Chapter 9

THE GLOBAL STATUS OF NUCLEAR POWER

6/23/2019

"Thinking is the hardest work there is which is probably why so few people engage in it."
Henry Ford

9.1 INTRODUCTION

Within 40 years, according to the United Nations (UN), the global population is expected to rise by 32 percent to 9 billion people, mostly in the developing world. The world least developed nations would double by 2050 to 1.7 billion, generating new energy, water and food demands.

A nuclear energy renaissance is under way globally as demand for electricity and energy in general surges and attitudes toward nuclear energy shift. As an indication of a shift in public opinion, some prominent environmentalists support nuclear electricity generation, recognizing that nuclear power plants produce hardly any greenhouse gas emissions.

The International Energy Agency (IEA) reports that since 2012, China has been the country with the largest installed nuclear power capacity, and it has increased this by 14% since then to reach 1,245 GWe in 2014, or 21% of global capacity, slightly ahead of the USA (20%).

The age structures of the power plants in these two countries differ remarkably: in China almost 70% (865 GWe) was built within the last decade, whereas in the USA half of the fleet (580 GWe) is over 30 years old.

China plans to give support to its nuclear programs and take advantage of "the opportunities provided by the Belt and Road Initiative (BRI). Going with nuclear power has already become a state strategy, and nuclear exports will help optimize our export trade and free up domestic high-end manufacturing capacity. The country needs to improve research and development of its nuclear sector, as well as localize the production of key nuclear power components. China could build as many as 30 overseas nuclear reactors over a decade as part of the BRI, which projects could bring in more than $145.5 billion to China by 2030. Fourty one BRI nations already have nuclear power programs or are planning to develop them. China only needs a 20% market share to create 5 million new jobs in the sector.

The country's "new Silk Road" BRI megaproject was announced by President Xi Jinping and covers 152 countries in Europe, Asia, the Middle East and Africa. The BRI is expected to increase global trade significantly, cut trading costs for many countries involved, and replace the USA with China as the primary political and economic counterparty for all the countries involved.

Nuclear power supplies about 16 percent of the world's electricity and accounts for about 34 percent of the European Union's (EU) electricity, and 19 percent of electricity in the USA, where the government is actively promoting new nuclear plants through tax breaks,. There are 439 working reactors worldwide, with another 34 under construction, 74 planned and 162 proposed.

Individuals living near coal-fired installations are exposed to a maximum raduation dose equivalent of 1.9 millirems of fly ash radiation yearly. The average person encounters 360 millirems of annual "background radiation" from natural and man-made sources, including substances in Earth's crust, cosmic rays, residue from nuclear tests and smoke detectors.

There are 104 nuclear power reactors operating in the USA, generating approximately 19 percent of USA electricity and meeting 9 percent of its energy needs. Most of these reactors have 40 year operating licenses, but several have recently received extensions for another 20 years. Even with extensions, the first plants will retire in 2029 and nearly all will retire by 2050. Currently 17 utility companies have plans to build 31 new reactors. The USA Congress passed legislation to provide loan guarantees to lenders of up to $18.5 billion to facilitate the development of next generation nuclear plants. This amount will not go far since the price tag associated with a single plant could reach $6-9 billion. Constellation Energy, considered building a third nuclear reactor at a cost of $4 billion in Maryland. The Yucca Mountain repository is on hold after having been designed to hold 77,000 tons of radioactive waste, all transported from multiple sites around the country. But the DOE suggests that the location should be structured to hold 150,000 tons, noting that nuclear plants will only become more productive. The nation's nuclear operators are currently storing the spent fuel on site in dry casks that are encased in concrete.

Fifteen of the EU's 27 members have nuclear power plants, with the percentage of electricity supplied ranging from 78 percent in France to 3.5 percent in the Netherlands. France has committed to renewing its reactor fleet, Finland is building a new plant, Germany and Sweden have committed to phasing out nuclear power and the Dutch have reversed a previous decision to phase it out. Italy used to have four nuclear power reactors, but it shut down the last two following the Chernobyl nuclear accident in 1986.

France has 50 nuclear power plants producing 79 percent of its electricity, and meeting half of its energy needs. France is a substantial exporter of nuclear electricity to other European countries. France's energy policy stems from its reaction to the oil crises of the 1970s, when the government decided to pursue nuclear power as a means of assuring its energy security.

China gets just 1.9 percent of its electricity from 11 nuclear reactors, with 5 more under construction, 23 are in the planning stages and there are proposals for another 54.

Russia built the world's first nuclear power plant in 1954. Industry expansion slowed down after the Chernobyl accident. Nuclear power plants produced 6 percent of the energy consumed in 2005.

Iran is in the process of building a nuclear power plant at Bushehr, with Russian help. Iran first planned the reactor with German assistance by the Siemens Company in 1974. The Germans withdrew from the project after the Islamic revolution in 1979, but it was restarted in 1992.

An estimated 12 percent of Germany's electricity consumption in 2006 came from nuclear power. However, Germany plans to shut down all its nuclear reactors by 2020. The government is investing in other energy sources, such as wind power, but there are concerns that the decision could propel the country into an energy crisis.

Nuclear power accounted for just 1 percent of India's national consumption in 2005, but projections suggest nuclear power plants could eventually meet more of the nation's energy needs. A government-backed deal with the USA to give India access to civilian nuclear fuel and foreign technology is has run into serious domestic opposition by those who say it compromises national sovereignty.

Japan intended to add 11 more by the year 2010before the Fukushima accident, and China hopes to add 24 to 30 nuclear power plants by 2020.

Around 18 percent of Britain's electricity is generated by nuclear power, but the last of Britain's existing nuclear plants is scheduled to be closed by 2035. It is considering adding a new fleet of nuclear power plants.

Saudi Arabia is pressing ahead with an ambitious plan to develop nuclear power to meet rising electricity demand and save oil for export. The Saudis have built a foreign assets cushion of around $500 billion from oil exports. Inefficient and wasteful energy consumption, coupled with a rising population, is leading the kingdom to burn even more of its natural resources at home rather than selling them abroad and adding to the proceeds of the half-trillion-dollar cash pile. Unless action is taken, the kingdom could find it needs the oil price to be $320 a barrel by 2030 just to balance the budget. In 2010, the King Abdallah Center for Atomic and Renewable Energy, known as KAcare, was established to oversee the gulf state's nuclear program. In 2010 it took 3.4 million barrels of oil equivalent a day (boe/d) to power electricity generation. This is expected to more than double by 2028 to 8.3 million boe/d. The aim of the Saudis' $100 billion nuclear program is to achieve an electricity output of 110 GigaWatts (GWs) by 2032. In 2009, the latest data available, Saudi electricity capacity was 52 GW from 79 power stations. At least 13-16 nuclear reactors, each costing around $7 billion, are planned, with the first producing by 2019. Some estimates state the kingdom, the world's largest oil exporter, will burn as much as 1.2 million barrels of oil daily on electricity production, almost double the 2010 total, to meet domestic and industrial demand. The Saudis are driving to build an industrial infrastructure to sustain the economy when the oil fields run down. Some have already begun to decline. For total reliance on nuclear power, 40-60 reactors would be needed by 2030. That is 4-6 reactors per year from 2020. In an energy mix including fossil fuels as the primary energy source, with wind, solar and nuclear power capabilities, solar power projects should produce 41 GWs within 20 years with geothermal and waste-to-energy systems providing 4 GW.

The United Arab Emirates (UAE) launched its nuclear energy program in 2009. It is the most advanced in the Arab world, with Saudi Arab running second. The United Arab Emirates' $30 billion program with $10 billion more than originally planned is smaller in scale than that in Saudi Arabia. Both states benefit from political stability and vast financial reserves. Other regional states are less fortunate. Bahrain, Qatar, Kuwait, Egypt and Jordan all have announced plans to invest in nuclear energy to crank up electricity generation but all have lagged behind or scrapped their programs because of lack of funds or foreign investment. Kuwait has the cash, but it has been through eight governments in the past six years.

Emirates Nuclear Energy Corp., the state-owned company received a $2 billion loan from the U.S. Export-Import Bank. The loan to the Barakah One Co., a unit of Emirates Nuclear, will pay for American products and services used in the construction of four 1,400 megawatt reactors. Westinghouse Electric Corp., based in Pittsburgh, Pennsylvania, a Toshiba, Japan unit, will supply some of the equipment for the facilities. The first of the plant’s four reactors will be ready in 2017, with each additional unit becoming operational every year through 2020.

Egypt drew up plans to build four nuclear reactors by 2025 with a capacity of 4,000 MWe. The first plant would have a capacity of about 1,200 MWe and will be located at El Dabaa, on Egypt's north-west coast. Egypt, which has an installed capacity of about 23,500 MWe, needs a further 3,000 MWe to meet the country's growing demand. Egypt remains convulsed by the political turmoil that ensued following the February 2011 overthrow of President Hosni Mubarak, its economy sagging dangerously.

In Jordan, heavily reliant on foreign aid, parliament recently scrapped nuclear plans as "hazardous and costly."

Failure to start boosting electricity generation for burgeoning populations in the coming decades almost certainly will mean more political upheavals. Nuclear energy applications in the peaceful domain are widely spread including the use of radio nuclides in nuclear medicine and propulsion. The most prominent use nowadays is its use in electricity production. According to data from the Energy Information Administration in the USA, the average retail price of electricity in December 2005 rose by 10.2 percent as compared with December of 2004 to a level of 8.13 cents/kwh. With fresh water shortage materializing on the horizon, in the future, nuclear energy will probably contribute to the distillation of fresh water from the world's oceans. In the longer term it will be needed for space exploration and colonization.

Energy demand in the form of electricity is expected to increase substantially into the 21st century, particularly among developing countries. With their fast population growth, about 1.6 billion people in them have virtually no access to modern energy services. The world population is reached the 7 billion mark by 2011, placing demand on food, fresh water and energy supplies.

Nuclear power, in conjunction with solar, wind and ocean thermal energy are hoped to become an important part of future strategies of energy production that alleviate the global concern about the increase in greenhouse concentrations in the atmosphere, and that will shift toward hydrogen fuel and away from carbon fuels.

Among the developed industrialized nations, nuclear energy is presently an important contributor to electrical energy production. It supplies about 1/6 of global electrical energy production, and a substantial 30 percent of the electrical needs in Western Europe.

Numerous Mobile Nuclear Systems in submarines and surface vessels have provided an excellent operating experience of reactors in the 40 to 200 Megawatt thermal (MWth) range.

A number of 439 land-based reactors with power in the range of 100 to 1,000 MWe or about 300 to 3,000 MWth, assuming an overall thermal efficiency of 1/3, are producing electricity world-wide.

Here, the relationship between the electrical power P_e in MWe and the thermal power P_{th} in MWth in terms of the overall thermal efficiency is:

$$\eta_{th} = \frac{P_e[\mathrm{MWe}]}{P_{th}[\mathrm{MWth}]} \tag{1}$$

where: η_{th} is the overall thermal efficiency.

Impediments to a wider use of nuclear electricity have been the large upfront capital costs for building the large size electrical units offered by the manufacturers, and their long construction times and payback periods, affecting the return on investment.

An increase in the price of uranium to $138/lb of U_3O_8 then back to $40/lb could affect the future expansion prospects. A long term price around $40-70/lb is needed. The nuclear fuel cost is about 5 percent of the electrical cost compared with 70-80 percent in fossil fuel electrical production.

Concerns about safety, nuclear proliferation, and the disposal of radioactive waste products have also affected public and political support. Addressing these issues, the nuclear power industry is proposing a new reengineered generation of plants offering inherently safe features, of standardized smaller unit sizes and competitive cost of electricity, in addition to the virtual absence of greenhouse gas emissions.

9.2 WORLD'S WEALTH

A person's wealth is measured in terms of the net worth which is defined as:

$$\text{Net worth} = \text{Physical assets} + \text{Financial assets} - \text{Debt liabilities} \quad (2)$$

A person's wealth can thus be thought to represent the ownership of capital. Capital is only one part of personal resources, but being a measurable quantity, it is widely accepted that it has a disproportionate impact on a household's well being and economic success, and more broadly on a populace economic development and growth.

A United Nations study suggests that the richest 2 percent of the world's population owns ½ of the world household's wealth and that $2,200 per adult placed a household in the top 1/2 of the world's wealthiest. To place among the richest 10 percent of adults in the world just $61,000 in assets is needed. More than $500,000 places a person among the richest 1 percent, which included 37 million people as of 2006.

The world's total wealth is valuated at $125 trillion. North America has only 6 percent of the world's adult population, but it accounts for 34 percent of household wealth. The fastest-growing population of wealthy people is in China. The average wealth is the USA is $144,000 per person, in Japan, with a larger saving rate it is a higher $181,000. Wealth is mostly concentrated in North America, Europe and high income Asian Pacific countries, the so-called Asian Tigers. People in these countries form an aristocracy collectively holding almost 90 percent of the total world's wealth.

Half the world or three billion people live on less than 2 dollars per day. The three richest people in the world have more money than the poorest 48 nations combined. Some relatively developed nations, because of their large populations, still have low thresholds of per person capital assets: in India it is $1,100, and in Indonesia it is $1,400.

Property, particularly land and farm assets, are more important in less developed countries because of the greater importance of agriculture.

9.3 WORLD DEMOGRAPHICS

The richest 1 percent of the world's population owns 40 percent of its wealth. This 1 percent lives in America, Japan, and Europe. More than 1/3 of them live in the USA; that is about 20 million people who are among the richest 1 percent in the world. Another 27 percent live in Japan. The UK and France, between them, have another 11 percent. The wealth ended up in those countries, rather than in the countries with the largest populations because Europe and America benefited from a lead ahead of the rest of the world through the industrial revolution as well as colonialism. Japan figured out what was going on in the west after Admiral Perry bullied his way into Yokohama harbor in the 19th century. Japan realized that it would be at the mercy of the west unless it too figured out how to use modern machinery and had one of the most modern armies on the planet until the complete destruction of its military, many of its cities, and its industrial capacity by 1945. By 1990, Japan recovered and had the most modern, most advanced, and most successful economy on Earth. China and India are following Japan's precedent and are industrializing at a fast rate

The United Nations' Population Division projects the world's population to rise from the year 2001 number of 6.1 billion, to about 9.3 billion in the year 2050. This world population has in fact doubled since 1950. Ninety percent of the world population would be living in developing countries. One out of each six persons will be in India alone.

The population growth is expected to occur primarily in Asia, Africa and Latin America. The population of the world's 48 poorest nations, mostly in sub Saharan Africa is expected to triple within 50 years, in spite of the expected hundreds of millions of deaths from malaria and the HIV/AIDS pandemic, cutting Africa's population growth by 15 percent by 2050. Europe and Japan are expected to see a declining work force and an elderly population due to their dropping birth rates. This predicts a very complex world with a "new world order," where some countries are growing, while others are staying the same, and others shrinking. This will call for adjustments in social services, immigration policies, and energy production.

This "new world order" could call upon a world dependent on migration to fill the gap between nations that cannot feed their people, and industrialized nations needing a cheap labor force. One uncertainty in this scenario pertains to the possibility of a declining fertility rate that would be associated with the declining birth and mortality rates.

The USA will see a projected 1 million immigrants per year. From 281 million as a population in 2001, its population is expected to grow to 400 million by 2050.

Without migration, and a continuation of nationalistic and ethnic barriers, Europe started seeing a decline starting 2003. For instance, the Ukraine's population is projected to decline by 40 percent by 2050, Russia's by 28 percent, and Italy's by 25 percent. In the year 2000, the 15 European Union nations recorded a Natural Population Growth (NPG), defined as:

$$\text{NPG} = \text{Births} - \text{Deaths} \tag{3}$$

of only 343,000 people. India matched that number in just 1 week.

Europe used to claim 22 percent of the world's population 50 years ago, and Africa, 8 percent. In the next 50 years, the situation could be reversed, with Africa's population 3 times as that of Europe, from 800 million in 2000, to 2 billion in 2050. If a vaccine for malaria and a cure for HIV/AIDS were identified, this number would be 300 million higher.

An aging population will characterize Europe, North America, Japan, Australia and New Zealand, as industrialized nations. Twenty percent of the European population was 60 years or older in 1998. This number is projected to about double to about 37 percent by 2050.

The Decennial Census of 2000 estimated the USA population at 281.4 million. As of 2006, its population is estimated to have reached 300 million. It is expected to nearly double to 571 million by the year 2100, with a median age rising above 40. The USA population reached 300 million in 2011, and is expected to increase to 400 million in 2049 and 500 million in 2081. This USA population grew from 5.3 million in 1800, and 75.9 million in 1900. In 1900, the combined population of the largest four European countries: France, Germany, Italy and England, was about twice the USA population. However, the USA population grew 4 fold, and now exceeds those four countries together. By the year 2050, the USA is expected to be twice as populous as these countries.

With emphasis on military spending and global foreign involvement to secure access to the depleting fossil energy supplies, the USA has been unable to adequately fund its education and health systems and has been slipping behind other countries in life expectancy, a measure of national economic wealth.

The main cause lies in 45 million of its citizens or 45 / 300 = 0.15 or fully 15 percent of its population lacking health insurance and inexorably falling into poverty, with no possibility of an increased ranking in sight, under a persistent debate emphasizing private insurance access rather than public health care.

Other factors also include health problems and bad lifestyles with 1/3 of the USA adult population 20 years and older classified as obese, with the 2/3 remaining primarily overweight.

Racial economical and social disparities contribute to the slippage: African Americans are relatively poorer, lack health care and consequently have a shorter life expectancy of 73.3 years; 5 years shorter than other American citizens. African American males are the most disadvantaged at 69.8 years, slightly larger than developing countries such as Iran, Syria and shorter than Nicaragua and Morocco. The USA is characterized with a large mortality rate of 6.8 deaths for every 1,000 live deaths among babies before their first birthday, again correlated with lack of health care. It is also twice that amount at 13.7 percent among African Americans; the same as Saudi Arabia. In 2004, 40 countries including Cuba, Taiwan and most of Europe had lower infant mortality rates than the USA.

Other countries have emphasized publicly, rather than individually financed, education, health care, nutrition and encouragement of healthier lifestyles. Other capitalist nations such as Canada and many European countries have universal health care for their citizens, with emphasis on economically effective approaches to prevention and early screening of cancer, heart disease, lung disease, reducing tobacco use, control of blood pressure, cholesterol reduction and diabetes blood sugar regulation.

Japan and most of Europe as well as Jordan, Guam and the Cayman Islands surpass the USA in life expectancies. To be specific, according to the USA Census Bureau and the National Center for Health Statistics, surveying 222 countries in 2004, a baby born in the USA in 2004 has a life expectancy of 77.9 years. This ranks as 42nd, down from 11th, 20 years earlier. For comparison, Andorra in the Pyrénées Mountains between France and Spain has a life expectancy of 83.5 years, followed by Japan, Macau, San Marino and Singapore.

Regrettably, the shortest life expectancies are clustered in Sub-Saharan Africa that is plagued by the health problems of Malaria and HIV/AIDS, droughts possibly caused by global warming leading to famine and civil strife and competition for the remaining resources. Swaziland has the shortest life expectancy at 34.1 years, followed by Zambia, Angola, Liberia and Zimbabwe.

9.4 GLOBAL ENERGY RESOURCES

The World and the USA, India and China populations' growth will add a pressure on the global energy needs and consumption. With ample energy supplies providing a higher standard of living, from 1900 to 1999, the USA life expectancy at birth almost doubled from 47.3 to 77 years. Per capita yearly gross income has increased from 2,500 dollars to 19,000 dollars correspondingly. The USA increased its population by 250 percent in the 20th century. Instead of a Malthusian population explosion degrading the quality of life, the rate of infectious disease fell 14 fold, heart disease by more than one half, accidental deaths by 61 percent and infant mortality by 93 percent. Wealth in the 20th century increased by 700 percent, wages went up 4 times, and poverty declined by a 3-fold, even though the work week decreased by 30 percent. Car ownership increased 90-fold, air pollution declined by 97 percent and commodities prices like wheat, for instance, declined by 95 percent.

Taking a glimpse back in time to the year 1900 in urban Europe and the USA, households did not have the benefit of electricity and were illuminated by syngas lights that were expensive to run, and were prone to catastrophic explosions since they were composed of a mixture of hydrogen, H_2 and carbon monoxide, CO. There were no laundry machines, vacuum cleaners to clean households from dirt and germs. Without the benefit of penicillin, small cuts could be fatal. Most physicians lacked any scientific training, and carried in their bags bottles containing no more than alcohol as a disinfectant, and some opiates as pain relievers. The absence of refrigeration, poor sanitary conditions, and adulteration of food lead to millions dying from spoiled or tainted food. Epidemics of scarlet fever, yellow fever, and smallpox, were a constant threat to families' well being and life. The air and water were polluted with coal dust, animal manure, and rotting garbage thrown from windows into the streets. Indoors plumbing did not exist, and raw sewage filled the streets. Only a few could afford a car, a telephone, or even a radio. Rooms in houses were dark, humid, and chilly.

The statistical variable that measures the rate of technological progress over time is the "Total-factor productivity." It tracks how efficiently the economy uses labor, capital, raw materials and new technology. It grew between 1913 and 1972 by an annual average of 1.08 percent. Between 1972 and 1995, it became 1/50 of the previous value. In recent years, it is back increasing, caused by greater efficiency at making computers and other manufactured goods.

Inventions that fundamentally altered the human condition are associated with increased use of energy in general, and electricity in particular. Consider the light bulb, which created more useful hours in a day for every human being, virtually extending the life span. The electric motor raised the productivity in every human endeavor, from speeding manufacturing assembly lines, to creating labor intensive devices in the home. The internal combustion engine allowed for mass transportation. Petroleum refining, synthetic chemicals as plastics, fertilizers and pharmaceutics made most raw materials more valuable. Without the genetically modified seeds efficiently using fertilizers in the green revolution of the 1970s, the World population would be now starving. The first telegraph reduced the time to send a message across the Atlantic from a week by ship to a few minutes. Computers and communication devices are evolving society into a new Information Technology Age.

The present age of technology is characterized primarily by a genius for reinventing and reengineering the inventions of the last technological period where they were first invented. Existing machines and gadgets, including cars, and nuclear reactors, can be remanufactured with greater efficiency. This leads to their prices declining even as their safety and quality improves. The average worker in 1997 would work 1,365 hours to buy a new car, for instance a Ford Taurus. His counterpart in 1955 needed to work 1,638 hours to afford the much inferior Ford Fairlane. Electrical equipment like stoves, dishwashers, refrigerators, washers and dryers, air conditioners, have all fallen in price since the 1950s, while providing better service in their intended use.

9.5 ENERGY UNITS

Energy consumption rates are conventionally estimated in the British System of units in terms of the Quad (for Quadrillion) or Q (perhaps for Quintillion) units, where:

$$1 \text{ Quad} = 10^{15} \text{ BTU}, \tag{4}$$

or:

$$1 \text{ Q} = 10^{18} \text{ BTU}. \tag{5}$$

Thus:

$$1 \text{ Quad} = 10^{-3} \text{ Q}. \tag{6}$$

In the Système International (SI) system of units, the Trillion GJ unit is commonly used instead, where:

$$\begin{aligned} 1 \text{ Trillion GJ} &= 10^{12} \text{ GJ} \\ &= 10^{21} \text{ J} \\ &= 0.948 \text{ x } 10^{18} \text{ BTU} \\ &= 0.948 \text{ Q} \end{aligned} \tag{7}$$

or:

$$1 \text{ Q} = 1.05 \text{ Trillion GJ}. \tag{8}$$

The Gigajoule , Terajoule, Exajoule, and Zetajoule units are also commonly used, where:

1 Gigajoule = 10^9 Joules
1 Terajoule = 10^{12} Joules
1 Exajoule = 10^{18} Joules
1 Zetajoule = 10^{21} Joules

9.6 ENERGY CONSUMPTION

With only 7 percent of the world's population in 1998, North America consumes 30 percent of the world's energy as shown in Table 1. Primary as well as electrical energy consumption correlates with higher standards of living and the degree of industrialization as shown in Table 2. The per capita rate of energy use in a typical industrialized country in Western Europe is from Table 2:

$$
\begin{aligned}
&121\frac{\text{GJ}}{\text{cap.year}}10^{9}\frac{\text{J}}{\text{GJ}}1\frac{\text{Watt.sec}}{\text{Joule}}\frac{1}{3.11\times10^{7}}\frac{\text{year}}{\text{sec}}10^{-3}\frac{\text{kWatt}}{\text{Watt}}\\
&=3.891\frac{\text{kWatt.year}}{\text{cap.year}}\\
&\simeq 4\frac{\text{kW}}{\text{cap}}
\end{aligned}
$$

Table 1. Energy Usage in different World Economies

Economical Region	Share of total energy consumption, [percent].
North America	29.8
Developing Asia	19.3
Western Europe	17.3
Eastern Europe and Former Soviet Union	13.3
Japan, Australia, New Zealand	7.0
Central and South America	5.2
Middle East	5.0
Africa	3.1

Table 2. Total and Electrical Energy Usage in different World Economies

Economical Region	Energy [GJ/(year.capita)]	Electricity [GJ/(year.capita)]
North America	297	38.52
Western Europe	121	15.84
Eastern Europe	179	16.92
Industrialized Pacific Rim	125	18.00
Asia	19	1.08

Latin America	51	4.32
Africa, Middle East	30	2.16
World Average	64	6.84

At a World's population of 6 billion persons, one can estimate a total yearly world energy consumption rate to maintain an industrial level standard of living need of:

$$
\begin{aligned}
E &= 4\,\frac{\text{kW.year}}{\text{cap.year}} \times 6 \times 10^{9}\,\text{cap} \times 10^{-3}\,\frac{\text{MW}}{\text{kW}} \\
&= 24 \times 10^{6}\,\frac{\text{MW.year}}{\text{year}}
\end{aligned}
$$

Since: 1 [Watt] = 1 [Joule/sec],

and: 1 [year] = 3.11 x 10^7 [sec]

Then:

$$
\begin{aligned}
E &= 24 \times 10^{6}\,\frac{\text{MW.year}}{\text{year}}\,10^{6}\,\frac{\text{W}}{\text{MW}}\,1\,\frac{\text{J}}{\text{W.sec}}\,3.11 \times 10^{7}\,\frac{\text{sec}}{\text{year}}\,10^{-9}\,\frac{\text{GJ}}{\text{J}} \\
&= 0.75 \times 10^{12}\,\frac{\text{GJ}}{\text{year}}
\end{aligned}
$$

In the year 2100 where the world population is expected to attain a level of about 10 billion persons, one can estimate the yearly energy consumption as:

$$
\begin{aligned}
E_{2100} &= 0.75 \times 10^{12}\,\frac{10}{6}\,\frac{\text{GJ}}{\text{year}} \\
&= 1.25 \times 10^{12}\,\frac{\text{GJ}}{\text{year}}
\end{aligned}
$$

For comparison purposes, the world's current energy yearly usage rate is about:

$$
E_{\text{actual world}} = 0.26 \times 10^{12}\,\frac{\text{GJ}}{\text{year}}
$$

The total USA's energy demand is about:

$$
\begin{aligned}
E_{\text{USA, total}} &= 72 \text{ Quads} \\
&= 72\times10^{-3}\text{Q} \\
&= 0.072\text{Q } 1.05\times10^{12} \frac{\text{GJ/year}}{\text{Q}} \\
&= 0.08\times10^{12} \frac{\text{GJ}}{\text{year}}
\end{aligned}
$$

Some comparisons as ratios based on Table 2 data are:

$$\frac{E_{\text{USA, electricity}}}{E_{\text{USA, total}}} = \frac{38.52}{297} = 0.13$$

$$\frac{E_{\text{Africa, electricity}}}{E_{\text{Africa, total}}} = \frac{2.16}{30} = 0.07$$

$$\frac{E_{\text{USA, electricity}}}{E_{\text{Africa, electricity}}} = \frac{38.52}{2.16} = 17.83$$

$$\frac{E_{\text{USA, total}}}{E_{\text{Africa, total}}} = \frac{297}{30} = 9.90$$

In addition:

$$\frac{E_{\text{USA, total}}}{E_{\text{actual, world}}} = \frac{0.08}{0.26} = 0.31$$

This suggests that the USA's energy use accounts for about 31 percent of the world's energy consumption, even though its population is:

$$\frac{315\times10^{6}}{7\times10^{9}} = 0.045$$

or just 4.5 percent of the world's population, reinforcing the observation that the standard of living and energy consumption correlate positively with each other.

Estimates of the practically recoverable fossil and nuclear fuels are shown in Table 3, suggesting that fossil fuels can satisfy the world's energy needs at the century level. Nuclear sources extend this capability to the several millennia level and even millions of years level, making them practically inexhaustible.

9.7 WORLD SHORT TERM FOSSIL AND FISSILE ENERGY RESOURCES

The USA is the largest user of coal for energy production as shown in Table 4, followed by China. Together, they account for about 50 percent of the world's consumption. Extracted from the ground and used at great risk to miners and users alike, its burning releases carbon, mercury, lead, sulfur and even radioactivity into the atmosphere. China and India are projected to account for the largest increase in the usage of coal worldwide.

Table 3. Long Term Recoverable Fossil and Nuclear Fuels.

Energy Sources	Practically Recoverable Amounts	Energy Content [10^{12} GJ]	Energy Content [TW.Year]
Fossil Fuels			
Coal and lignite	2.35×10^{12} tonnes	53.2	1690
Crude oil	2.10×10^{12} barrels	12.4	390
Natural gas	3.40×10^{14} m^3	13.1	415
Tar sands oil	3.00×10^{11} barrels	1.8	57
Shale Oil	1.9×10^{11} barrels	1.1	35
Total		81.6	2590
Fission Fuels			
Uranium for U^{235} Converters	4.04×10^6 tonnes	10	300
U^{238}, Th^{232} Breeders	6.80×10^6 tonnes	>10,000	>300,000
Fusion Fuels			
Lithium for DT Cycle			
Land	8.0×10^8 tonnes	2,000	60,000
Oceans at 0.17 ppm Li	2.4×10^{11} tonnes	2×10^7	6×10^8
Deuterium for DD Cycle			
(D_2O in oceans)	4.6×10^{13} tonnes	8×10^9	2×10^{11}
Consumption Rates			
World Energy Use/year		0.26	8.26
USA Energy Use/year		0.08	2.54

Together, fossil fuels as oil, coal and natural gas, emit some 22 billion tons of carbon dioxide into the Earth's atmosphere each year. As the world's population increases, these emissions could increase by 55 percent by 2020. An increase in carbon dioxide and other greenhouse gases would boost smog, ozone depletion, and global warming.

Table 4. Total and Electrical Energy Usage in different World Economies

Economical Region	Share of world consumption, percent (1999)
USA	25.5
China	24.0
India	7.0

As transportation fuel, gasoline is being used at larger rates. Table 5 shows that the USA leads the world both in per capita use and total consumption. As developing nations such as India and China industrialize, more cars and emissions will degrade the air's quality.

Table 5. World per capita consumption of gasoline

Economical Region	Gallons per capita (1997)
USA	459
Canada	303
Germany	140
Japan	113
Russia	55
China	10

Natural gas, which was earlier burned out as oil fields waste, is increasingly being used as a primary energy source. Since it is considered as cleaner and more efficient fuel than coal or oil, its use increased by 40 percent in 2010. The USA again leads the world in natural gas consumption, as shown in Table 6.

Table 6. Percent share of World Consumption of Natural gas.

Economical Region	Share of world consumption, percent (1999)
USA	26.9
Russian Federation	15.9
United kingdom	4.0

Table 7. Total and Electrical Energy Usage in different World Economies.

Energy Source	Share of World energy Sources, percent (1999)	Growth Rate, percent (1990-1999)
Oil	32	1.2
Natural Gas	22	1.6
Coal	21	-0.6
Nuclear	6	0.5
Renewables:	19	
Biomass	14	
Hydroelectric		1.8
Geothermal		4.3
Solar Photovoltaic		17.3

Wind Energy		24.2

9.8 ENERGY SOURCES SUBSTITUTION

Encouraged by environmental concerns, as well as economics, industrial and developing nations are enhancing energy efficiency and turning into renewable energy resources as shown in Table 7. Coal is undergoing a negative growth rate. Renewable energy sources include 14 percent as biomass in the form of firewood, crop waste, and animal dung or manure used as fuel in developing countries instead of as crop fertilizer. Wind energy and solar thermal and photovoltaics are undergoing the fastest growth rates.

Renewable resources such as hydroelectric power, sustainable biomass, solar, wind, geothermal and ocean thermal are attractive to the general public, and are hoped to contribute to the future energy mix, being considered inexhaustible. Afterall, each day, the Earth receives enough solar energy that, if fully extracted, an impossible task, would power civilization for 20 years. Ocean thermal is even considered a negative entropy system, in that it extracts thermodynamic order from the oceans, and operating without waste heat.

However, some of these have been already fully exploited and have limitations on their future availability, such as hydroelectric power environmentally affecting river systems and their associated fisheries. Others such as wind energy and solar photovoltaic are characterized by low energy supply densities and need energy storage and/or backup systems from the conventional systems when wind speeds are low or solar radiation is unavailable at night or on stormy or cloudy days. This prevents them from providing supply on demand. They are also characterized by low energy conversion efficiencies, which reduce their economic potential and makes them suitable for special niche applications such as at remote sites. Low energy densities also imply large land requirements and potential land use conflicts.

The limitations on renewable energy sources are not in their magnitude or their availability in nature, which is indisputable and obvious. The limitations are primarily technological and economical due to their diffuse nature. It is difficult to concentrate and then convert their energy flows into energy services at the rates required by the urban and the technological energy market place.

It must also be remembered that these technologies are not fully "green," and have significant environmental effects that cannot be ignored. To absorb solar energy, solar collectors must cover large areas of land with efficient black absorbers. Some efficient photovoltaic systems use highly toxic chemical elements such as cadmium. Dams for hydroelectric power kill river systems and fisheries. Windmills blight landscapes, kill birds, bats and insects, break down in high winds, attract lightning, and cause pollution in the form of low frequency noise. Biomass takes land away from natural flora and fauna.

For the short term of the coming 50 years, the world is compelled to depend on fossil and nuclear energy supplies, since it takes about 50 to 100 years for an alternate energy system to become dominant.

Fossil fuels now supply 87 percent of the world energy needs. They also supply 63 percent of its electricity usage. Both fossil and nuclear fuel resources are sufficient in the short term to satisfy the world's needs, as shown in Table 8. This is particularly true if one looks beyond the "proven reserves" in conventional deposits, and considers technological advances in exploration and extraction, creating new "resources" and leading to a larger Resource Base (RB), where:

$$RB = \text{Reserves} + \text{Resources}. \quad (9)$$

Over the next 50 years, fossil fuels are expected to dominate, with Natural Gas as Methane competing with oil and coal. Fission energy already works in the form of Open Cycle thermal fission reactors such as the Pressurized Water Reactor (PWR) and the Boiling Water Reactor (BWR) designs. It is expected to grow through the latter part of the 21st century in the form of closed cycle fast reactors systems such as the Liquid Metal Fast Breeder Reactor (LMFBR). A nuclear fuel cycle using thorium instead of uranium, with thorium 4 times as abundant in the earth's crust as uranium, may be introduced. Fusion energy should start to contribute to the energy mix on a commercial scale perhaps between 2030 and 2100.

Table 8. Short Term Global Energy Resource Base in ZJ (Zetajoules)[1].

Resource	Type	1998 Yearly Consumption [ZJ/yr]	Reserves	Resources	Resource Base[2]	Consumed By end of 1998	Additional Occurrences
Oil	Conventional	0.13	6.00	6.08	12.08	4.85	-
	Unconventional	0.01	5.11	15.24	20.35	0.29	45
	Total Oil	0.14	11.11	21.31	32.42	5.14	45
Natural Gas	Conventional	0.08	5.45	11.11	16.56	2.35	-
	Unconventional	0.00	9.42	23.81	33.23	0.03	930
	Total Gas	0.08	14.87	34.92	49.79	2.38	930
Coal	Total Coal	0.09	20.67	179.00	199.67	5.99	-
Total Fossil		0.31	46.65	235.23	281.88	13.51	975
Uranium	Open Cycle Thermal Reactors[4]	0.04	1.89	3.52	5.41	-	2,000[3]
	Closed Cycle Fast Reactors	negligible	113.00	211.00	324.00	-	120,000

[1] 1 ZJ (ZetaJoule) = 10^3 EJ (ExaJoule) = 10^{21} J (Joule)
[2] Resource Base = Reserves + Resources
[3] Includes uranium from sea water
[4] 1 tonne Uranium = 589 TJ
[5] 1 tonne Uranium = 35,340 TJ, a sixty times increase over the open cycle

9.9 GLOBAL STATUS OF NUCLEAR POWER GENERATION

There are 439 nuclear power plants in operation worldwide with a total installed capacity of 369,585 GW(e), with 34 plants under construction, where:

$$1 \text{ GW(e)} = 10^9 \text{ Watts(e)}.$$

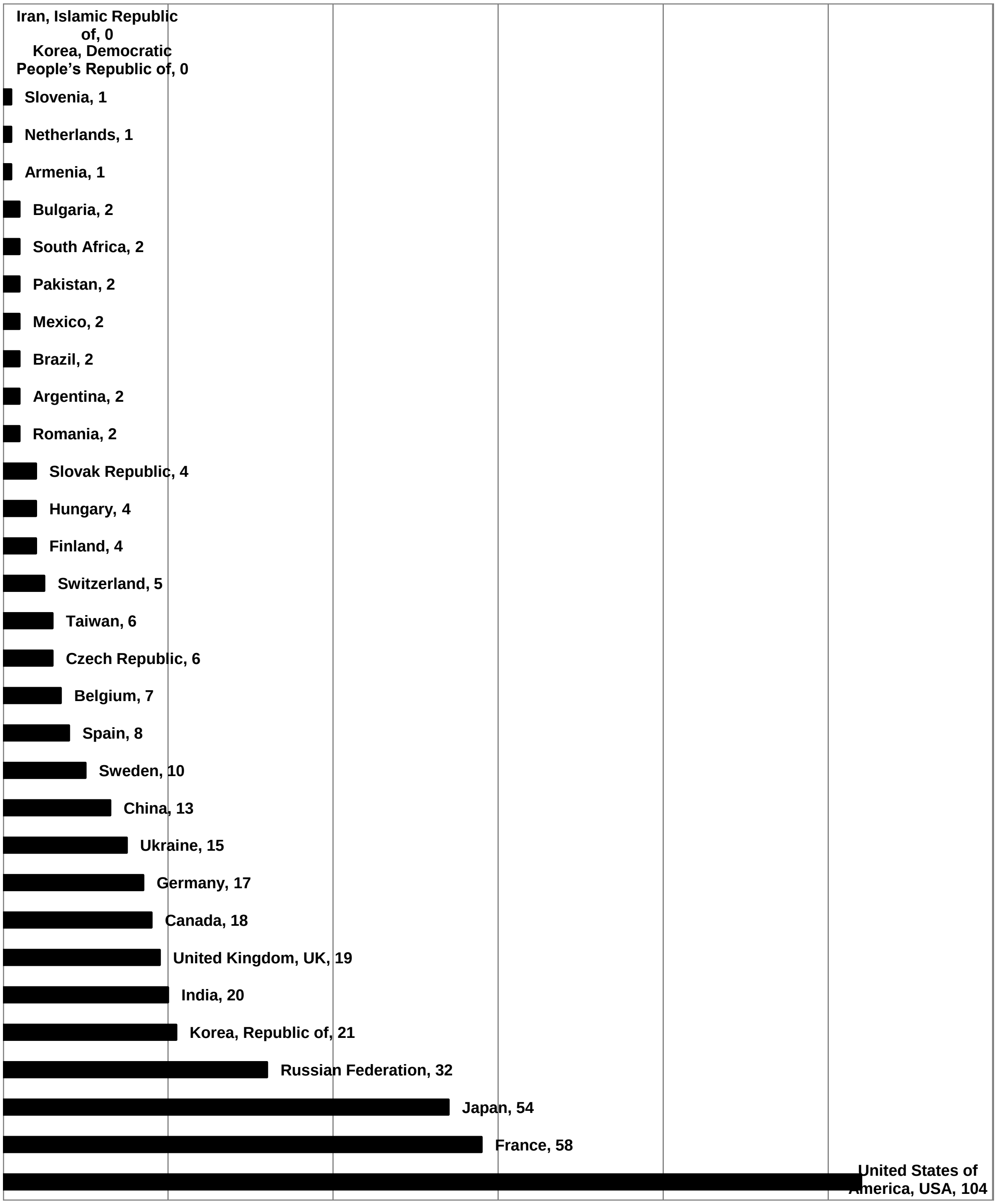


Figure 1. Number of power reactors in operation worldwide. Total: 448. Source: IAEA, 2011.

Table 9. Types of reactors and their capacity in operation and under construction as of 2006.

Type	Operational	Under Construction

	No. of Units	Total MW(e)	No. of Units	Total MW(e)
Advanced Boiling Water Reactor (ABWR)	4	5,259	2	2,600
Advanced Gas cooled Reactor (AGR)	14	8,380	-	-
Boiling Water Reactor (BWR)	90	79,168	-	-
Fast Breeder Reactor (FBR)	3	1,039	1	470
Gas Cooled Reactor (GCR)	8	2,284	-	-
Light Water cooled Graphite moderated Reactor (LWGR, RBMK)	16	11,404	1	925
Pressurized Heavy Water Reactor (PHWR)	41	20,933	7	2,645
Pressurized Water Reactor (PWR)	214	205,408	4	3,766
Rusiiab design Pressurized Water Reactor (WWER)	53	35,710	10	9,499
Total:	**443**	**369,585**	**25**	**19,905**

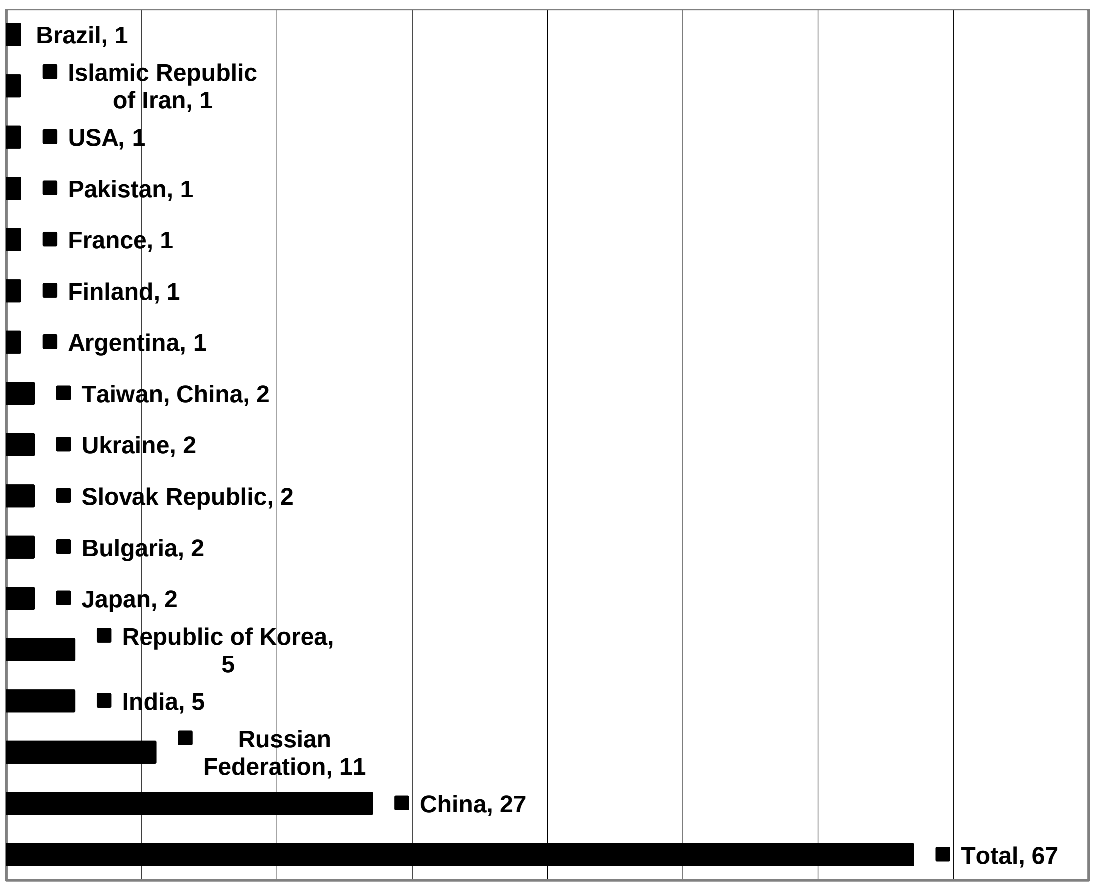


Figure 2. Number of power reactors under construction worldwide. Total: 67. Net electrical capacity: 62.9 GWe. Source: IAEA, 2011.

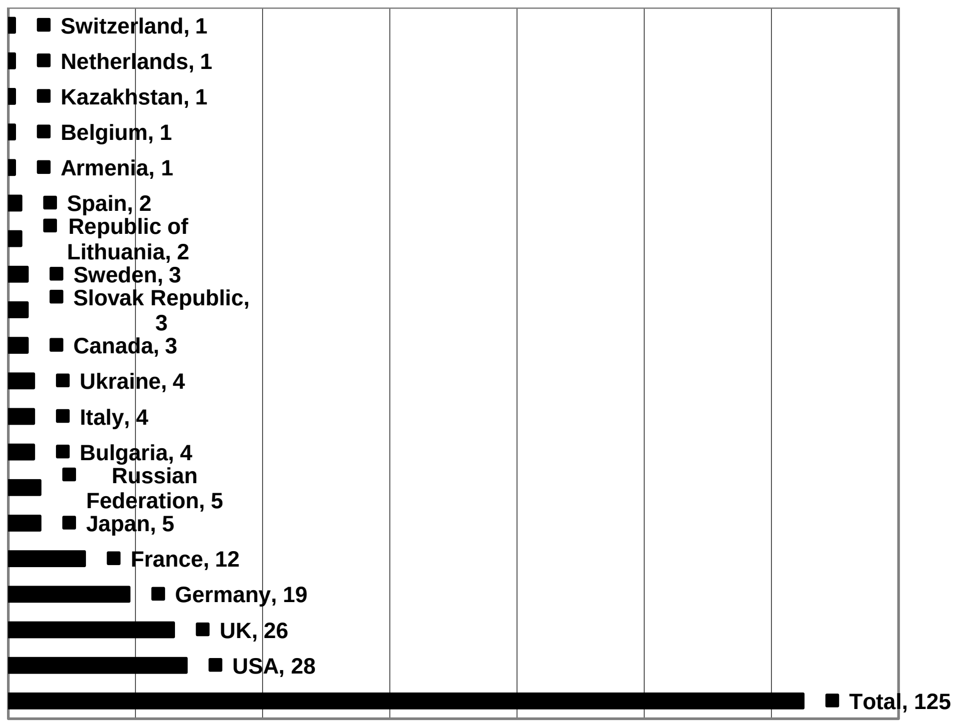


Figure 3. Number of shutdown reactors. Total: 125. Total capacity: 37.794 GWe. Data: IAEA, 2011.

The nuclear share of electricity production globally amounted to 16 percent. In some developed nations with limited fossil energy supplies the share of nuclear electricity is higher, such as France whose nuclear electricity share of the total electricity produced is 78 percent as shown in Fig. 3.

In the USA, the nuclear share of electricity production is 19 percent, with the largest number of operating nuclear units at 104 or about one fourth of the total number of operational units worldwide. In Canada, the nuclear share is 14 percent, produced by 17 reactors.

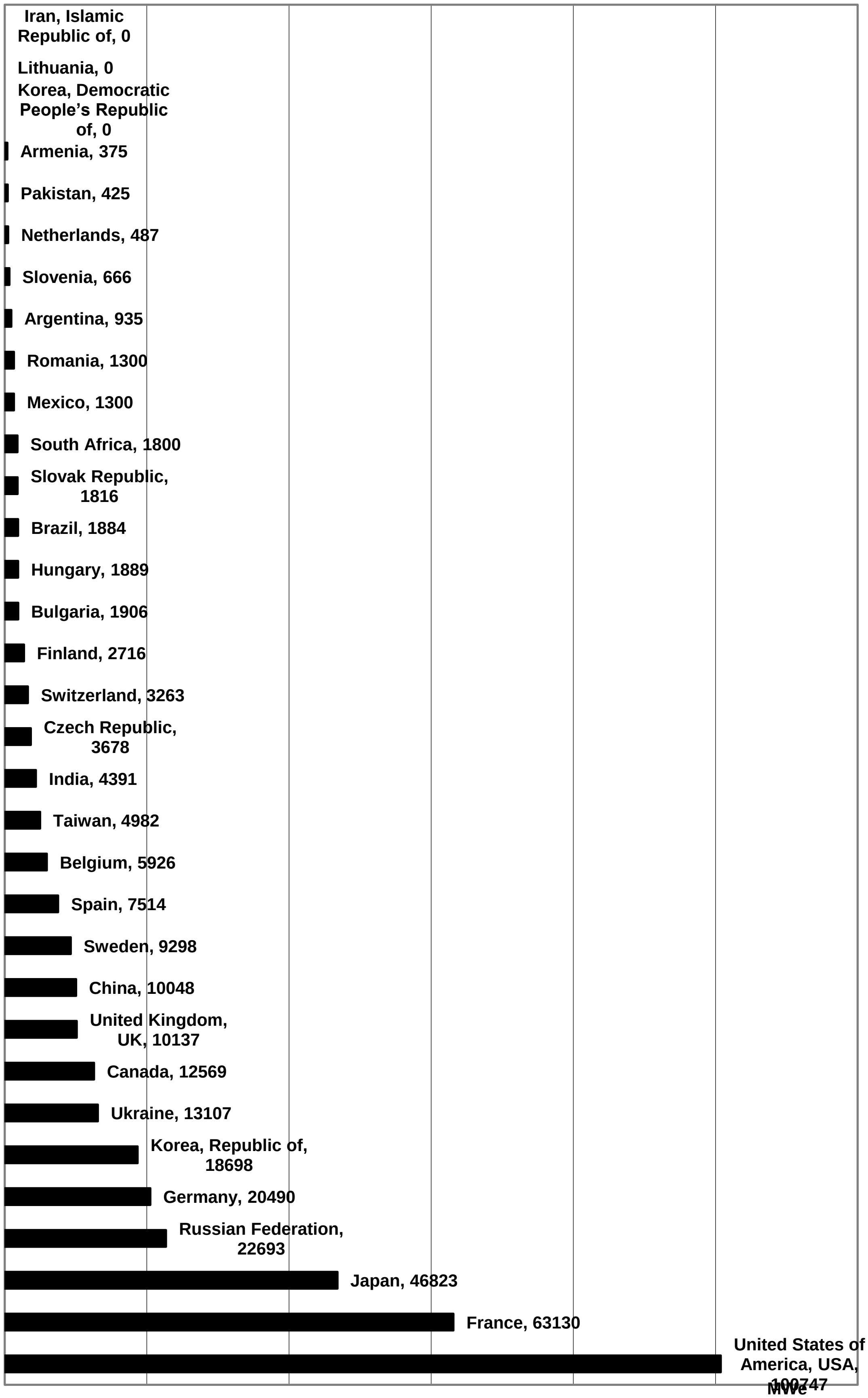
A number of 15 of the EU's 27 members have nuclear power plants. France has the most plants in Europe, generating 73 percent of its electricity.

Western Europe had 150 nuclear power plants which is about 36 percent of the world's nuclear power capacity. There they generated 30 percent of the region's electricity supply.

In Eastern Europe and the newly independent states, 68 nuclear power plants are in operation.

There were 84 plants in operation in South Asia, the Far East and the Middle East. There, construction of new nuclear plants continues, particularly in India.

Developing countries in Latin America and Africa account for a meager 2 percent of global nuclear capacity, and are not benefiting from nuclear power, based on considerations of non proliferation and denial of dual use technology.



Iran, Islamic Republic of, 0
Lithuania, 0
Korea, Democratic People's Republic of, 0
Armenia, 375
Pakistan, 425
Netherlands, 487
Slovenia, 666
Argentina, 935
Romania, 1300
Mexico, 1300
South Africa, 1800
Slovak Republic, 1816
Brazil, 1884
Hungary, 1889
Bulgaria, 1906
Finland, 2716
Switzerland, 3263
Czech Republic, 3678
India, 4391
Taiwan, 4982
Belgium, 5926
Spain, 7514
Sweden, 9298
China, 10048
United Kingdom, UK, 10137
Canada, 12569
Ukraine, 13107
Korea, Republic of, 18698
Germany, 20490
Russian Federation, 22693
Japan, 46823
France, 63130
United States of America, USA, 100747
MWe

Figure 4. Nuclear power installed capacity worldwide. Total installed capacity: 375.343 GWe.. Data: IAEA, 2011.

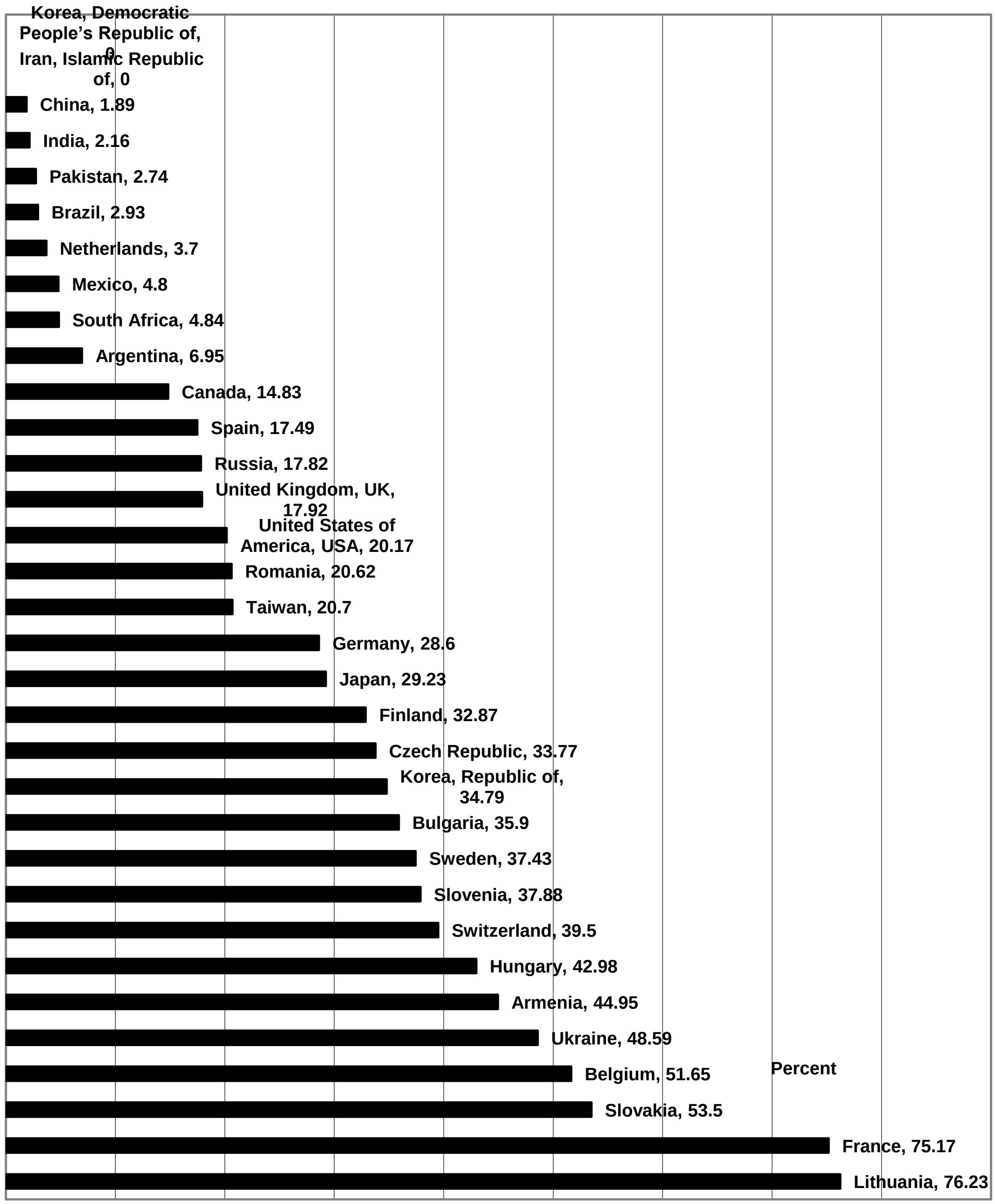


Figure 5. Nuclear Share of Electricity Generation, 2011. Data: IAEA.

In Western Europe there exists an over capacity in the electrical sector. Thus no new capacity is being added to nuclear power plants. The same is true in North America. Where new generation capacity is needed, gas turbine plants with low capital intensive requirements are being built for power topping purposes. Belgium, Germany, the Netherlands and Sweden plan to gradually phase out their existing nuclear units. In some countries like Austria, Denmark, Greece, Ireland and Norway, national political restrictions prevent its use.

However, for existing plants, an interesting situation exists. Their initial capital investment has already been depreciated, and since their fuel and operational costs are low, they are presently very competitive sources for electricity production acting as cash cows for their owners. In fact, some far sighted international utility consortiums have taken advantage of recent improvements in plant output, investments for the extension of the operational lifetimes of existing plants, and the incentives for consolidation in the regulatory realm. They acquired existing plants from weaker under-managed utilities and are operating them at a great economical advantage.

Table 10. Nuclear Power Reactors in Operation and Under Construction in the World as of June 2004.

Country	Reactors in Operation		Reactors under construction		Nuclear electricity supplied 2003	
	Number of Units	Total installed capacity, MW(e)	Number o units	Planned capacity MW(e)	Energy produced (TW.hr)	Percent of total
Argentina	2	935	1	692	7.03	8.59
Armenia	1	376			1.82	35.48
Belgium	7	5,760			44.61	55.46
Brazil	2	1,901			13.34	3.65
Bulgaria	4	2,722			16.04	37.71
Canada	17	12,113			70.29	12.53
China	9	6,587	2	2,000	41.59	2.18
Czech Republic	6	3,548			25.87	31.09
Finland	4	2,656			21.82	27.32
France	59	63,363			420.70	77.68
Germany	18	20,643			157.44	28.10
Hiungary	4	1,755			11.01	32.69
India	14	2,550	8	3,622	16.37	3.30
Iran, Islamic Republic of	-	-	2	2,111	-	-
Japan	54	45,464	2	2,371	230.80	25.01
Korea, Democratic People’s Republic of	-	-	1	1,040	-	-
Korea, Republic of	19	15,850	1	960	123.28	40.01
Lithuania	2	2,370			14.30	79.89
Mexico	2	1,310			10.51	5.23

Netherlands	1	449			3.80	4.48
Pakistan	2	425			1.81	2.37
Romania	1	655	1	655	4.54	9.33
Russian Federation	30	20,793	3	2,825	138.39	16.54
Slovakia	6	2,442			17.86	57.35
Slovenia	1	656			4.96	40.45
South Africa	2	1,800			12.66	6.05
Spain	9	7,584			59.36	23.64
Sweden	11	9,451			65.50	49.62
Switzerland	5	3,200			25.93	39.73
Ukraine	13	11,207	4	3,800	76.70	45.93
United Kingdom, UK	27	12,052			85.31	23.70
United States of America, USA	104	98,298			763.74	19.86
Total	**442**	**363,819**	**27**	**22,676**	**2,524.74**	

The total includes the following data in Taiwan, China: 6 units, 4,884 MW(e) in operation; 2 units, 2,600 MW(e) under construction;

The Russian Federation has three nuclear power plants under construction, with plans for more. In Eastern Europe and the Newly Independent States, most nuclear power plants have operated for more than half their expected design lifetimes. While expansion continues in several countries, in some others, debates continue on whether or not to finish the construction of some partially finished plants. Lately, the Ukraine has agreed to close the remaining Chernobyl units based on the RBMK-1000 design, in favor of obtaining foreign aid, which has not materialized from the USA toward building modern safer units.

The Far East and South Asia are the regions where nuclear power continues to grow in the short term with the objective of satisfying anticipated a future large regional energy demand.

Japan

Japan does not have any basic energy resource and relies on imported LNG and oil from different countries. It also relies on nuclear electric power generation notwithstanding the history of Hiroshima and Nagasaki.

About 29 percent of Japanese power is generated from nuclear plants. There are 55 units are in operation, 2 are under construction, and 11 planned. Japan has 17 research reactors.

The Japanese reactors are all of third generation type having modern safety systems. Japan planned on doubling its nuclear capacity to 90 GWe by 2050 to meet its obligation for limiting green house gases emissions under the Kyoto protocol. Japan has a high temperature test reactor operating at 950 ^{o}C. This is high enough to enable thermo chemical production of hydrogen. Japan plans to use some 20 GWth of nuclear process heat for hydrogen production by 2050. The first commercial plant is planned to be started in 2025. Japan suffered a powerful earthquake in July 2007. It reignited fears of radiation leakage from nuclear power plants, forcing the shutdown of a major nuclear reactor. Ever since the shutdown, Japan has had to make up for the lost electricity with gas fired power. Utilities have been importing as much LNG as storage facilities will allow, paying premiums of about 50 percent over benchmark USA natural gas prices.

As a result of new Japanese government guidelines, nuclear plant operators will have to analyze seismic events over a 130,000 year span, in stark contrast to the current mandated 50,000-year period. Geological faults screened to be active could nullify new reactors site proposals and even lead to closures of some operational nuclear capacity. Regulators may delay or cancel some of the 10 GWatts in new nuclear capacity slated to come online by 2015. After the 2011 Fukushima accident this goal has been scaled down to nuclear energy supplying 15 percent od its electricity demand.

Republic of Korea

About 45 percent of South Korea’s power requirement is met with nuclear power plants. Like Japan, Korea also does not have any basic oil or gas energy source. It has 20 nuclear reactors in operation, 1 under construction, and 7 planned. It also has 2 research reactors.

It has a plan to expand to 28 reactors and include advanced reactor designs and achieve 60 percent nuclear power supply 2035. Korea has an alliance with the USA to expand its nuclear generation capability. It has committed $1 billion plan for research and development and a demonstration program to produce commercial hydrogen utilizing nuclear heat by 2020.

India

India has signed an accord with the USA for expanding its nuclear power generation capability. It has attained nuclear arms production capacity and successfully tested nuclear devices. It has not signed the nuclear non proliferation treaty. It has 15 units in operation, 8 under construction, 24 planned and has also 5 research reactors. Nuclear power currently supplies about 4 percent of its total power requirement. It has achieved independence in its nuclear fuel cycle.

To fuel its rapidly growing economy India needs massive expansion of power generation. But considering the environmental impact cannot go for more coal plants. It does not have enough oil and gas of its own. Neither has it assured access to regional or international energy source. So it is looking forward to expand its nuclear generation to satisfy its need for energy security. By 2020 it is targeting an increase to 20 GWe by starting up another 24 units.

India is a pioneer in developing the thorium fuel cycle, and has several advanced facilities related to it.

China

China’s power demand expands at 8 percent per year. It is trying every option to secure assured growth of power generation. It has mostly coal plants and has been one of the major polluters spreading mercury emissions globally as far as the USA. It has realized the adverse impact on its own population and is opting for environmental friendly power generation. It has significant reserve of oil and gas, but to fuel its growth it is aggressively accessing regional and international resources. It has a good trade relation with Iran, is setting up energy import projects with Russia, and Chinese companies are active in Africa. It is exploring possibilities of gas import from Myanmar (Burma).

It is expanding its nuclear power generation with 10 units already in operation. It has 5 more under construction, 13 planned and 50 proposed. Its national plan indicates 40 GWe by 2020 and 240 GWe of installed nuclear capacity by 2050.

China has built a pilot high temperature gas cooled reactor (HTGR) with pebble bed fuel in 2000. A commercial prototype HTGR started by 2010. It is also partnering with South Korea to produce hydrogen.

China operates Canadian CANDU reactors. Most commercial reactor designs use normal water as the moderator. Water absorbs some of the neutrons, enough that it is not possible to keep the reaction going in natural uranium. CANDU replaces this "light" water with heavy water. Heavy water's extra neutron decreases its ability to absorb excess neutrons, resulting in a better neutron economy. This allows CANDU to run on unenriched natural uranium, or uranium mixed with a wide variety of other materials such as plutonium and thorium. This was a major goal of the CANDU design; by operating on natural uranium the cost of enrichment is removed. This also presents an advantage in nuclear proliferation terms, as there is no need for enrichment facilities, which might also be used for weapons. CANDU reactors produce tritium produced from neutron capture in deuterium which is used in commercial products such as emergency signs and future fusion reactors. CANDU not only "burns" natural uranium, but it does so more effectively as well. Overall, CANDU reactors use 30–40% less mined uranium than light-water reactors per unit of electricity produced. This is a major advantage of the heavy-water design; it not only requires less fuel, but as the fuel does not have to be enriched, it is much less expensive as well. The CANDU was deliberately designed to reduce the need for very large machined parts, making it suitable for construction by countries without a major industrial base.

A unique feature of heavy-water moderation is the greater stability of the chain reaction. This is due to the relatively low binding energy of the deuterium nucleus (2.2 MeV), leading to some energetic neutrons and especially gamma rays breaking the deuterium nuclei apart to produce extra neutrons. Both gammas produced directly by fission and by the decay of fission fragments have enough energy, and the half-lives of the fission fragments range from seconds to hours or even years. The slow response of these gamma-generated neutrons delays the response of the reactor and gives the operators extra time in case of an emergency. Since gamma rays travel for meters through water, an increased rate of chain reaction in one part of the reactor will produce a response from the rest of the reactor, allowing various negative feedbacks to stabilize the reaction. CANDU can breed fuel from the more abundant thorium. This is being investigated by India to take advantage of its natural thorium reserves.

In 2011, the Canadian Federal Government licensed the CANDU design to Candu Energy, a wholly owned subsidiary of SNC-Lavalin, which also acquired the former reactor development and marketing division of AECL at that time. Candu Energy offers support services for existing sites and is completing installations in Romania and Argentina through a partnership with China National Nuclear Corporation. SNC Lavalin, the successor to AECL, is pursuing new Candu 6 reactor sales in Argentina (Atucha 3), as well as China and Britain.

Pakistan

Pakistan meets about 3 percent of its power demand through nuclear power plants. It started its second nuclear plant in 2000 and the third supplied by China is under construction. It has 2 active reactors, 1 under construction, 2 planned. It also has 1 research reactor. It has a plan to expand its nuclearcapacity to 7.5 GWe by 2030.

Taiwan

Taiwan meets 20 percent of its electricity demand from nuclear plants. It has 6 reactors in operation and 2 under construction. The plants under construction are third generation advanced plant.

Democratic People Republic of Korea (DPRK)

North Korea partially built 2 units that remain unfinished after the non fulfillment of an international “Framework agreement” with USA Clinton administration. It was close to commissioning a small reactor but halted its construction under international pressure.

United Arab Emirates, UAE

The United Arab Emirates (UAE) is a signatory of the Nuclear Non Proliferation Treaty (NPT) and it further ratified a safeguards agreement with the International Atomic Energy Agency (IAEA) in 2003. In 2009 it signed the Additional Protocol whereas it pledged not to enrich nor reprocess spent nuclear fuel.

The UAE was founded in 1971, as a federation of seven emirates, which were earlier under British rule. The federation includes Abu Dhabi and Dubai. Abu Dhabi city is the federal capital of the UAE, and the Abu Dhabi emirate accounts for 86 percent of the land area of UAE, as well as 95 percent of its petroleum. Dubai is the UAE's largest city.

The Emirates Nuclear Energy Corporation, ENEC awarded six contracts related to the supply of natural uranium concentrates, conversion and enrichment services, and the purchase of enriched uranium product. These contracts were worth some $3 billion and will enable the Barakah nuclear power plant to generate up to 450 terawatt-hours (TWh) of electricity over a 15-year period starting in 2017, when the first of four units at the plant is scheduled to begin operating.

Enec signed agreements with both France's Areva and Russia's Techsnabexport (Tenex) to provide services across the front-end of the fuel cycle, including the supply of uranium concentrates as well as conversion and enrichment services. The Canada-based Uranium One and UK-based Rio Tinto will also supply natural uranium, the USA's Converdyn will provide conversion services and UK-headquartered Urenco will provide enrichment services. The enriched uranium will be supplied to Kepco Nuclear Fuels, a part of Enec's prime contractor consortium, led by Korea Electric Power Corporation (Kepco), which will manufacture the fuel assemblies for use in the Barakah plant.

In a $20 billion deal in December 2009, Enec selected a Korean consortium led by Kepco to build four APR-1400 reactors. All four units planned for Barakah, close to the border with Saudi Arabia, should be in operation by 2020. The first concrete for the initial unit was poured in mid-July 2012.

Legislation adopted in October 2009, prohibits "the development, construction or operation of uranium enrichment or spent fuel reprocessing facilities within the borders of the UAE." The UAE promised not to enrich and reprocess uranium or other fuel and to instead obtain nuclear fuel from reliable international suppliers, in line with a cooperation agreement signed with the USA. The UAE has nuclear cooperation agreements in place with the UK, South Korea and France, plus a memorandum of understanding with Japan. In late July 2011, it signed a cooperation agreement with Australia, enabling the supply of Australian uranium to fuel its forthcoming nuclear power reactor fleet. Both Rio Tinto and Uranium One have uranium assets in Australia.

The UAE is committed to a "dual track" radioactive waste management strategy that involves developing a national storage and disposal program in parallel with exploring regional cooperation options. Sweden’s SKB is studying the prospects of a geological waste repository in the UAE, and the Arab Atomic Energy Agency (AAEA), with a widened group of participating Middle East and North Africa (MENA) countries, is considering regional options along the lines of EU precedents.

According to Enec, though the Barakah site "is in an area with a very low probability of earthquakes" and that the area has been "tectonically inactive for nearly 100 million years," it has nonetheless taken on board lessons learned from the accident at Japan's Fukushima Daiichi plant.

Several design changes were proposed including enhancing the seismic resistance of the back-up diesel generator buildings and other auxiliary buildings. Watertight doors are to be fitted to these building in case of severe flooding. In the event of a station black-out, Enec has increased the availability of fuel for the emergency diesel generators to allow 24 hours of operation rather than just 8 hours. It has also extended the availability of back-up battery power from 8 hours to 16 hours. In the event of a severe accident, the Barakah plant design will enable external water injection to the steam generators, reactor coolant system and the used fuel pools. Following a review by the Federal Authority for Nuclear Regulation, FANR, of Enec's proposed changes to the Barakah plant in response to the Fukushima accident, the regulator concluded that "sufficient information has been presented to conclude that structures, systems and components in combination with proposed safety improvements will provide substantial margin above the design basis capabilities to ensure that a multiple-unit plant can be brought to safe shutdown condition or cope with and mitigate the effects of severe but low probability events."

The UAE's nuclear power program is closely coordinated with the IAEA, which in the wake of an Integrated Nuclear Infrastructure Review (INIR) mission to the UAE reported in January 2011 that the emirates had followed its recommended comprehensive 'milestones' approach for such countries. Areas of good practice identified by the mission included "cooperation, without compromising their independence, between the regulatory bodies and utility, human resource development, a well-structured management system, and a strong safety culture." ENEC has joined the World Association of Nuclear Operators (WANO) to benefit from its peer review process to ensure high standards of safety.

NUCLEAR POWER PLANTS CONSTRUCTION

One in Argentina, the Atucha plant near the capital Buenos Aires. Two in Bulgaria, both near the northern town of Belene. Five in China, including two in Taiwan. One in Finland at Olkituoro, will be the world's largest single unit when it is finished. Scheduled to be on line by 2011, it is being built by French nuclear group Areva and Germany's Siemens.

France has one plant being built at Flamanville in Normandy, scheduled to be on line in 2012. France's latest addition at Flamanville will be the third reactor on the same site and will bring the country's fleet up to 60 nuclear power plants.

Six plants in India are being built to add to the country's existing 17 operational facilities. India plans to build a further seven.

Iran is trying to build one plant at Bushehr on the Gulf coast in the south. It is the subject of close inspection by the IAEA and the basis of diplomatic tensions between Iran and the West.

Japan has one power plant under construction which is being built by the Tokyo Electric Power Company. It has been delayed until 2015/16, a year later than planned to comply with tougher safety plans.

Three are being built in South Korea.

Pakistan has one plant under construction at Kundian in the Punjab province. This will bring Pakistan's tally of operational units to three when it is online.

Russia is building seven nuclear power plants to add to its 31 operational facilities and is helping China with its projects.

Two are being built in northwest Ukraine.

The United States is building one nuclear power plant in Tennessee.

Finland's 1,600 megawatt Olkiluoto 3 reactor is seen as a test case for Europe's nuclear future. It was originally scheduled to open in 2009 but has been delayed until 2011 due to slower-than-expected construction work. When complete, Olkiluoto, which will cost 3 billion euros ($4.4 billion), will be the world's largest single unit and Western Europe's first new reactor for over a decade.

9.10 ANTICIPATED SHORT TERM FUTURE ENERGY NEEDS AND TRENDS

The need for nuclear Power would not be so urgent if the demand for electricity would remain constant at the present level. However, 75 percent of the 6 billion people world's population lives in developing countries that are trying to catch up with the standard of living in the developed nations, with a resulting increase in the demand for electricity. These people consume a disproportionate 36 percent of primary energy, and 1.6 billion of them have no access to modern energy services that are taken for granted in the industrialized nations. The United Nations median estimate is for an additional 4.4 billion people addition to the world population, an increase of 75 percent, by the year 2100. This addition to the world population will increase the need for additional electricity sources.

The Intergovernmental Panel on Climate Change Special Report on Emission Scenarios [3], projects that the global primary energy use will increase from 1.7 to 3.7 times between the year 2000 and the year 2050, with a median increase by a factor of 2.5 times, as shown in Table 11.

Electricity demand is expected to grow by a factor of 8 in the high growth scenarios associated with the new Information Technologies. Even in an energy conservation environment, the increase is expected to be by a factor of 2, with a median increase by a factor of 4.7.

The scenarios consider future accelerating improvements in the final energy use intensities from 1 to 2 percent per year, compared to the average value in the 20th century of about 1 percent per year. The Final Energy Intensity (FEI) is defined as the ratio:

$$FEI=\frac{\text{Sum of Energy Delivered to End-user}}{\text{Gross Domestic Product (GDP)}} \tag{10}$$

This serves as a measure of energy use efficiency improvements at the end-user side such as the use of more energy efficient appliances, of structural economic change, and for behavioral change such as conservation. Higher final energy intensity values are associated with lower total energy requirements. Lower final energy intensities normally result from a large share of electricity in the overall energy mix.

Nuclear electrical power needs are expected to range from the present 350 Gigawatts electric (GW(e)), to 5,200 GW(e), with a median of 1,700 GW(e). These projected growth levels would require the addition of 50 to 150 GW(e) per year of nuclear electrical capacity over the period of 2020 to 2050, even without the implementation of policies aimed at the reduction of greenhouse gas emissions from fossil fuels.

Table 11. Anticipated primary and Nuclear Energy Demand.

		Future Energy Demand (EJ)			Nuclear Energy Demand GW(e)	
Year	Lower Limit	Upper limit	Median	Lower Limit	Upper Limit	Median
2000	400	400	400	350	350	350
2010	450	550	500	350	800	500

2020	475	800	600	300	1500	600
2030	500	1050	750	250	2500	900
2040	550	1300	850	200	3500	1200
2050	680	1480	1000	200	5200	1700

If nuclear energy were also needed not just for the production of electricity, but also for the production of fresh water from sea water and brackish water through the process of desalination, the required nuclear capacity would be higher. The need would be even higher if the world needs to adopt a non carbon energy system based on hydrogen, and nuclear energy would be used in the chemical processes dissociating water to obtain the hydrogen, such as high temperature electrolysis.

9.11 CHINA'S NUCLEAR ENERGY DEVELOPMENT

China is considering spending $8 billion to build 4 nuclear power plants. Three foreign companies are vying for the contract to build the first third generation reactors in China: Pittsburgh, Pennsylvania based Westinghouse Electric Company, France's Areva and Russia's Atomstroiexport.

It plans to invest some 400 billion yuan ($49.3 billion) in building around 30 new nuclear reactors by 2020, bringing its total installed nuclear capacity to 40 GW(e).

Currently it has nine operating reactors that supply around 2.3 percent of its electricity needs, but aims to boost the amount of power it gets from nuclear plants to 4 percent within 15 years.

It has been building up its domestic manufacturing capacity with an eye on eventual exports and global competition in the energy production market. According to He Yu, general manager of China's Guangdong Nuclear Group: "Introducing third generation technology will swiftly promote our own technology. It could even create conditions for us to export nuclear technology in the future."

9.12 STATUS OF NUCLEAR GENERATION IN THE USA

Six to ten nuclear reactor units are expected to be ordered within the coming five years in the USA. Since the accident at Three Mile Island in 1979, the worst such incident in USA history, no company has followed through with new plans to build a nuclear plant since.

Under the 2005 energy bill, electric utilities are in line to get $3.1 billion in tax credits to build new nuclear plants, with the first two plants to be built receiving substantially more than those that follow.

One impediment to the approval of new plants is the absence of a repository or storage area for nuclear waste in the USA like the one under study at Yucca Mountain in the Nevada desert. By realizing that 95 percent of the energy is left in the spent fuel when it is discharged from fission reactors, uranium will ultimately become scarce; suggesting that nuclear fuel reprocessing technology will make spent fuel a tremendous resource.

Without any new plants construction, it is remarkable that an increase in the production of nuclear electricity in the USA has occurred, as shown in Table 12.

Table 12. Nuclear Electricity Generation in the USA.

Year	Electrical Energy(10^9 Kw.hr)
1998	673.7
1999	727.9
2000	756.5

The figure for 2000 is 4 percent higher than for 1999, and 12.3 higher than for 1998. The 12.3 percent increase corresponds to satisfying the needs of 6.3 million residential, commercial, industrial and public users, at an average of 13.14 [MW.hr] per customer.

A consolidation process has happened, and many operations were merged. Some far sighted power producers purchased power plants from utilities, which prefer to become power distributors rather than power producers, at quite advantageous prices. In fact, a fragmentation process has occurred, where the electrical utilities have been polarized into power producers and power distributors. Electricity being a service as well as a commodity, some experts question the long term viability of those short sighted utilities that have morphed themselves into power purchasers and lost control of their electrical supply under the pressure of the deregulation process.

9.13 FUTURE OUTLOOK FOR NUCLEAR GENERATION

There exists a consensus that renewable energy sources should be fully exploited in the future whenever possible in their appropriate niches, particularly in arid regions and rural areas with low demand densities. Only a minute amount of 130 MW(e) of photovoltaic electricity capacity using solar electric cells is available [4]. Since 1980, the USA Department of Energy (USDOE), spent $6 billion on solar, $2 billion on geothermal, $1 billion on wind, and $ 3 billion on other renewable energy sources. However, renewable energy sources other than hydroelectric power still remain at 2 percent of the USA electric capacity, most of it is in the form of biomass as wood byproducts burned to produce power for the wood products industry.

In a 20 to 100 TW(e) (1 TW = 1 TeraWatts = 10^{12} Watts) world, dependence can only be on fossil and nuclear energy sources. The feasible increment of one windmill with a capacity of 20-100 MW(e), is welcome, but is limited in its contribution. Even with renewable energy sources taking a part in future energy options, energy backup will have to be based on nuclear and fossil sources.

The USA's more than 90 quadrillion (1 quadrillion = 10^{15}) British Thermal Units (BTUs) consumed in the year 2000, are primarily based on fossil and nuclear sources, and such dependence can only be realistically expected to continue in the next century.

In the hands of the consolidated surviving far sighted and well managed nuclear utilities, the nuclear industry is acting on the following priorities that would enhance its long term viability:

1. **Shift in emphasis in nuclear energy use:**

Nuclear energy production will be called upon to shift its emphasis from just producing electricity to the emerging need of producing a mix of electricity, hydrogen fuel, and process heat for desalination and industrial processes.

Table 13. World Uranium production, 2004.

Location	Production Million lbs U_3O_8	Percentage
Africa	18	17
Australia	23	22
USA	2	2
Other	3	3
CIS/China	28	27
Canada	30	29
Total	104	100

Hydrogen fuel produced from high temperature electrolysis, would require a mix of electricity and process heat, and would need a new generation of reactor designs based on the High Temperature Gas Cooled Reactor (HTGR). Hydrogen from water would become an energy carrier providing transportation fuel that is carbon free since the product of its combustion is water instead of carbon dioxide from fossil fuels. This could become nuclear energy's major contribution in avoiding the global effects of fossil fuels green house gas emissions.

Whereas there exists an immediate shortage of energy or not, there definitely exists a shortage of fresh water supplies, particularly in arid regions of the world. This is leading to local conflicts for the control of fresh water supplies as is occurring in the Middle East conflict. In this regard desalination requires a different type of reactor concept that does not exist, consisting of small unit sizes, low temperature, simple technology reactor designs that are inherently safe, proliferation resistant and operating at low power densities.

2. Proliferation resistant regimes:

This is crucial to gain political support for its use in developing nations, where the greatest need for nuclear power is identified. It is also crucial for the industrialized nations to acquiesce in the transfer of a technology that is perceived as being of a dual purpose; civilian and military, in nature.

In addition to the Nuclear Nonproliferation Treaty (NPT), the Safeguards regime and the export controls of nuclear materials, any new nuclear reactors and fuel cycle designs must facilitate the safeguarding of nuclear materials. The use of highly enriched fuel can be avoided, and new designs should facilitate the verification of international agreements on the peaceful use of nuclear materials.

A counter current is the adoption of the USA of a “Counter Proliferation Policy,” that is weakening and possibly destroying the existing “Non Proliferation Regime.”

3. Cost Reductions.

These first involve improvements in existing operations, engineering support, strategic management, nuclear fuel supply and spent fuel disposition. During the 1990s such measures increased the available power at nuclear power plants by 28 GW(e), which is equivalent to building 28 new power plants of 1,000 MW(e) unit size.

To be able to build a new generation of nuclear power plants, the nuclear industry must demonstrate a capability to reduce the required construction costs. This would have to include building smaller size plants in the 500 MW(e) range to compete with the wave of building gas fired topping units that are being built by the USA power producing utilities to satisfy peak electrical demand, under the umbrella of deregulation of the utility industry. These smaller size units would also be definitely capable of satisfying the demand in small electricity grids in developing countries. The possibilities in this regard would include simpler and safer designs that will use factory built structures components. These plants would depend on modular units for fast installation, and on passive fail-safe safety features.

In the USA, nuclear power had the lowest cost of electricity production after hydroelectric power in 2004.

Table 14. USA Electricity Costs, 2004.

Source	USA cents/(kWe.hr)
Natural Gas	5.87
Oil	5.39
Coal	1.92
Nuclear	1.68

4. Publicly supported waste disposal options.

The amounts of radioactive wastes produced by the nuclear industry are relatively small, compared with the toxic wastes produced by fossil fuels and even solar photovoltaic systems. Being small in size, "confinement" is a feasible strategy that must be eagerly pursued by the power producers themselves, not just by proxy government agencies and must be technically proven. In contrast, for fossil fuel combustion, the amounts produced, including greenhouse gases, toxic gases like the Nitrogen Oxides (NO_x) and the Sulphur Oxides (SO_x), particulate matter, heavy metals such as mercury, and even radioactivity, are so large that they cannot be confined. The only economical approach is a "dispersal" strategy involving dilution and release to the atmosphere and the environment.

Most of the waste from nuclear power plants is of the low radiation level category, and can be simply handled and transported. Its disposal near the surface will decay by a factor of 100 to the natural radiation level within about 200 years. This low level waste is also not just radioactively toxic, but is also chemically toxic, and its surface disposal should still be engineered so as to avoid its leakage to the water table. High level waste resulting from spent or used fuel is the smallest part of nuclear waste. About 30 metric tonnes are discharged annually from a 1,000 MW(e) plant. The total amount discharged through the end of 1999 worldwide is 220,000 metric tonnes. About 75,000 metric tonnes have been reprocessed.

The only operating disposal site is the Waste Isolation Pilot Plant in New Mexico in the USA which became operational in 1999. Another site for disposal in volcanic tuff is being pursued at Yucca Mountain in the USA. Other countries like Belgium, Canada, Finland, France, Japan, Sweden and Switzerland are also engaged in deep disposal studies. There does not exist yet an authorized commercial facility.

4. Improved safety:

The Three Mile accident and the Chernobyl accident in 1986 emphasized the human factor role in plant operations. Whereas existing facilities have been upgraded, from the operational and hardware perspective, it must be recognized that no new facilities will be built based on the existing reactor designs. The only recourse is to seek inherently safe and simple reactor designs depending on fail safe systems and passive safety features that avoid human intervention in the case of transients or accidents. Regulatory procedures could more effectively focus on end results such as low off site radiation exposure levels to members of the public in the case of accidents. The current emphasis appears to be on procedures that give feelings of safety, but may not be relevant to the end goal of protecting the public's safety.

Safety and cost effectiveness go hand in hand: investors will only support new plants that are both safe and cost effective. It must be recognized that the safety level, being inversely proportional to the risk level, is as much a factor in the price of electricity, as are the capital cost, the fuel cost and the operation and maintenance costs.

NUCLEAR RENAISSANCE IN THE USA

By 2006, no new nuclear plants have been built in the USA in more than 30 years, but that may change because of several trends:

1. Global energy demand is expected to keep growing by more than 50 percent over the next 20 years, according to the USA Energy Information Administration estimate.
2. Fossil fuels such as natural gas and petroleum are getting increasingly expensive.
3. Public support for nuclear power seems to be reborn. Polls conducted by the Nuclear Energy Institute in May 2005, found that 70 percent of the 1,000 people surveyed supported nuclear power.
4. The passage of a federal energy bill, signed into law on August 8, 2005, offering financial incentives, liability protections and research funding to the nuclear industry.
5. Some prominent and respected environmentalists, considering the threat of global warming, are accepting nuclear power as part of the future energy mix. The mainstream environmental community still remains opposed, but the defections mark a significant departure for a movement that was once rock solid in opposition to nuclear power.

ENERGY BILL OF 2005

The 2005 energy bill includes provisions that should advance nuclear power in the next decades: a new test reactor for hydrogen production at the Idaho National Engineering and Environmental Laboratory (INEEL), an extension of industry funded liability protection for nuclear facilities and incentives to jump-start construction of some advanced design reactors.

This federal energy bill is expected to help jump start the nuclear power industry through four key provisions:

1. A 20 year extension of the Price Anderson Act, which provides liability insurance that indemnifies companies that design and build nuclear power plants.
2. An allocation of $1.2 billion to fund research on next generation nuclear power plants, including designs that would produce hydrogen as an energy carrier.
3. Up to $2 billion to offset the costs of regulatory or legal delays in the licensing and construction of new nuclear power plants. This includes up to $500 million each for the first two new plants, and up to $250 million for the third, fourth, fifth and six new plants to be built.
4. A production tax credit of 1.8 cents/(kW.hr) of energy produced for the first eight years of a new nuclear power plant's operations.

FORMATION OF NUCLEAR POWER CONSORTIA

The nuclear industry can point to several advances: existing plants are more efficient and cost effective, designs for the next generation of reactors makes them reliable and safe, standardized construction plans and a streamlined licensing process should help make nuclear power an attractive investment.

A consortium designated as NuStart Energy was organized in response to the 2005 USA Energy Bill and announced locations in 6 states as possible sites for new nuclear power plants. Four of the six states already house operating nuclear power plants. The sites, by location, are:

1. Scottsboro, Alabama: The Bellefonte Nuclear Power Plant, an unfinished site owned by the USA government owned utility Tennessee Valley Authority.
2. Port Gibson, Mississipi: The Grand Gulf Nuclear Power Station, owned by the Entergy utility.
3. St. Francisville, Louisiana: The River Bend Nuclear Power Station, owned by Entergy.
4. Aiken, South Carolina: The Savannah River Site, a USA Department of Energy nuclear weapons laboratory.
5. Lusby, Maryland: The Calvert Cliffs Nuclear Plant, owned by Constellation Energy.
6. Oswego, New York: The Nine Mile Point Plant, owned by Constellation Energy.

The six sites chosen by NuStart are owned either by a consortium member or by the USA Department of Energy.

The consortium, hopes to work on two advanced plant designs. NuStart President Marilyn Kray said that: “The four sites with operating power plants have the most comprehensive licensing basis, and the five sites housing power plants have the benefit of established transmission systems.”

The consortium will evaluate the sites on 75 factors including seismic activity, availability of water and emergency preparedness issues. It is sending letters to state and local politicians and development leaders to determine what incentives they might offer to attract the two proposed plants.

The NuStart consortium appears not worried about protests from environmental activists at the local level, but does expect some resistance from environmentalists on the national level.

The NuStart consortium consists of nine utilities, including Exelon, Entergy, and Duke Energy, as well as nuclear reactor manufacturers GE Energy, a unit of General Electric, and the Westinghouse Electric Company, a unit of the British government owned British Nuclear Fuel Limited (BNFL) Plc. GE is a parent in the joint venture that owns Microsoft-National Broad Casting system (MSNBC). In 2006 both GE and the Toshiba companies have presented bids to purchase the Westinghouse Company.

Under the USA Department of Energy’s Nuclear 2010 program, half of the estimated $520 million cost of the project would be shouldered by the Department of Energy and half will be paid by the consortium members.

The consortium expects to apply for licenses in 2008. Construction could then begin in 2010 with completion in 2014.

LOAN GUARANTEES

In his $3.8 trillion budget plan for 2011, President Barack Obama called for boosting loan guarantees to $55 billion to help jump-start construction of USA nuclear plants. In his January 26, 2010 State of the Union address, the president urged “building a new generation of safe, clean nuclear power plants in this country." His words marked a shift toward more public support for an industry that has brought just one new USA nuclear power plant online in 20 years.

Administered and pushed by the Department of Energy, the financing scheme would cover as much as 80 percent of the likely $7-10 billion-plus cost of designing, licensing and building each new USA nuclear reactor that receives a loan guarantee. The guarantees would extend up to 30 years.

At President George Bush’s behest, the Energy Policy Act of 2005 provided $13 billion in subsidies to the nuclear power industry for research, construction, operations and site cleanup, and it authorized the loan guarantees. The Department of Energy selected recipients for an initial round of $18.5 billion in guarantees.

Four projects at the top of DOE’s list for a first round, culled from 19 applications, all are facing squabbling among partners, cost overruns and reactor design difficulties.

Figure 6. Calvert Cliffs Nuclear Power Plant in Lusby, Maryland, south of Washington D. C. operated by Constellation Energy.

As of 2010, these projects were under serious consideration in the USA:

Summer Station, South Carolina

The Summer Station Nuclear Station's proposal to add two 1,117-megawatt reactors to its Fairfield County, S.C., site, which currently operates a single reactor. The new reactors would be Westinghouse AP 1000s, not in operation anywhere yet and under new scrutiny from the U.S. Nuclear Regulatory Commission over the design of the shield building and other issues. The station's owner warned that the projected cost of the reactors could be $500 million higher than expected.

Vogtle Site, Georgia

An expansion plan at the Vogtle site in Waynesboro, Ga., which currently operates two reactors with a total of 2,430 megawatts of capacity. The plant's owners want to nearly double that by adding a pair of the Westinghouse AP 1000s. In addition to the hurdles faced by the reactors, the project is the subject of a lawsuit over its finances.

Calvert Cliffs, Maryland

A plan to add a 1,600-megawatt reactor at the Calvert Cliffs Nuclear Power Plant, which operates two reactors near Lusby, Md., with a combined output of 1,750 megawatts. The plant's owner has chosen Areva's Evolutionary Power Reactor. The first installation of that reactor in Okiluoto, Finland, is running two to three years behind schedule, with cost overruns pushing the price from $4.4 billion to $6.5 billion. And the design has not yet received certification from the NRC.

The Calvert Cliffs plant is one of a six sites being considered for a new advanced reactor by the NuStart consortium. When built, it would be the USA's first new commercial reactor since the 1979 Three Mile Island accident.

It will cost $520 million to develop a new reactor design and submit the first two plants licensing applications. A new plant would start operations in 10 years at the earliest.

At the local level in Calvert County, leaders are supportive of an expansion of the plant. Linda Vassallo, director of the county's economic development department, anticipates that a new reactor at Calvert Cliffs could bring in 250 to 400 permanent jobs as well as more than 2,000 construction jobs. The existing plant pays more than $15 million in annual property taxes to the county.

South Texas Project, Texas

The South Texas Project's bid to become the nation's largest nuclear power plant by adding a pair of reactors to its Matagorda County facility for a total generating capacity of more than 5,000 megawatts — enough electricity to supply the needs of about 2 million homes and businesses. STP's plans are threatened by a courtroom squabble among its partners over the estimated cost of the expansion, which has skyrocketed from $6 billion to $17 billion. The Texas project is the only proposal on the loan guarantee list that calls for using a reactor — General Electric's Advanced Boiling Water Reactor — currently in operation.

9.14 POSITION OF THE ENVIRONMENTAL MOVEMENT

A reason for the reborn public support comes from the environmental movement. Several prominent and respected environmentalists have said they are open to nuclear power, if not outright supportive.

It is recognized that nuclear energy produces none of the sulfur dioxide, nitrogen oxide and carbon dioxide that are spewed into the atmosphere when fossil fuels are burned. It is greenhouse gas free. The State of Washington nuclear power plant, for example, kept 8,000 tons of sulfur dioxide emissions, 13,500 tons of nitrogen oxide emissions and 7.6 million metric tons of carbon dioxide emissions out of the sky in 2004. Without even considering global warming, avoiding these emissions helps areas where car and industrial emissions degrade air quality.

Renewable energy sources such as wind, solar, and hydroelectric are also emission free sources. However, wind and solar are a small part of the USA energy production and have become smaller in recent years. Hydro power now runs afoul of efforts to protect native fish, particularly in the Northwest USA.

Hydrogen is considered as the energy carrier of the future. To produce it, electricity and heat energy are needed. This becomes a greenhouse gas problem if producing the electricity and heat to produce the hydrogen also produces carbon dioxide. It is not a greenhouse gas problem if the vast amounts of electricity used in electrolysis come from nuclear power. Solar and wind power can contribute but will not suffice to supply the USA transportation, industrial and residential energy needs.

Renowned ecologist James Lovelock in 2004 announced support for nuclear power. He was joined by Patrick Moore, co founder of the Greenpeace movement, and the Whole Earth Catalog founder Stewart Brand.

Greenpeace founder Patrick Moore and head of Greenspirit Strategies testified before the USA Congress in April 2005: “There is now a great deal of scientific evidence showing nuclear power to be an environmentally sound and safe choice. A doubling of nuclear energy production would make it possible to significantly reduce total (greenhouse gas) emissions nationwide. In order to create a better environmental and energy-secure future, the (USA) must once again renew its leadership in this area.”

Other key environmentalists expressed the view that nuclear power might be worth another look. These include author Jared Diamond, World Resources Institute president Jonathan Lash, and British bishop and environmental leader Rev. Hugh Montefiore.

Britain's Hugh Montefiore, a longtime trustee of Friends of the Earth made a pronouncement: “I have now come to the conclusion that the solution (to global warming) is to make more use of nuclear energy.” His colleagues made him resign. However as fears about greenhouse gases and global warming grow, and the practical problems of filling the world's energy needs with non emission sources become more apparent, today's nuclear environmentalists may come to be seen as prophets.

Roel Hammerschlag, environmentalist and executive director of the Seattle based Institute for Lifecycle Environmental Assessment suggests that “Coal is the enemy.” He describes himself as open minded on nuclear power, calling it perhaps "The lesser of two evils." He said that he believes the potential negatives of nuclear power may be less than what he sees as the certain catastrophe of global climate change.

However opposition persists from the Sierra Club. Sierra Club executive director Carl Pope still thinks that: “Nuclear power poses a major security risk and produces a radioactive waste, which we have no way to store safely over the long term. It also makes absolutely no sense to waste tax dollars on new power plants when we have not secured or cleaned up the waste from existing nuclear power plants.”

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