NUCLEAR AND RADIATION SCIENCE

Inventing the Future

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PREFACE

“Nothing can make our life, or the lives of other people, more beautiful then perpetual kindness.”
Leo Tolstoy

“The anti-nuclear movement to which I once belonged has misled the world about the impacts of radiation on human health.”
George Monbiot, The Guardian, April 2011

“Do not go where the path may lead;
go instead where there is no path and leave a trail.”
Ralph Waldo Emerson

“Choose a job you love, and you will never have to work a day in your life.”
Confucius, Chinese philosopher

“There is only one thing in life worse than being talked about,
and that is not being talked about.”
Oscar Wilde

According to the International Committee of the Red Cross (ICRC) operating according to the Geneva Conventions of August 12, 1949, the world today needs the promise of a future without fear of annihilation and civilization extinction, and this promise is one step closer to becoming a reality with the adoption of the Treaty on the Prohibition of Nuclear Weapons in 2017: “The treaty strengthens the taboo against use of nuclear weapons and provides a strong disincentive for their proliferation. The treaty alone will not make nuclear weapons disappear overnight, but signals to all that use, threat of use and possession of these weapons is completely unacceptable.”

USA President Dwight D. Eisenhower made the following historic “Atoms for Peace” pledge about the peaceful use of nuclear energy at the 470th Plenary Meeting of the United Nations General Assembly on December 8th, 1953, the inspiration of a USA stamp:

> “To the making of these fateful decisions, the United States pledges before you – and therefore before the world – its determinations to help solve the fearful atomic dilemma – to devote its entire heart and mind ***to find the way by which the miraculous inventiveness of man shall*** not **be** *dedicated to his death,* but ***consecrated to his life***.”

Figure 1. President Dwight D. Eisenhower "Atoms for Peace" historical address at the 470th Plenary Meeting of the United Nations General Assembly on December 8th, 1953.

The harnessing of fire; a chemical process, by humanity defines its past and present. However, nuclear energy defines the future of humanity. Both fire and nuclear energy are feared for their possible destructiveness, but their benefits and advantages are indisputably recognized. Today, nuclear energy is a safe, clean, carbon-free most available and cheap form of mass and base-load power generation.

The National Science Foundation (NSF) released its "Science and Engineering Indicators" report in February 2014, including statistics that detail what Americans know about science. The report caused a stir by revealing that just 74 percent of Americans know that the Earth revolves around the sun [1].

In much of the world 1.6 billion people have no access to electricity whatsoever, 2.4 billion people still burn wood and manure as their main source of energy and 3.0 billion more people will be born in the next 30 years. Nuclear energy has the potential to provide a huge amount of energy and lift an astonishing number of people out of abject poverty.

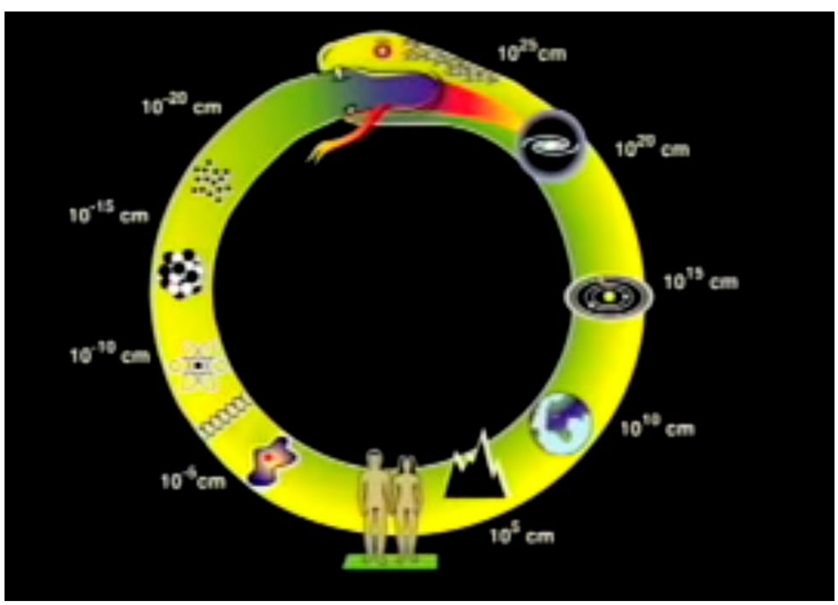


Figure 2. Cosmological scale. Unified theory of the small (Quantum Mechanics) and large (Gravitation, Relativity). Source: Cosmologist Sir Martin Rees.

KARDASHEV COSMOLOGICAL SCALE

The observable universe existed for 13.7 billion years. Two trillion galaxies made up of something like 20,000 billion billion stars surround our home galaxy. In the milky way alone scientists assume there are some 40 billion Earth like planets in the habitable zone of their stars.

The "Kardashev Scale" is a hypothetical measurement of a civilization's level of technological achievement. It was suggested by Russian astronomer Nikolai Kardashev in 1964. It is based on the magnitude of power a technological civilization is capable of harnessing and utilizing, and the fraction that a civilization can harness of the power from its parent star and from other native sources such as volcanic sources.

The scale considers the power level on a cosmological perspective and helps us understand how advanced our civilization will evolve into the future. Presently we are placed at around 0.75 over 100 on the Kardashev scale. A civilization using a theoretical Dyson's sphere surrounding its star would reach the 100 level.

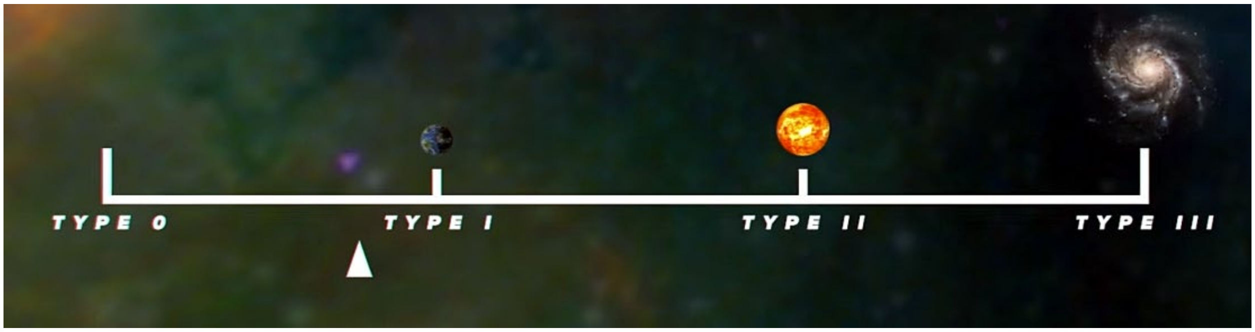


Figure 3. Kardashev cosmological scale. Earth is around 0.73 on this scale. Reaching higher scales for a civilization implies surviving successive termination or evolutionary filters and overcoming ever more challenging hurdles. An advanced civilization may have a rule that protects its security and safety. If a contained civilization gets too advanced to threaten their space, it would employ special forces to exterminate the threat. "Two possibilities exist: either we are alone in the Universe or we are not. Both are equally terrifying." - Arthur C. Clarke.

The scale has 3 base classes, each with a power usage level in Watts (W): Type I (10^{16}W) in their own planet, Type II (10^{26}W) within their star system, and Type III (10^{36}W) within their galaxy. Other astrophysicists have prolonged the scale to Type IV (10^{46}W) and Type V (the energy accessible to this kind of civilization would equal that of all energy accessible in not just our cosmos, but in all universes and in all time-lines). These additions reflect both energy access as well as the amount of knowledge the civilization has access to.

According to a formula advanced by cosmologist Carl Sagan, considering intermediate values not considered in the original Kardashev scale, by interpolating and extrapolating the values given for Type I to III levels:

$$K = \frac{\log_{10} P - 6}{10} \tag{1}$$

where P is power in Watts, W.

Accordingly, when in 1973 we harnessed 10 Terawatts of power, the Kardashev value was:

$$\begin{aligned} K &= \frac{\log_{10} 10 \times 10^{12} - 6}{10} \\ &= \frac{\log_{10} 10^{13} - 6}{10} \\ &= \frac{13 - 6}{10} = 0.7 \end{aligned} \tag{2}$$

In 2018, the world power consumption was 18.40 TW which placed humanity at 0.73 on the Kardashev scale.

One terawatt could power about 10 billion home-used 100-watt lightbulbs at the same time.

Jean-Luc Picard suggests that there are no type three or four civilizations as we would have found evidence of them because those types would inevitably leave trails of their existence. A type Omega civilization could however watch over us. Other type 0-1 civilizations cannot be ruled out since those would be undetectable with our current methods.

As humanity still sustains its energy needs from dead plants and animals as fossil fuels, it is sobering to realize that it is considered as a poor Type 0 civilization. It is hoped that humanity will reach Type I civilization in 100 – 200 years, if it is able to protect itself and survive against threatening calamities such as nuclear war, seismic and volcanic events, astral assailants as comets and asteroids and global pandemics: the Spanish flu outbreak in 1918-1919 lasted 15 months and killed over 50 million people.

FERMI PARADOX

A popular statement of the Enrico Fermi Paradox is:

"If the Universe is so big, where are all the aliens?"

In the summer of 1950, over lunch, American physicist Enrico Fermi, in reference to alien existence, addressed his colleagues:

"Don't you ever wonder where everybody is?"

This became known as the "Fermi Paradox". The Earth is 4.6 billion years old, and we could say that that was roughly the time it took a kind of life to be capable of space travel. Our universe is approximately 13.7 billion years old. Fermi postulated that during this period of time, the galaxy should have been overrun with intelligent, technologically advanced civilizations; yet we have no evidence of this despite decades of searching. Different theories tried to answer the Fermi Paradox, including the possibility that all alien life forms in oceans below a planet's surface, the "zoo hypothesis" which suggests that societies in our galaxy decided to not contact us to "preserve" us in the same way to how humans preserve some natural places, to prevent them from getting some kind of "disease" from humans.

Figure 4. Enrico Fermi.

Is there a "Great Filter" that limits the continuous existence of other forms of technological civilizations? A plausible optimistic answer is:

"We are here! We are just too early!"

Figure 5. The Apollo missions to the moon are the farthest humans travelled into their galaxy.

GREAT FERMI PARADOX FILTER HYPOTHESIS

The pessimistic answer to the Fermi Paradox is:

> ‘Some steps and hurdles to technological civilizations are so improbable to pass that virtually no one does.”

Some insurmountable hurdles could be astral impacts, gamma ray’s bursts, supernovae. earthquake and volcanism events. Some surmountable filters can be identified as self-inflicted extinction such as nuclear war, anthropogenic global climatic change and disease bacterial and viral pandemics caused by flawed-logic Gain of Function (GOF) Research. GOF is suspected to be a transparent disguise of Biological Weapons research in the USA, France, UK, Canada, Australia, Israel, Russia and China.

A Fine-Tuned Universe would be subject to the “The Anthropic Principle” which could be advanced as: “In order for the Universe to be observed, conditions inside it must permit for observers to exist in the first place.” Basically, you cannot observe how likely or unlikely your existence is if you do not exist. The Simulation Hypothesis and the Doomsday Argument have also been advanced.

SANKEY USA ENERGY DIAGRAM

According to the Energy Information Administration (EIA):

> “As of June 18, 2019, there are 59 commercially operating nuclear power plants with 97 nuclear reactors in 29 U.S. states. Of these nuclear plants, 33 plants have two reactors and 3 plants have three reactors. (The Indian Point Energy Center in New York has two nuclear reactors that the U.S. Energy Information

Administration counts as two separate nuclear plants).

The Palo Verde nuclear power plant in Arizona is the largest nuclear plant, and it has three reactors with a combined net summer electricity generating capacity of 3,937 MegaWatts (MW). The R. E. Ginna Nuclear Power Plant in New York is the smallest nuclear plant, and it has one reactor with a net summer electricity generating capacity of 508 MW.

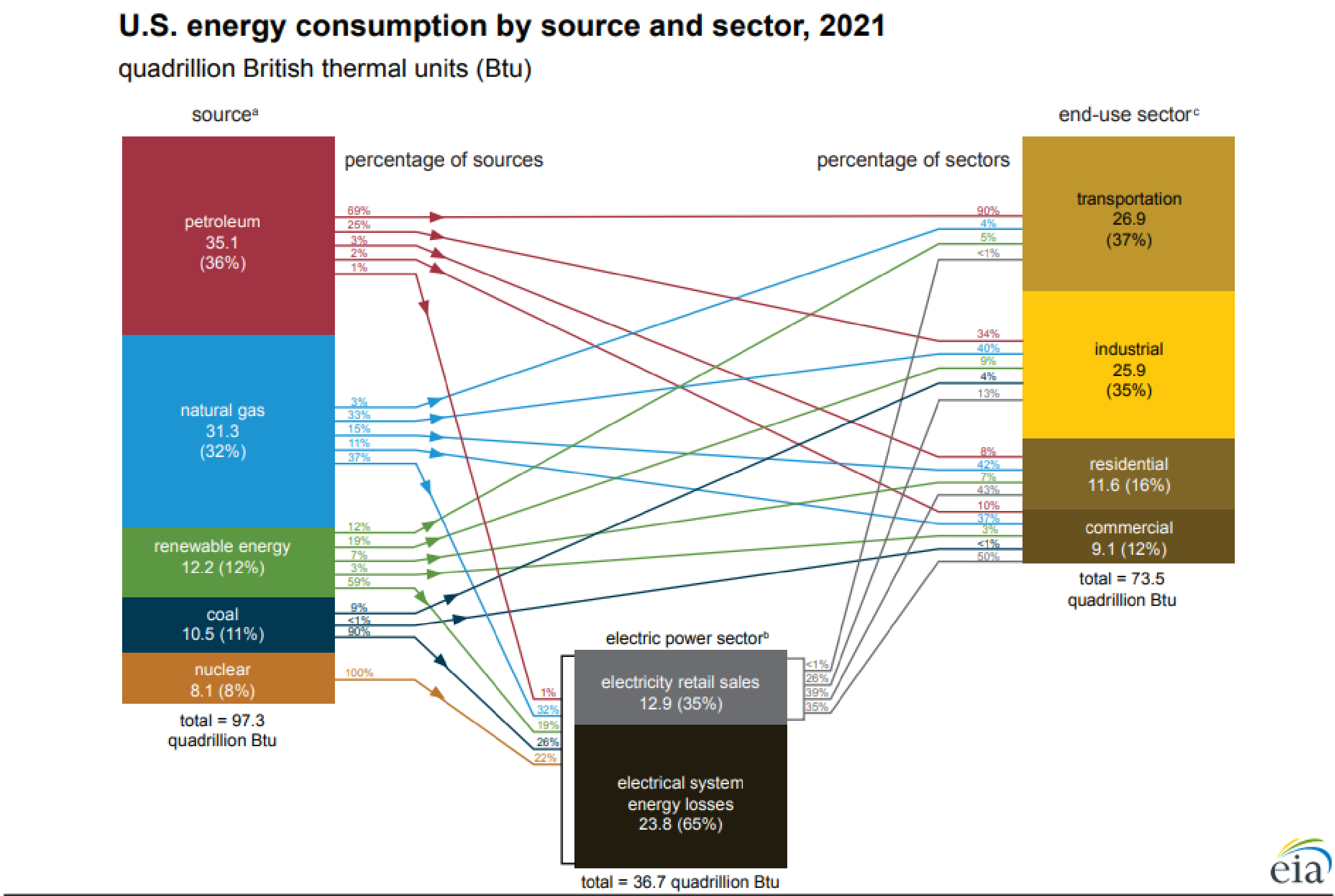
The newest nuclear reactor to enter service, Watts Bar Unit 2 with 1,150 MW net summer electricity generating capacity, began commercial operation in October 2016."

Two AP1000 units by Westinghouse/Toshiba of new nuclear reactors are under consideration: Vogtle Unit 3 started operation in 2023 and Unit 4 under construction in Georgia.

A number of 97 nuclear power plants of about 1,000 MWe of electrical power each, produce 20 percent of the USA electricity. If replaced by 5 new plants at each existing plant site, these can produce 100 percent of the USA's electricity. At $5,000 per kWe of installed capacity, this would require an infrastructure investment of (5 x 100 x 1,000 x 1,000 x 5,000) = $\$2.5 \times 10^{12}$ or 2.5 trillion dollars. Spent over a 20 years period, this would amount to $1.25 \times 10^{11} = 125 \times 10^{9}$ or $125 billion per year.

For a $500 billion dollars investment, the USA could build 400 new nuclear reactors in addition to its 97 existing nuclear reactors. This would allow the USA to generate 100 percent of its electrical energy needs with nuclear sources.

Three decades into the future, the world would have added 2 billion more people to its population, the global economy would double its present size. The world would need about 35 percent more food and energy than we produce now, and the growth in demand for electricity will nearly double.



Sources: U.S. Energy Information Administration (EIA), *Monthly Energy Review* (April 2022), Tables 1.3 and 2.1-2.6.

Note: Sum of components may not equal total due to independent rounding. All source and end-use sector consumption data include other energy losses from energy use, transformation, and distribution not separately identified. See "Extended Chart Notes" on next page.

[a] Primary energy consumption. Each energy source is measured in different physical units and converted to common British thermal units (Btu). See EIA's *Monthly Energy Review* (MER), Appendix A. Noncombustible renewable energy sources are converted to Btu using the "Fossil Fuel Equivalency Approach", see MER Appendix E.

[b] The electric power sector includes electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Energy consumed by these plants reflects the approximate heat rates for electricity in MER Appendix A. The total includes the heat content of are electricity net imports, not shown separately. Electrical system energy losses calculated as the primary energy consumed by the electric power sector minus the heat content of electricity retail sales. See Note 1, "Electrical System Energy Losses," at the end of MER Section 2.

[c] End-use sector consumption of primary energy and electricity retail sales, excluding electrical system energy losses from electricity retail sales. Industrial and commercial sectors consumption includes primary energy consumption by CHP and electricity-only plants contained within the sector.

Figure 6. USA Energy consumption by source and sector, 2021. Source: EIA.

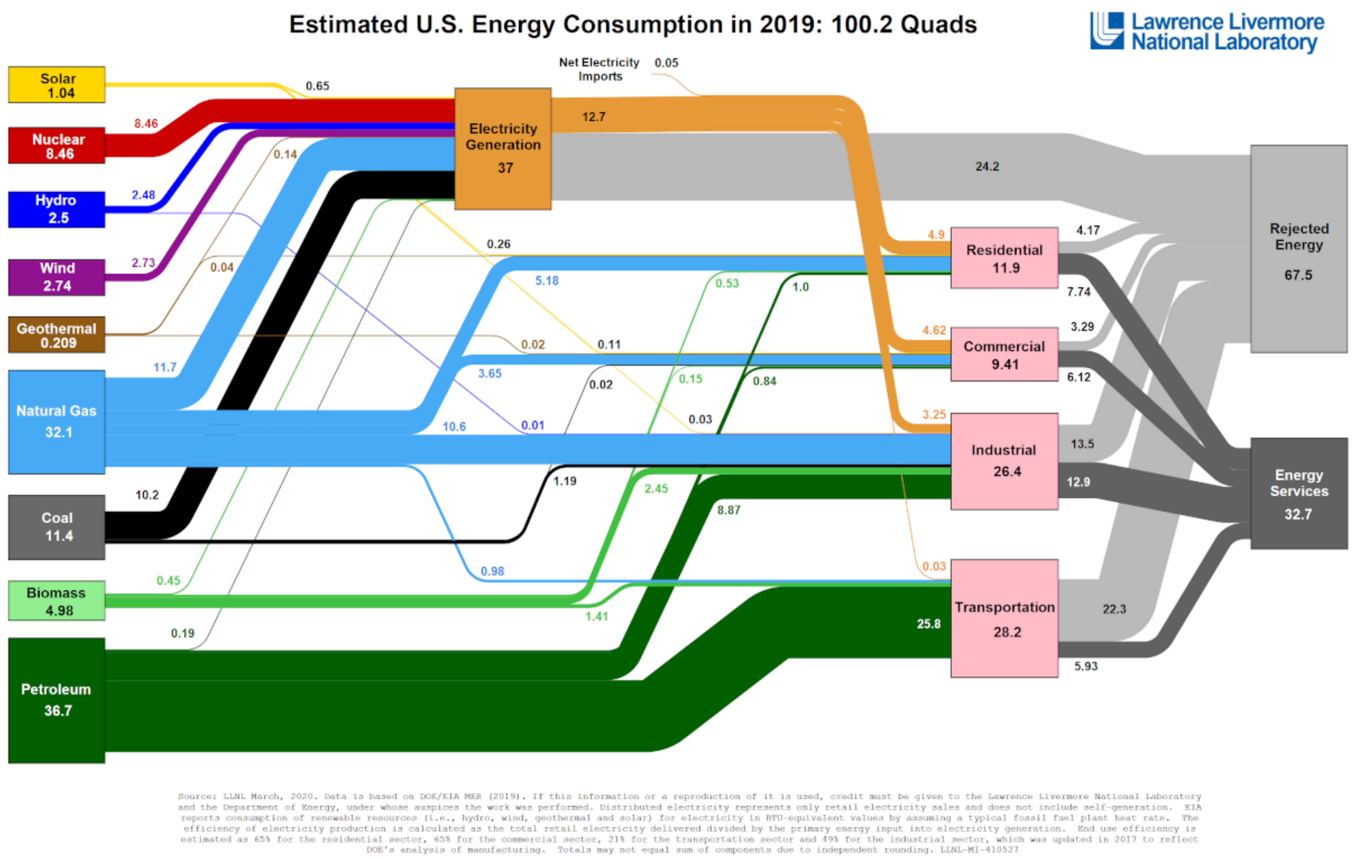


Figure 7. Sankey diagrams are a type of flow diagram in which the width of the arrows is proportional to the flow rate. USA energy flows 2018, 2019. The "quad" is a unit of energy equal to one quadrillion or 10^{15} BTUs (British Thermal Units) or 1.055 exajoules or 1.055×10^{18} Joules. With USA energy sources and consumption in 2018 as 101.2 Quads, Nuclear energy represents 8.44 Quads of the primary energy supply. USA energy sources and consumption in 2017, as 97.8 Quads, Nuclear energy represents 8.42 Quads of the primary energy supply. Source: EIA, LLNL.

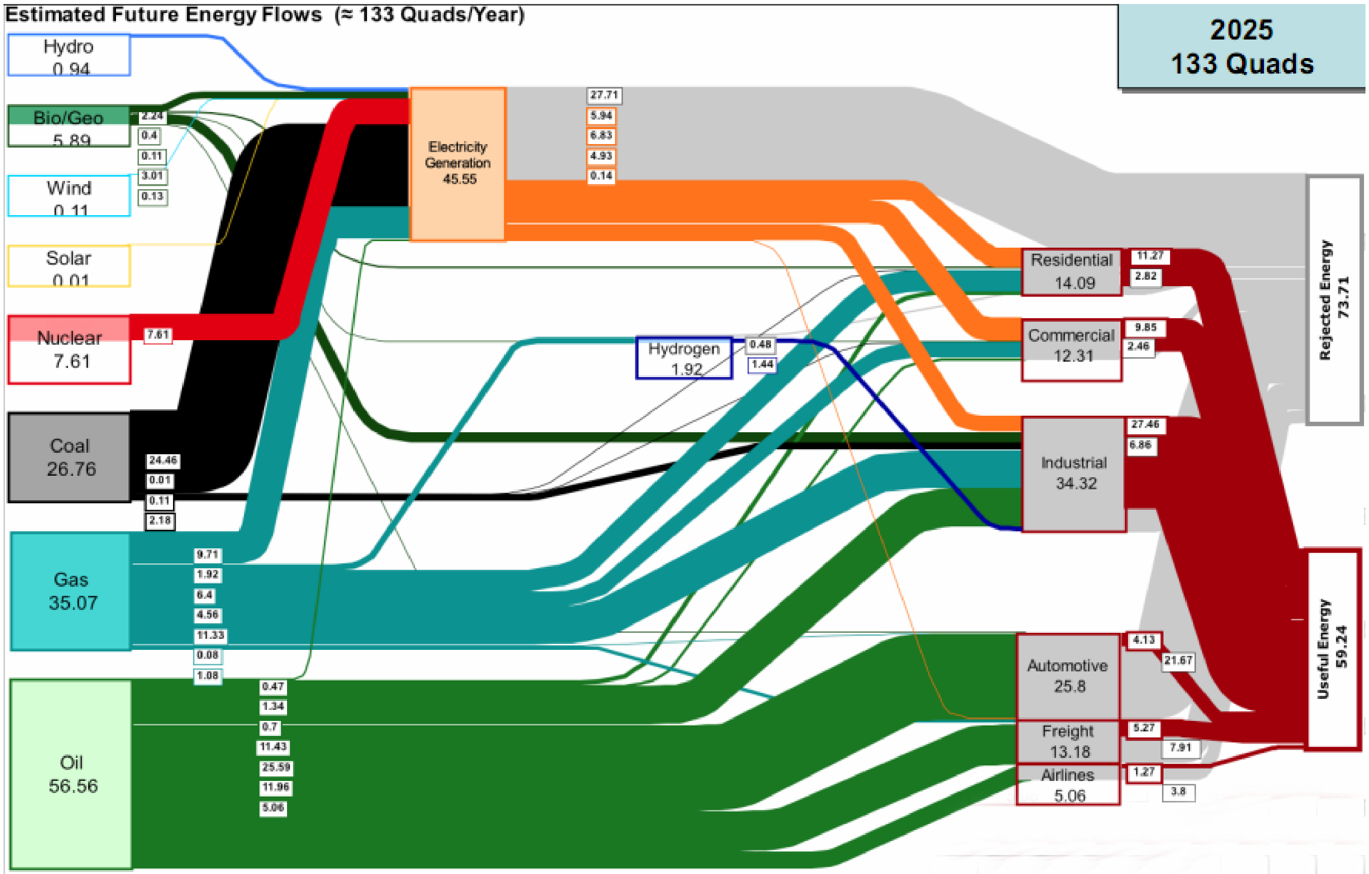


Figure 8. Projected Sankey Diagram, 2025. Source: LLNL.

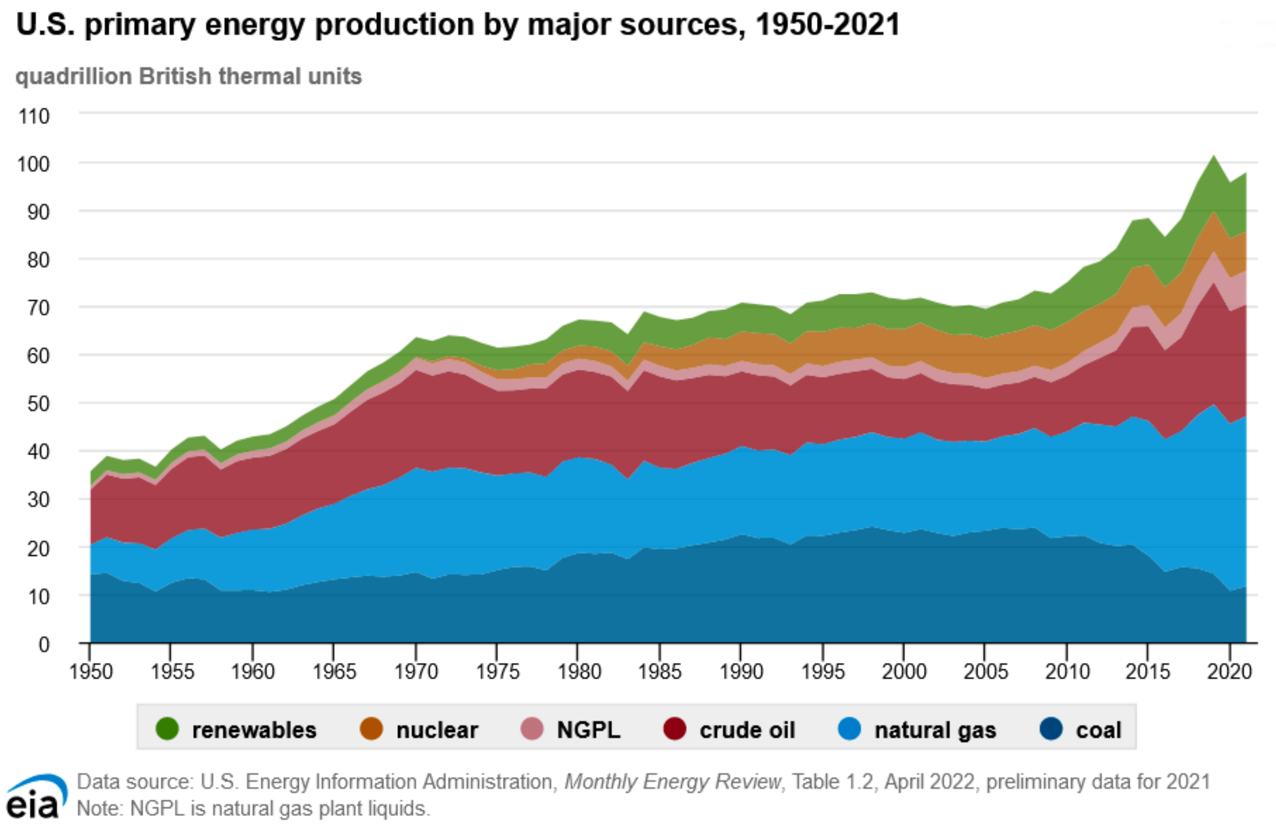


Figure 9. USA primary energy production sources, 1950-2021. Source: EIA.

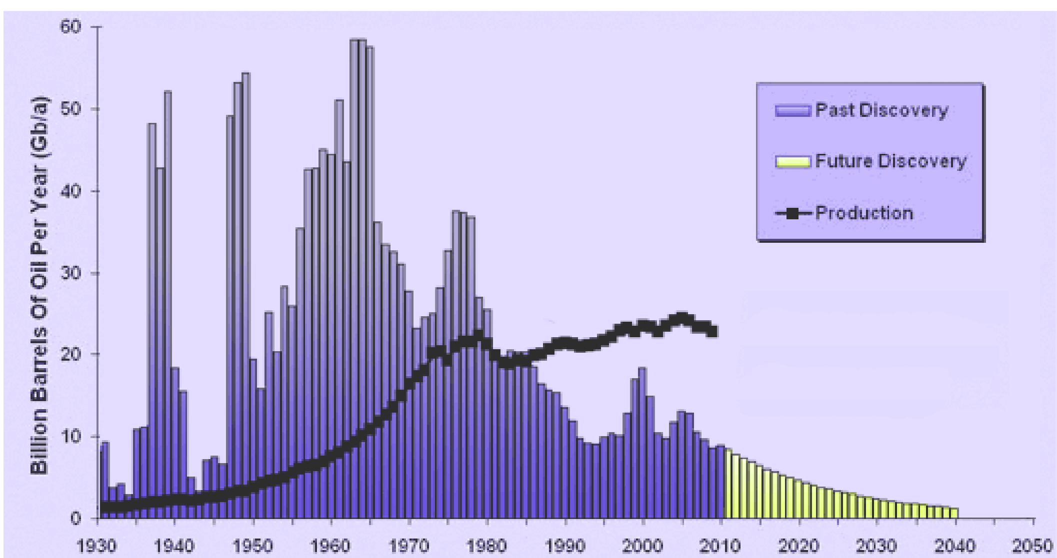


Figure 10. Peak Oil: Depletion of conventional petroleum discovery will eventually lead to lower production with a time lag.

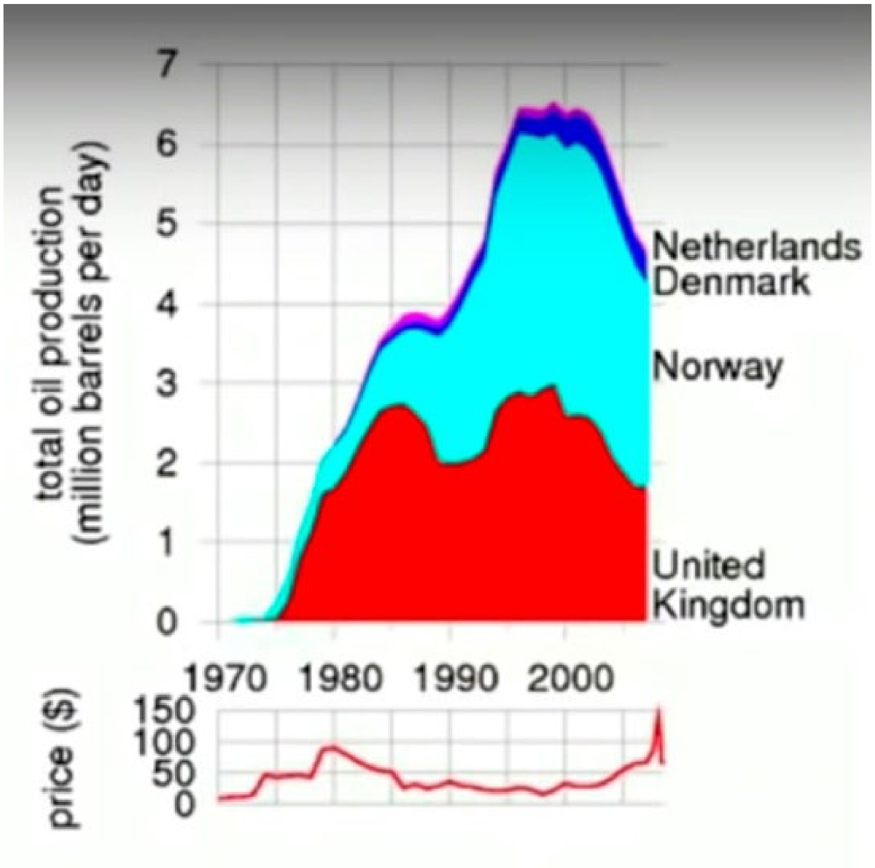


Figure 11. Peak "conventional oil" did in fact already occur in the North Sea: UK, Norway, Denmark and Netherlands. Source: David MacKay.

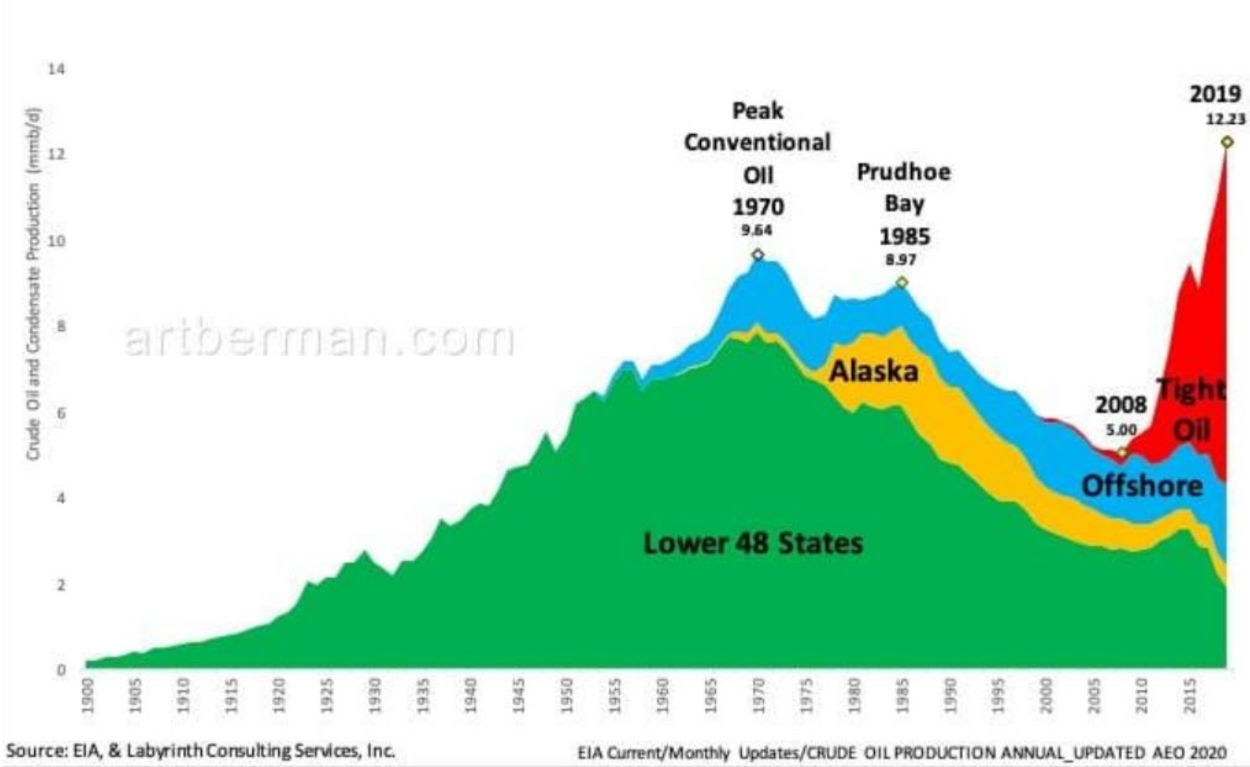


Figure 12. Peak conventional oil production did occur in 1970 in the USA. Tight oil from horizontal wells drilling and hydraulic fracturing or fracking generated a temporary peak in 2019 from "tight formations.". Permian Basin oil yearly production rate is declining at a 27 percent rate for horizontal tight oil wells. The Bakken and Eagle Ford plays have largely collapsed. None of the shale companies has been profitable on balance and cash positive. "The USA imported nearly 7 mmb/d of crude oil and condensate in 2019 and more than 9 mmb/d of crude oil and refined products. That is almost as much as China; the world's second largest economy, consumes." The USA being a net oil exporter is a myth: "The USA imports other people's crude oil, refines it and then, exports it. If a country imports unpainted cars, paints them green and then exports them, is it a net exporter of cars? No. It is an exporter of green paint." Source: Arthur Berman.

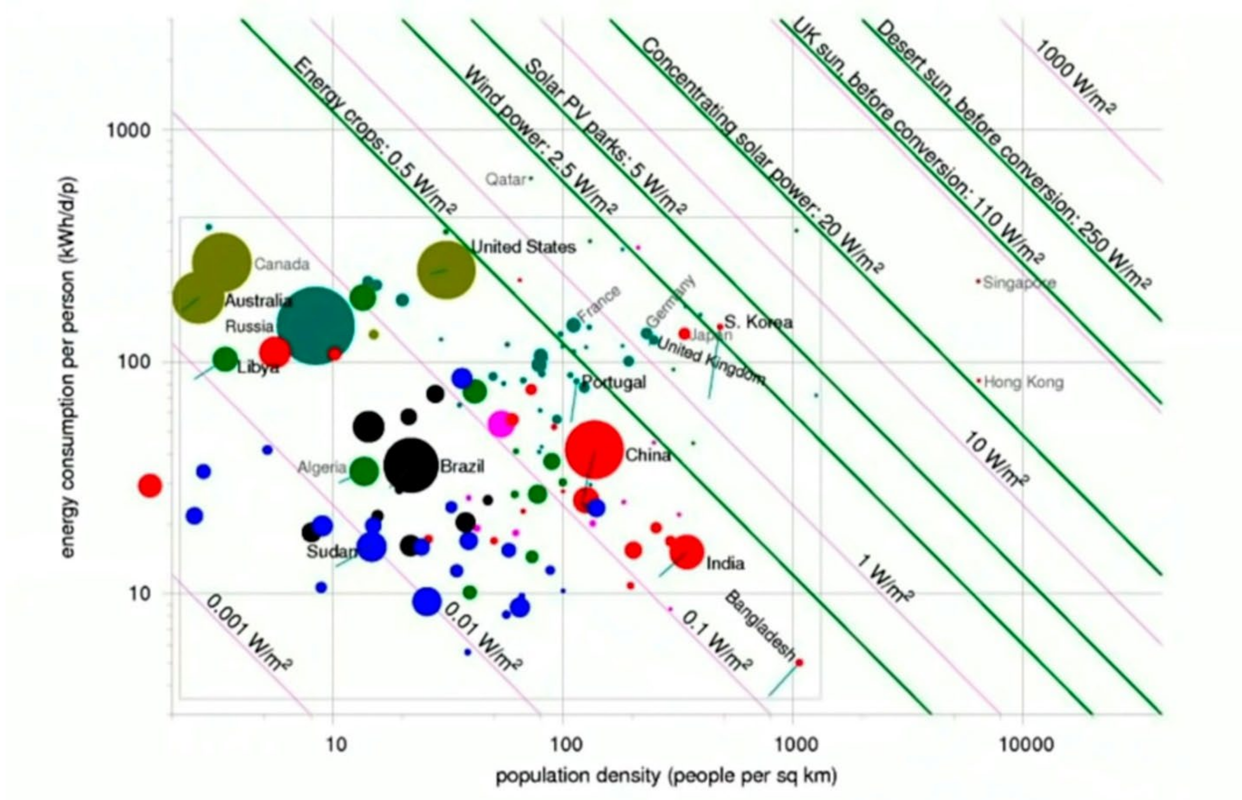


Figure 13. Only Nuclear Power at a power flux of 1,000 Watts/square meter and a combination of renewables can satisfy future global energy needs from the perspective of land area availability. Source: David MacKay.

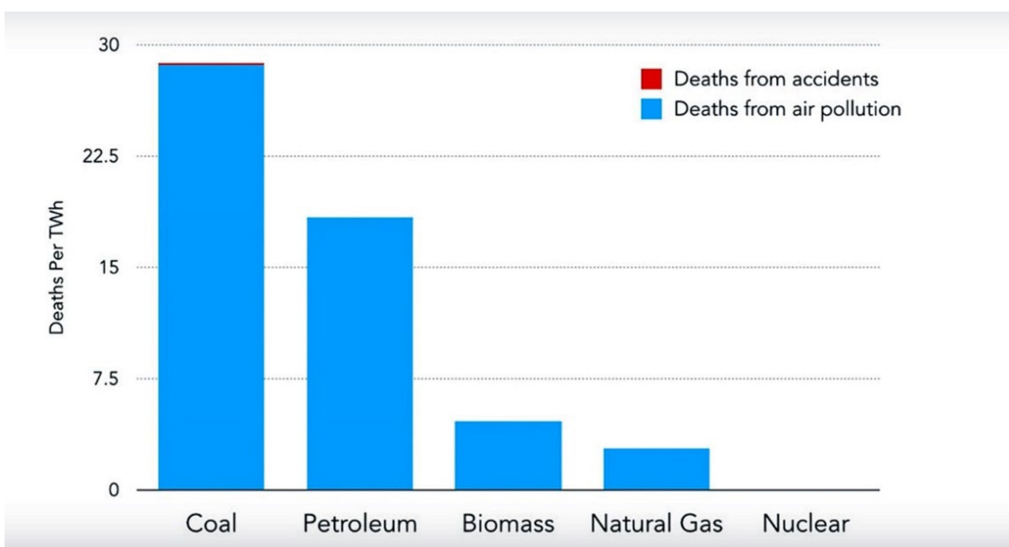


Figure 14. Risks from different energy sources. Source: Michael Shellenberger.

Table 1. Trends in energy usage in quads. Use of renewable sources is increasing and coal is being phased out.

	2015	2017	Percentage change
Solar	0.532	0.775	+45.7
Wind	1.82	2.35	+29.1
Hydroelectric	2.39	2.77	+15.9
Biomass	4.72	4.91	+4.0
Petroleum	35.4	36.2	+2.3
Nuclear	8.34	8.42	+1.0
Natural gas	28.3	28.0	-1.1
Geothermal	0.224	0.211	-5.8
Coal	15.7	14.0	-10.8

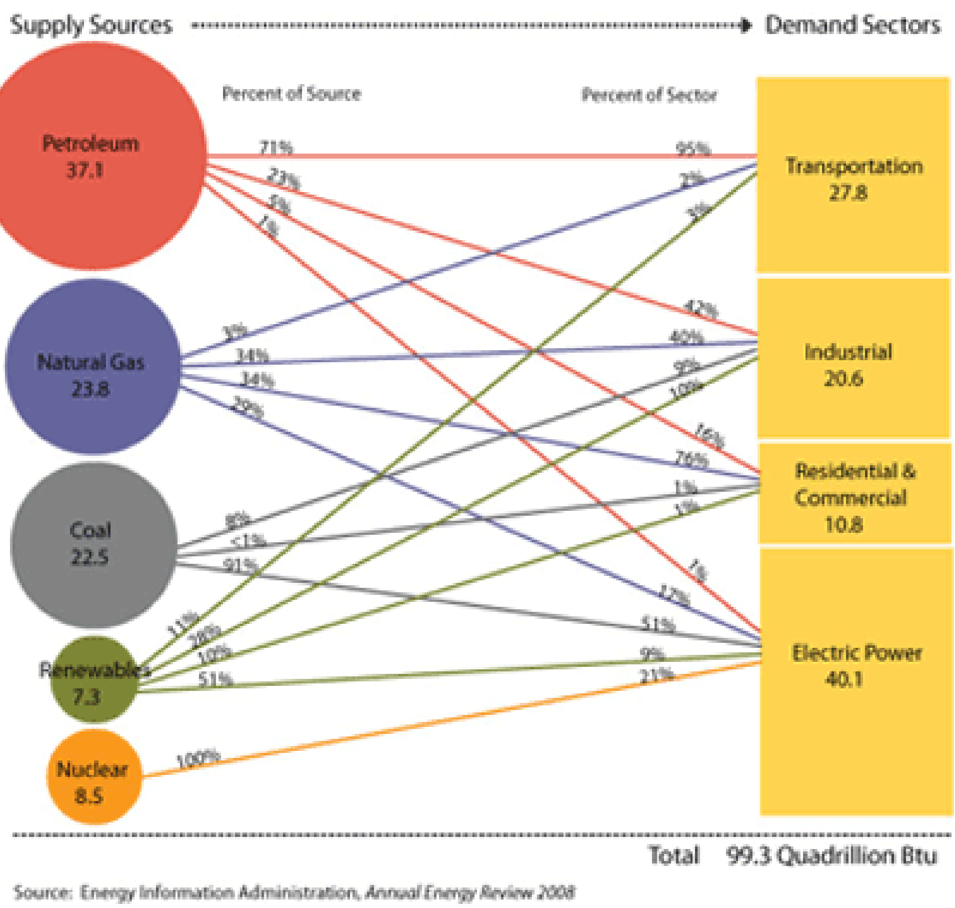


Figure 15. Energy supplies and uses, 99.3 Quads, 2008. Source: DOE.

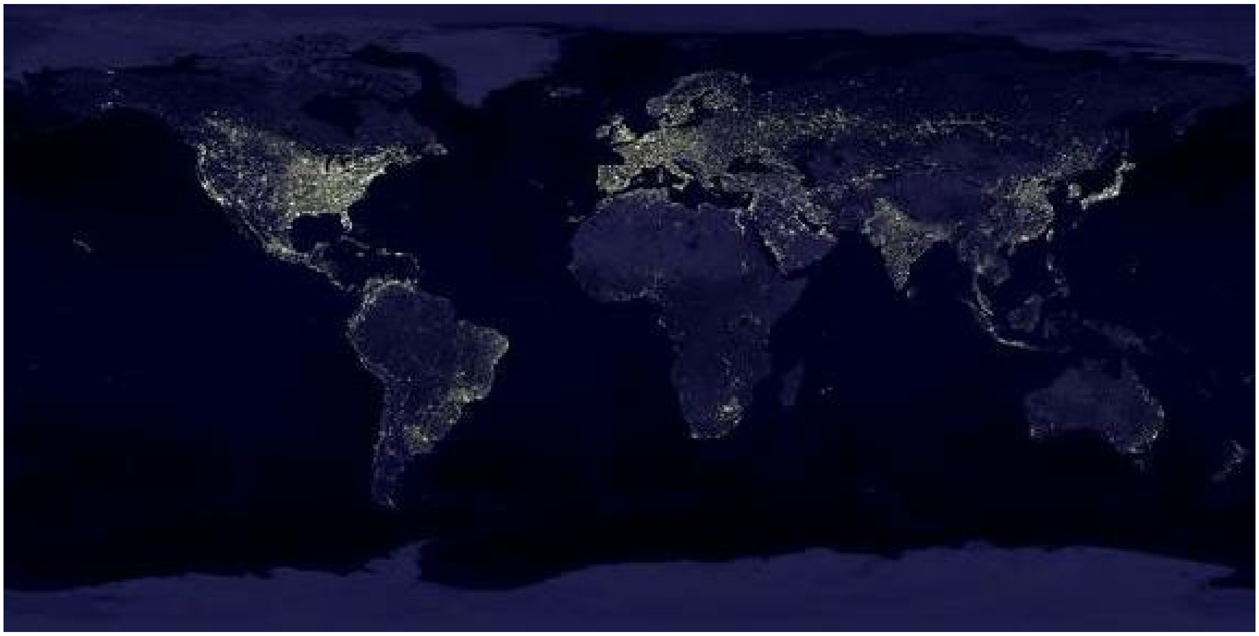


Figure 16. Earth night lights in industrialized nations use electricity from different sources. Source: NASA.

Figure 17. North Africa and Middle East night electrical lights. Source: NASA

Figure 18. Nile valley electrical lights. Source: NASA.

Nuclear energy's limited contemporary role in producing electricity is being redefined into a visionary future role of producing process heat for fresh water production from sea water, hydrogen from water and natural gas as an energy carrier and storage medium for a battery-based or fuel-cell-based transportation economy replacing the Internal Combustion Engine (ICE), fertilizer, steel, aluminum production and other agro-industrial processes. This is in addition to long distance transportation using magnetically levitated trains on superconducting hydrogen cooled wires, ship propulsion on Earth, and in the future, rocket propulsion among planetary systems, fulfilling human's destiny to spread life among other planetary systems surrounding their stars.

Figure 19. Nuclear agro-industrial complex for arid regions of the world along sea shores producing fresh water for agriculture and electricity for industrial processes.

Table 2. USA energy and electricity consumption, 2016. Source: EIA, Energy Information Administration.

Source	Percent of total
Hydrocarbons: Coal, oil, natural gas	80.7
Nuclear	8.7
Biomass	5.0
Hydroelectricity	2.7
Wind	2.1
Solar	0.6
Geothermal	0.2

Table 3. USA electricity generation by source, amount, and share of total in 2017.

Energy source	Billion kWh	Percent of total
Total - all sources	4,015	
Fossil fuels (total)	2,516	62.7
Natural gas	1,273	31.7
Coal	1,208	30.1
Petroleum (total)	21	0.5
Petroleum liquids	13	0.3
Petroleum coke	9	0.2
Other gases	14	0.4
Nuclear	805	20.0
Renewables (total)	687	17.1
Hydropower	300	7.5
Wind	254	6.3
Biomass (total)	64	1.6
Wood	43	1.1
Landfill gas	11	0.3
Municipal solid waste (biogenic)	7	0.2
Other biomass waste	3	0.1
Solar (total)	53	1.3
Photovoltaic	50	1.2
Solar thermal	3	0.1
Geothermal	16	0.4
Pumped storage hydropower	-6	-0.2
Other sources	13	0.3

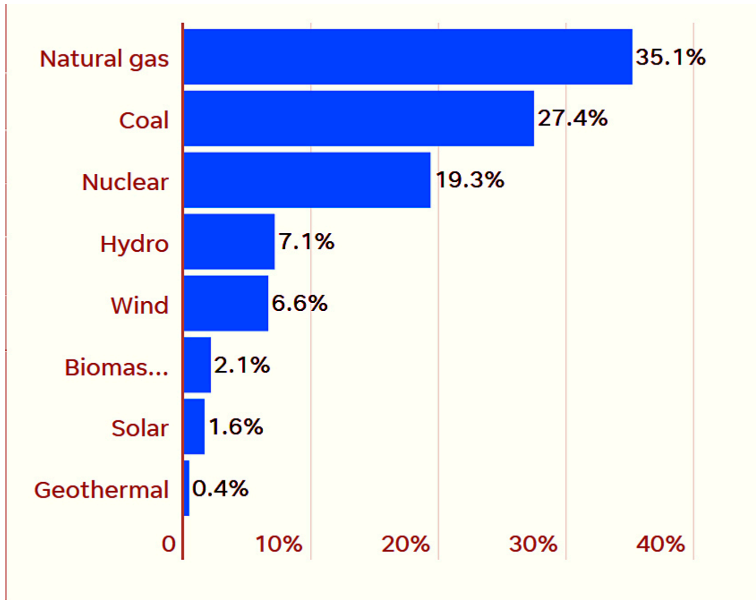


Figure 20. USA sources of electricity. Source: EIA, Energy Information Agency.

Nuclear energy as humanity's new fire is being reconsidered in conjunction with wind, tidal, geothermal and solar energies as the clean, non-carbon and green energy options for what is referred to as the post-petroleum economy. The threat of global climatic variation came along and the world woke up to the fact that burning fossil fuels for a planet with 7 billion energy hungry souls as of October 2011, longing to emerge from poverty, just was not the only option.

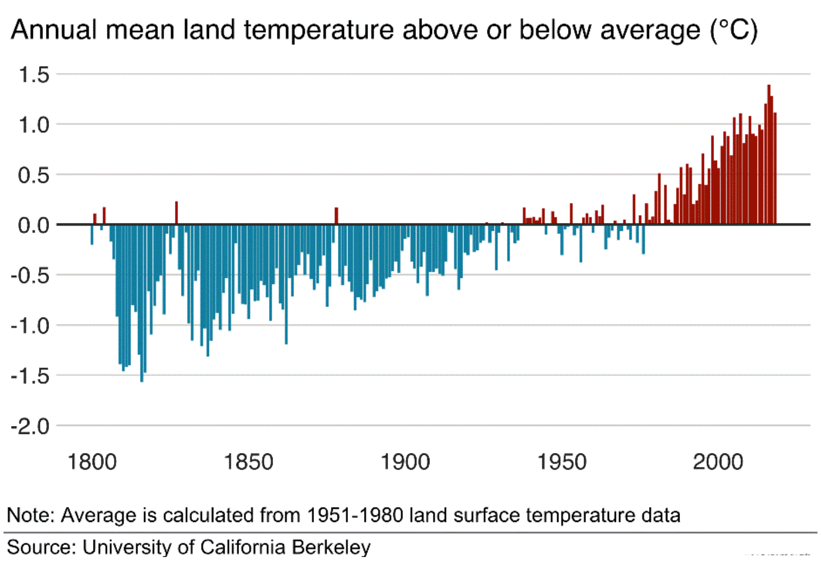


Figure 21. Annual Temperature above and below average, degrees Celsius.

Figure 22. The South Texas Project nuclear power plant is surrounded by a 22,200 acres nature preserve and wildlife habitat. 1988-1989 photograph.

Figure 23. The Barakah four-unit South-Korean-designed APR-1400 reactors are being built at Barakah, in the Dhafrah region of Abu Dhabi, United Arab Emirates (UAE) by a consortium led by Korean Electric Power Corporation (Kepco). Construction began on the first unit in July 2012, unit 2 in May 2013, unit 3 in September 2014 and unit 4 in September 2015. The Barakah plant was developed by the Emirates Nuclear Energy Corporation (ENEC). The 1,400 MWe Unit 1 started operation in August 2020. The four units are expected to supply 25 percent of the UAE's electricity demand.

Uranium is an alternative to coal which produces 1,000 grams of CO_2 per kilowatt-hour of electrical energy, versus uranium which produces no more than 21 grams for the equivalent amount of electrical energy. With 40 percent of the world's CO_2 emissions being produced through the generation of energy, the use for uranium provides a solution as the climatic change debate evolves.

As of 2019, The USA operated a fleet of 97 reactors, producing 19 percent of its electricity. Globally, there were 435 reactors in 30 countries operation with 72 under construction, 164 in the planning stage and 317 as proposed projects.

In the USA a half-dozen aging reactors announced shutdowns. The most vulnerable are small, old, single-reactor plants with high operating expenses relative to typical USA plants, and reactors located in unregulated merchant electricity markets where they get out-competed by cheap natural gas power plants. Post-Fukushima safety upgrades are also playing a role at reactors with slim operating margins and short remaining operating lives.

In the USA, nuclear power represents about 100 GW of operating capacity. It will continue to lead the world until surpassed by China in the mid-2020s. In March 2013 construction began on the Vogtle units 3 and 4 in Waynesboro, Georgia. These units are all of the AP-1000 (Advanced Passive 1,000 MWe) by the Toshiba-Westinghouse company.

The Tennessee Valley Authority (TVA), a USA public utility has completed in 2016 the construction of the Watts Bar unit 2 that it started in the 1980s after its decision in 2007 to complete the construction of the unit.

SUSTAINABILITY OF ENERGY ELECTRICAL RESOURCES: THE SMART GRID

For a sustainable electrical energy supply into the future, the engineering and scientific consensus is the need for the implementation of a "Smart Energy Grid System" in both developed and emerging economies. Using a Complex Systems description, its different components would include an energy mix at its nodes with interconnected exchanges:

1. Base power stations including nuclear, coal, hydroelectric and geothermal stations. These supply continuous electric service to industries and basic infrastructures such as street lighting,
2. Renewable Energies. These include wind, solar thermal and photovoltaic, and essentially have a zero cost of the energy supply but suffer from their nature as intermittent sources and must be provided with backup systems such as gas turbines, except for biomass,
3. To overcome the intermittency problems of the renewables, storage systems such as battery, hydrogen and pumped storage, as well peaking sources such as natural gas turbines plants are also needed.
4. Decentralized power production, conservation and Smart Metering for consumers and industry would encourage the use of the produced energy when it is available. In this case, they are paid for the energy they produce and pay for the actual unsubsidized price of the energy they buy, which would encourage its production.

To advance an analogy, consumers must be encouraged by laws and regulations to catch the fish, use some of it for their own need, and sell the surplus into the marketplace. This concept is implemented in Germany where farmers use part of their pastures to produce photovoltaic electricity, use part of it on their farms, store part of it, and sell the surplus to the electrical grid system. In Denmark, homeowners with small tracts of lands produce wind power for their own use

and the electrical utilities are obligated by law to purchase their excess surplus production and feed it into the electrical grid.
5. The Internet of Things (IoT), decentralized control of the smart grid system turning components of the Smart Grid system on and off, depending on the demand.

Energy Internet of Things "IoT" Smart Electric Grid Configuration

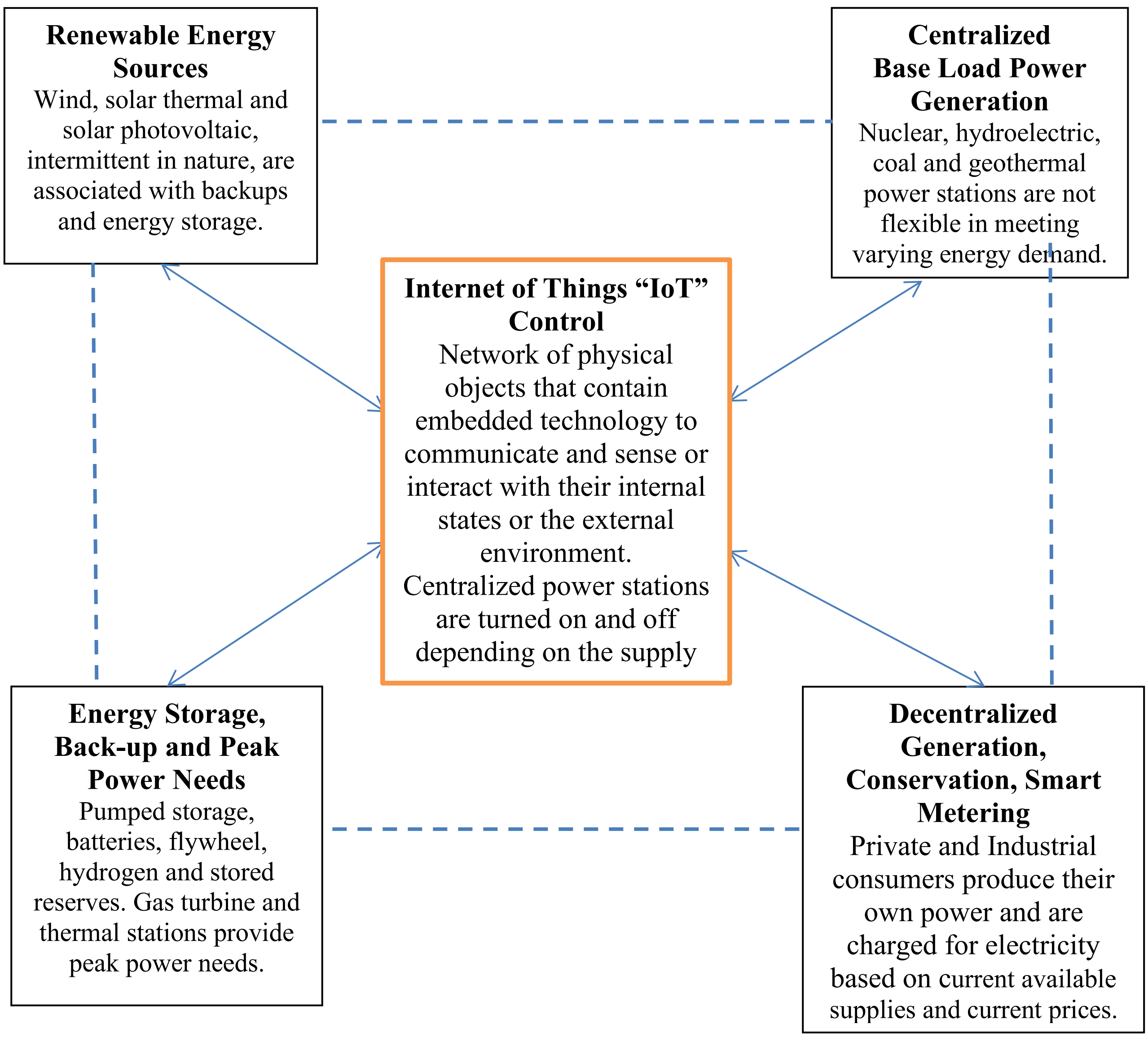


Figure 24. Architecture of Smart grid configuration using the Energy Internet of Things "IoT', connecting renewables and conventional energy sources to electricity consumers within the smart power grid paradigm.

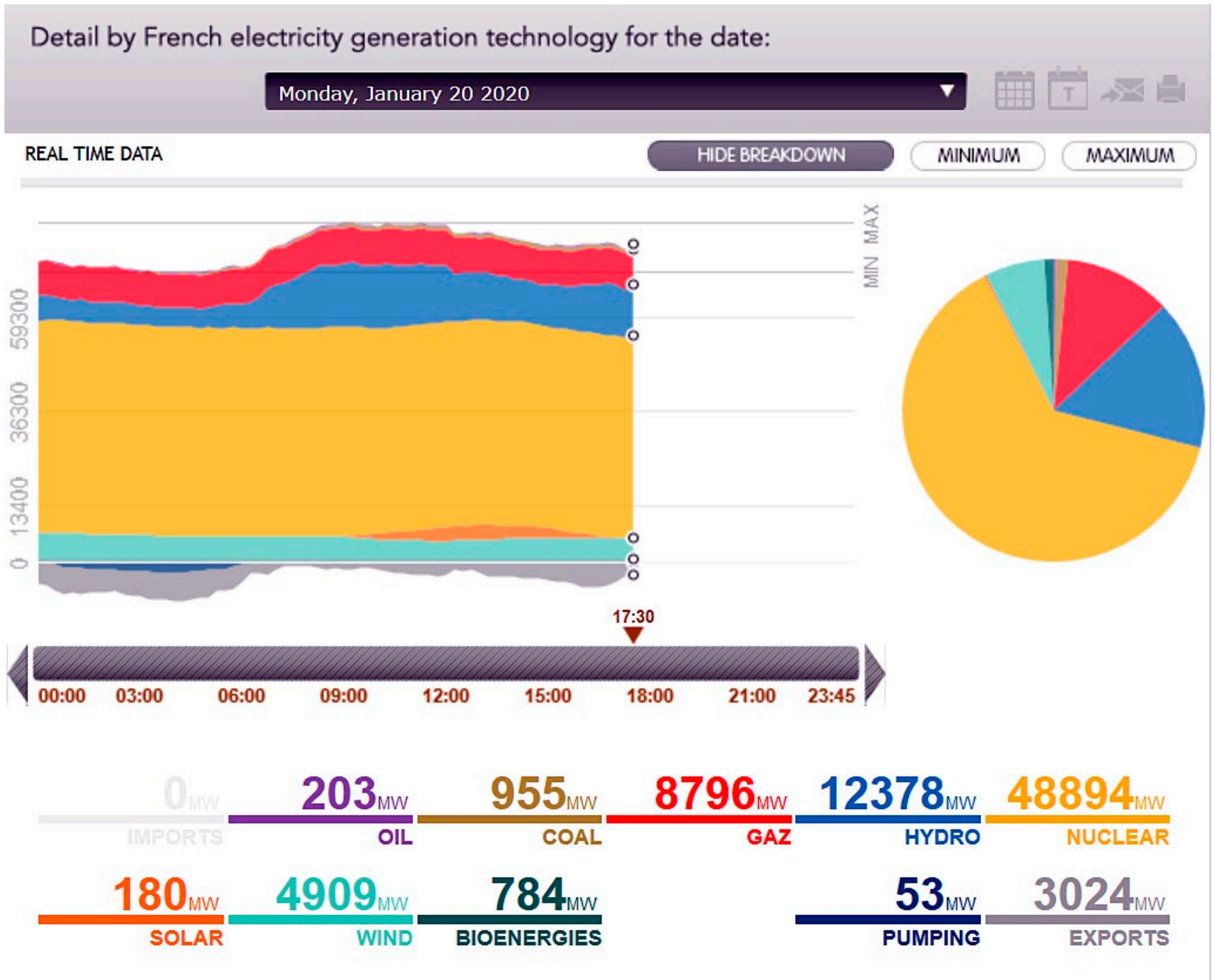


Figure 25. Energy Source allocation in electrical power production over 17.3 hours of a 24 hours period, France 2020. Source: RTE.

In the choice of the base-load supplies of energy, the existing resources of hydro-power, fossil fuel resources and nuclear fuel ores must be taken into consideration. It is obvious that the construction of hydroelectric power stations is predicated on the availability of dam sites, gas turbine stations on the availability of natural gas resources, and nuclear plants on the availability of uranium resources from primary ores or from secondary sources such as from phosphate rocks and from sea-water in the future.

According to the 2014 British Petroleum's (BP) Company 2035 Energy Outlook Report, the USA is projected to become energy independent by 2035 while also becoming the world's top liquids and natural gas producer. The report predicts worldwide energy demand to grow by 41 percent within the next 10 years; a slowdown of the 52 percent growth rate of the last 20 years. Energy production in the USA is expected to increase by 24 percent, while consumption would increase by just 3 percent. Energy used in power generation would increase by 10 percent. Coal is expected to remain as the dominant power source, but its share would drop from 43 to 35 percent.

Globally, petroleum, natural gas, and coal accounted for 27 percent of the total energy mix by 2015, with nuclear, hydropower and renewables accounting each for 5-7 percent of energy demand.

Renewables, including biomass, are the fastest growing source of electricity generation and would exceed nuclear as a source of primary energy by 2025. The USA and other industrialized nations will see increased energy efficiency and see their economies grow whilst energy use falling down.

It must be noted that the renewable sources of energy are characterized by the use of a large labor supply providing job opportunities in highly populated economies. Their implementation is rapid: it takes about 2 years in the USA for the implementation and production from wind parks since they only require local licensing and regulations, whereas nuclear power stations require 10 years or more because they are bound by federal bureaucratic regulations. Local county boards encourage power generation as a source of property taxes helping in financing roads, schools, water, sanitary and health care facilities.

On the issue of human-power availability, the statistics are that the engineering staff at nuclear power stations is composed of 40 percent as mechanical and chemical engineers, 30 percent as electrical engineers, and the rest are nuclear, civil and other engineers from the other engineering disciplines. The point is that all the engineering and technical disciplines must be educated in the operation and management of nuclear power plants, which is a cross-disciplinary activity.

Nuclear Power is advisably introduced into an economy as part of a balanced energy mix. Some experts suggest 1/3 Fossil, 1/3 Nuclear, and 1/3 Renewable energy sources. In early 2014, the USA was subject to a cold wave, designated as a "Polar Vortex," that froze the piles of coal at coal power plants, and gas turbine and diesel fuel plants could not be started. What saved the nation from brownouts and blackouts was its installed wind and nuclear capacities.

The USA operates about 500 coal power stations producing 37 percent of its electricity and a fleet of 97 nuclear power plants in 31 of its states and accounting for 19 percent of its electrical generation. These operate as a base load source of electricity production at a reliable 90 percent Capacity Factor (CF).

At the Clinch River, Oak Ridge, Tennessee, abandoned fast breeder reactor project site, the Tennessee Valley Authority, the largest public utility in the USA, is joining the engineering firm Babcock & Wilcox to build two prototype 180 MW Small Modular Reactors (SMRs).

Globally, there are 439 nuclear power plants in operation, with 62 plants in the construction stage, 139 plants in the planning stages, and 326 plants in the proposal stages, according to data from the World Nuclear Association. Japan is recovering from the Fukushima earthquake and tsunami, and is restarting its fleet of nuclear power plants. China plans on constructing 50 reactors by 2030 in addition to its 26 under construction. India plans to build 35 reactors.

NUCLEAR POWER LOAD FOLLOWING

In a coordinated energy mix system a nuclear fleet is capable of a degree of load following, even though the capability of individual units to follow the load may be limited. France's nuclear reactors comprise 90 percent of Electricité de France, EdF's capacity and hence are used in load-following mode. They are even sometimes closed over weekends, so their capacity factor is low by world standards, at 77.3 percent. However, availability is almost 84 percent.

Plants being built today according to European Utilities' Requirements (EUR), have load-following capacity fully built-in. Normally base-load generating plants, with high capital cost and low operating cost, are run continuously, since this is the most economic mode. But also it is technically the simplest way, since nuclear and coal-fired plants cannot readily alter power output, compared with gas turbine or hydroelectric plants.

The high reliance on nuclear power in France poses technical challenges since the reactors collectively need to be used in a load-following mode. Electricity, without energy storage is being produced on a per-demand basis. As it is not usually stored, the generation output must be exactly matched to the consumption rate at all times. Any change in demand or generation of electricity at a given point on the transmission network has an instant impact on the entire system.

In France, because electricity is cheap relative to other sources, electric heating is widespread and a 1°C temperature change in the winter season means that demand on the grid changes by about 2,400 MWe, making it the most temperature-sensitive demand in Europe, adding to the normal challenge of satisfying the balance between supply and demand.

France has the biggest grid network in Europe, made up of some 100,000 km of high and extra high voltage lines, and 44 cross-border lines, including a DC link to the UK. Electricity is transmitted regionally at a 400 and 225 kilovolts level. Frequency and voltage are controlled from a national control center, but dispatching of capacity is done regionally.

France's nuclear capacity is from Pressurized Water Reactor, PWR units. There are two ways of varying the power output from a PWR:

1. Using normal control rods to reduce power means that there is a portion of the core where neutrons are being absorbed rather than creating fission, and if this is maintained it creates an imbalance in the fuel burnup, with the lower part of the fuel assemblies becoming more reactive that the upper parts.
2. Shim control or boron addition to the primary cooling water: Adding boron as boric acid to the water diminishes the reactivity uniformly, but to reverse the effect the water has to be treated to remove the boron, which is slow and costly, and it creates a radioactive waste.
3. Use of less absorptive 'grey' control rods which weigh less from a neutronic point of view than ordinary control rods and they allow sustained variation in power output.

Flexible load following from a nuclear fleet contributes to regulation of three issues:

1, Primary power regulation for system stability: when frequency varies, power must be automatically be adjusted by the electric turbine.
2. Secondary power regulation related to electricity trading contracts.
3. Adjusting power in response to demand such as a decrease from 100 percent during the day, down to 50 percent or less during the night, and responding to changes in renewable inputs to the grid, such as from wind power generation.

PWR plants are only flexible at the beginning of their life-cycle, with fresh fuel and high reserve reactivity. A freshly loaded reactor can reduce its power from 100 percent to 30 percent within 30 minutes. But when the fuel cycle is at around 65 percent burnup, these reactors are less flexible, and they take a rapidly diminishing part in the third, load-following, aspect above. When they are at 90 percent burnup through the fuel cycle, they only take part in frequency regulation, and essentially no power variation is allowed, unless necessary for safety. So at the very end of the cycle, they are run at steady power output and do not regulate or load-follow until the next refueling outage.

Only in a coordinated system a nuclear fleet is capable of a degree of load following, even though the capability of individual units to follow load may be limited. Plants being built according to European Utilities' Requirements (EUR), have load-following capacity fully built in.

SOCIO-ECONMIC CONSIDERATIONS

Access to nuclear technology and hydrocarbon resources remains a privilege to the developed nations. On December 10, 1948, the United Nations General Assembly ratified the Universal Declaration of Human Rights whose Article 25 states:

> "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control."

This establishes the right of humans world-wide to material welfare and security through access to energy sources. The highest energy use in human history occurred in 2010 when global energy consumption rose by 5.6 percent, while emissions that affect the climate increased by 5.8 percent. Petroleum consumption; which accounts for a third of primary energy use, is forecast to grow from 84 billion barrels per day in 2005 to 116 million barrels per day by 2030, despite increasingly difficult access to petroleum and the resulting heightened risks to the environment.

One-seventh of the 7 billion humans as of 2011 remained undernourished, two billion people lacked adequate medical care, one billion had no access to clean water, and more than 200 million children were enslaved into child labor. From this perspective, Article 25 of the United Nations General Assembly's Universal Declaration of Human Rights still remains as a utopia for the billion people at the bottom of the socio-economic ladder.

Great disparities of wealth are increasing globally. It is shocking to learn that just 1,200 persons own about three percent of the worldwide private assets, while half of humanity owns less than two percent, resulting in a generational injustice of historic proportion. Contemporary society and its politics refuse to restrict the privileges of resource use as it was through history. Protecting privileged access to sources of energy to the developed nations, including nuclear technology, is presently the main purpose of political activity in contradiction to the main tenets of human rights.

About 39 percent of the USA nuclear power workers became eligible for retirement by 2016 according to the Nuclear Energy Institute and necessitates their replacement by 25,000 new recruits into the work force. With the availability of about 10,000 possible recruits from Germany where its aged nuclear plants are being retired in response to the Fukushima accident, the number of nuclear jobs openings in the USA can be estimated as around 15,000. There exists a dearth of students in the field of Nuclear Engineering, with the USA universities granting just 715 graduate and undergraduate degrees in 2009. A Nuclear Regulatory Commission (NRC) statistic estimates the composition of the typical 800-persons work force at a nuclear power plant as composed of 40 percent Mechanical and Chemical Engineers, 30 percent Electrical Engineers and just 15 percent as Nuclear and other engineers. This necessitates the education of engineers from the other disciplines of Electrical, Mechanical, Chemical, Bioengineering, Computer Science and Civil and Environmental Engineering for employment in the nuclear field.

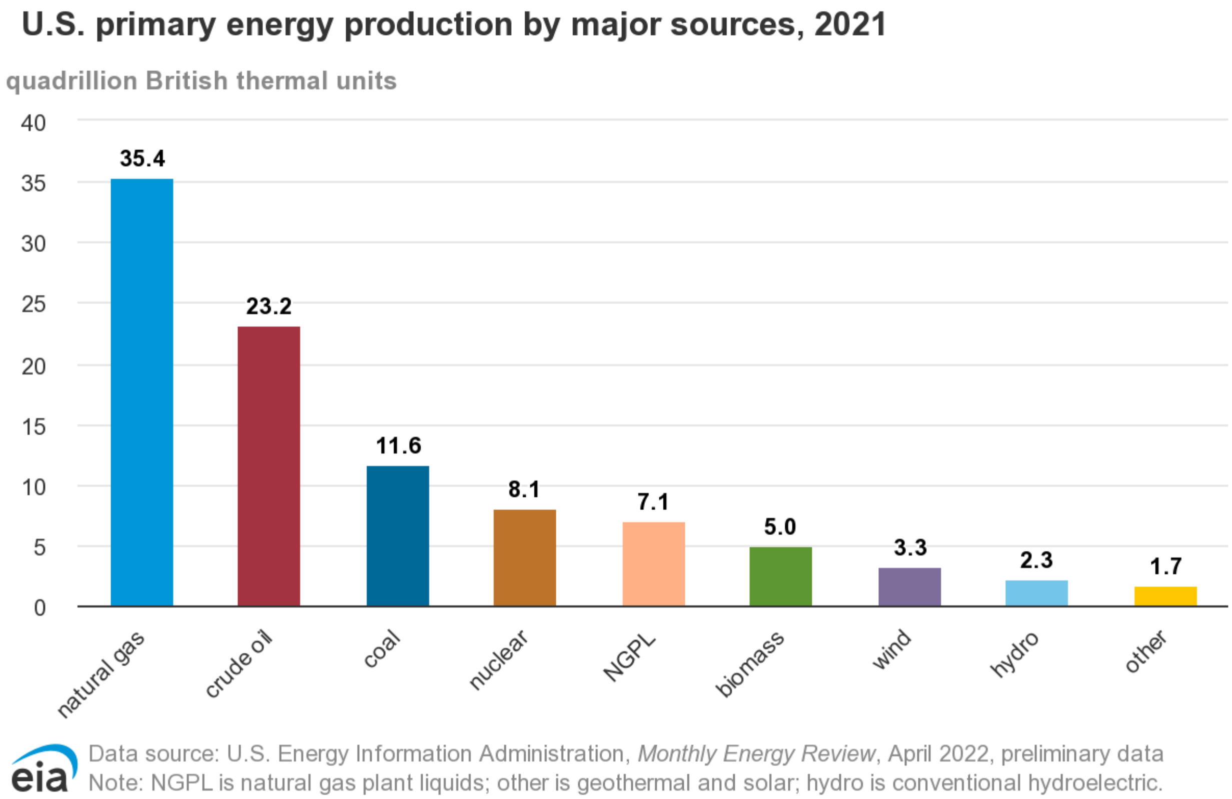


Figure 26. Global energy use according to energy source, 2011. Source: EIA.

Nuclear power production offers favorable economic, political, social and scientific advantages as a viable source of energy and is likely to be an answer to the expected supply and demand imbalances that the energy sector is likely to see in the near and far futures. According to the Nuclear Energy Agency (NEA), the global demand for electricity is expected to rise by 2.5 times over the next 40 years and it is suggested that nuclear energy should be part of an energy mix in answer to this increased demand, including wind, solar and geothermal sources. The NEA forecasts the number of nuclear reactors worldwide to grow to 600-1,400 by 2050, translating into a needed investment of $680 billion to $3.9 trillion.

The first consideration behind this forecast is that at current utilization rates, nuclear energy generates about 15 percent of all global electricity. In some countries, nuclear energy plays a more significant role in providing electricity. In France, the country with the second largest number of nuclear plants after the USA operating 59 reactors, 80 percent of all electricity is generated from nuclear sources. The cost of nuclear electricity is competitive with other energy sources and is necessary in an energy mix to provide base load operation at a high capacity factor. The world's largest net exporter of nuclear electricity is France, which produces around 80 percent of its power from nuclear reactors. Italy is next door, has no nuclear reactors, is the world's largest importer of electricity, and consequently suffers economic dislocation.

Figure 27. The Paluel four-unit nuclear power station, Northern France.

Figure 28. The Cattenom four-unit nuclear power station, and their cooling towers, France.

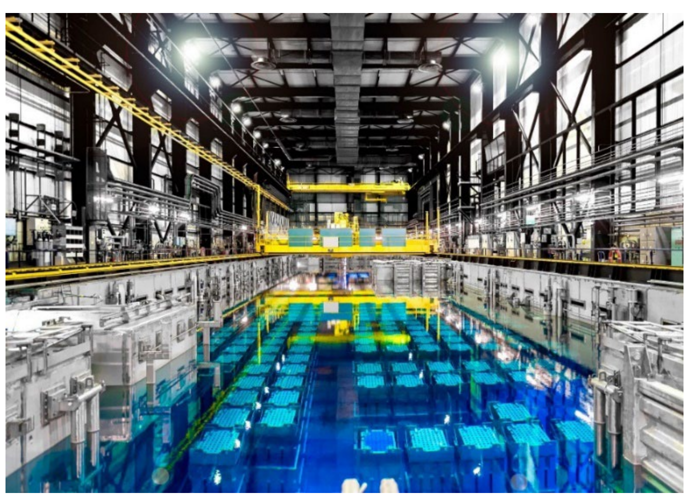
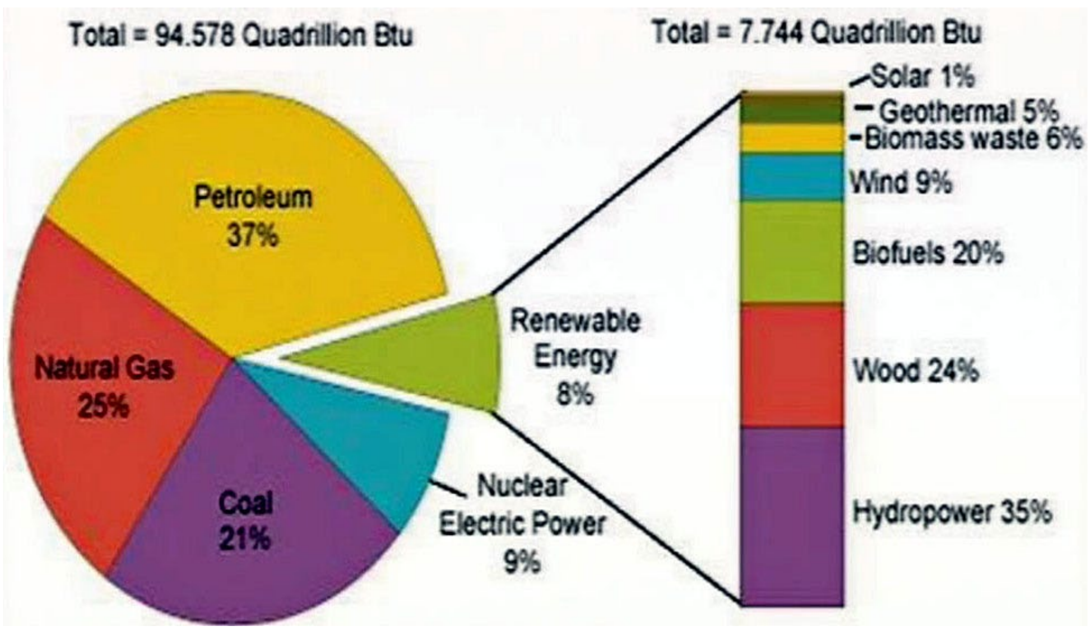


Figure 29. Spent nuclear fuel water cooling pond, La Hague, France.

Table 4. Share of electricity from different energy sources in the USA, 2012. Source: EIA.

Source	Electricity share [percent]
Coal	37.00
Natural gas	30.00
Nuclear	19.00
Hydroelectricity	7.00
Wind	3.46
Biomass	1.42
Petroleum	1.00
Geothermal	0.41
Solar	0.11
Other sources	0.60



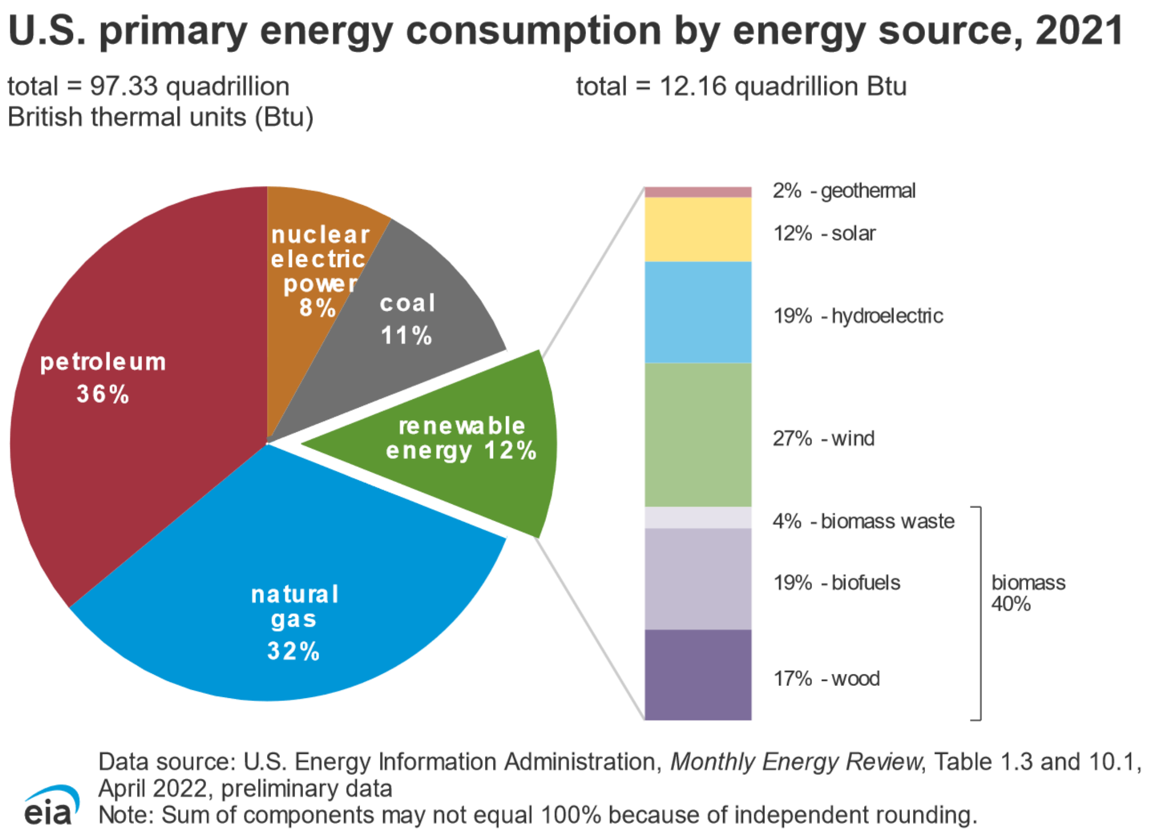


Figure 30. USA Energy consumption by energy source, 2009 and 2021. Source: DOE-EIA.

Table 5. Cost of electricity from different energy sources, 2010.

Source	Electricity cost [¢/(kW.hr)]
Hydroelectricity	4.6
Coal	6.6
Geothermal	6.7
Nuclear	6.7
Natural gas	6.9
Biomass	9.5
Wind	11.0
Solar	38.0

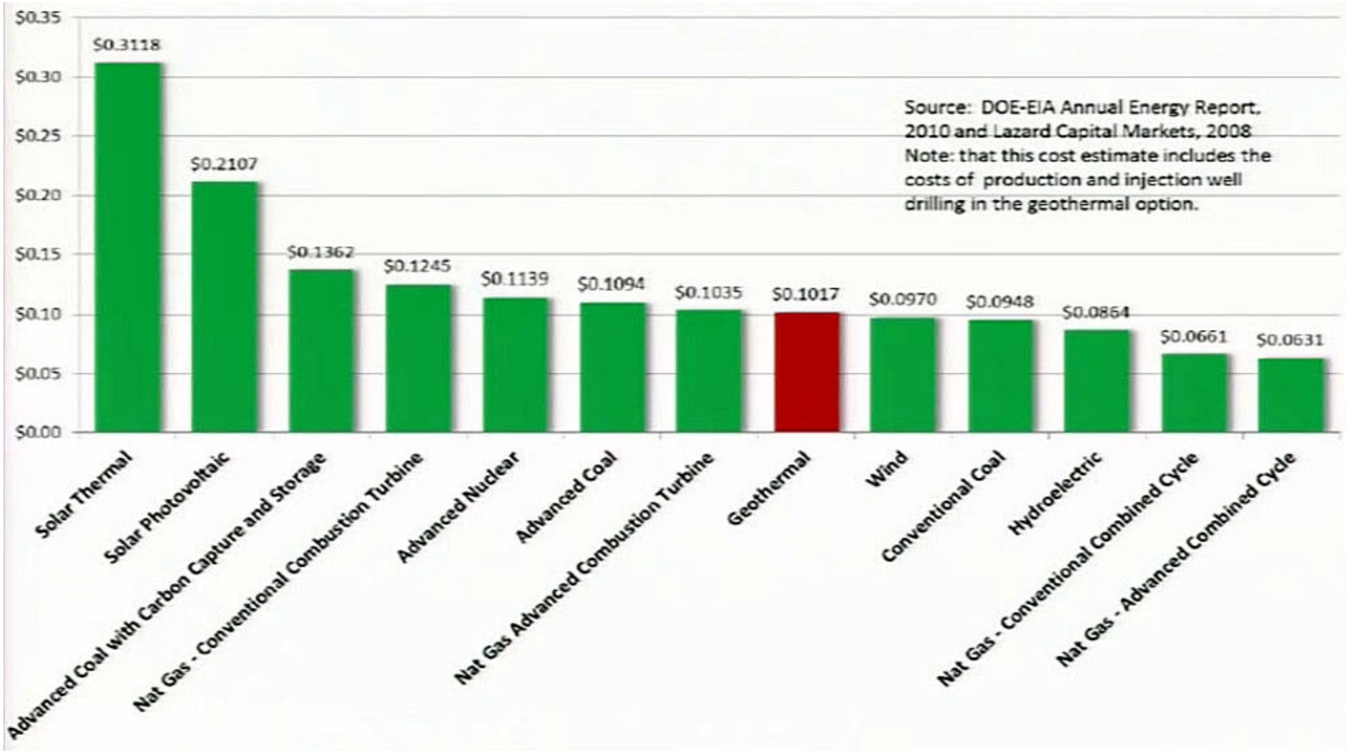


Figure 31. Total System Levelized Cost of Electricity for various methods of electricity generation. Source: DOE-EIA.

Table 6. Typical capacity factors of different energy sources, 2010.

Source	Capacity factor [percent]
Nuclear	91.1
Coal	72.2
Natural gas, combined cycle	40.7
Petroleum	9.2
Geothermal	90
Hydroelectric	37.2
Onshore wind	20-40
Offshore wind	40
Biomass	90
Photovoltaic solar	12-19
Thermal solar	15

Table 7. Sources of electricity supplied over 12 months by September 30, 2016 by the electric utility Ameren Illinois.

Source	[percent]
Biomass	0
Coal	48
Hydroelectric	1
Natural gas	23
Nuclear	16
Oil	4
Solar	0
Wind	7
Other sources	1
Total	100

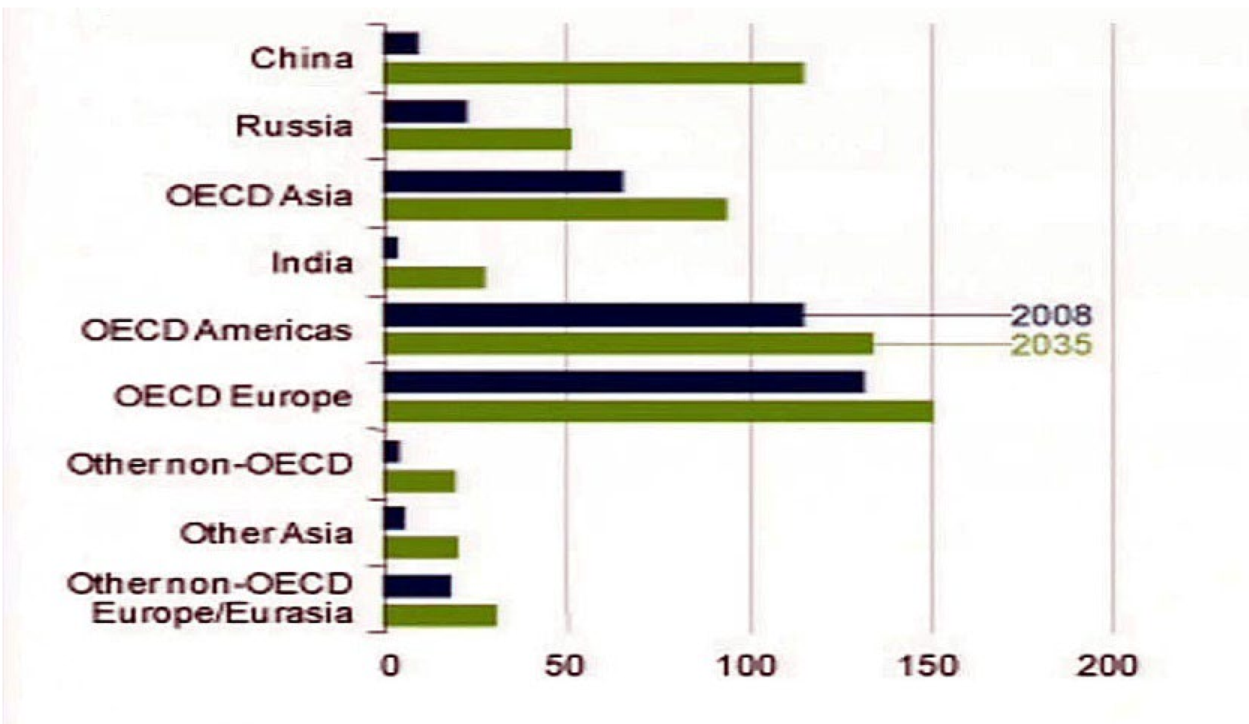


Figure 32. Expected growth in the world's Nuclear Generation from 2008 to 2035, GWs. OECD: Organization for Economic Cooperation and Development. Source: EIA.

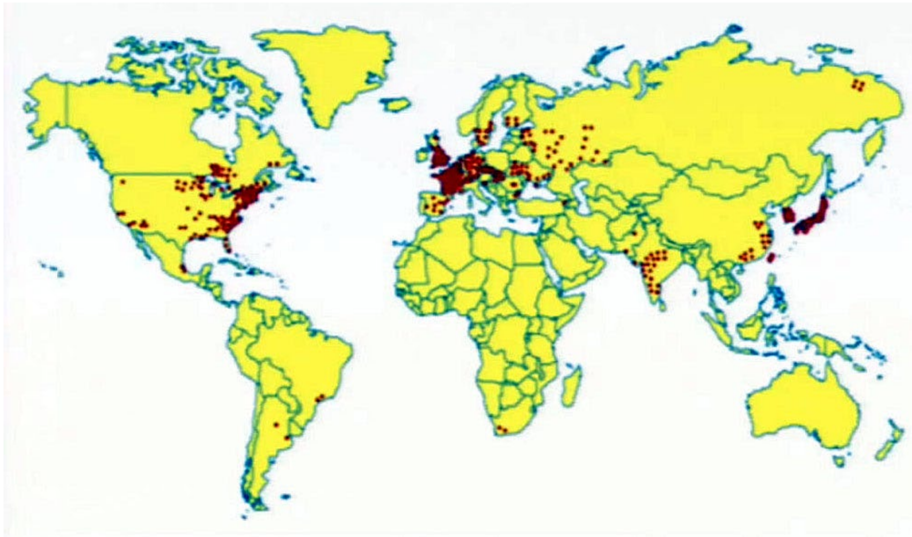


Figure 33. Concentration of world reactors in the industrialized nations and the emerging economies. Source: EIA.

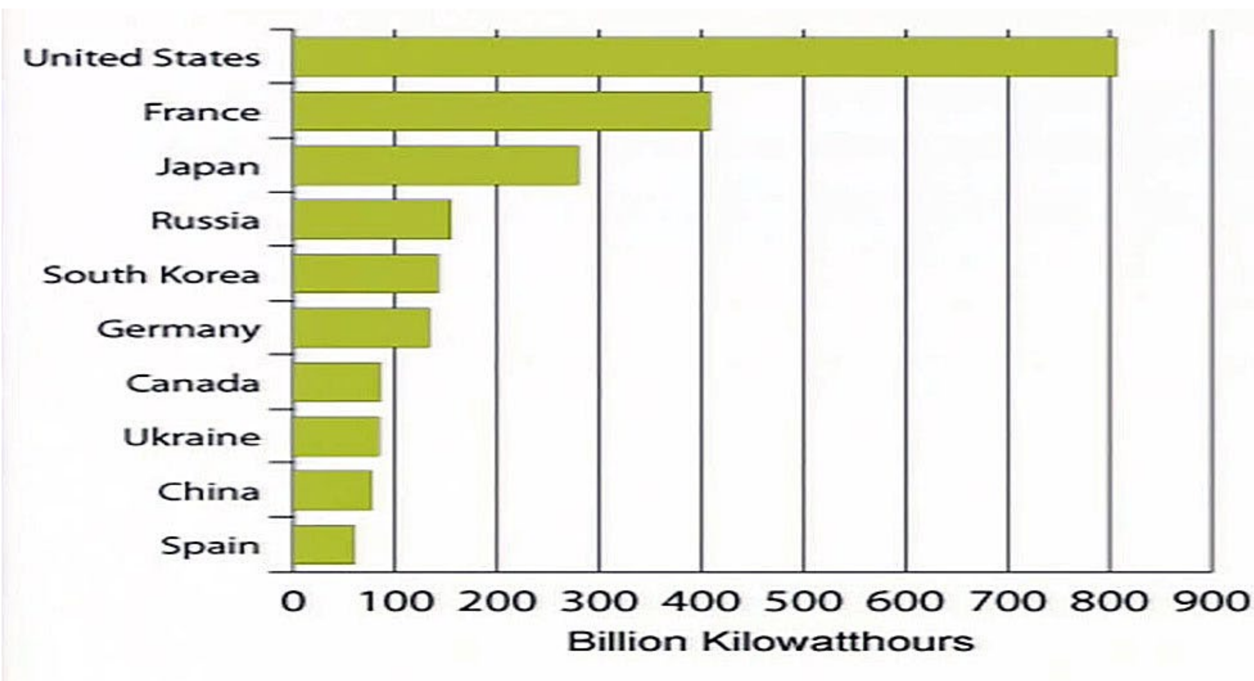


Figure 34. Top ten countries in Nuclear Energy Generation (2,229 billion kW.hrs) as of 2010. Another 21 countries generated 1,000 billion kW.hrs. Source: IAEA, Power Reactor Information System file.

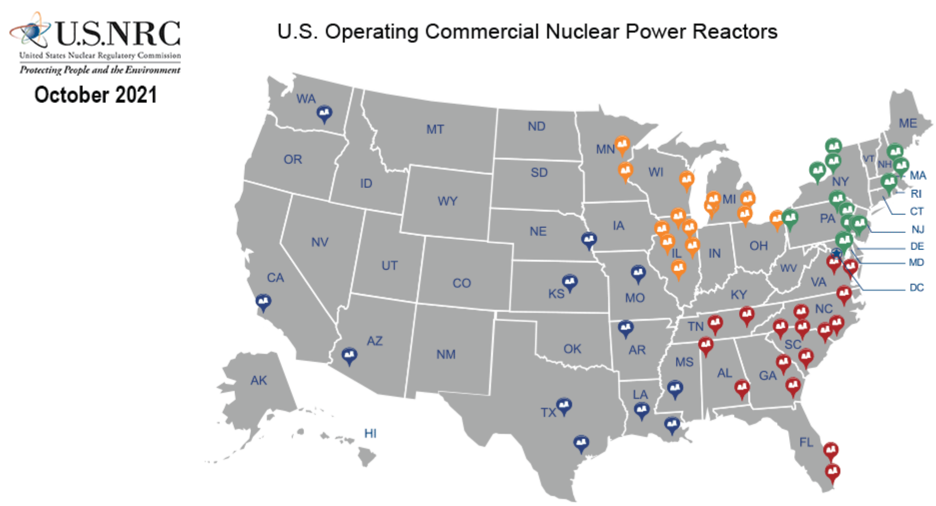


Figure 35. There are 93 licensed to operate nuclear power plants in the United States: 62 PWRs and 31 BWRs, which generate about 20% of the nation's electrical use. Nuclear Power plants in the USA, October 2021. Source: USNRC.

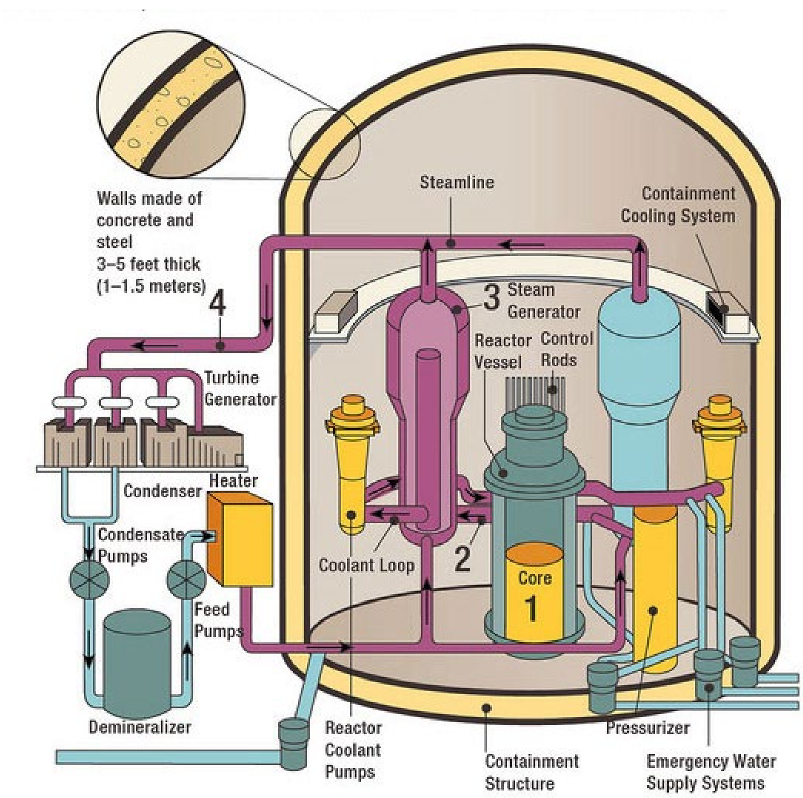


Figure 36. Pressurized Water Reactor PWR design. Source USNRC.

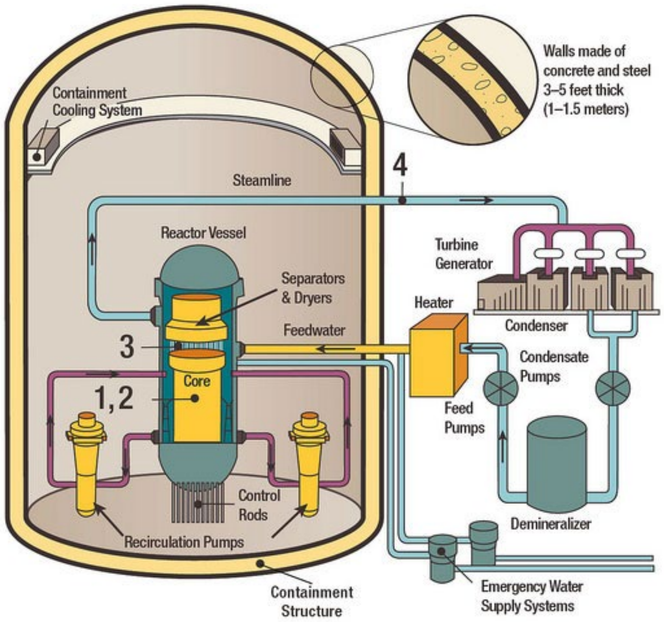


Figure 37. Boiling Water Reactor BWR design. Source USNRC.

The second consideration is the eco-friendliness of nuclear energy which does not produce CO_2 like its fossil fuel competitors.

As a third consideration, nuclear energy is receiving wide range global political support in spite of setbacks such as the Fukushima, Chernobyl and Three-Mile Island accidents. President Barack Obama in the USA launched a federal program which gave $8.3 billion worth of loan guarantees for funding the construction of two new nuclear reactors and was expected to seek an additional $46 billion. Additionally, the Russian Prime Minister/President Vladimir Putin has pledged that Russia would boost nuclear-energy use on its soil and dedicated $6 billion to the project. Similar trends have been seen in Asia. China has 16 operational reactors, and has 51 planned and 120 proposed new nuclear power reactors to become operational over the next 10 years. India plans on doubling the share of nuclear power on its grid to greater than 8 percent over the next 20 years.

A fourth consideration is that the use of nuclear energy seems to make economic sense. The initial construction costs of a nuclear plant are admittedly substantial, but the operation and maintenance and fuel costs are far lower than that of other energy sources. In addition, new nuclear power plants seem to have a longer life-span of nearly 60 operational years compared to 30 or 40 for the older ones.

As of January 2013, in 31 out of 200 countries, 435 nuclear power plant units with an installed electric net capacity of about 368 GWe were in operation, and 65 plants with an installed capacity of 61 GWe in 15 countries were under construction. There were 167 reactors in the planning stages, and 317 more proposed. The cumulative operating experience amounted to 14,570 years August 2011.

Unlike fossil fuel-burning power plants, nuclear power plants do not emit harmful gases, and all the spent nuclear fuel produced for one person's lifetime would fit in a single soda can, about 2 lbs of waste. A typical USA fossil power plant for a city of one million people might burn 9,000 tons of coal or 40,000 barrels (bbl) of petroleum per day. For a nuclear power plant this might take 7 lbs of uranium. At $90/barrel petroleum and $43/lb uranium, the daily fuel cost works out to $3,600,000 for petroleum versus $301 for uranium.

Once built and operational, nuclear power plants become cash cows for their utility operators. Roughly speaking, consider a 1,000 MWe nuclear power plant costing about $5,000 per installed kWe at 5,000 x 1,000,000 = 5,000,000,000 = $5 billion. If it operates for 60 years at a capacity factor of 90 percent, it would produce about 1,000,000 x 0.90 x 365 x 24 = 7.884 x 10^9 kW.hr of electricity per year. Sold to electrical consumers at a profit over expenses of 5 cents / kW.hr, this generates a profit stream of 0.05 x 7.88 x 10^9 = 3.94 x 10^8 = $394 million /year, or 394 x 60 = $23.64 billion over its 60 years operational time.

Table 8. Operational and planned Nuclear Power Plants worldwide, 2011.

Location	Operational nuclear power plants	Plants under construction	Planned reactors	Proposed reactors
USA	97	2	11	19
France	58	1	1	1
Russia	33	10	17	24
India	20	7	16	40
China	15	26	51	120
World	433	63	160	329

About 133 reactors are in the planning stage for the next decade. Thirteen countries that already have nuclear capacity, and 10 that do not, were in the process of building new reactors. The new reactors would double the existing installed capacity at an average capital cost of $5-9 billion each for a typical 1,000 MWe plant.

The largest industrial players are Areva from France, Rosatom from Russia, Toshiba-Westinghouse (Japan, USA), Mitsubishi Nuclear Energy Systems (Japan), and a joint venture between General Electric (USA) and Hitachi, Japan and Siemens from Germany.

Nuclear power has been proven over the course of 3,500 combined reactor.years of operation in the USA and 14,000 combined reactor.years of operation worldwide. The USA Department of Energy estimates that the USA demand for electricity will increase by a rather optimistic 23 percent by 2030. This is the equivalent of about 200 power plants of a standard 1,000 MWe capacity.

Nuclear energy has the smallest environmental impact of any current energy production alternative per unit of energy produced. One fuel pellet about the size of a pencil eraser produces the same energy as burning 1 metric tonne (1,000 kgs) of coal. From this perspective, nuclear power is a reliable, environmentally friendly base-load electrical power production alternative.

Table 9. Emissions per MW.hr of energy produced in the 12 months through September 30, 2016 by the electric utility Ameren-Illinois.

Emission	Amount
Carbon dioxide, CO_2	1,372 lbs
Nitrogen oxides, NO_x	0.80 lbs
Sulfur oxides, SO_x	1.54 lbs
Nuclear Waste, high level	0.0009 lb
Nuclear Waste, low level	0.0002 ft^3

The most negative impediment to nuclear power growth in the USA is that the used nuclear fuel is not being recycled to minimize its volume, isolate its fission products and burn its actinides, producing useful energy in the process. If recycled, the resulting waste would deteriorate to the level of, and then lower than, the radioactive toxicity of the already radioactive uranium ore (from billions of years ago, and for billions of years into the future) from which it was mined in the first place within about 500-600 years.

In the unsustainable once-through fuel cycle that is currently used, the spent fuel still containing usable fissile elements, together with its cladding and spacers materials, has been conveniently stored in large volumes on plant sites for a half-century in used water fuel storage pools or in dry storage consisting of concrete and steel silos built at the plant sites. The USA Nuclear Regulatory Commission has determined that this used fuel can be safely stored on these plant sites for another century, turning them into a distributed instead of a centralized depository.

The clear alternative is to hand down future generations a sustainable technology with its problems solved with present-day knowledge. Regardless, the amount of used fuel produced each year by the average 1,000 MWe USA reactor is small and can fit in the bed of a standard long-bed pickup truck, as compared to burning 4 million tons of coal or 62 billion cubic feet of natural gas to produce the same amount of electricity.

At the January 20, 2014 World Future Energy Summit in Abu Dhabi, Jeffrey Sachs, Director of the Earth Institute at Columbia University commented:

> "We are emitting about 35 billion tons of CO_2 this year. By 2050, in a much larger world economy, we have to be emitting less than 15 billion tons. So the world economy is going to grow by three times, but we have to cut back by more than half our carbon emissions.
>
> What does that mean?
>
> It means keeping the coal under the ground.
>
> It means changing to electric vehicles.
>
> It means radically different building codes.
>
> It means facing the fact that our energy, when we produce power, has to be emitting about 100 grams of CO_2, rather than 700 grams per kW.hr [of electricity generated] that is now emitted when we produce electricity.
>
> In a way, this is straightforward arithmetic. But our political systems do not want to face straightforward arithmetic because it means making choices.
>
> It means telling the coal industry that unless you have carbon capture and sequestration, the coal must stay under the ground.

It means saying to the oil industry that by 2030, our vehicle fleets must be electric powered; they cannot be internal combustion engine if we're serious about this problem.

So far, we're not serious about the problem. I pity our children, and I'm scared for them because we're not facing the honest carbon budgets of the planet."

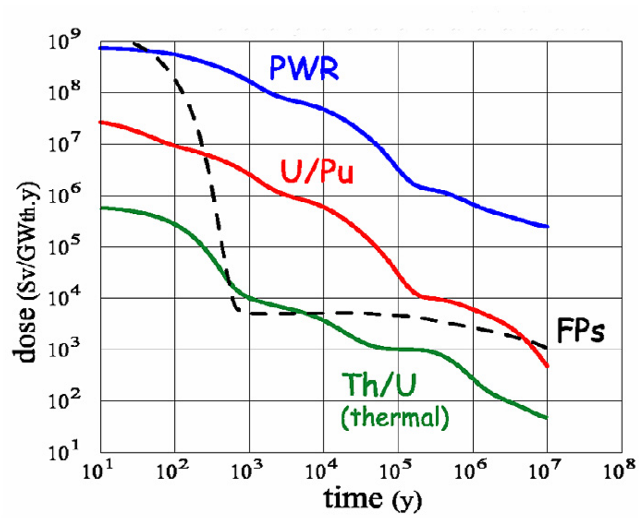


Figure 38. Relative toxicities of the actinides and Fission Products (FPs) in the different fuel cycles. FPs: Fission Products, PWR: Pressurized Water Reactor [3].

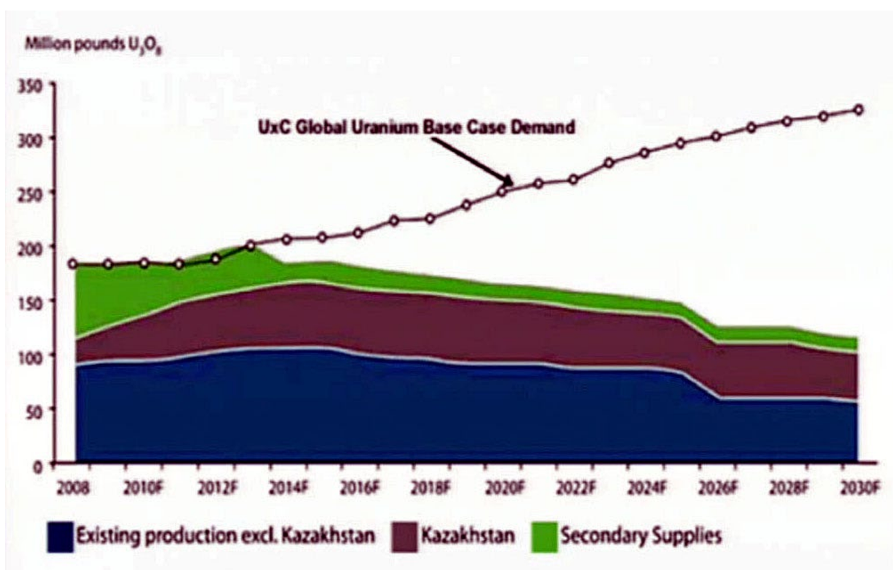


Figure 39. Expected Global demand and shortfall in million lbs of U_3O_8 over the period 2008-2030 from conventional and secondary sources. The shortfall implies the need to supplement uranium resources with the thorium resources. Source: EIA.

In another alternative, the adoption of the Thorium-U^{233} fuel cycle as a complement and eventual replacement of the present Uranium-Pu^{239} fuel cycle would offer a four-times larger resource base (Th^{232} is four times more abundant than U in the Earth's crust), lower wastes generation, as well as higher proliferation resistance prospects. What historically favored the U-Pu^{239} fuel cycle to the Th-U^{233} was a need to provide the world weapons stockpiles with Pu^{239}, and the initial unavailability of fissile isotopes to jump-start the thorium fuel cycle. Uranium occurs in nature with the fissile U^{235} isotope allowing the attainment of a critical fissile mass, whereas Th occurs in nature as the single non-fissile isotope Th^{232}.

The USA's Department of Energy (DOE) has offered conditional commitments for a total of $8.33 billion in loan guarantees for the construction and operation of two new nuclear reactors at a plant in Burke, Georgia. The project is scheduled to be the first USA nuclear power plant to break ground in nearly three decades. Two new 1,100 MWe Toshiba-Westinghouse Advanced Passive, AP-1000 nuclear reactors at the Alvin W. Vogtle Electric Generating Plant will supplement the two existing reactor units at the facility. The project will create approximately 3,500 onsite construction jobs. Once the nuclear reactors become operational, the project will create 800 permanent jobs. The project sponsors include Georgia Power Company (GPC), Oglethorpe Power Corporation (OPC), the Municipal Electric Authority of Georgia (MEAG) and the City of Dalton, Georgia.

One unit at the Vogtle complex in Georgia are under construction in the USA. The Energy Policy Act of 2005 authorized the DOE to issue loan guarantees for projects that avoid, reduce, or sequester air pollutants or anthropogenic emissions of greenhouse gases and employ new or significantly-improved technologies as compared to technologies in service in the USA at the time the guarantee is issued. These are the first conditional commitments for loan guarantees to be offered by DOE for a nuclear power facility since enactment of the 2005 law.

The State of Georgia's need for electricity is growing and is expected to increase by approximately 30 percent over the next 15 years. When the new nuclear reactors come on line, they will provide reliable, base-load electricity capable of serving about 550,000 residences or 1.4 million people. Compared with a similar sized coal plant, the new Vogtle units will avoid significant pollutants and greenhouse gas emissions each year: 16 million tons of carbon dioxide, 3,900 tons of nitrogen oxides, and 5,500 tons of sulfur dioxide.

The two AP-1000 reactors under construction at Vogtle are eligible for subsidies similar to but significantly less than those applied to wind power generation. Under the Energy Policy Act (EPA) 2005, up to 6,000 MWe of new nuclear is eligible for Production Tax Credits (PTCs). PTCs are divided pro rata among those applicants which had filed combined Construction and Operating License (COL) applications by the end of 2008, commenced construction of advanced plants by 2014, and which enter service by 2021. At the start of 2018, an extension to the PTC was passed by the USA Senate and Congress. This was critical for the Vogtle plant, where unit 3 entered operation in 2023, with unit 4 under construction. The level of the PTC is 1.8 cents per kW.hr, for eight years, and cannot be claimed until an asset is producing electricity. There is an annual payment limit of $125 million for each 1,000 MWe of capacity.

Globally, Germany and Switzerland decided to retire their aging fleet of nuclear power plants in the aftermath of the Fukushima earthquake and tsunami in Japan. Japan decided to keep its 20 percent proportion of nuclear electricity instead of a planned increase to 50 percent. Italy maintained a building freeze on nuclear power plants. On the other hand, the UK plans 4 new reactors. China plans on a nuclear generating capacity of 86 GWe by 2020 from the 2009's 11

GWe capacity. It is adding 14 reactors to the 11 it operated by 2009. It is planning for 35 more plants for the next decade.

Figure 40. Symbiotic coupling of nuclear and wind technologies views during winter and summer. The two-units 2,309 MWe Boiling Water Reactors, BWRs LaSalle nuclear power plant near Marseilles, Illinois operated by Exelon Nuclear corporation and the Grand Ridge Wind Farm operated by Invenergy LLC in the adjacent farmland near Ransom in Illinois, USA. The nuclear reactor and the wind turbines are both manufactured by the General Electric (GE) Company. The GE 1.5 MW SLE wind turbines have a hub height of 80 m and are net recipients of electrical power from the grid at 5 kWe on a standby basis for its HVAC (Heating, Ventilation and Air Conditioning) system, but then become net exporters of electricity into the electrical grid under favorable wind conditions.

Each additional GWe needs 500 metric tonnes of uranium for the first load and 170 metric tonnes of natural uranium-equivalent of the fissile isotopes U^{235} and Pu^{239} per year for the next years. The uranium demand is expected to increase from 65,000 tons in 2008 to 90,000 tons by 2015. Of the 31 countries operating nuclear power plants only three: Canada, South Africa and Russia are self-sufficient in their uranium needs.

In the USA, nuclear power generation is concentrated along the industrial Eastern Seaboard, but the interior state of Illinois has more nuclear plants at 11 out of 97 in the USA and generates more nuclear power at nearly 95 million MW.hrs than any other state. These nuclear plants do not generate noise, they do not pollute the air with dirty smokestacks, and they do not kill birds and bats, with many of them surrounded by striving nature preserves.

Public radiation exposure from nuclear power is negligible, with nobody getting more than about 0.1 percent of what they get from the natural background radiation sources. Nuclear Power is an industry that fully contains all its waste generation, because of its small volume, and ensures that they remain contained for as long as they remain hazardous. Other industries using fossil fuels, because of their large volumes that cannot be contained, just dilute their wastes into the environment in the air and water bodies as the only available way of disposing of their large volumes.

Over the next decade, the state of Texas may become the biggest USA builder of nuclear-generating plants. NRG Energy Inc., Energy Future Holdings Corp., Exelon Corp., an Illinois utility, and a new utility: Amarillo Power in partnership with Constellation Energy group from Baltimore, have proposed 8 reactors, about a quarter of the planned USA total of 30, according to the USA Nuclear Regulatory Commission (NRC). Texas ranks first in producing and consuming energy, according to the USA Department of Energy (DOE). Its population will grow 45 percent to 33.3 million by 2030, according to the USA Census Bureau.

New plants are planned to be built near existing nuclear facilities, which minimizes both costs and the likelihood of the Not In My Back-Yard (NIMBY) syndrome. Also in the first wave of new construction: An Entergy facility in Grand Gulf, Mississippi, a TXU plant at Comanche Peak, Texas, a Dominion Power facility in Louisa County, Virginia, and a Constellation Energy plant in Calvert Cliffs, Maryland.

While nuclear reactors may cost as much as $5-9 billion each, they are more reliable than wind or solar energy. The total cost of electricity is comparable to coal and wind, according to the DOE: 5.4 cents / kW.hr from coal, 6.8 cents from wind and 5.9 cents from nuclear power. Solar electricity from photo-voltaic solar cells still costs 25.5 cents / kW.hr, even though it is expected to substantially decrease in the future due to economies of scale in manufacturing.

The average USA household spends $1,900/year on energy bills for just heating and cooling the home; excluding the transportation needs. Average homes in 2001 were 2,555 square feet in area, up from 2,072 in 1981 adding to more demand on cooling and heating. American homes are increasingly wired for the new information technology with outlets charging new gadgets such as cellular phones, iPods and iPads, multiple computers, and 2-3 televisions including big screen televisions, creating a higher demand for electricity. The plasma large screen televisions have screens four times larger than the earlier units and consume 8-10 times as much electricity as those that they are replacing. Entertainment and telecommunications account for 15 percent of home energy use. Six out of every 10 homes have a computer, up from one in 5 in 1992.

Figure 41. Plug-in Electric Vehicles EVs could charge and store their batteries overnight with electricity supplied by wind, solar and nuclear power plants.

According to a survey conducted by the Clean and Safe Energy Coalition in 2006, the more people learn about nuclear energy, the more supportive they are of it. After a session on energy issues, 73 percent of the respondents said that they felt favorably or somewhat favorably about the use of nuclear energy. The Bisconti Research firm found that 86 percent of USA citizens consider nuclear energy as an important part of meeting future electricity needs and 77 percent agree that the electrical utilities should prepare to build new nuclear plants in the next decade.

Prominent environmentalists including Gaia theorist James Lovelock, Greenpeace cofounder Patrick Moore, and UK's Bishop Hugh Montefiore, a longtime board member of the Friends of the Earth organization, argue that nuclear energy produces a fraction of the greenhouse emissions made from fossil fuels. James Lovelock believes that nuclear energy is the only way to avoid a catastrophic climate change. Britain's Bishop Hugh Montefiore, was forced to resign from the Friends of the Earth's board after he wrote a pro-nuclear article in a church newsletter. Norris McDonald, president of the African American Environmental Association, said: "If we believe that global warming is a real threat to our planet, then the very best way to provide base load electricity is through emission-free nuclear power." The political and social activist Patrick Moore who became a nuclear energy advocate, said: "You do not ban the beneficial uses of a technology just because that same technology can be used for evil, otherwise, we would never have harnessed fire." Bill Chameides, chief scientist for Environmental Defense, said anything that helps alleviate global warming must be an energy option: "I think it is somewhat disingenuous that folks who agree that global warming is such a serious issue could sort of dismiss it out of hand. It's got to be at least considered."

Patrick Moore, cofounder of Greenpeace wrote in 2006 in the Washington Post newspaper:

> "In the early 1970s, when I helped found Greenpeace, I believed that nuclear energy was synonymous with nuclear holocaust, as did most of my compatriots. Thirty years on, my views have changed, and the rest of the environmental movement needs to update its views, too, because nuclear energy may just be the energy source that can save our planet from another possible disaster: catastrophic climate change. Look at it this way: More than 600 coal-fired electric plants in the United States produce 36 percent of USA emissions, or nearly 10 percent of global emissions of CO_2, the primary greenhouse gas responsible for climate change. Nuclear energy is the only large scale, cost effective energy source that can reduce these emissions while continuing to satisfy a growing demand for power."

James Lovelock, the British environmental scientist, in his book: "The Revenge of Gaia," has come to the hard illuminated conclusion that the unprecedented challenge of global warming leaves us no choice but to make a massive global investment in nuclear power, which emits no greenhouse gasses. Lovelock places the risks of different energy alternatives into perspective when he considers the risk associated with China's Yangtze Dam, a huge source of renewable hydroelectric power: "If the dam burst, … perhaps as many as a million people would be killed in the wave of water roaring down the course of the Yangtze River."

Nuclear power is economically competitive to other sources of energy. As of 2007, the electrical generation costs were 1.82 cents per kilowatt-hour versus 2.13 cents for coal fired plants and 3.69 cents for natural gas. As far as carbon emissions, nearly 700 million additional tons of CO_2 would be released into the atmosphere every year without nuclear power; the equivalent of the exhaust from 100 million automobiles. In comparison, the Clean Air Council reports that coal power plants are responsible for 64 percent of sulfur dioxide SO_x emissions, 26 percent of nitrous oxides NO_x and 33 percent of mercury (Hg) emissions in the USA.

A not so well known fact is that coal fired plants release 100 times more radioactive material as uranium, thorium and their daughter radioactive decay nuclides such as radium in the particulate ash released as smoke, than an equivalent nuclear reactor.

The recent USA-led initiative: Global Nuclear Energy Partnership (GNEP) has several goals. One is to control nuclear proliferation by providing Low Enrichment Fuel (LEF) suitable for nuclear power plants; but not Highly Enriched Fuel (HEF) that is usable in nuclear weapons, to nations willing to submit to international oversight and safeguards. Another goal is to reduce the volume of nuclear waste by reprocessing spent fuel so that part of it can be reused. The GNEP would not eliminate the need for a nuclear waste disposal site like Yucca Mountain in the USA, but it could mean that whatever waste is generated will have a much shorter radioactive life. The USA has 55,000 metric tonnes of spent nuclear fuel in temporary storage waiting for a facility at Yucca Mountain in Nevada that has not received regulatory approval to start planned operation. As a new cartel built along the lines of the Organization of Petroleum Exporting Countries (OPEC), a condition for membership is that the uranium producing nations must agree to accept, process, and dispose of the spent nuclear fuel from other states. Australia as the world's second largest uranium exporter after Canada, signed onto the GNEP, but refused to accept spent fuel.

The next generation of nuclear reactors known as Generation IV designs, would be safer, more reliable and more versatile than the current ones. They are applicable to uses in the coming hydrogen economy and fresh water production from sea water. A demonstration reactor was planned with a design that is ready for commercialization.

The idea of lingering nuclear waste sitting around for hundreds of millions of years is overstated. Within 40 years, used nuclear fuel has less than 1/1,000th of the radioactivity it had when it was removed from the reactor. And 95 percent of the potential energy is still contained in the used fuel after the first cycle. The USA has recently removed the ban on recycling used fuel as an alternative to the current once-through fuel cycle, making it possible to use that energy and to greatly reduce the amount of waste that needs treatment and recycling.

Jesse Ausubel, director of the Human Environment program at New York's Rockefeller University, called renewable energy sources as "False Gods" in a Wired Magazine interview. Despite all the tax breaks, subsidies and incentives, the proportion of USA electricity production from renewable sources has actually fallen in the past 15 years, from 11 percent to 9.1 percent. Renewable sources are not that attractive to land conservationists: a 1,000 MWe photovoltaic plant would require about 60 square miles of glass panes alone, which would be the largest industrial structure ever built. Jesse Ausubel contends that 1,300 birds of prey are killed by the rotors of the 5,400 windmills in California's Altamont Pass each year. Growing the amount of cellulose required to shift USA electricity production to biomass would require farming an area the size of 10 states of Iowa.

Regarding safety, while nothing is 100 percent risk-free, paraphrasing Patrick Moore, if we banned everything that is potentially risky, humans would never have harnessed fire. When a reactor core melted down at Three Mile Island, its containment system and Engineered Safety Features, (ESFs) did just what they were designed to do and prevented radiation from escaping to the environment. There were no worker injuries nor deaths, and none among the nearby residents. No one has ever died of a radiation-related accident in the history of the USA civilian nuclear reactor program. In comparison, 100 coal miners die each year in the USA in coal mine accidents and another 100 die transporting it. Considering the Chernobyl accident, the RBMK-1000 reactor design had no containment vessel, was an inherently unstable design with a positive power coefficient of reactivity and its operators literally blew it up by side-stepping the established safety rules. The United Nations (UN) Chernobyl Forum reported that 56 deaths could be directly attributed to the accident, most of those from radiation or burns suffered while fighting the fire. The earthquake and tsunami in March of 2011 resulted in about 28,000 direct fatalities; among which 2 workers were recognized as direct casualties of the resulting Fukushima Station Blackout accident.

According to PBS's "Frontline," between 1931 and 1995 some 33,134 fatalities occurred in the USA's coal mining industry. In the USA civilian aviation between 1938 to the present there has been more than 54,000 fatalities. There have been no deaths historically with civilian USA nuclear power.

The "not in my own back yard" or nimby objections about nuclear plants are fading in favor of economic development. About Entergy's Grand Gulf Nuclear Generating Station near Port Gibson, Mississippi, Michael Herrin, pastor of Port Gibson's First Presbyterian Church commented: "In this town, the dragon is unemployment. Entergy is the hero."

A typical 1,000 MWe reactor of the world's 446 nuclear power plants provides electricity to 700,000 typical homes and uses just five pounds of uranium which amounts to a 2 cubic inches of pure uranium per day. A fossil fuel power plant of the same capacity burns 20 million pounds of coal using 200 million pounds of air, yielding an equal weight in polluting particulate ashes and gases that are disposed-off by outright dilution in the Earth's atmosphere and water.

Globally, within 20 years, growth in electricity demand is expected to add 5,000 billion kW.hrs to annual electrical consumption. This would require either burning 10 billion barrels of oil annually, or three billion tons of coal per year. Alternatively this would require mining just 150,000 tons of uranium yellowcake or U_3O_8. Supplying that amount of electricity would require one million more of the largest solar arrays currently deployed.

Worldwide, nuclear power is an existing success and provides 78 percent of France's electricity, 58 percent of Belgium's, 50 percent of Sweden's, 40 percent of South Korea's, 37 percent of Switzerland's, 31 percent of Japan's, 27 percent of Spain's and 23 percent of the UK's. Overall, 30 percent of the entire European Union's electricity is generated by nuclear power.

Nuclear energy provides 19 percent of the USA's electrical power. It prevents the release of 700 million additional tons of CO_2 into the air every year; and it helps reduce the USA's unwarranted dependence on foreign petroleum. In 1985 about 27 percent of its petroleum came from other countries, by 2007 this has risen to about 60 percent. Energy experts believe that the USA needs to build 3 new nuclear plants per year, just to keep pace with the projected electrical energy needs.

There were 112 power reactors operating in 1990 in the USA. By 2019 there were 97. The Energy Policy Act of 2004 is encouraging the planning for building over 30 new nuclear power plants. These would provide electricity to about 30 million typical American homes.

In 1979, the Three Mile Island reactor accident caused no deaths, no injuries and resulted in an irrelevant radiation exposure that is 1/6 of a typical chest x ray to the two million residents in the area around the reactor. A World Health Organization (WHO) report showed that 56 deaths could be directly attributed to the Chernobyl accident. The amount of radiation from the accident was just slightly higher than background radiation and there is no indication of higher rates of cancers in the Chernobyl population than any other population. To a certain degree, excluding radiation release, this is comparable to industrial accidents such as the gas explosion in the Macondo oil well and the sinking of the Transocean-owned Deepwater Horizon oil rig causing a daily spillage of 20,000-60,000 gallons of petroleum per day and the loss of 11 lives among its

126-member crew, and the industrial explosion in Texas City, Texas, that triggered a massive fire at an oil refinery and caused the death of 15 people and the injury of 170. Neither event stopped oil exploration, drilling, and refining.

In the 2005 Energy Policy Act, the USA Congress signaled its interest in nuclear power by including $13 billion in incentives for the industry. New spending in the act included risk insurance and loan guarantees for the construction of new plants. It included tax credits of 1.8 cents/kW.hr of energy generated in a plant's first eight years of operation. And the law lowered from 35 percent to 20 percent the tax rate on investment gains utilities make in funds they must set aside to decommission plants.

Table 10. New Reactors commitments, USA, 2023.

Reactor Type	Reactor units	Location
PWR, AP 1000 Toshiba-Westinghouse	2 units: Vogtle units 3 and 4.	Near Waynesboro, Georgia. Southern (SO) subsidiary of Georgia Power and partners.

Figure 42. Georgia Power Vogtle plants units 3 and 4 under construction. Unit 3 entered operation in 2023

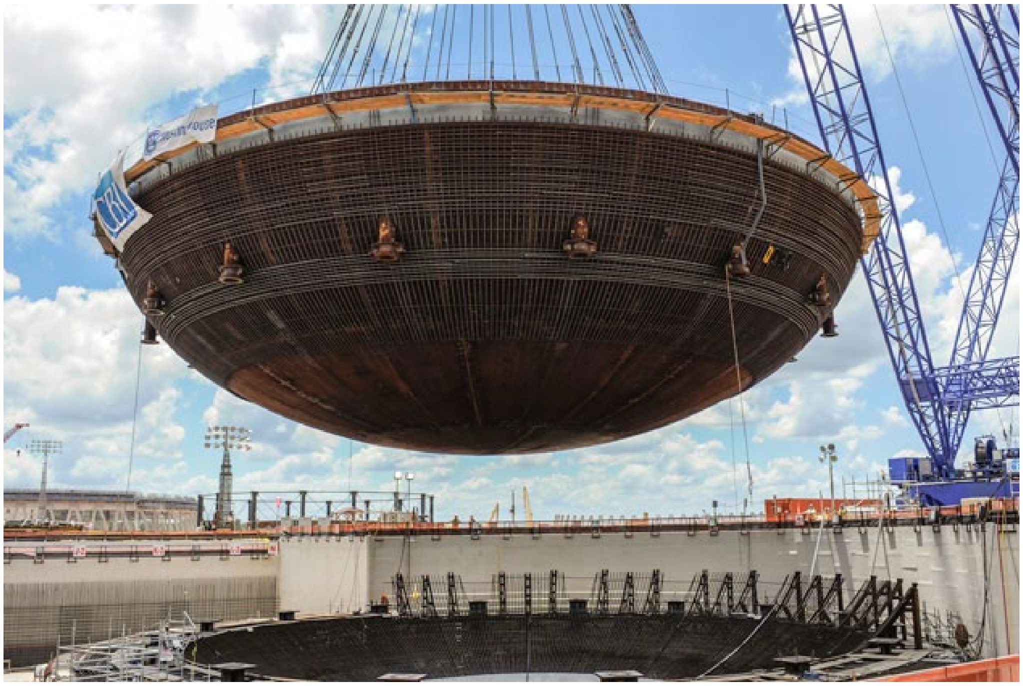


Figure 43. Georgia Power Vogtle 3 PWR unit 900 tons bottom of pressure vessel installation, Georgia, USA.

The USA Department of Energy (DOE) projects a 45 percent growth in electricity demand by 2030, suggesting 35 to 50 new nuclear plants will be needed by then just to maintain the nuclear energy share of the electricity market at around 20 percent. The 2005 energy bill passed by Congress provides subsidies for the first six plants, which the industry sees as a one-time “jump start.” electricity demand would require significant new nuclear capacity by 2025 in addition to the two nuclear reactors currently under construction in order to maintain this share.

Several designs of Small Modular Reactors (SMRs) are proceeding towards NRC design certification application or the alternative two-step route of construction permit then operating license:

1. A demonstration unit of the 160 MWe Holtec SMR-160 PWR (with external steam generator) is proposed at Savannah River with DOE support, and a construction permit application is likely, or a similar application in Canada. In September 2016 Mitsubishi Electric Power Products and its Japanese parent became a partner in the project, to undertake the I&C design and help with licensing. In 2017 SNC-Lavalin joined the project. South Carolina and NuHub also back the proposal.

2. A demonstration unit of the NuScale multi-application small reactor, a 50 MWe integral PWR planned for the Idaho National Laboratory. Subsequent deployment of 12-module power plants in western states is envisaged under the Western Initiative for Nuclear. The NRC accepted NuScale's design certification application in 2017 and a COL application is planned for mid-2020. Nuscale had spent some $170 million on licensing to mid-2015, and expects the NRC review to take 40 months, with the first unit operating in the mid-2020s. In 2013 NuScale secured up to $226 million DOE support for the design, and applied for the second part of its loan guarantee in

September 2017.

3. SCEG is evaluating the potential of X-energy's Xe-100 pebble-bed SMR (50 MWe, a high temperature gas-cooled reactor) to replace coal-fired plants, in 200 MWe 'four-pack' installations.

4. In August 2015 Russia's AKME-Engineering received a USA patent for its modular SVBR-100 lead-bismuth cooled integral fast reactor. The company said that it wants to protect its intellectual property as it prepares for the construction of a prototype SVBR-100 unit at Dimitrovgrad. No plans for the USA have been announced.

If today's nuclear plants retire after 60 years of operation, 22 GWe of new nuclear capacity would be needed by 2030, and 55 GWe by 2035 to maintain a 20 percent nuclear share.

Europe, with the exception of Germany, Switzerland and Italy, is poised to begin a new nuclear age, reversing two decades of policies aimed at abandoning nuclear power as an energy source following the Chernobyl accident in 1986 and the Fukushima earthquake and tsunami accident in 2011. Driving the turnaround are high petroleum and natural gas prices, possible peak oil, climate change worries; and concerns about the reliability of supplies from Russia, which provides 25 percent of Europe's natural gas and 12 percent of its petroleum. The UK wants to replace some of the 18 aging nuclear plants that are due to be shut-down by 2023. Finland is building the first new nuclear generating plant in Western Europe. Sweden and the Netherlands have either abandoned plans to phase out old nuclear plants or opened discussions on construction of new ones. Italy, which shuttered its four nuclear plants after Chernobyl and is Europe's biggest energy importer, ironically has plans to buy power from a nuclear power plant under construction in France. Poland agreed to help build a plant in Lithuania. It will provide power to Latvia and Estonia in addition to Poland and Lithuania. Belarus plans the construction of a plant and plans additional units.

France is almost entirely powered through nuclear and hydroelectric power and has some of the lowest CO_2 emissions rates in the world. Germany has heavily invested in wind and solar energy and has reached a decision to phase out its 40-years old aging fleet of nuclear power plants. If it still thinks it can lower its carbon emissions, this places it in an impossible situation since it has to resort to burning polluting brown coal. In addition, it is ironically importing nuclear electricity produced in neighboring countries such as France and Poland and importing natural gas supplies from Russia.

Even though nuclear power accounts for just 19 percent of the USA's electrical energy, it provides 80 percent of France's electricity needs; 79.9 percent of Lithuania's; 55 percent of Belgium's; and 50 percent of Sweden's. China has built 9 new reactors since 1991, with plans to accelerate its nuclear power program. India is building 8 reactors. Half of the Ukraine's energy is nuclear despite the Chernobyl reactor accident. Russia has 31 reactors at 10 nuclear power plants sites, accounting for 16-17 percent of its electricity generation and plans to increase the proportion of nuclear-generated power to at least 25 percent by 2030.

In the USA, 16 energy companies and consortia have announced their intention to file license applications with the USA Nuclear Regulatory Commission to build as many as 30 new nuclear power plants. China plans 23 new nuclear reactors.

Table 11. Proposed USA electric generating plants, 2018. Source: EIA, Energy Information Administration.

Source	Capacity, GWe	Added plants, percent
Natural gas	65	67
Wind	21	22
Solar, PV	11	11

The twenty first century is witnessing the dawn in some cases, and maturation in others, of some prominent sciences and technologies: Nucleonics, Proteomics, Informatics as well as Bioinformatics, Nanotechnology, Space Science, and Hydrogen Energy, in as much as the twentieth century has seen the emergence of Electronics.

Without energy, there would have not been an Industrial Revolution. The USA would not be the bread-basket to the world. There would be no technological, information and communication revolution. Experts suggest that cutting the average yearly energy consumption per capita to 1,600 kilowatts.hr, a person's life expectancy would be cut in half to about 36.5 years. With the world population adding 250,000 new people every day, or 1 million new people every 4 days, nuclear energy as fission today and fusion in the future is perceived as the only alternative to combat the scourge of poverty and enhance the health and well-being of the world population.

American colleges are good at getting people enrolled and get students lined up with education loans. The money goes to pay for textbooks, meal cards and tuition and fees. Parents go along and shell out until their bank accounts are barren. About 80 percent of students think they will graduate from college. Yet statistics show that only half that number do actually graduate. As education as well as health are basic human rights, education must be made universal in nations that aspire for greatness and a future prominent place under the sun. In terms of universal education and health care, the USA lags behind the European Union (EU), industrialized nations and many developing countries.

What colleges are not good at is arming the students with degrees in the highly skilled areas of the job market. The new paradigm in the job market is that automation and robotics are inexorably replacing human labor. Only those with the high-level skills to design, program, construct and operate the new energy and information-age tools are needed. Those without degrees in the high-skill fields have a hard time getting a good job to pay back their exorbitant student loans. Instead, they fall into delinquency, starting off life saddled with debt. More than half of college graduates under 25 are unemployed or underemployed. This makes going back to school and reengineering one's skill level in the energy field a reasonable option.

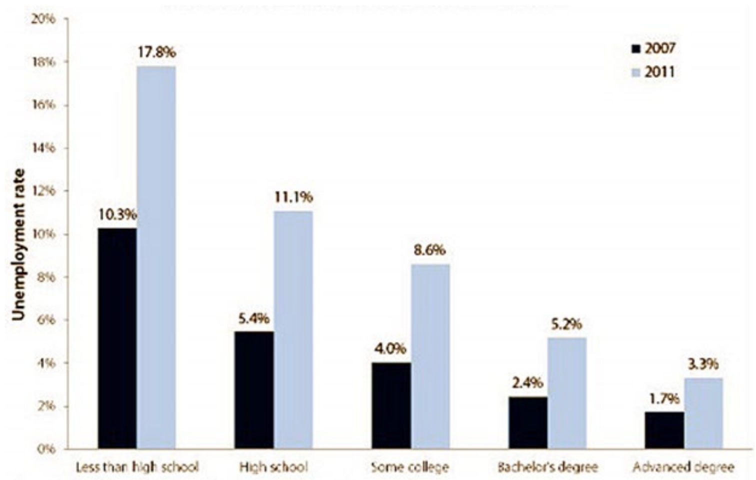


Figure 44. Unemployment rate in 2007 and 2011, is much higher among students lacking a university degree. Unemployment has curiously grown larger after the Great Recession of 2007-2011, suggesting an illusion in the expected recovery. Source: Economic Policy Institute (EPI) analysis of basic monthly Current Population Survey microdata.

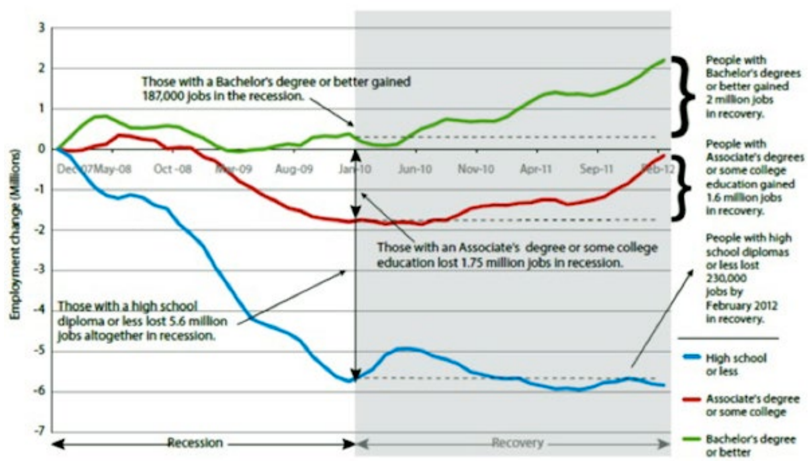


Figure 45. University degree holders gained jobs during both the 2008 recession and the subsequent recovery. Only high-skill jobs are needed in the new economy. Source: Economic Policy Institute (EPI).

At American Universities, for the 2010–2011 academic year, annual current dollar prices for undergraduate tuition, room, and board were estimated to be $13,600 at public institutions, $36,300 at private not-for-profit institutions, and $23,500 at private for-profit institutions. Between 2000–2001 and 2010–2011, prices for undergraduate tuition, room, and board at public institutions rose 42 percent, and prices at private not-for-profit institutions rose 31 percent, after adjustment for inflation. The inflation-adjusted price for undergraduate tuition, room, and board at private for-profit institutions was 5 percent higher in 2010–2011 than in 2000–2001 [4].

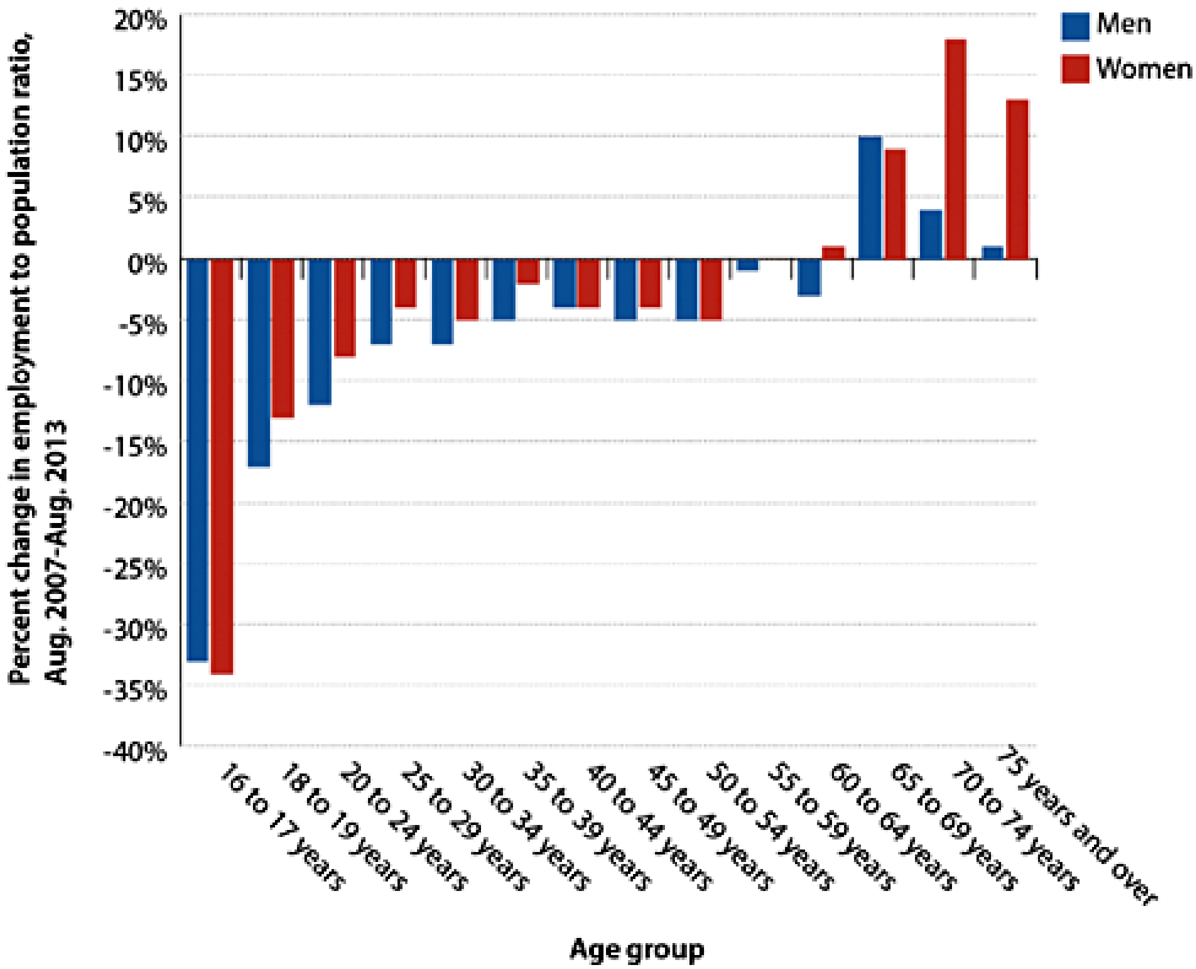


Figure 46. De-employment in the USA. Young people are abandoning the work force or cannot find employment, whilst older people are forced to rejoin it for the depletion and lack of retirement funds, especially among women, which have a longer life-expectancy than men. Source: Bureau of Labor Statistics (BLS).

Figure 47. Risk of Artificial Intelligence AI and Robotics and automation replacing human manufacturing and transportation jobs and robotizing education. Source: Tesla Motors.

Nuclear, Plasma and Radiation Science refers here to branch of science and engineering dealing with phenomena related to the "nucleons" which compose the atomic nucleus. These phenomena encompass nuclear reactions such as fission and fusion, as well as radioactivity. They cover the cosmic scale of the nucleus at 10^{-12} cm, compared with the scale of the atom at 10^{-8} cm. In fact, this includes three of the four basic forces in nature: the electromagnetic, the strong and the weak forces. Only the gravitational force is not covered.

The present work was written, and is continuously updated literally day-and-night, over weekends and breaks, over multiple years starting in 1998, primarily for the benefit of the author himself in a modest attempt at understanding the topics covered. The material served as course notes for students from the different engineering disciplines, as well as students from the Social Sciences and Humanities at the University of Illinois at Urbana-Champaign. The course covered the topic of Nuclear Power Engineering and was taught at the Department of Nuclear, Plasma and Radiological Engineering at the University of Illinois at Urbana-Champaign. The course has been attended primarily by seniors in Mechanical, Electrical, Chemical, Aerospace, Civil and Environmental Engineering, as well as by Nuclear Engineering students. Students in Law and Physics and officers being commissioned into the USA Armed Forces have also attended it. Visiting scholars to the University of Illinois sat and audited it. At a graduation rate of about 1,000 engineers per year, and the material being taught in the Fall and Spring semesters, with the attendance of about 120 students per semester, this class is fortunate and proud to have touched and contributed to the educational background of about 25 percent of the Engineering graduating class at the University of Illinois at Urbana-Champaign.

The material in this work covers the course curriculum, but attempts to supplement it with issues, concerns and questions, raised by the students, related to the class material. This includes energy resources management, the move toward a hydrogen carbonless energy economy, climatic variation and change and its relationship to nuclear power generation and CO_2 emissions from fossil fuels, the recycling of nuclear fuel and its waste, the remediation of radioactive contamination, fresh water augmentation, fusion energy in both its magnetic and inertial confinement approaches, and the use of radioisotopes in space missions, and space nuclear sources including propulsion. These issues arose from the intellectual curiosity of the students and the course attendees.

In its State of the World Reports, the World Watch Institute echoes these concerns. To the trends it started considering since 1984: shrinking forests, falling water tables, disappearing plant and animal species, it has added the new concerns of pandemics, rising temperatures, melting arctic ice, melting glaciers, ozone depletion, more destructive storms, and dying coral reefs and amphibians. In general, signs of a growing world ecological stress and decline. Some of these symptoms can be attributed to the burning of fossil fuels. This makes the content of interest to members of the general public other than engineers, without sacrificing its scientific, academic, physical and mathematical rigor and an emphasis at the consideration and comparison of existing as well as potential new alternatives.

The author humbly hopes to address here the fundamental aspects of the topic of Nuclear, Plasma and Radiation Science that these young professionals are curious about, but will not be able to cover in depth in their other specialized courses. They appear curious about the nuclear nature of our universe and the processes of nuclear fusion in the stars, the sun and thermonuclear weapons. They want to learn about fission nuclear power plants, their safety or potential accidents, the recycling of nuclear fuel and its waste, and fission weapons. They are apprehensive about radioactivity and how it affects their personal life, from radiation emissions from computer video monitors and phones, environmental radioactivity in food, to its medical, biological and industrial uses. They want to understand how radiation can affect their health and how it is used in beneficial uses in food preservation, the sterilization of medical products, nuclear medicine, and power sources in space probes and satellites, and want to form their own opinion about it.

The presented material is available to any computer platform equipped with a web browser including smart phones, tablets and laptops, in the portable document format (pdf) and the html format, and requires a download of the freely accessible Adobe Acrobat Reader on any information or communication platform. The chapters are relatively self-contained and can be read in the order that the reader wishes. The work is still in progress and is evolving and is frequently being updated. It is continually “under construction.” In fact, it is an ongoing experiment that started in 1998.

The hope is that this modest effort will contribute to the scientific literacy of the readers in the Nuclear Plasma and Radiological area of knowledge, and satisfy their intellectual curiosity about our universe and our world, whose better future we all dream about.

Dr. Magdi Ragheb

Champaign-Urbana, Illinois, USA
8/18/2023

APPENDIX

Nuclear Energy: Systemic Risk or Climate Change Cure

By Geoffrey Pohanka
July 14, 2021
Geoffrey Pohanka lives in Vienna, VA.

Many of the world's political leaders and people of influence have made it very clear that they view climate change as an existential crisis. President Joe Biden in his first days in office declared climate change the "number one issue facing humanity." The UN warns that we have but twelve years to avoid a climate catastrophe, that searing, unrelenting heat could lay waste to large swaths of the planet, killing millions who have no means to escape a massive climate event. Unabated carbon pollution will spawn heatwaves exceeding the absolute limit of human endurance. According to the UN Intergovernmental Panel on Climate Change (IPCC), net-zero CO2 requires "transformative systemic change." The International Energy Agency calls decarbonizing the energy sector "perhaps the greatest challenge humankind has faced."

Many of the world's leading climate scientists state that there are only a dozen years for global warming to be kept to a maximum of 1.5C, beyond which even a half degree will significantly worsen the risk of droughts, floods, extreme heat, and poverty for hundreds of millions of people. Vice-President Kamala Harris has determined that climate change is "driving migrants to the U.S. Border." U.S. climate envoy John Kerry says the world needs a 'wartime mentality' to combat climate change. Even Hollywood is engaged with Angelina Jolie saying climate change will force hundreds of millions into refugee status and Rosanna Arquette warning that fossil fuels 'will be the end of mankind." Rising CO2 levels are also being named as a potential cause of the condominium collapse in Surfside Florida.

Clearly no one should have any doubts that many genuinely believe the Earth is facing a tipping point of no return unless radical and drastic action is not immediately taken to reduce 'carbon pollution' emissions. Yet there is one threat that seems even more ominous than the CO2 generated from burning fossil fuels…..and that is nuclear energy which produces 20% of U.S. electricity. I wonder how it's possible that a power source with such a small footprint and large energy intensity, that can reliably produce massive amounts of electricity and that generates no CO2, can be even be worse than electricity generated from fossil fuels.

What is causing the fear of nuclear energy? Is it a connection with nuclear weapons?

Growing up during the Cold War, I can certainly understand this, the periodic testing of warning systems, howling sirens and interruptions of TV programming from testing of the emergency broadcast system. Is it the fear of nuclear winter and mutual mass destruction? Is it also the fear of what we cannot see since radiation is invisible? Perhaps this is similar to being afraid of the dark, something I experienced as a child. Certainly Hollywood does not help either with such movies as the China Syndrome which was based on Pennsylvania's Three Mile Island nuclear power plant emergency in the late 1970s. I had to drive just west of that plant on my way to college during the emergency and hoped the wind didn't change in my direction. Even today, movies such as "Chernobyl," continue to fuel nuclear fear.

The recent closing of the Indian Point Nuclear Power plant near West Point, NY, just north of New York City, highlights this point. This power plant, with its zero CO2 emissions, supplied ten percent of the state's electricity as well as 25% of New York City's power. Governor Cuomo worked diligently to close the plant and recently celebrated his success doing so "this is a victory for the health and safety of New Yorkers, and moves us a big step closer to reaching our aggressive energy goals." However, the closure of the plant is causing statewide CO2 emissions to significantly increase. In the first full month without the plant, there has been a 46% increase in the average carbon intensity of statewide electric generation compared to when the Indian Point plant was fully operational according to Environmental Progress.

The State also emitted 37% more carbon dioxide from electricity generation on an absolute basis. It appears that many, including Governor Cuomo, view nuclear energy to be so absolutely dangerous that a significant rise in carbon pollution caused by the closing of nuclear power plants is simply worth the price. While the state enjoys an abundance of clean hydroelectric power replacing reliable nuclear energy with wind and solar power might be more difficult than many realize. One can easily observe the state's sources of power using a website of the New York Independent System Operator (NYISO). The hundreds of wind turbines in the state produced a miniscule 0.034% of energy generation one morning last month, significantly less than the 10% percent of energy reliably produced by the Indian Point plant while it was operational.

The calls for closure of nuclear power plants have become even more pronounced with the major reactor accidents at Chernobyl and Fukushima. The damage from both accidents could have been limited had the Chernobyl plant been constructed with a containment structure and if the Fukushima plant had been fortified to protect against tsunamis. At Chernobyl no nuclear workers or members of the public have died as a result of exposure to radiation though 31 died at the beginning of the accident, two from the blast, and 29 firemen who fought the fire.

At Fukushima there have been no deaths or serious injuries due to the release of radioactivity though 19,500 people there were drowned by the tsunami. These are the only major accidents to have occurred in over 18,500 cumulative reactor years of commercial nuclear power operation in sixteen countries (World Nuclear Association). Nuclear energy has the lowest fatality rate per unit of energy than any source of electricity and including wind and solar. Deadly tsunamis will undoubtedly occur again so perhaps the abandonment of threatened populated coastal zones might be of greater benefit to public safety than the closing of zero CO2 emitting nuclear plants.

The U.S. Nuclear Regulatory Commission (NRC) specifies that reactor designs must exceed a theoretical 1 in 10,000 year core damage frequency but modern designs exceed this. U.S. utility requirements are 1 in 100,000 years. The best currently operating plants are 1 in one million and those likely to be built in the next decade are almost 1 in ten million (WNA). Even with the Three Mile Island accident where the reactor core did melt, the effects were contained as designed, without radiological harm to anyone. There was talk at the time about a potential "China-Syndrome," a scenario where the heat from the core would melt its way through the floor of the reactor and keep going, perhaps as far as China. In reality, the molten core only penetrated 15mm of the floor and is now frozen at the bottom of the reactor pressure vessel (WNA).

Every power source has its dangers and limitations but in order to provide for the greater good for society, energy must be reliable, abundant, and affordable. Bill Gate's advanced nuclear reactor company TerraPower had teamed up with Warren Buffett's PacificCorp to design and eventually construct the first Natrium reactor in Wyoming. A Consortium led by Rolls-Royce have designed a mini reactor that can power 100,000 homes. France has the lowest CO2 density in the

EU by generating over 70% of its electricity from nuclear power and supplies surplus power throughout Europe. About 17% of France's energy comes from recycled nuclear fuel.

Several environmentalists have begun to recognize the many challenges we face with regard to energy choices. One is Michael Shellenberger who now strongly supports nuclear energy. Another is Michael Moore whose movie Planet of the Humans questions if renewable energy technology is a workable solution to climate change.

Others have attempted to end nuclear power by depriving the industry a permanent nuclear waste repository. While nuclear waste does remain dangerous for a very long time there simply is not much of it. Today, this country generates about 2,000 tons of waste annually. The 83,000 tons of waste generated here since the 1950s would fit in a single football field with a depth of less than ten yards. I am sure a permanent waste facility such as the one begun at Yuka Mountain in Nevada would be safer than where nuclear waste is now stored at nuclear plant parking lots. Per unit of energy solar panels produce 300 times more toxic waste than nuclear power plants. The only energy waste that is safely kept out of the environment is from nuclear plants. All other energy waste, from coal, natural gas plants, wind turbines and solar panels ends up in the environment in landfills.

A 2013 study published in the peer reviewed journal Environmental Science and Technology found that nuclear energy has saved an estimate two million lives by replacing coal-fired and other high emission energy generation.

It's easy to understand why wind and solar power appears on the surface to be more attractive as a source of energy than nuclear power but wind and solar power are inherently unreliable since the wind does not always blow nor the sun shine. They certainly won't work without significant battery backup. Today's battery technology is not up to the task simply because there are not enough minerals on this planet to make enough of them and we could not afford them even if there were. Our country has been blessed with a reliable and affordable electricity generation and distribution system. If people are really serious about fighting climate change and achieving the goal of net zero emissions, I don't understand how this will be possible without them also embracing zero CO2 nuclear energy.

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