vibrational energy, or heat. Neutrons released by the fission process are absorbed by other U-235 atoms, turning them into U-236. The process repeats, creating a self-sustaining chain reaction. Control rods are inserted into or withdrawn from the reactor core to regulate the chain reaction by absorbing neutrons and thus preventing them from striking more U-235 atoms.

The heat produced by this self-sustaining chain reaction is used to turn water to steam. The steam then is used to spin a turbine attached to a generator, producing electricity.

In addition to the fission fragments, neutrons that are absorbed by U-235 that do not result in fission or are absorbed in U-238 will produce other radioactive isotopes called actinides or transuranic elements, including plutonium, neptunium, americium and curium.

Reactor Types

The two most common types of commercial nuclear reactors used to generate electricity are pressurized water reactors (PWRs) and boiling water reactors (BWRs). Of the 104 commercial reactors in the United States, 69 are PWRs and 35 are BWRs.[18] Both Comanche Peak and STP use PWRs.

Pressurized water reactors (PWRs) involve three "loops." The primary loop passes through the reactor core and carries away the heat energy generated in the fuel. The secondary loop absorbs the heat from the first loop in a component called a steam generator, and carries it to the turbine. A

The two most common types of commercial nuclear reactors used to generate electricity are pressurized water reactors and boiling water reactors.

third loop rejects the unused heat energy to the atmosphere, either through a cooling tower or into a cooling pond or river. The primary water loop is heated to about 600°F; because the water is under high pressure, it does not boil. Water in the secondary water loop is under lower pressure and heated to 450 to 500°F, which creates steam. The steam hits turbine blades with a pressure of about 1,000 pounds per square inch. The turbine turns a generator that produces electricity (**Exhibit 8-1**).

BWRs have only two loops. Water passes through the reactor core where it boils, creating steam. From the steam generator, a steam line is directed to a turbine that turns a generator used to produce electricity. The steam passes through a condenser where it is turned into water and returned to the reactor core, repeating the process. A secondary coolant loop rejects excess heat energy to the atmosphere. The steam used to turn the turbine comes in contact with the reactor core, making it radioactive (**Exhibit 8-2**).

Depending on variables unique to each reactor, fuel assemblies within the reactor core are replaced about every 18 months to ensure optimum performance.

Next-Generation Reactors

The U.S. Nuclear Regulatory Commission (NRC) has certified or is reviewing design certification applications for a new generation — "Generation III" — of nuclear reactors in the U.S. Generation III reactors feature design improvements over Generation II reactors, which are currently operating in the U.S.

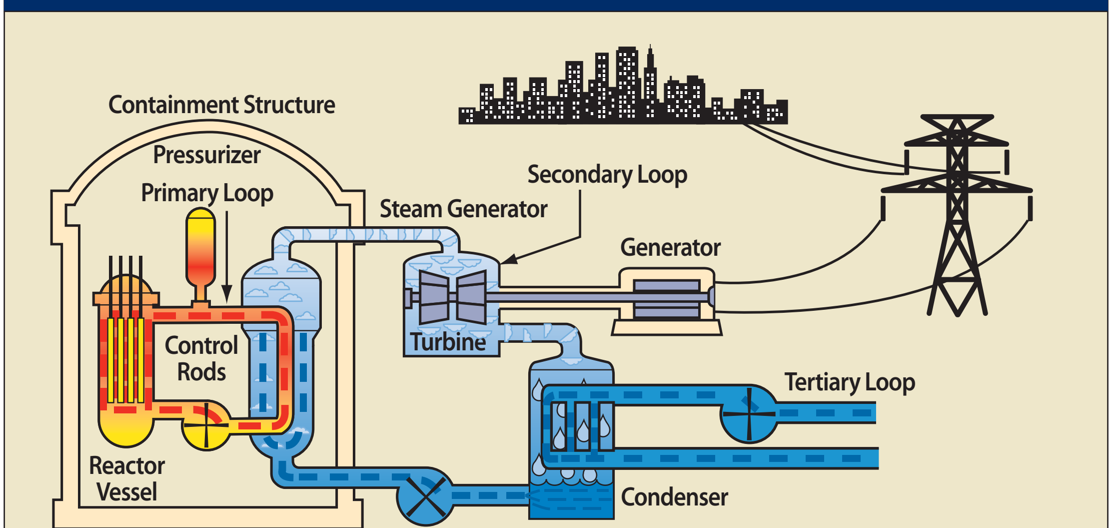
NRC has certified the design of the Westinghouse AP1000, a 1,000 to 1,200 MW (electric) pressurized water reactor. Six utility companies have selected the AP1000 for 14 reactors to be constructed at seven sites across the U.S.[19]

General Electric has received design certification for its advanced boiling water reactor (ABWR) design, capable of producing 1,350 to 1,600 MW.[20] NRG Energy has chosen the ABWR design for two new reactors it plans to build at the South Texas Project in Matagorda County.[21] On September 24, 2007, NRG submitted the first combined Construction and Operating License Application to NRC for the new reactors. NRG expects both units to be operational by 2015.[22]

NRC also has received an application for design certification for General Electric's Economic

Exhibit 8-1

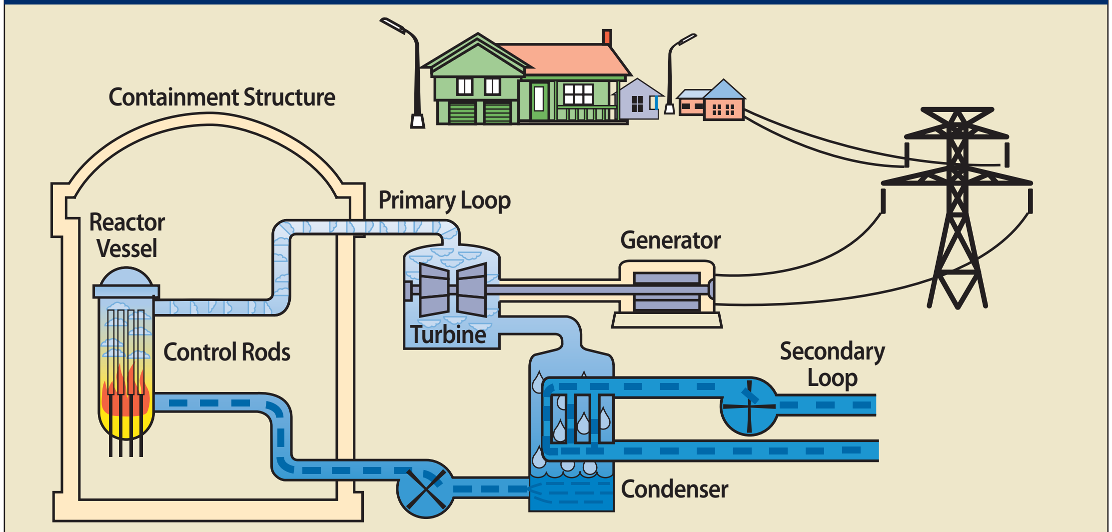
Pressurized Water Reactor



Source: U.S. Nuclear Regulatory Commission.

EXHIBIT 8-2

Boiling Water Reactor



Source: U.S. Nuclear Regulatory Commission.

Simplified Boiling Water Reactor (ESBWR). The review process for the ESBWR should be completed by fiscal 2012.[23] NRC received design certification applications for the Mitsubishi U.S. Advanced Pressurized Water Reactor (US-APWR) and the Areva Evolutionary Pressurized Water Reactor (EPR) in December 2007.[24]

Other types of reactors include pressurized heavy water reactors, high-temperature, gas-cooled reactors, pebble-bed reactors, sodium-cooled reactors, heavy metal-cooled reactors, supercritical water reactors and molten salt reactors. With the exception of the heavy water reactor, all are considered to be "Generation IV" designs that could be ready for commercial deployment by 2030. So far, none of these types have been submitted to the NRC for use in civilian power plants in the U.S.

Storage

Once removed, the highly radioactive spent fuel is stored in containment pools or dry casks.[25] At present, in the U.S., all commercial spent nuclear fuel is stored on site at the reactor where it was produced. Environmental issues related to storage are discussed below.

Availability

In its natural state, uranium must be mined or extracted using one of three methods: underground mining; open-pit mining; or in-situ leach (ISL) mining. Underground and open-pit mining involves removing rock from the ground, breaking it up and sending it to a mill to remove the uranium. ISL mining, also called solution mining, pumps a leach solution through the ground to separate uranium ore from its source rock. It causes little surface disturbance or rock waste. The source rock, however, must be permeable to the leach solution and located in a geologic formation that prevents groundwater contamination.[26]

Canada, Australia and Kazakhstan were the three leading producers of uranium in 2006. Canadian mines produced 9,862 tons of uranium, accounting for 25 percent of world supply; Australian mines produced 7,593 tons, 19 percent of world supply; and Kazakh mines produced 5,279 tons, 13 percent of world supply in 2006.[27]

U.S. uranium mines are found in western states and produced 1,672 tons, or just over 4 percent of the world supply, in 2006.[28]

Uranium is originally deposited on the earth's surface in igneous rock. Uranium is easily oxidized and very soluble in water. As water percolates through a source rock or sediments, uranium is dissolved into the water and flows downhill. When the water comes into contact with a "reducing environment" containing chemical compounds such as coal, oil and gas or sulfides, uranium precipitates from the solution and is deposited in an ore body called a "roll front" (**Exhibit 8-3**). Uranium deposits capable of sustaining commercial mining accumulate over millions of years.[29]

Uranium deposits in Texas are found in relatively narrow bands that parallel the coastline, deposited by uranium-laden water flowing toward the Gulf of Mexico (**Exhibit 8-4**). In Texas, all uranium is mined using in-situ recovery, since it is deposited in permeable sands.

There are three companies with permits to mine uranium in Texas. Two, Mesteña Uranium, L.L.C. and Uranium Resources, Inc. (URI), are producing uranium and one, COGEMA Mining, has a mine reclamation. A fourth company, South Texas Mining Venture, expects to be producing uranium by the end of 2008.

According to Paul Goranson, Mesteña's vice president and Alta Mesa operations manager, the Alta Mesa project produced more than 1 million pounds of yellowcake in 2006.

At the Mesteña mine, a leach solution is pumped into the ore body through injection wells. After flowing through the ore body, the "pregnant" solution is recovered through production wells and pumped to a processing mill, where the uranium is precipitated out of the solution, run through a filter press and placed in a vacuum dryer. The finished yellowcake is loaded in drums and shipped to Metropolis, Illinois, where it is enriched.[30]

Uranium Resources, Inc. (URI) mines and processes uranium at Kingsville Dome in Kleberg County and mines uranium at Vasquez in Duval County. According to Mark Pelizza, URI vice president for health safety and environmental affairs, the two

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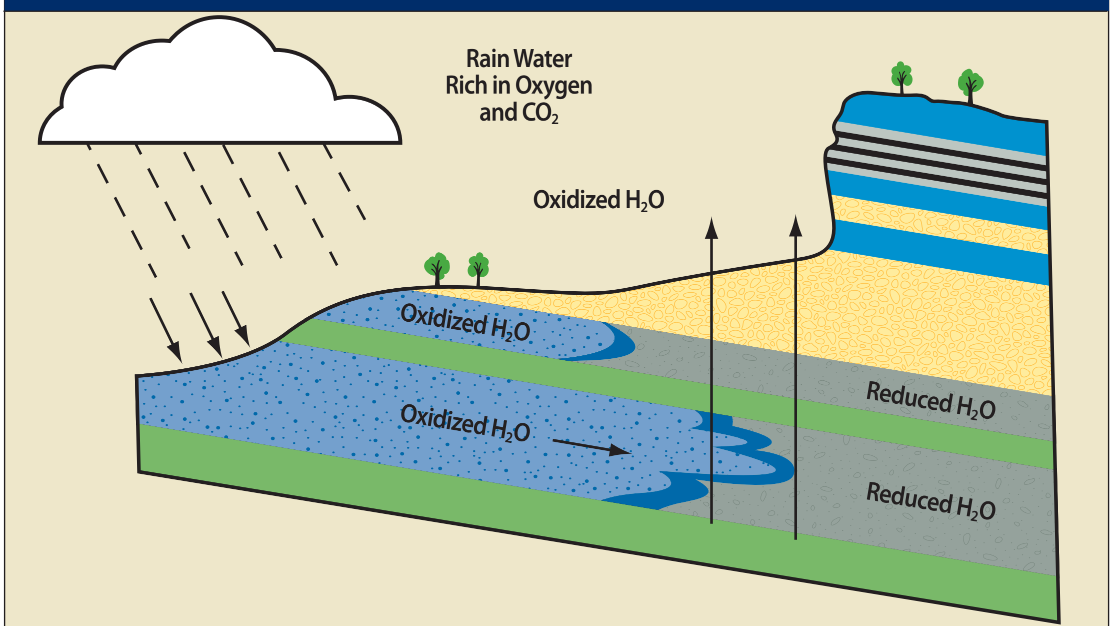
Exhibit 8-3

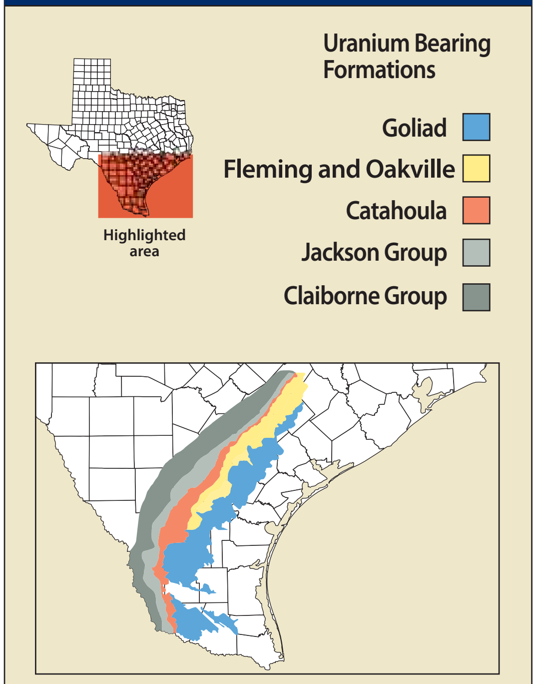
Uranium Roll Front



Source: Texas Mining and Reclamation Association.

EXHIBIT 8-4

Uranium Deposits in Texas



Source: Texas Mining and Reclamation Association and Bureau of Economic Geology.

mines combined produced 260,000 pounds of yellowcake in 2006. URI plans to recommence mining and processing at a Rosita facility in northern Duval County by the end of 2007 or early 2008.[31]

Between the Mesteña mine and the URI mines, Texas produced 1,260,000 pounds of yellowcake in 2006. One pound of yellowcake is equivalent to 10 tons of coal, meaning that Texas uranium mines produced an equivalent to 12.6 million tons of coal, with a total energy content of 262 trillion Btu.[32]

South Texas Mining Venture has submitted an area permit application with the Texas Commission on Environmental Quality (TCEQ) for ISL mining at its La Palangana site in Duval County. According to Larry McGonagle, general manager for South Texas Mining Venture, they expect to secure all necessary permits by the fourth quarter of 2008, with production beginning by the end of 2008.[33]

COGEMA Mining operated wells in Duval County, all of which are in reclamation. According to David Benavides, COGEMA's radiation safety officer, the reclamation process should be completed in 2009, and that the company has no plans for future uranium mining operations in Texas.[34]

ISL mining in Texas is advantageous because of the state's mild climate. ISL mining in Wyoming requires lines carrying mining solution to and from the well field to be buried and machinery to be contained in buildings to prevent freezing. Subsequently, capital costs for ISL in Texas are about two-thirds less than in Wyoming.[35] Another benefit to above-ground ISL mining is that leaks are visible and easily detected and fixed. Buried infrastructure can hide leaks until detected in monitor wells surrounding the ore body.

Another uranium mining company is currently in the exploration phase near Goliad, Texas. Citizens of the area claim that the company's explorations have caused contamination of drinking water and are a violation of the U.S. Safe Drinking Water Act. Goliad County commissioners have filed suit against the company for this alleged violation, and they claim that test holes were left unplugged allowing chemicals to leak into the aquifer. The Railroad Commission of Texas, however, determined that the company was not in violation of their exploration permit and that no groundwater contamination had occurred.[36]

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Costs and Benefits

A 2004 University of Chicago study, *The Economic Future of Nuclear Power,* estimated the levelized cost of electricity (LCOE), which is the price necessary to recover operating and capital costs, for new nuclear power plants coming on line during the next decade. The study estimated the price for new nuclear energy to be from $47 to $71 per megawatt-hour. By contrast, the LCOE for coal-fired plants ranges from $33 to $41 per MWh and between $35 and $45 per MWh for natural gas-fired plants.[37] Prices for nuclear power generation are higher due to higher initial capital costs.

The University of Chicago study also stated that the first new nuclear power plants coming on line in the next decade will have higher LCOEs due to engineering costs that could raise capital costs by 35 percent.[38]

The study estimated that, with the assistance of loan guarantees, accelerated depreciation and investment and production tax credits, the LCOE for nuclear power could fall to $32 to $50 per MWh. With lessons learned from the first few new-generation nuclear plants, LCOEs could fall to $31 to $46 per MWh, which would alleviate the need for financial assistance and allow nuclear energy to compete in the marketplace with coal-fired and natural gas-fired plants.[39]

Fuel costs to the U.S. nuclear energy industry fall in two parts: the front-end cost of ore purchase, conversion, enrichment and fabrication, and the back-end costs of storage and disposal. In its study, the University of Chicago calculated the front-end cost of nuclear fuel at between $3.56 and $5.53 per MWh in 2003 dollars, including ore purchase, conversion, enrichment and fabrication costs.[40] World uranium prices have risen substantially since 2003.

According the World Nuclear Association, the nuclear energy industry is the only energy-producing technology that takes full responsibility for the cost of its waste and builds the full cost of storage and disposal of spent nuclear fuel into the price of generation.[41]

Under U.S. law, the U.S. Department of Energy (DOE) is responsible for the ultimate disposal of spent nuclear fuel. This disposal is funded by a surcharge on nuclear power plant operators of 0.1 cents per kilowatt hour of electricity.[42] DOE has not yet taken responsibility for spent fuel, however. Again, all commercial spent nuclear fuel currently is stored at the reactor; the cost of this storage is borne by the utility that owns or operates it. (The nation's search for a permanent storage facility is discussed below.)

The University of Chicago study estimated spent fuel storage and disposal costs, at 2003 prices, to be $1.09 per MWh — nine cents for temporary on-site storage and $1 to pay for eventual permanent disposal at a centralized geologic repository.[43] Converted from megawatt hours, the cost of spent fuel storage and disposal is 0.109 cents per kilowatt hour (kWh) of electricity produced.

According to the U.S. Energy Information Administration, *not including capital costs*, the total cost of producing electricity using nuclear power was 1.95 cents per kWh in 2006. This includes costs of 0.893 cents for operations, 0.568 cents for maintenance and 0.485 cents for fuel costs. By contrast, it costs 2.96 cents per kWh to produce electricity from fossil fuel steam and 5.78 cents per kWh to produce electricity from gas turbines. When capital costs are excluded, only electricity produced from hydroelectric generation is cheaper than nuclear, at 0.85 cents per kWh (**Exhibit 8-5**).[44]

Environmental Impact

The increased acceptance of nuclear power is not without criticism and challenges. Critics of nuclear power cite the potential environmental impact of accidents at nuclear reactors, ranging from a catastrophic meltdown of a reactor core to minor

EXHIBIT 8-5

Average Operating Expense of Electricity Generation for Major U.S. Investor-Owned Electric Utilities, 2002-2006
In Cents Per Kilowatt Hour

Year	Nuclear	Fossil Steam	Hydroelectric	Gas Turbine
2002	1.82	2.13	0.87	3.69
2003	1.87	2.26	0.75	4.89
2004	1.83	2.39	0.87	5.01
2005	1.82	2.77	0.89	5.89
2006	1.95	2.96	0.85	5.78

Note: Excludes capital costs, a major expense for nuclear electricity.
Source: U.S. Energy Information Administration.

accidents that release relatively small amounts of radioactivity into the environment.

On March 28, 1979, Pennsylvania's Three Mile Island's Unit 2 suffered a partial meltdown of its reactor core. According to a report by the Nuclear Regulatory Commission, equipment failures, design-related problems and human error led to this, the nation's most serious commercial nuclear accident.[45] No lives were lost as a result of the accident. Following the accident, NRC improved the level of safety at reactor sites by increased safety regulations inspection procedures.[46]

On April 26, 1986, the world's most significant nuclear accident occurred in the Ukraine, then part of the Soviet Union. A sudden surge of power in the Unit 4 reactor at the Chernobyl nuclear power plant caused an explosion and fire that destroyed the reactor and released massive amounts of radioactive material into the surrounding area. The accident was caused by breaches of technical operating procedures as well as inadequate safety systems. About 116,000 people were evacuated from the surrounding area. The death toll from the explosion and immediate aftermath is officially 30, with 28 deaths due to radiation exposure among power plant employees and firemen.[47]

In addition, nuclear power plants use large quantities of water for cooling purposes. Depending upon the plant type, electricity generation from nuclear power requires withdrawals of between zero and 17,590 gallons per million Btu of heat produced.[48] This is the amount of water extracted from a water source; most of the water withdrawn is returned to that source.

Water consumption refers to the portion of those withdrawals that is actually used and no longer available. Nuclear energy consumes between zero and 211 gallons of water for each million Btu of heat energy produced.[49]

Storage and Disposal

High-Level Waste

Disposal of high-level radioactive waste — spent reactor fuel — is the most hotly debated issue between critics and proponents of nuclear power. Almost all nuclear experts agree that a permanent geologic repository is the best means to store it.

Two options for handling and storing spent fuel are: reprocessing to extract the remaining energy and separate out fission products, actinide elements and fissionable material, called a *closed-fuel cycle*; or storage and final disposal without reprocessing, called a *once-through fuel cycle*.

The 104 U.S. commercial nuclear reactors produced about 2,400 tons of high-level radioactive waste in the form of spent fuel in 2002 (most recent data available).[50] In all, about 47,000 tons of spent nuclear fuel is being held in storage and awaiting final disposal around the nation, almost all of it on site at nuclear power plants. Ninety percent of the spent fuel is stored underwater in containment pools, while the remainder is contained in dry casks.[51]

The U.S. nuclear industry uses a once-through fuel cycle. Fuel assemblies are removed from reactor cores after about 18 months due to a loss of "reactivity," as a result of the decrease in the number of fissionable atoms in the fuel. The spent fuel assemblies are roughly 14 feet long and weigh several tons apiece.

In the late 1970s, the U.S. Department of Energy began considering Yucca Mountain, Nevada as a permanent geologic repository for high-level radioactive waste (**Exhibit 8-6**). Yucca Mountain is located in a remote, federally-owned section of Nye County, Nevada, about 100 miles northwest of Las Vegas.[52]

The federal Nuclear Waste Policy Act of 1982 and the Nuclear Waste Policy Amendments Act of 1987 directed the DOE and NRC to develop Yucca Mountain as a permanent repository for high-level radioactive waste. DOE estimates that Yucca Mountain can begin accepting spent nuclear fuel no earlier than 2017. Before this can happen, however, the U.S. Environmental Protection Agency, DOE and NRC must work together to set safety standards and obtain all required licenses for the facility. DOE plans to submit a license application to NRC by June 30, 2008. This license would allow DOE to begin building the storage facility beneath Yucca Mountain.[53]

Most countries with nuclear programs have begun programs to develop similar sites for geologic repositories. At present, however, no country has opened a permanent geologic repository.

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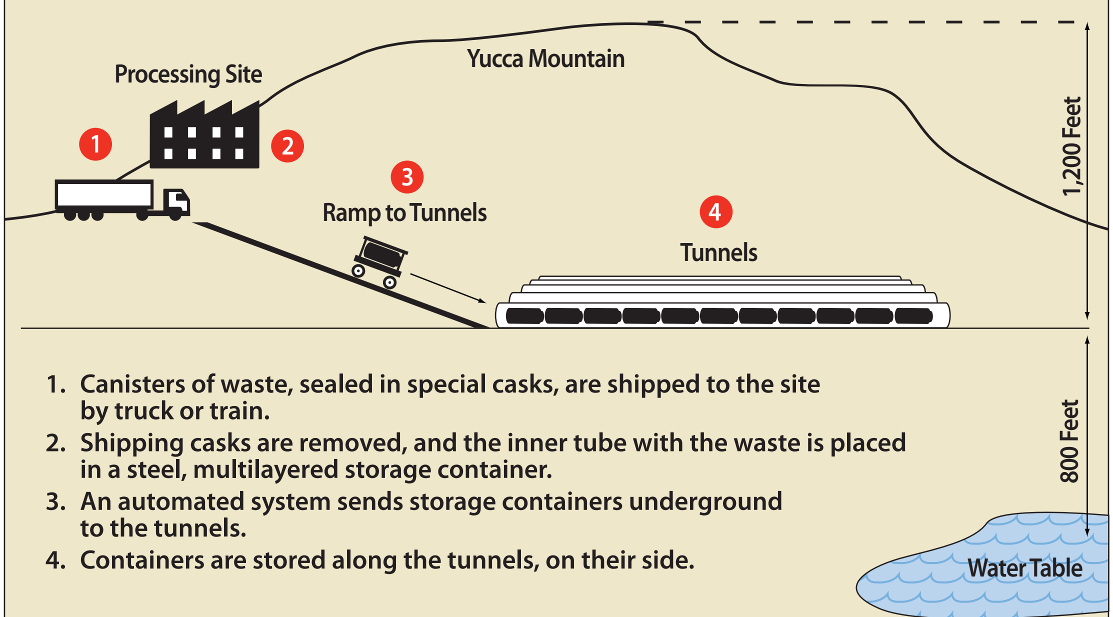
EXHIBIT 8-6

Yucca Mountain Storage Facility



1. Canisters of waste, sealed in special casks, are shipped to the site by truck or train.
2. Shipping casks are removed, and the inner tube with the waste is placed in a steel, multilayered storage container.
3. An automated system sends storage containers underground to the tunnels.
4. Containers are stored along the tunnels, on their side.

Source: U.S. Nuclear Regulatory Commission.

Low-Level Waste
Nuclear power plants also produce significant amounts of low-level radioactive waste. Low-level waste includes protective clothing used at nuclear reactors and parts from inside dismantled reactors, among others. The same waste policy act that directs DOE to take responsibility for the disposal of spent fuel dictates that the states are responsible for disposing of low-level radioactive waste. Medical facilities also produce low-level radioactive waste.

Many states, including Texas, have joined Congressionally approved compacts that allow them to deposit low-level waste in a single facility serving the compact member states, without having to accept waste from other states. The Texas Compact currently consists of Texas and Vermont.[54] Currently, no low-level waste is being stored in Texas as a result of the compact, because no storage facility exists at this time. In its compact, Texas is the host state — meaning that the low-level waste storage site will be located in Texas. In return, Vermont has agreed to pay Texas $25 million to help with construction costs.[55]

Waste Control Specialists, a company based in Andrews County, Texas, has applied to TCEQ for a license to construct a storage facility for commercial low-level radioactive waste from the compact state, Vermont, as well as DOE.[56]

Eight states (Maine, Massachusetts, Michigan, Nebraska, New Hampshire, New York, North Carolina and Rhode Island), the District of Columbia and Puerto Rico do not belong to any compact, and run the risk either of not being able to dispose of their own low-level waste or, should they build a facility, having to accept waste from the other states without a compact.[57]

Low-level waste is stored on site in special containers. Medical facilities — including hospitals, research institutions and industries store this waste until they have enough to ship to one of three low-level waste facilities in the U.S. These three facilities are located in Washington, Utah and South Carolina.[58]

Reprocessing

Reprocessing spent fuel separates its remaining uranium (U), plutonium (Pu) and higher actinides from fission products, or high-level waste (HLW) (**Exhibit 8-7**). The uranium must be "re-enriched" and can be formed into uranium oxide fuel pellets, or combined with plutonium to form a mixed-oxide fuel that can be used in reactors.[59]

Reprocessing nuclear fuel would extend the availability of nuclear fuel by hundreds of years. It would also greatly reduce the volume of high-level radioactive waste that must be stored. Spent fuel is regularly reprocessed at facilities in France, the United Kingdom, Russia and Japan.[60]

In the U.S., however, spent fuel reprocessing has been and continues to be controversial. Critics argue that spent fuel reprocessing increases the world's supply of plutonium, which could be obtained by countries and terrorist organizations and used to manufacture nuclear weapons.

Due to concerns over nuclear weapons proliferation, in 1977 President Jimmy Carter decided to indefinitely defer the reprocessing of spent fuel from commercial nuclear power plants in the U.S.[61]

The Reagan administration opened the door for the reprocessing of spent fuel from commercial reactors, but economic factors, regulatory issues and potential litigation proved prohibitive to private investment in reprocessing facilities. In July 2007, the Global Nuclear Energy Partnership (GNEP) announced that the U.S. Department of Energy would award $16 million to support studies on spent fuel recycling. The goal of the GNEP funding is to spur the development of advanced

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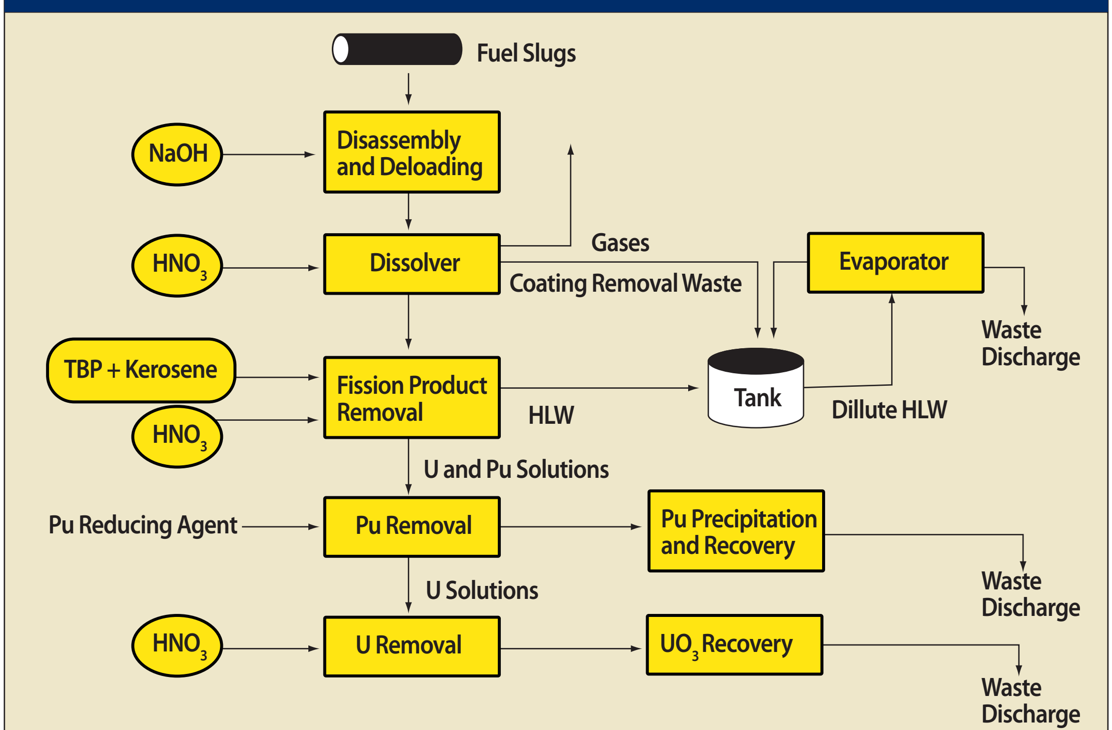
Exhibit 8-7

Uranium Reprocessing



Source: U.S. Department of Energy.

technologies to recycle spent nuclear fuel in ways that enhance proliferation resistance.[62]

Dr. Phillip Finck of the Argonne National Laboratory has stated that, at the currently projected growth rate for U.S. nuclear plants, the nation will need up to nine repositories the size of Yucca Mountain by 2100 if the fuel is not reprocessed.[63]

State and Federal Oversight and Regulation

The U.S. Nuclear Regulatory Commission (NRC) sets all standards and regulations for nuclear power plants and the power they generate. NRC provides the guidelines and standards that must be followed to receive a construction and operating license.

NRC sets out guidelines for prospective operators in Title 10 of the Code of Federal Regulations. These guidelines cover all relevant areas, including building, power generation, energy transportation, waste disposal, recycling, radiation monitoring and terrorism prevention.[64]

The federal Energy Policy Act of 2005 provided the nuclear industry with a variety of financial incentives for new nuclear power plants.

The Texas Commission on Environmental Quality (TCEQ) has some limited rules pertaining to nuclear plants regarding water quality, but these rules are based on the NRC standards.

The Railroad Commission of Texas regulates uranium exploration. Companies engaged in uranium exploration must obtain an exploratory permit that designates the area to be explored and the method of exploration. The most common method used is borehole drilling.

Once an ore body has been identified, the company must obtain an area mining permit, a production area authorization, a wastewater disposal permit and a radioactive material handling license from TCEQ, which regulates uranium mining. The company also must obtain an aquifer exemption from TCEQ and the U.S. Environmental Protection Agency if it wishes to use injection mining in or near a drinking water aquifer.

The Texas Department of State Health Services (DSHS) regulates the transportation and routing of all radioactive material, including radioactive waste.[65] In addition, DSHS prepares and maintains emergency response plans for all fixed nuclear facilities and coordinates full-scale safety exercises in support of local government at each nuclear plant.[66]

Subsidies and Taxes

The federal Energy Policy Act of 2005 provided the nuclear industry with a variety of financial incentives for new nuclear power plants. These included:

- An eight-year production tax credit of 1.8 cents per kilowatt-hour for up to 6,000 megawatts of capacity from new, qualified advanced nuclear power facilities;
- Loan guarantees for up to 80 percent of project costs for advanced nuclear energy facilities;
- Extended Price-Anderson Act protection until December 31, 2025, which establishes an insurance system for nuclear plants in the case of accidents;
- DOE authorization to enter into contracts to pay utilities that incur costs due to regulatory delays and litigation;
- A total of $1.25 billion for fiscal 2006 through 2015 for a prototype next-generation nuclear power plant at the Idaho National Laboratory that will produce both electricity and hydrogen; and
- An advanced fuel recycling technology, research, development and demonstration program for proliferation-resistant fuel recycling and transmutation technologies.[67]

Texas Tax Code Section 151.318 exempts manufacturing equipment used to generate electricity from sales tax. Nuclear plant equipment exempted from sales tax includes steam production equipment and fuel, cooling towers, generators, pollution control equipment and heat exchangers.[68] There is no limit to this exemption.

In states where the electricity market is not deregulated, nuclear power producers are permitted to include construction costs into the rate base. The rate base is the value upon which a utility is permitted to earn a specific rate of return — this rate base must be approved by the state's utility regulators. In some states, such as North Carolina and Virginia, special incentives allow nuclear power producers to include construction costs in the rate base during the construction phase of the project — well before any nuclear power is produced.[69] Other states, such as Florida and Georgia, allow utilities to recover pre-construction and construction costs even if a plant is started and then the project is canceled.[70]

This is not the case in Texas, which has deregulated its wholesale electricity market. During the last legislative session, however, the Legislature passed bills granting certain incentives to nuclear power producers in Texas.

In 2007, the Texas Legislature passed House Bill 1386, which provides guidelines for a nuclear plant to establish a decommissioning fund to cover the costs of decommissioning and decontaminating a reactor, making annual payments. Additionally, this legislation requires retail electric customers to cover any shortfalls in the cost of decommissioning a nuclear plant.[71]

The 2007 Legislature also passed legislation to allow local taxing authorities to grant property tax value limitations for nuclear power plants. In recognition of the lengthy licensing process for nuclear power plants, House Bill 2994 allows local taxing authorities to defer commencement of the property tax value limitation period for up to ten years.[72]

More information on subsidies for nuclear power can be found in Chapter 28.

Other States and Countries

The accidents at Three Mile Island and Chernobyl, along with environmental difficulties of dealing with waste, slowed the commercial development of nuclear power in the U.S. The Nuclear Regulatory Commission issued the last separate construction permit for a new nuclear plant in January 1978. (As noted earlier, NRG Energy of Houston has submitted an application for two new reactors to be built at the South Texas Project.)

Recently, NRC developed a combined construction and operating license called a COL. None of these have been issued yet. At this writing, the last operating license issued by the NRC was for the Tennessee Valley Authority's Watts Bar nuclear power plant in 1996.[73]

Concerns about global climate change and energy independence have led to increased worldwide interest in nuclear energy. Proponents and critics agree that nuclear power plants generate electricity with little or no greenhouse gas production. Nuclear energy has received increasing support from the federal government, state governments and even some environmental organizations. NRC expects to receive 22 COL applications for new nuclear power plants with 33 reactors in the U.S. between 2007 and 2010.[74]

Thirty foreign nations operate commercial nuclear reactors, with the greatest concentration of them in North America, Europe and Asia. A total of 439 power reactors are operating around the world.[75]

France

After the 1973 oil shock, the French government realized it had "no oil, no gas and no coal," and no choice but to pursue nuclear energy aggressively to ensure its energy independence.[76] Nearly 35 years later, France operates 59 nuclear reactors that generate over 63,000 MW, or 78 percent its electricity.[77] By contrast, as previously noted, nuclear reactors produce just 20 percent of U.S. electricity.

France operates 59 nuclear reactors that generate over 63,000 MW, or 78 percent its electricity.

Today, France is the world's leading exporter of electricity and an active exporter of nuclear technology. NRC expects the French company Areva to submit its Evolutionary Pressurized Water Reactor technology for design certification in early 2008. Five U.S. utilities have chosen EPR technology for seven new reactors; four reactors will be built at existing plant locations, and three at new facilities.[78]

The French nuclear program reprocesses spent fuel at its La Hague facility in Normandy. This facility also combines plutonium with uranium to make a mixed-oxide (MOX) fuel that can be used in about 35 European nuclear reactors.[79]

Like most countries that produce high-level radioactive waste, France has declared deep geologic storage as its preferred method of disposal. The government has set a target date of 2015 for licensing a repository, and 2025 as its opening date.[80]

Japan

Japan has pursued nuclear energy for more than 50 years. Japan has few natural resources of its own and must import about 80 percent of its energy supply. Today, 55 nuclear reactors generate 47,500 MW or about 30 percent of Japan's electricity.[81]

Japan's first nuclear reactors were designs imported either from the U.S. or the United Kingdom. By the end of the 1970s, Japanese companies had developed the capability to design and build their own light water reactors. Today, Hitachi Co. Ltd., Toshiba Co. Ltd. and Mitsubishi Heavy Industry Co. Ltd. are among the world leaders in nuclear reactor design and construction.

Mitsubishi Heavy Industry has notified NRC that it plans to submit its USAPWR for design certification and will market the reactor to American utility companies. Luminant chose Mitsubishi's technology for the two new reactors it plans to build at Comanche Peak near Glen Rose, Texas.[82]

Japan reprocesses its spent fuel. In May 2000, Japan's parliament, the Diet, passed legislation mandating deep geologic disposal for high-level radioactive waste, which it defined as vitrified waste from reprocessed spent fuel. The nation's private sector has established a Nuclear Waste Management Organization to develop plans for final disposal. Japan's geologic repository is expected to be operating by 2035.[83]

A new generation of advanced reactors, rising global energy demands and the cost of natural gas coupled with the need to reduce greenhouse gas emissions all point to a renaissance for nuclear energy.

Canada

Canada leads the world in uranium production, supplying about a third of the world's supply. In 2004, Canada produced nearly 14,000 tons of uranium dioxide concentrate. Production will increase after 2011 when new mines come into production. Canada's reserves total 524,000 tons, second only to Australia's, which has two and a half times that amount.

Canada's 18 nuclear reactors produce 12,600 MW, or 16 percent of the nation's electricity, using domestically developed technology. Canada Deuterium Uranium (CANDU) reactors are pressurized heavy water reactors (PHWRs). Heavy water contains a higher-than-normal proportion of deuterium, an isotope of hydrogen. Its physical and chemical properties are similar to those of normal water, but it has significantly different neutronic properties.

In 2002, Canada established a Nuclear Waste Management Organization (NWMO) to explore options for nuclear waste storage and disposal. NWMO has proposed extended on-site storage, centralized dry cask storage and a deep geologic repository for high-level radioactive waste.[84]

Other Countries

Russia has 31 operating nuclear reactors, seven under construction, eight planned and 20 proposed. China has 11 operating nuclear reactors, five under construction, 29 planned and 86 proposed. India has 17 operating reactors, six under construction, 10 planned and nine proposed. Ukraine has 15 operating reactors, two planned and 20 proposed. South Africa has two operating reactors, one planned and 24 proposed.[85]

Outlook for Texas

The aging of existing nuclear reactors, a new generation of advanced reactors, rising global energy demands and the cost of natural gas coupled with the need to reduce greenhouse gas emissions all point to a renaissance for nuclear energy. But several regulatory and economic hurdles must be addressed before the next generation of nuclear reactors comes on line.

As noted above, Luminant plans to add two Mitsubishi advanced pressurized water reactors at Comanche Peak; NRG Energy LLC, one of the partners in STP, has submitted an application to add two General Electric advanced boiling water reactors at the site in Matagorda County, each capable of generating more than 1,300 MW.[86]

In addition, Exelon has announced plans to submit a combined construction and operating license application for two reactors in September 2008. The site is 20 miles south of Victoria in Victoria County. Exelon has chosen the ESBWR as its reactor of choice.[87]

Amarillo Power, LLC has announced plans to build a nuclear power plant with two UniStar U.S. evolutionary power reactors in the Texas panhandle. Together, these two reactors would be capable of generating 2,700 MW. Amarillo Power has not submitted a COL application, but they have notified the NRC that it plans to do so in the last quarter of 2008.[88]

If all eight proposed reactors are built and operating in Texas, they and the four existing nuclear reactors would have the capacity to generate more than 17,000 MW of electricity, or about 16 percent of Texas' total 2006 capacity, compared to the 4.6 percent of capacity that the four existing reactors contributed in 2006.[89]

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