Chapter 2
Electricity, an Essential Necessity in Our Life

Early man relied on fire for the luxuries of light, heat, and cooking. Today, we take all these luxuries for granted. At the flick of a switch, a push of a button, or the turn of a knob, we can have instant power. Electricity plays a huge part in our everyday lives. Whether it is at home, school, the local shopping center, or our workplace, our daily routines rely heavily on the use of electricity. From the time we wake up in the morning until we hit the pillow at night, our daily life is dependent on electricity. The alarm we have to turn off each morning runs on electricity. The light in our bedroom, the hot shower we take before breakfast, Dad’s electric razor. All these things need electricity in order to function. Even our first meal of the day is heavily dependent on electricity. The fridge that keeps all our food cool and fresh needs electricity to run or the grill that cooks your bacon and eggs also needs power to operate. This power generally (unless you have gas stove) comes from electricity. Electricity not only plays a big part in our daily lives at home, but it is extremely important for all the things that go on in the world around us in our modern life, such as industry that we depend on, communication as in the form of radio, television, e-mail, Internet, etc. Transport is another aspect of our daily life that depends on electricity to some degree.

2.1 Cost of Generating Electricity Today

One of the first questions that come to our mind about the necessity of electricity for our day-to-day life is this:

*How much does it cost to generate electricity with different types of power plants?*

The Annual Energy Outlook 2014 (AEO2014), prepared by the US Energy Information Administration (EIA), presents long-term annual projections of energy supply, demand, and prices focused on the USA through 2040, based on results
from EIA’s National Energy Modeling System (NEMS). NEMS enables EIA to make projections under alternative, internally consistent sets of assumptions, the results of which are presented as cases. The analysis in AEO2014 focuses on five primary cases: a Reference case, Low and High Economic Growth cases, and Low and High Oil Price cases. Results from a number of other alternative cases also are presented, illustrating uncertainties associated with the Reference case projections. EIA published an Early Release version of the AEO2014 Reference case in December 2013. The projections in the US EIA’s Annual Energy Outlook 2014 (AEO2014) focus on the factors that shape the US energy system over the long term.

EIA has historical data on the average annual operation, maintenance, and fuel costs for existing power plants by major fuel or energy source types in Table 2.1. Average Power Plant Operating Expenses for Major US Investor-Owned Electric Utilities, 2001–2012 (Mills per kilowatt-hour) of the Electric Power Annual.

There are about 19,023 individual generators at about 6997 operational power plants in the USA with a nameplate generation capacity of at least 1 MW. A power plant can have one or more generators, and some generators may use more than one type of fuel.

There are currently 61 commercially operating nuclear power plants with 99 nuclear reactors in 30 states in the USA. Thirty-five of these plants have two or more reactors. The Palo Verde plant in Arizona has three reactors and had the largest combined net summer generating capacity of 3937 MW in 2012. Fort Calhoun in Nebraska with a single reactor had the smallest net summer capacity at 479 MW in 2012.

Four reactors were taken out of service in 2013: the Crystal River plant in Florida with one reactor in February; the Kewaunee plant in Wisconsin with one reactor in April; and the San Onofre plant in California with two reactors in June. The Vermont Yankee plant in Vermont, with a single reactor, was taken out of service in December 2014.

The role electricity plays in our lives by enhancing our productivity, comfort, safety, health, and economy is obvious. We live with the benefits of electricity every day. So much so that we take it for granted that whenever we plug our gadgets into the wall socket, the power will be there. While most people give little thought to where electricity comes from, there are many different ways to generate electricity—including coal, oil, gas, hydroelectric, nuclear, and solar. Each option inherits certain advantages that merit consideration whenever there is a need for a

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1 A mill is equal to 1/1000 of a US dollar, or 1/10 of 1 cent. Mills per kilo-watt-hour (kWh) equals dollars per mega-watt-hour (MWh). To convert mills per kWh to cents per kWh, divide mills per kWh by 10

1 mill/kWh = 0.1 cent/kWh
1 mill = 0.1 cents = 0.001 dollars
1 MW = 1000 kW
1 mill/kWh = 1 dollar/MWh.
new power plant. Nuclear generated electricity is unique in that it inherently addresses many of the shortcomings of the other means for power generation. The use of nuclear power provides answers for many problems in the areas of environment, safety, economics, reliability, sustainability, and even waste.

### Table 2.1 Average power plant operating expenses for major US investor-owned electric utilities, 2003–2013 (Mills per kilowatt-hour)

<table>
<thead>
<tr>
<th>Year</th>
<th>Operation</th>
<th>Fossil steam</th>
<th>Hydroelectric</th>
<th>Gas Turbine and Small Scale</th>
<th>Nuclear</th>
<th>Fossil steam</th>
<th>Hydroelectric</th>
<th>Gas Turbine and Small Scale</th>
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<td>3.19</td>
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<td>2008</td>
<td>9.89</td>
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<td>7.32</td>
<td>4.48</td>
<td>4.63</td>
<td>2.75</td>
</tr>
</tbody>
</table>

Hydroelectric category consists of both conventional hydroelectric and pumped storage
Gas Turbine and Small Scale category consists of gas turbine, internal combustion, photovoltaic, and wind plants

**Notes:** Expenses are average expenses weighted by net generation. A mill is a monetary cost and billing unit equal to 1/1000 of the US dollar (equivalent to 1/10 of 1 cent)
Total may not equal sum of components due to independent rounding
2.2 Nuclear Power Plants

Right now, nuclear energy provides about 20% of the US electricity, a little bit less of the world’s electricity. That works out to about 7% of total energy we consume. There is a lot of opportunity for total energy fraction to go up, because nuclear energy can be used to produce transportation fuels. We can use it to produce hydrogen. We can use the heat to help with biofuel processing.

Nuclear generated electricity is not just produced in the USA. Most developed countries worldwide have nuclear power plants generating electricity for their citizens. Furthermore, nuclear power generation continues to grow annually. With concerns over the environmental effects of global warming and pollution from gases emitted from coal-fired plants, the demand for nuclear power is projected to continue to increase a great deal in the next decades.

Currently, 30 countries worldwide are operating 437 nuclear reactors for electricity generation and 67 new nuclear plants are under construction in 14 countries. Included in this number are 100 plants operating in 31 states.

While the USA can boast about having the most nuclear power plants, electrical power from these plants provides less than 20% of all power supplied in the USA. Other countries are much more dependent on nuclear than the USA. The next figure ranks the per capita supply of nuclear power for the top 10 nuclear power generating countries. Currently, nuclear energy represents about 77% of total electricity production in France, 54% in Slovakia, 54% in Belgium, 47% in Ukraine, 43% in Hungary, 42% in Slovenia, 40% in Switzerland, 40% in Sweden, 35% Korea Republic, and 33% in Armenia.

2.3 Cost of Electricity from New Nuclear Power Plants Stations

Current discussions about possibilities to mitigate the effects of global warming have also opened discussions about a potential revival of nuclear power. In this context, it is often argued with very low cost of electricity from nuclear power plants. This seems to be one of the strongest arguments in favor of atomic energy. To determine the future cost of electricity from nuclear power, the cost from currently operating power stations is taken into account. However this is not correct.

In the abovementioned discussions about building new nuclear power stations, the cost for electricity from new and not from already existing nuclear power stations should be taken into account. This makes a huge difference as we will see further below. As a matter of fact, it is nearly impossible to estimate the cost of building new nuclear power stations. This is mainly a consequence of missing national and international safety standards. It is not clear which safety measures will have to be
applied and as a consequence the investment costs can barely be estimated. Figure 2.1 shows the structure of a typical nuclear power plant from outside.

Outside of USA, Finland is the only country in Europe, where a nuclear power plant is currently being built. In this situation, the best possible practice is to use the costs for the plant in Finland for cost comparisons with other technologies.

2.3.1 Pros and Cons of New Nuclear Power Plants

As a result of the current discussion how further global warming could be prevented or at least mitigated, the revival of nuclear power seems to be in everybody’s—or at least in many politicians’—mind. It is interesting to see that in many suggestions to mitigate global warming, the focus is put on the advantages of nuclear power generation, and its disadvantages are rarely mentioned. With new generation of nuclear power plants known as GEN-IV, any disadvantages are playing very low key anyway. Bear in your mind that there is no perfect energy source. Each and every one has its own advantages and compromises.
Environmentally, nuclear power is once again considered a prominent alternative, despite the disregard it was met with in the 1970s. This is because it is now being touted as a more environmentally beneficial solution since it emits far fewer greenhouse gases during electricity generation than coal or other traditional power plants.

The environmental impact of any power generation station can be measured by quantifying the burden of fuel delivery, emissions of by-products and wastes, and the potential impact on the lives (human or otherwise) of those living nearby.

It is widely accepted as a somewhat dangerous, potentially problematic, but manageable source of generating electricity. Radiation is not easily dealt with, especially in nuclear waste and maintenance materials, and expensive solutions are needed to contain, control, and shield both people and the environment from its harm.

In contrast to fossil fuel plants (coal, oil, and gas), nuclear power plants do not produce any carbon dioxide or sulfur emissions, which are major contributors to the greenhouse effect and acid rain, respectively. According to the Nuclear Energy Institute, US nuclear power plants prevent 5.1 million tons of sulfur dioxide, 2.4 million tons of nitrogen oxide, and 164 million metric tons of carbon from entering the earth’s atmosphere each year.²

Nuclear power reactors do contribute a measurable increase in radiation to the environment around a nuclear power plant. However, this increase is relatively small compared to natural background radiation and is less than the radioactivity released from a typical coal plant. Even with this increase in radiation, most employees of nuclear power plants receive exposures typically of workers in all occupations. In addition, no evidence exists that shows that small increases in radiation exposure have negative health effects.

Because nuclear power plants are relatively self-sufficient, plant siting is more amenable to environmental concerns. Oil and gas plants must be sited close to major pipelines and hydroelectric plants must be sited on rivers. Impact to wildlife habitat and municipalities may have to be compromised in order to site these types of plants. For example, public outrage over fish kills from hydroelectric power plants have limited new plant construction and policy makers are seriously considering the removal of existing dams around the USA. Meanwhile, strict siting regulation ensures that nuclear power plants have minimal impact to their surrounding areas.

The most pressing environmental concern facing the nuclear industry is the issue of waste disposal. All processes produce waste. Nuclear waste from a power plant is unique in that it can be highly radioactive. While highly radioactive waste is hazardous to all living beings, nuclear fuel is amenable to containment, treatment, reduction, and reprocessing (recycling). Processes have been developed to separate reusable fuel and the highly radioactive elements from used nuclear fuel. The waste products can then be made into a glass or ceramic waste pellet for disposal.

² http://www.nuclearconnect.org/know-nuclear/applications/electricity.
The hazard associated with this pellet has an expected duration of about 100 years. Considering that chemical hazards maintain their nature indefinitely, this waste form may be preferable. Currently, such a waste treatment process is not being utilized in the USA because of political resistance; however, research continues to find new solutions to this problem.

The dialogue about using nuclear power—and expanding it—centers on weighing these risks against the rewards, as well as the risks inherent in other forms of power generation. These are just some of the issues involved.\(^3\)

1. **PROS**

   - Lower carbon dioxide and other greenhouse released into the atmosphere in power generation.
   - Low operating costs (relatively).
   - Nuclear power generation does emit relatively low amounts of carbon dioxide (CO\(_2\)). The emissions of greenhouse gases and therefore the contribution of nuclear power plants to global warming is therefore relatively little.
   - Known, developed technology “ready” for market, in particular, new generation of power plant (GEN-IV) and related research led by industries and universities on combined cycle such as Brayton that is a promising effort to drive the output efficiency of such reactors upward \([1–8]\).
   - This technology is readily available; it does not have to be developed first.
   - It is possible to generate a high amount of electrical energy in one single plant.
   - Large power-generating capacity able to meet industrial and city needs (as opposed to low-power technologies like solar that might meet only local, residential, or office needs but cannot generate power for heavy manufacturing).
   - Existing and future nuclear waste can be reduced through waste recycling and reprocessing, similar to Japan and the EU (at added cost).

2. **CONS**

   - High construction costs due to complex radiation containment systems and procedures.
   - High subsidies needed for construction and operation, as well as loan guarantees.
   - Subsidies and investment could be spent on other solutions (such as renewable energy systems).
   - High-known risks in an accident.
   - Unknown risks.
   - Long construction time.
   - Target for terrorism (as are all centralized power generation sources).

\(^3\)http://www.triplepundit.com/special/nuclear-energy-pros-and-cons/.
• Waivers are required to limit liability of companies in the event of an accident. (This means that either no one will be responsible for physical, environmental, or health damages in the case of an accident or leakage over time from waste storage, or that the government will ultimately have to cover the cost of any damages.) Nuclear power plants as well as nuclear waste could be preferred targets for terrorist attacks. No atomic energy plant in the world could withstand an attack similar to 9/11 in New York. Such a terrorist act would have catastrophic effects for the whole world.

• Nuclear is a centralized power source requiring large infrastructure, investment, and coordination where decentralized sources (including solar and wind) can be more efficient, less costly, and more resilient. The time frame needed for formalities, planning and building of a new nuclear power generation plant is in the range of 20–30 years in the western democracies. In other words: It is an illusion to build new nuclear power plants in a short time.

• Uranium sources are just as finite as other fuel sources, such as coal, natural gas, etc., and are expensive to mine, refine, and transport, and produce considerable environmental waste (including greenhouse gases) during all of these processes.

• The majority of known uranium around the world lies under land controlled by tribes or indigenous peoples who do not support it being mined from the earth. The energy source for nuclear energy is Uranium. Uranium is a scarce resource; its supply is estimated to last only for the next 30–60 years depending on the actual demand.

• Shipping nuclear waste internationally poses an increased potential threat to interception to terrorism (though this has not happened yet with any of the waste shipped by other countries). Increasing the amount of waste shipped, particularly in less secure countries, is seen as a significant increase in risk to nuclear terrorism. The problem of radioactive waste is still an unsolved one. The waste from nuclear energy is extremely dangerous and it has to be carefully looked after for several thousand years (10,000 years according to US Environmental Protection Agency standards).

There is no doubt that the devastating earthquake, tsunami, and consequent multi-reactor damage in Japan will have a significant impact on the future use of nuclear energy, the nuclear industry, and the global nuclear order. The full impact will not be known for some time. Data about the incident unfolding at the Fukushima Daiichi nuclear power reactors were still being compiled and nobody for sure has any idea about the extended damage of this event.

To make wise choices about the future of nuclear power, we need improved knowledge of the safety, safeguards, and security features of both existing and new nuclear energy plants. Understanding the potential advantages and disadvantages of nuclear energy is critical for those stakeholders and decision-makers facing national energy challenges.
2.4 Is Nuclear Power a Global Warming Solution?

It is only possible to mitigate global warming if the worldwide consumption of fossil fuels can be drastically reduced in the next 10–15 years. There is simply no room for a scenario as it is predicted by the International Energy Agency (IEA).

It is also obvious that no combination of alternative technologies can replace the current usage of fossil fuels. There is simply not enough non-fossil fuel available for this. In order to mitigate global warming, we have to use the available energy much more efficiently. But this will not be enough either: We will have to change our behavior to reduce our personal energy consumption. We must change our current lifestyle and seriously strive for a sustainable living.

To answer the question of 

*Is Nuclear Power a Global warming Solution?*

The IEA says that:\footnote{http://timeforchange.org/nuclear_power_articles?filter0%5B%5D=60.}

*The contribution of nuclear energy to reduce the cause of global warming is only 10%.*

The IEA predicts a strong increase of the carbon dioxide emissions by the year 2030. Additionally, IEA investigated to which extent the abovementioned emissions of CO₂ could be prevented if politics applied rigorous measures.

From all measures investigated, nuclear energy was found to have the least effect (only 10%). Almost 80% of the desired effects are due to increasing the energy efficiency. This result is surprising, in particular if you think about how nuclear power is praised as solution to global warming by politicians like George W. Bush and Tony Blair. It seems like they would (again) head into the wrong direction. See Fig. 2.2.

Instead of talking about measures to increase the energy efficiency, which accounts for 80% of the effects, some politicians propagate building nuclear power plants, which according to IEA can only account for 10% of the desired effects. Here the focus is clearly on the wrong subject!\footnote{http://timeforchange.org/nuclear_power_articles?filter0%5B%5D=60.}

So, then the question comes to that: Do we have a serious problem in hand? Thus as it was said earlier

*Do we have to change our behavior to reduce our personal energy consumption? We must change our current lifestyle and seriously strive for a sustainable living.*

As part of an answer to the above question and statement, the following sections are presented for further argument on the matter of electricity generation cost and consumption worldwide.
2.5 Prediction of Energy Consumption Worldwide

The other question is this:

*How much energy will we consume in the future?*

According to the American Energy Information Administration (EIA) and to the International Energy Agency (IEA), the worldwide energy consumption will on average continue to increase by 2 % per year. The graph below shows the actual values starting from 1980 until today in blue and the predictions of the energy consumption until the year 2030 in orange. See Fig. 2.3a and b.

More detailed data (in quadrillion BTU) of the actual and predicted energy consumption worldwide by geographic area is given by Table 2.2 in the following page.

The highest annual growth of energy consumption is predicted for Asia (3.7 %), non-OECD countries (3 %), and Central and South America (2.8 %). The lowest annual growth of energy consumption is predicted for Europe with 1 %.6

A yearly increase by 2 % leads to a doubling of the energy consumption every 35 years. This means the worldwide energy consumption is predicted to be twice as high in the year 2040 compared to today (2007).

The future of civilization will depend upon the indefinite supply of electricity. Clearly, there is a limit to the supply of fossil fuels. The most optimistic estimates have fossil fuel lasting no more than 100 years; however, they may become economically undesirable in much less time. Obviously wind, solar, and other renewable energy sources (such as ethanol) can sustain our world with power indefinitely. However, the power generation potential from even a small amount of uranium is so great, even nuclear fuel can be included on this list. In the right

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configuration, nuclear power can provide electricity for generations. The right configuration is in the “Breeder Reactor.” The design of the breeder reactor is such that even as fuel is consumed, new fuel is created as a by-product. Only a few breeder reactor plants have been built. Since plutonium—a material used in nuclear weapons—is created in these plants, governments have been hesitant to allow their construction. Nonetheless, applying the breeder concept can reduce fuel prices so low that even the extraction of uranium from the world’s oceans would not be an overly expensive endeavor. In an article printed in the American Journal of Physics (vol. 51, Jan. 1983, B. Cohen), there is enough uranium in all the world’s oceans and the earth’s crust under the oceans to last 5 billion years (assuming that 6500 metric tons of uranium is removed annually). For all practical purposes, nuclear is a reliable and sustainable power source.

Nuclear power plants are one of the most economical forms of energy production. Nuclear fuel costs (as a function of power generation potential) represent only a fraction of the cost of fossil fuels. Including capital and non-fuel operating costs,
the cost of operating a nuclear power plant is roughly equivalent to fossil fuels. Recently, the average electricity production cost for nuclear energy was recognized as the cheapest source of electricity. As 2012, the average cost of power generation by nuclear plants was 2.40 cents/kW-h, for coal-fired plants 3.27 cents, for oil 22.48 cents, and for gas 3.40 cents. Costs for solar and wind are still well beyond that considered to be competitive to the public.

The cost of regulation and industry oversight of nuclear power generation is substantially more than that of other power generation sources; however, improvements in reliability and operational and maintenance efficiencies have contributed to reducing those costs. Currently, nuclear power plant capacity factors average over 85%. This is competitive with those of fossil fired plants (average 50–60%), or solar and wind which have capacity factors in the 30% range, or even lower. Most plants are designed to operate in a base load configuration; that is, they run at full power regardless of the demand on electricity. Nuclear power plants are particularly well suited for this purpose since they are designed to produce large quantities of power and can sustain operation for up to 2 years without refueling.

The US nuclear energy plants can supply large amounts of predictable, reliable electricity through virtually every period of extreme heat and cold. During the 2014 Polar Vortex, nuclear energy generation saw no drop in output and on the coldest day operated at 95% capacity. See Fig. 2.4.

From the fuel equivalency point of view, like fossil fuels, the nuclear fuel raw materials come from the Earth. Uranium, the primary fuel material, is mined. The environmental impact of mining is well known; however, the advantage of nuclear power comes from the amount of power that comes from a small amount of uranium. The power from 1 kg of uranium is approximately equivalent to 42 gal of oil, 1 ton of coal, or 17,000 cubic feet of natural gas. Therefore, as a function of

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**Table 2.2** Actual and predicted energy consumption worldwide by geographic area (http://timeforchange.org/prediction-of-energy-consumption)

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<tr>
<td>OECD</td>
<td>234.3</td>
<td>256.1</td>
<td>269.9</td>
<td>281.6</td>
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<td>Non-OECD</td>
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<td>Central and South America</td>
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<td>563.4</td>
<td>613.0</td>
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power consumption, very little uranium needs to be removed from the ground; hence, the environmental impact of uranium mines is much less compared with mining and drilling for fossil fuels.

Unlike oil or gas, nuclear fuel is solid; hence, nuclear fuel is immune to the environment problems posed by spillage during transportation to a power plant. Unused nuclear fuel is only slightly more radioactive than naturally occurring underground. Fuel delivery casks are designed with a high margin of safety to ensure that even in the event of a transportation accident, the environment remains free of contamination from the nuclear fuel.

2.6 Current Energy Consumption by Capita

The values are indicated as “kg oil equivalents” or kgoe. An example from the graph: People living in North America use per year and per person the energy equivalent to approx. 8000 kg oil, which is about 10,000 l of oil. To convert “kg oil equivalent” into kWh, multiply it with the factor 11.628. Example: 8000 kg oil is about 93,024 kWh (11.628 × 8000) or 93 MWh.
There are huge differences between individual regions of the world. Data has been extracted from Earthtrends.wri.org, an excellent, very flexible source of data. This site is recommended if you want to go into more details. See Fig. 2.5a and b.

Here is an update of the energy consumption per capita and for the predicted energy consumption for the top energy-consuming countries (see Fig. 2.6).
2.7 The Next Nuclear Age: Can Safe Nuclear Power Work for America or the World?

Before for us to be on our way and focus on the subject of this book, “Compact Heat Exchanger Design For Combined Cycle Driven Efficiency In New Generation of Nuclear Power Plants,” we need to understand the basic rules and different generation of nuclear power from past to present and go the future aspect this source of generating electricity. This allows us to understand what would be the Total Cost of Ownership (TCO) and Return On Investment (ROI) for the owners of these power plants (i.e., utility companies) and how technology will help them to reduce TCO and increase ROI over the course of life cycle for each type and design of these plants, how safe they are, and which generation works for us better. For that we need to briefly describe each of these generations of nuclear power plants, then we can argue “Can Safe Nuclear Power Work for America or the World?”

Later on we can describe more details about each generation in particular GEN-IV which most of the research by this author and rest of the world are based on. Chapter 5 is devoted to such details and before that we have laid down the basic thermodynamic cycle in Chap. 3, in order to have better understanding of combined cycle and how the compact heat exchanger will play a role in order to drive the efficiency of such a system to a higher level in order to reduce the TCO and increase ROI.

Historically, the Department of Energy’s (DOE) Advanced Test Reactor (ATR) located at Idaho National Laboratory (INL) through fission chain reaction started to produce 250 MW output energy—enough to power almost 200,000 homes. This reactor which is the epicenter of American nuclear energy research was a step toward commercialization nuclear power plants here in USA and around the world.
Over the past half century, 51 reactors have been built here, including first-generation prototypes of the 1950s; only three still operate. But it is among the relics of these early experiments that the country’s energy future is taking shape.7

In recent years, the debate over nuclear power has moved to the front and center of quest for an alternative source of energy, spurred by concerns about foreign oil and the specter of global warming and rise of demand on production of more electricity for our day-to-day life, which is getting more and more dependency on it. But what many on both sides of the issue often fail to note is that America’s 103 existing nuclear reactors are aging and coming to the end of their life cycle. Over the next few decades, they will have to be decommissioned—taking 20 % of the country’s electrical supply with them.

In the Energy Policy Act of 2005, Congress approved up to $2.95 billion in incentives for new nuclear plants, and set aside another $1.25 billion for an experimental reactor to be built in the Idaho desert. The reactor will be the centerpiece of a modern-day of global life on earth with its population growing and its industry expanding, with scientists from around the world working together to revolutionize the production of nuclear power at reasonable cost and safer shape and form.

In principle, for nuclear reactors to produce energy in form of electricity, a chain reaction usually uranium as fuel takes place that turns into heat and fast-moving neutron with the core of reactor. A coolant (i.e., heat exchanger) takes away the heat and uses it to generate superheated steam and in return to spin a turbine to generate electivity, while a moderator within the core slows down the fast-moving neutron to keep the chain reaction under control. Hence, any material used in building a reactor needs to withstand the heat generated by this chain reaction as well as intense buildup of pressure and a constant barrage of neutrons for the reactor’s projected life cycle. This is where reactors such ATR comes to play as a research reactor to pave the road for commercialization of nuclear power plant from concept of design to prototype and finally production stage.

The ATR uses 92 % enriched uranium (i.e., anything more than 20 % is considered weapons-grade) to generate a quadrillion neutrons per square centimeter per second—100 to 1000 times greater than commercial reactors. By cranking up the neutron dose, this reactor can simulate as much as 40 years of wear and tear on a new fuel or alloy in a single year.

This reactor is a simple water-cooled model built in 1967. But by tuning the pressure, temperature, and chemistry inside its core, scientists can use it to reproduce the conditions in just about any other type of reactor. Recently, folks in charge of ATR operation have tested chunks of graphite to see whether it is safe to extend the life of Britain’s antiquated Magnox reactors. INL staffs are now gearing up for an even bigger challenge and that is testing parts for proposed Generation IV reactors, which would leap technologically two steps ahead of the Gen II designs operating commercially in the USA as of today.

Arguments by pro-nuclear power plants stand behind the cost-effectiveness of GEN-II plants, despite concerns about catastrophic accidents and radioactive waste disposal.

Rise of demand for production of more electricity at reduced total cost of ownership yet increase the return on investment has pushed a dozen utility companies around the country and the world once again to start the lengthy process of applying to Nuclear Regulatory Commission (NRC) for licensing to built new nuclear power plants and renew the operational license for their existing one. If all goes smoothly, they could produce power by the middle of the next decade. These reactors would be Generation III and III+ designs—evolutionary improvements on today’s Generation II reactors, which use water in some form as both a coolant and a moderator (i.e., LWR, BWR, or PWR).

But, according to the DOE, what are really needed are even safer, cheaper reactors that produce less waste and use fuel that is not easily adapted for weapons production. To develop this kind of reactor, 10 countries, including the USA, joined forces in 2000 to launch the Generation IV International Forum. A committee of 100-plus scientists from participating countries evaluated more than 100 designs; after 2 years, they picked the six best. All of the final Gen IV concepts make a clean break from past designs. Some do not use a moderator, for instance. Others call for helium or molten lead to be used as coolants.

A top level view of Generation II and III reactors is depicted in Fig. 2.7 below and all 103 operational nuclear power plants today in USA are employing light water reactor (LWR) technology, which uses ordinary water as both a moderator and a coolant. The next wave of nuclear plants has taken these Generation II concepts to the next level, improving both safety and efficiency. Utilities plan to begin building Generation III reactors by the end of the decade.

In a Gen II Pressurized Water Reactor, water circulates through the core (1) where it is heated by the fuel’s chain reaction. The hot water is then piped to a steam generator, and the steam spins a turbine (2) that produces electricity. The Gen III Evolutionary Pressurized Reactor improves upon this design primarily by enhancing safety features. Two separate 51-in.-thick concrete walls (3), the inner one lined
with metal, are each strong enough to withstand the impact of a heavy commercial airplane. The reactor vessel sits on a 20-ft slab of concrete with a leak-tight “core catcher,” (4) where the molten core would collect and cool in the event of a meltdown. There are also four safeguard buildings (5) with independent pressurizers and steam generators, each capable of providing emergency cooling of the reactor core.

Fourth-generation nuclear power plants differ radically from current reactors by replacing water coolants and moderators, reaching higher temperatures, and gaining the potential to create hydrogen, as well as electricity. Figure 2.8 is an illustration of high-level Generation IV of nuclear power plant, where six types of reactors are designated as GEN-IV as of today [1, 2].

One of the six Gen IV designs under consideration is the meltdown-proof pebble-bed reactor, which uses grains of uranium encased in balls of graphite as
fuel. Helium gas is heated as it circulates through a vessel of these pebbles (1) and then powers a turbine (2) to generate electricity.

A heat exchanger (3) can transfer heat from the helium to adjacent facilities (4) for the production of hydrogen. The plant relies on “passive safety”: If the cooling system fails, the nuclear reaction grinds to a halt on its own.

More details on these six reactors and the concept behind their design are given in Section 3.8 and they can also be found in Refs. [1, 2] or any search on the web as well.

References

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