A Nuclear Redemption:

The Future of Nuclear Energy in an Advancing World

Hazel Abetti

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Doctor Christy Anne Vaughan Ed.D, Advisor

A British scientist by the name of James Lovelock vividly remembers being in St. Louis, Missouri, when a massive tsunami shook the world in March 2011. He remembers reading a detailed account in the Wall Street Journal on the tsunami that swept the Japanese coast, leading to the Fukushima nuclear accident. Despite an editorial in the paper pleading to avoid giving the false impression that 20,000 people had died, it was distinctly ignored, and deep-rooted fear spread throughout the world as false accounts of deaths from the accident were published globally. Mr. Lovelock was intrigued by the fact that France uses nuclear energy on a large scale to generate over two-thirds of the country's energy yet is not dangerously radioactive or in a large depression. He and his wife traveled to a nuclear reprocessing plant near Avignon, called La Hague in France. The rods within this plant were enriched with plutonium. On his person, Mr. Lovelock carried a radiation monitor to see how safe nuclear reactors were.

Mr. Lovelock recalls a body of water the size of a large swimming pool where the nuclear fuel from the reactors was placed to cool off. A bright glow was shining from the highly radioactive uranium rods in the water (Lovelock). This glow was caused by Cherenkov radiation, a blue or violet glow that occurs when electrically charged particles are moving faster than light in a clear medium, such as water (International Atomic Energy Agency). Mr. Lovelock remembered seeing this bright glow from the radioactive uranium rods and thinking the rods looked quite deadly. He discreetly asked the guide, "What would happen if someone swam in the pool?" The answer he received was one that he did not expect.

Clean energy, greenhouse gases, and carbon dioxide are common terms used when referring to energy sources. In the modern age, coal and oil have slowly been discouraged, and clean energy sources such as solar and wind have been promoted. One clean energy source that has long been publicly debated is nuclear energy. Before uncovering the performance and production of nuclear energy, the history of energy in America must be examined closely.

When energy sources in the United States are mentioned, a wide number of various sources are stated---coal, natural gas, nuclear power, solar power, and wind energy. The diverse energy system that America has is a recent occurrence. Only a few centuries ago, not many energy sources were used throughout the United States. Fossil fuels have been the foundation of global energy production for more than 150 years. In the United States, the sun had always been the first source of energy; however, wood was the first real source of energy consumption, dating to 1775, with the use of coal beginning in the 1850s (National Grid Group). The first commercial use of renewable energy began in 1927 with commercial wind turbines being used at remote farms. In 1958, both solar and nuclear energy were brought to the United States (Project Solar UK). Since then, the use of renewable energy has continued to advance and increase.

Atomic research during World War II led to the beginning of nuclear power being used for civilian purposes (Department of Energy). Scientists realized a fission reaction could be caused by radioactive material, in which atoms are split to create large amounts of energy. Wartime nuclear scientists worked with the Manhattan Project, an attempt to create and design a weapon that would harness the extreme power nuclear energy creates (University of Chicago News). This harness would allow detonation to be controlled. The main reason nuclear reactors were built was to create a supply of radioactive material for researchers to test their atomic bomb. Scientists began viewing nuclear reactors as a possible energy source after the development of uranium and plutonium-based bombs that were dropped on Hiroshima and Nagasaki (World Nuclear Association). The first nuclear reactor that generated electricity was in Arco, Idaho, in 1951. Four years later, another reactor was built and was able to power an entire town's electricity needs for one hour during a demonstration (Department of Energy). In 1956 in Sellafield, England, the first successful commercial nuclear power plant was able to produce more than fifty megawatts of electrical power, which would be equivalent to burning 100 tons per day of coal. In a country that did not have its own source of fossil fuels, such as France and Japan, nuclear power increased in use and popularity (World Nuclear Association). It has continued to be an alternative energy source in many countries, including the United States.

Earth is a beautiful planet that provides for all the needs life entails. It is perfectly positioned in the atmosphere so that no one burns up or freezes to death. It has food, water, heat from the sun, and sources of matter that can be used to create condensed heat. It has volcanoes, mountains, deserts, oceans, and tundra. All that live on this planet are called to be stewards of it and to take care and cultivate the land. Being diligent stewards of Earth includes taking care of the environment while being efficient. It is commonly agreed that Earth's climate is constantly changing, even if only temporarily at times. A clean source of renewable energy is needed to efficiently solve the issue of increasing carbon dioxide in the environment (U.S. Global Change Research Program).

Carbon dioxide concentrations continue to rise because of fossil fuels being burned for energy (NASA). According to Oceanic and Atmospheric Research, "In addition to warming temperatures, rising carbon dioxide levels can cause increased hurricane intensity, sea level rise, ocean acidification, and social inequities." In 2023, a new record high was set for the global average atmospheric carbon dioxide, at 419.3 parts per million. Before the industrial revolution, the atmospheric carbon dioxide was 50% lower than it is now. Breathing small amounts of greenhouse gases is safe; however, with increasing fossil fuels being burned, carbon dioxide levels continue to rise (NASA). The increased level of carbon dioxide in the atmosphere can cause various health problems such as headaches, dizziness, difficulty breathing, and increased heart rate. Carbon dioxide has been attributed to being the main source of air pollution, which has a detrimental effect on health. Clean energy sources are needed to fight the rising level of carbon dioxide coming from fossil fuels (Environmental Protection Agency).

Some examples of clean energy sources are solar energy, wind, hydropower, and nuclear energy. All these sources of energy are clean, which means they are not releasing any carbon dioxide into the environment, unlike fossil fuel sources like coal and gas (MIT Climate Portal). Why does nuclear energy matter? Nuclear energy is a vital solution to help protect our planet, maintain air quality, and meet the energy needs of eight billion people globally (World Nuclear Association). In concentrated cities such as New York City, Chicago, or Nashville, there is a high concentration of population, which requires massive amounts of energy. Solar and wind cannot fuel these large cities because they do not create a massive amount of energy (LPP Fusion). Nuclear energy is extraordinary because of its density. A small nuclear reactor can produce a massive amount of energy, "Small modular reactors (SMRs) are advanced nuclear reactors that have a power capacity of up to 300 MW(e) per unit, which is about one-third of the generating capacity of traditional nuclear power reactors," (International Atomic Energy Agency). To produce the same amount of energy using solar and wind, a large quantity is needed to match the output of a SMRs (Department of Energy). Over 1.2 million standard 300 mw solar panels would have to be used, and 100-150 wind turbines depending on location, needing a minimum of 4,000 acres (National Renewable Energy Laboratory). Because there is such a high global demand for energy, it is essential to have efficient sources of energy, like nuclear energy.

How can the United States change so that nuclear energy can be promoted instead of being decreased over the years? Many people desire to solve the issue of carbon dioxide by replacing fossil fuels with renewable energy sources like wind and solar (Pew Research Center). Yet, these sources of energy are weather dependent and do not have as high of an energy output as nuclear energy (Britannica). It is impossible to replace fossil fuels with just solar and wind (Fraser Institute). Nuclear energy could be the main energy source used to substitute for fossil fuels because of its effectiveness in creating large amounts of clean energy. It is important to support the development and deployment of advanced reactor designs, particularly small modular reactors, as well as address the common misconceptions about nuclear energy. According to Pew Research, "56% say they favor more nuclear power plants to generate electricity…Americans remain more likely to favor expanding solar power (78%) and wind power (72%) than nuclear power." As indicated in this study, other renewable energy sources like solar and wind are more favored by Americans than nuclear energy. In light of nuclear energy's potential and benefits, public support can be built with better education and communication.

Concerning the issue of whether or not nuclear energy should be the main energy source used to substitute for fossil fuels, one must first ask: What is nuclear energy? Nuclear energy is the energy in the core of an atom. During nuclear fission, a neutron collides with a uranium atom, causing it to split and release a large amount of energy, creating heat and radiation. More neutrons are released and the process repeats; this is called a nuclear chain reaction. The nuclear power plant reactors control this reaction to the desired amount of heat (U.S. Energy Information Administration). Nuclear power is energy that is released when fission takes place, which is created by breaking atoms in a reactor. When the atoms are broken, heat is produced, warming water, which then produces steam. This steam is used to power a turbine, thus creating electricity.

Nuclear energy should be the main clean energy source used to substitute for fossil fuels. One reason is because it is a dependable energy source, producing zero greenhouse gases. One of the main benefits of nuclear energy is that it produces fewer emissions than fossil fuel power sources. *The Environmental Health Perspectives* states that over 17.6 million Americans are exposed daily to toxic air pollution from oil and gas, transportation, and processing facilities. When fossil fuels are used, pollution increases, leading to serious health impacts. In addition to polluting the air, coal, oil, and gas lead to toxic runoffs in rivers, lakes, and streams. Spills and leaks from extractions and transportation pollute oceans and water ecosystems. The burning of fossil fuels, specifically for power and transportation, is the cause of three-fourths of the United States' carbon emissions (Natural Resources Defense Council).

One fossil fuel polluting the environment is coal. According to Harvard's Center for Health and Global Environment, research has shown that eight percent of warming emissions in the United States are caused by coal (Harvard T.H. Chan School of Public Health). Sadly, coal is not the only fossil fuel that is harming our environment; oil and gas have been attributed to destroying wildlife and natural habitats with spills, explosions, fires, and many deaths of workers. Nuclear power is one solution to solve the constant and extreme issue of carbon dioxide (Department of Energy). Nuclear energy is the solution that can reduce greenhouse gas emissions and meet the energy demands of America. Americans must invest in nuclear energy to reduce carbon dioxide in the environment. Though there are other clean energy sources such as solar and wind, these energy sources are unable to produce the power generation or meet the rising demand of energy (World Nuclear Association).

The United States has long been promoting the production of energy that does not produce fossil fuels. Loudermilk from the National Strategic Studies warns, "On the global level, without nuclear power, carbon dioxide emissions from electricity generation would rise nearly twenty percent" (Liberty University). The only power source that can meet the amount of energy necessary for life in the United States while also reducing greenhouse gas emissions is nuclear energy (World Nuclear Association). The International Atomic Energy Agency states that without nuclear energy, reaching net zero emissions will not be plausible. However, to reach a net zero goal, nuclear energy must be significantly increased. Solar power and wind turbines create a small energy output, which is very beneficial to powering homes or small businesses that do not demand high energy output (International Atomic Energy Agency). However, massive energy amounts are required for cities, large companies, and manufacturing. When nuclear energy is not being used for these large industries, fossil fuels are heavily relied on to generate power. To decrease fossil fuels, nuclear energy is the logical substitute to create a low-carbon environment (Brook).

Some might suggest that eventually uranium will be used up; however, according to the U.S. Energy Information Administration, "Uranium is about 100 times more common than silver," and there is enough accessible uranium to last the earth for hundreds of centuries. During the process of nuclear energy, zero greenhouse gases are released; only heat from atoms is. Nuclear energy and wind turbines produce 12 grams of carbon dioxide per kilowatt hour, the least amount of carbon dioxide emissions any energy source releases, while solar releases 27-48 grams of carbon dioxide per kilowatt hour, depending on location (World Nuclear Association 24). It is evident that nuclear energy is among the cleanest sources of energy (Rehm).

Safety is a crucial factor when discussing energy sources. Workers must have safe, healthy, and reliable jobs that are not harmful when mining and working in power plants. Another way that nuclear energy is beneficial to the United States is that nuclear energy is safe for workers in nuclear power plants, making it dependable for those working. Despite the huge coverage of accidents like Chernobyl, Fukushima, and Three Mile Island, nuclear energy is considered one of the safest sources of energy in the world (Rehm 23). This includes all fossil fuels and all renewable energy sources.

> "To make these comparisons fair, we can't just look at the *total* deaths from each source: fossil fuels still dominate our global electricity mix, so we would expect that they would kill more people. Instead, we compare them based on the estimated number of deaths they cause *per unit of electricity*. This is measured in terawatt-hours. One terawatt-hour is about the same as the annual electricity consumption of 150,000 citizens in the European Union. Let's call this town 'Euroville'.If Euroville were completely powered by coal, we'd expect at least 25 people to die prematurely every year from it. Most of these people would die from air pollution. This is how a coal-powered Euroville would compare with towns powered entirely by each energy source: Coal: 25 people would die prematurely every year; Oil: 18 people would die prematurely every year; Gas: 3 people would die prematurely every year; Hydropower: In an average year, 1 person would die; Wind: In an average year, nobody would die. A death rate of 0.04 deaths per terawatt-hour means every 25 years, a single person would die; Nuclear: In an average year, nobody would die — only every 33 years would someone die. Solar: In an average year, nobody would die — only every 50 years would someone die." (Ritchie 20).

Accidents happen when relating to all energy sources, but the bias and coverage on Chernobyl and Fukushima have greatly damaged the potential that nuclear energy has. Fear has been stronger than the truth. Many are not aware that the deaths caused by nuclear energy are shockingly low, yet it is still believed to be deadly because of the coverage by the press. The first accident that will be examined is one that occurred in Chernobyl Raion, Kiev Oblast, Ukrainian SSR, Soviet Union, on April 26, 1986. Unit 4. of the V I. Lenin Nuclear Power Station exploded, causing the top of the reactor building to tear off (Wellerstein). This led to the core of the reactor being exposed to the Ukrainian winds. Within seconds, a second explosion occurred with the force of ten tons of TNT. Radioactive debris, half-split uranium atoms, and burning graphite shot powerfully into the atmosphere. A fire raged for days. According to the World Nuclear Association, "Two Chernobyl plant workers died due to the explosion on the night of the accident, and a further 28 people died within a few weeks as a result of acute radiation syndrome." For many all over the world, Chernobyl served as a referendum on nuclear power. It had a very strong political influence. However, the nuclear power plant was a rare disaster, and the danger that it brought forth could have been controlled by the country. "The April 1986 disaster at the Chernobyl nuclear power plant in Ukraine was the product of a flawed Soviet reactor design coupled with serious mistakes made by the plant operators. It was a direct consequence of Cold War isolation and the resulting lack of any safety culture." (World Nuclear Association). Exaggerated American reports on Chernobyl were common; on May 2, the New York Times posted: "Late Word From Inside

Figure 1 "2,000 Dead Riddle" The Sun, (April 1986)

Figure 2"Nuclear Nightmare is Here" Daily Express (April 1986)

Russia: Mass Grave for 15,000 N-Victims," (New York Times). As seen, the Chernobyl disaster only directly caused 30 deaths: however, those affected by radiation number around 400,000 living in areas that were contaminated and under strict control. Though this accident was tragic and caused much harm, it could have been prevented easily.

The next highly publicized accident occurred on March 11, 2011, in Okuma, Fukushima, Japan. This accident highlighted the truth that some dangers associated with nuclear energy are outside of human control. Nuclear reactors, like other energy sources, are vulnerable to damage from outside sources. The Great East Japan Earthquake of 9.0 did extreme damage in the region but also created a very large tsunami offshore the city of Sendai. The entire local coastline subsided half a meter from the earthquake, causing the seafloor to extend 650 km. The human death toll numbered about 19,500 and destroyed millions of buildings (World Nuclear Association). According to the World Nuclear Association, "Eleven reactors at four nuclear power plants in the region were operating at the time and all shut down automatically when the earthquake hit. Subsequent inspection showed no significant damage to any from the earthquake." Though the reactors were saved from the earthquake, they were vulnerable to the tsunami. At Fukushima Daiichi, power was lost, and the entire site was flooded by the tsunami. This disabled 12 of 13 backup generators, causing reactor waste heat to be dumped into the ocean. "Three Tepco employees at the Daiichi and Daini plants were killed directly by the earthquake and tsunami, but there have been no fatalities from the nuclear accident…official figures show that there have been 2313 disaster-related deaths among evacuees from Fukushima prefecture. Disaster-related deaths are in addition to the about 19,500 that were killed by the earthquake or tsunami." (World Nuclear Association). The nuclear accident at Fukushima did not cause any radiation-related deaths; instead, deaths were caused close to the nuclear power site because of the earthquake and tsunami and the evacuation that took place after the nuclear accident.

Fukushima has constantly been in public awareness, shaped by memories of horror that have influenced nuclear power debates for a decade. Many have misused models to predict the deaths of millions of people because of radiation exposure, which is scientifically untenable (Wendland and Sarma). One renewable energy researcher and a huge advocate against nuclear energy claimed that there were 130 cancer-related deaths and 180 cancer-related cases because of Fukushima. Mark Lynas recalled that, "In this deeply flawed paper, he succeeds only in illustrating some of the absurdities in current radiological protection models, and that one thing we know for sure—even if those absurdities are ignored—is that the evacuation killed more people than the accident." (Lynas 2012). The evacuation from the tsunami that led to the nuclear accident was the cause of the deaths at Fukushima. No deaths occurred directly because of the Fukushima nuclear reactor melting down. Reports of contaminated water being released into the sea because of the accident have been released from a myriad of different countries. Though the Fukushima accident was a very serious industrial accident, the consequences pale against the severe destruction and casualty caused because of the natural disaster. Fukushima was not the global catastrophe that the world has published that it is.

The next accident that has caused more fear than the impact from the accident occurred in the United States. At four a.m. on March 28, 1979, the Three Mile Island Unit Two partially melted down (Nuclear Regulatory Commission). This has been the most serious accident in U.S. history when related to nuclear energy, yet its small radioactive release did not cause any detectable deaths or health effects on employees or the public (World Nuclear Association). The accident was due to the failure of the secondary, non-nuclear section of the power plant. It was caused by a mechanical failure that prevented the main feedwater pump from sending water into the generators for steam, which removes heat from the reactor core. This caused the reactor to automatically shut down because the temperature in the primary coolant began to rise. A relief valve failed to close, leading to cooling water in the form of steam seeping out of a jammed-open valve. This caused the core to suffer severe damage. Unfortunately, the operators did not respond properly to the unplanned automatic shutdown and did not diagnose the cause of the shutdown. Insufficient emergency response training and deficient control room arrangement were the foundational causes of the accident. A couple of days after the accident, radioactive gas was released into the environment, yet the levels were not high enough to cause any harm to residents. No injuries or health effects occurred from the Three Mile Island accident. The Nuclear Regulatory System, Environmental Protection Agency, Department of Health, Education, Energy, and the Commonwealth of Pennsylvania conducted detailed studies on the radiological consequences. Radioactive gases built up from the reactor cooling system, leading to operators using pipes and compressors to move the gases to tanks. Some radioactive gases were released into the environment from compressor leaks (Nuclear Regulatory Commission).

When the public recalls the TMI-2 accident, fear, stress, and confusion are attributed to those two days. *Crisis Contained, The Department of Energy at Three Mile Island* by Philip L. Cantelon and Robert C. Williams, 1982 is an official history of the Department of Energy's role during the accident, “The deliberate venting of radioactive gases from the plant Friday morning which produced a reading of 1,200 millirems (12 mSv) directly above the stack of the auxiliary building. What made these significant was a series of misunderstandings caused, in part, by problems of communication within various state and federal agencies. Because of confused telephone conversations between people uninformed about the plant's status, officials concluded that the 1,200 millirems (12 mSv) reading was an off-site reading (Department of Energy). They also believed that another hydrogen explosion was possible, that the Nuclear Regulatory Commission had ordered evacuation, and that a meltdown was conceivable." They further go on to state that the accident did not incur a planned evacuation, but government officials and media created a politics of fear around TMI. According to the World Nuclear Association, "The Pennsylvania Department of Health for 18 years maintained a registry of more than 30,000 people who lived within five miles of Three Mile Island at the time of the accident. The state's registry was discontinued in mid 1997, without any evidence of unusual health trends in the area." Over a dozen major studies have continuously been done to look for an abnormal number of cancers or health effects; however, no evidence has been found (World Nuclear Association).

Training reforms were the effect of the TMI-2 accident. Protecting a plant's cooling capacity became a vital part of the training of operators. Because of disciplined training and operations because of the TMI-2 accident, the nuclear industry is significantly safer and more reliable. Sadly, the communication problems that occurred during the accident led to much conflicting information, leading to excessive and unnecessary public fears. Though there were no deaths, "Public confidence in nuclear energy, particularly in the USA, declined sharply following the Three Mile Island accident. It was a major cause of the decline in nuclear construction through the 1980s and 1990s." (World Nuclear Association 24). In conclusion, no deaths or negative health effects resulted from the radiation releases at Three Mile Island.

Nuclear energy has been demonized as dangerous and unsafe because of the three widely publicized accidents: Chernobyl, Fukushima, and Three Mile Island (American Security Project). Yet it has been among the safest forms of electricity generation; Chernobyl resulted in the deaths of 30; the accident was caused by failing safety protocols and updates in the Russian Federation.

Fukushima did not cause any deaths or incidents to harm the public from radiation exposure, nor did it directly kill anyone. Lastly, Three Mile Island resulted in no deaths or health effects. Just as other industries are aiming to minimize the likelihood of accidents, nuclear power plant designs and operations are constantly advancing to make them a safer source of energy. Out of 18,500 nuclear reactors in over 36 countries, there have only been three major accidents (World Nuclear Association). The evidence of over sixty years of nuclear power plants shows the safe means of generating electricity using nuclear power. The risk of accidents is low and not increasing. The false propaganda of newspapers, news, radio, or television is shifting the truth on nuclear energy and greatly affecting the potential that it has. Accidents happen when relating to all energy sources, but the bias and coverage on Chernobyl and Fukushima have greatly damaged the potential that nuclear energy has (Lovelock). Fear has been stronger than the truth.

Nuclear energy should be the main clean energy source used to substitute for fossil fuels because it is the most efficient source of clean energy (International Atomic Energy Institute). It is important to understand the universal demand for energy and how it is constantly progressing. In Figure 1.4 the increase in energy that the United States consumed has only increased over the past 70 years. “The United States…is the second largest consumer of electric energy in the world, with the first being China. As of 2021, the USA consumes over 4.01 trillion kWh of electric energy annually” (U.S. Energy Information Administration). The huge demand for energy in the United States is because of the constantly increasing population. About 70% of the energy produced is from fossil fuels. A very

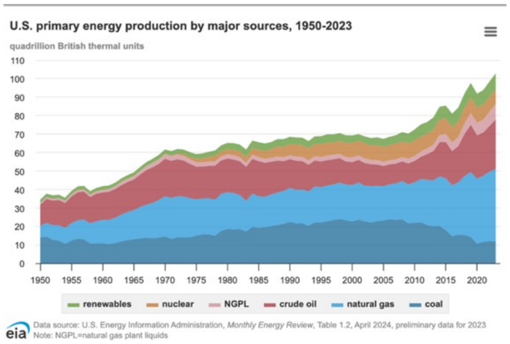

Figure 3“U.S Primary Energy Production by Major Sources” U.S Energy Information Administration (April 2024) small fraction of this energy is from renewable energy sources. One of the reasons that nuclear energy has a large amount of energy production is because of its efficiency. Unlike solar, wind, or other renewable energy sources, nuclear energy is not dependent on the weather and can produce large amounts of energy by splitting atoms. According to the Nuclear Energy Institute, "There are many benefits to select nuclear energy as a reliable source of electricity generation because of its provision of services the field of national security, climate change, leadership, international development, and electrical reliability." Nuclear energy is the most reliable and efficient source of energy, because of its high-capacity factor, minimal maintenance, reliable baseload power, and high-energy density fuel (U.S. Department of Energy).

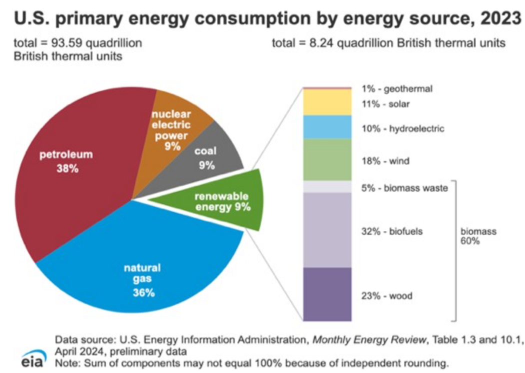

Figure 4 "U.S Primary Energy Consumption by Energy Sources" U.S Energy Information Administration (April 2024)

One of the main reasons that nuclear energy is so efficient is because of its extremely high-capacity factor. The capacity factor can be described as, "the ratio of a specific period's total electrical energy output to the maximum achievable electricity produced during that time." Capacity is measured by megawatts (MW) or kilowatts; these measurements help utilities estimate how large an electricity load a generator can handle. The capacity factor of nuclear power facilities is 93.10%, which is equivalent of running full power for 340 days out of the 365 days of the year. This compares to solar with a capacity factor of only 23.30%, which is equivalent to running full power for only 85 days out of 365, because it is dependent on the weather (Office of Nuclear Energy 21). Wind has a slightly higher capacity factor, at 33.5%, which is equivalent to running full power for 122 days out of the year. Interestingly, the capacity factor of wind and solar has decreased from 2022 to 2023, while nuclear energy has improved by

0.50%. "Based on the capacity factors above, you would need almost two coal or three to four renewable plants (each of 1 GW size) to generate the same amount of electricity onto the grid" (U.S. Department of Energy). Because of the constant advancement and improvement of nuclear energy, the capacity factor has only increased over time. Nuclear power plants can produce more annual energy overall because they run continuously. If the United States is to be decreasing greenhouse gases, nuclear energy will have to be the leading energy source because of the amount of energy it can produce compared to the other renewable energy sources. According to the U.S. Department of Energy, "U.S. nuclear generation capacity exceeded more than 95 gigawatts in 2021…Nuclear power plants had a 8% share of the total U.S. generation capacity in 2021 but actually produced 19% of the country's electricity due to its high capacity factor…all 54 U.S. commercial nuclear power plants were capable of producing that year," (U.S. Department of Energy).

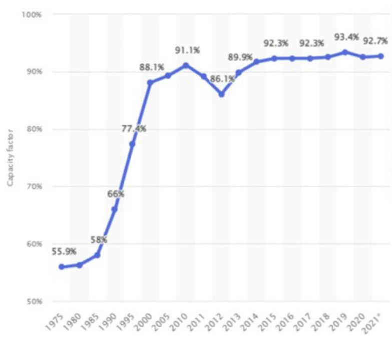

Figure 5 "Capacity Factor of Nuclear Energy from 1975-2021" Office of Nuclear Energy (2022)

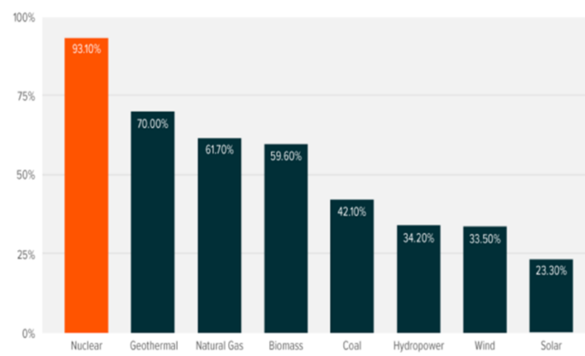

Figure 6 "Capacity Factors for Energy Sources in the United States" Statista Research Department (April 2024)

A reactor can generate around 1 GW of electricity if it operates at full capacity for one year. How much energy is 1 GW of energy? In 2021, one nuclear reactor, with a capacity of 1 GW-hour, is equal to 3.125 million PV solar panels or 431 utility-scale wind turbines. One reactor has the power of 100 million LED bulbs, or 1.3 million horses, and 2,000 Corvette Z06s (U.S. Department of Energy).

Nuclear power plants are used more consistently because they require minimal routine maintenance, operating for long stretches between refueling, which is performed every one to two years. Renewable plants are variable sources because they are limited by a lack of fuels such as wind, sun, or water, which is what makes nuclear energy unique. Many renewable plants require a backup source of power such as large-scale storage. Coal and natural gas additionally have lower capacity factors because of the routine maintenance and refueling that the facilities require. Two coal plants or four renewable plants would generate the same amount of electricity as one gigawatt reactor.

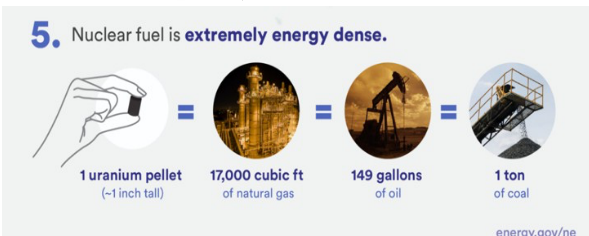

Figure 7 "Nuclear Fuel is Extremely Energy Dense" Office of Nuclear Energy (April 2024)

In 2024, the average electricity that a nuclear reactor is producing is equal to 8.5 million solar panels or 700 land-based wind turbines (MIT Climate 24). The number of solar panels and wind turbines needed to match one nuclear power plant is shockingly massive. 20% of NYC power comes from 3 nuclear power plants; a 1 GW reactor takes up an average of 1.3 square miles. To take into perspective the amount of land solar and wind occupy, the state of New York is 54,555 miles. 41,1965 1 GW nuclear reactors would be able to fit inside the state of NY. 909 solar panel farms could be built in the state of NY, and 151 wind turbine farms could be built. "Wind farms require up to 360 times as much land area to produce the same amount of electricity as a nuclear energy facility, a Nuclear Energy Institute analysis has found. Solar photovoltaic (PV) facilities require up to 75 times the land area," (Nuclear Energy Institute). There is only so much land left to build solar panels and wind turbines on. In addition to a higher demand for energy, there is also a demand for more homes, which also takes up land (National Association of REALTORS). For a long-term solution, nuclear energy is the most reliable and consistent source of energy. It is always dependable, running almost every day of the year, and produces minimal greenhouse gases.

Not only is nuclear energy highly efficient, but it is cleaner than both solar and wind energy. "Unlike many renewable energy sources, power from nuclear energy can be generated 24 hours a day and isn't dependent on the weather, like wind and solar power tend to be. Because of this, nuclear power is more readily available to meet energy demands, which helps to lower the carbon intensity of the electricity supply during times when other renewable energy sources might not be as readily available" (National Grid 2024). Wind and solar energy are most promoted to replace fossil fuels, but according to the IEA, electricity grids need stable, resilient, and dispatchable power. This cannot be provided by solar and wind energy, yet nuclear energy fulfills all the criteria. "When compared with other sources of electricity from cradle to grave, nuclear energy has the lowest carbon footprint, uses fewer materials and takes up less land. For example, solar power needs more than 17 times as much material and 46 times as much land to produce one unit of energy." According to the IEA Director, "Nuclear is one of the safest, cleanest, least environmentally burdensome and — ultimately, over the lifetime of a nuclear power plant — one of the cheapest sources of energy available," (International Atomic Energy Association).

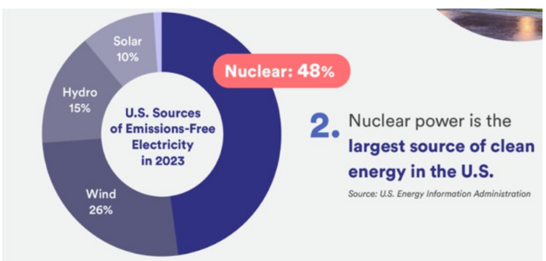

Figure 8 "Nuclear Fuel is the Largest Source of Clean Energy in the U.S" (April 2024)

It is globally agreed by all that nuclear energy does have high upfront costs (World Nuclear Association). While nuclear energy is cheap to run, it is costly to build a nuclear power plant. The construction of one singular nuclear reactor requires substantial investment in infrastructure, technology, and safety. External costs must be taken into consideration, such as regulatory hurdles and public scrutiny that can add to the overall expense of building a nuclear reactor (Eash-Gates). However, the price of nuclear energy is a worthwhile investment, with the money eventually coming back (MIT Energy Initiative).

Nuclear energy has long-term cost efficiency because of its long operational lifespans. Though the initial costs of nuclear power plants are high, each reactor runs an average of 40-60 years, allowing decades for cost recovery time (World Nuclear Association). According to the World Nuclear Association, “The levelized cost of electricity (LCOE)…is the total cost to build and operate a power plant over its lifetime divided by the total electricity output dispatched from the plant over that period, hence typically cost per megawatt hour,” (World Nuclear Association). By using this economic metric, all the financial costs are considered, not just the daily costs. “The operating cost of these plants is lower than almost all fossil fuel competitors, with a very low risk of operating cost inflation” (World Nuclear Association 24). Nuclear power plants create stable, low-cost electricity once they have been built and are producing energy. “Nuclear power plant fuel costs are typically much lower on a dollar-per-megawatt hour ($/MWh) basis than coal or natural gas plant fuel costs: in 2011, the estimated average national fuel costs for coal and natural gas plants were $25/MWh and $36/MWh, respectively. In contrast, the national average cost of nuclear fuel was $6/MWh. As a result, given the same wholesale electricity price, nuclear power plants generally produce more revenue net of fuel cost on a dollar-per-megawatt basis than coal- or natural gas-fired plants,” (U.S. Energy Information

U.S. Nuclear Plant Costs ($/MWh in 2022 dollars)

Year	Fuel	Capital	Operating	Total Generating
2002	6.83	4.68	22.18	33.69
2004	6.32	6.76	22.18	35.26
2007	6.17	7.36	22.93	36.46
2010	8.22	11.39	25.34	44.95
2011	8.72	12.57	27.14	48.43
2012	9.15	14.01	28.05	51.22
2015	8.30	9.68	25.33	43.32
2016	8.09	8.11	24.58	40.78
2017	7.60	7.84	24.21	39.65
2018	7.33	7.16	22.78	37.27
2019	6.97	6.47	21.01	34.45
2020	6.44	5.97	20.43	32.84
2021	5.94	5.89	19.34	31.17
2022	5.37	6.88	18.68	30.92
2021-2022 Change	-9.7%	16.8%	-3.4%	-0.8%
DNP (2012-2022)	-41.4%	-50.9%	-33.4%	-39.6%

Figure 8 “U.S. Nuclear Plant Costs” Nuclear Energy Institute (2022)

Administration). The cost of uranium, which is the main fuel of power plants, remains inexpensive when compared to fossil fuels.

As advancements are made in technology, which improve and update nuclear reactor design and efficiency, the cost of building reactors only decreases over the years. A new Nuclear Energy Institute study proves that “the nuclear industry has reduced its total generating costs by 19 percent since their peak in 2012” (Nuclear Energy Institute). As seen in the figure, the cost of nuclear energy has only decreased since 2012 and continues to lower. Not only have construction costs continued to decline, but small modular reactors (SMRs) promise lower construction and operational costs compared to the average 1 GW large-scale nuclear reactor (Kuca etc. Materna).

Nuclear energy does require significant initial investment upon building a new reactor, yet the financial benefits outweigh the costs (World Nuclear Association). With nuclear power plants being so extremely efficient and having long lifespans, it makes them cost-effective sources of electricity over time (Antonini). With nuclear energy, the rising costs of fossil fuels can be mitigated. Nuclear energy offers price stability, unlike oil and gas, which face constantly changing global markets (World Nuclear Association).

Another argument made against promoting nuclear energy is that reactors produce nuclear waste, especially when being decommissioned (Igini). It is undeniable that all nuclear reactors eventually require decommissioning after a long operational life. Furthermore, managing waste is a significant challenge. Safely disposing of waste has been a contentious issue for many countries. The waste produced by nuclear power plants remains high-level waste for around 1,000 years.

Although nuclear waste is a challenge that nuclear energy creates, small reactors are beginning to be built, causing less waste to be used, as well as advancements in waste management are constantly being made such as small reactors burning nuclear waste, reduction of waste transportation, and deep geological storage. Small modular reactors (SMRs) have a capacity to produce 300 MW per unit. This is one-third of the generating capacity of a large, conventional nuclear power reactor. SMRs are physically smaller and modular, which makes it possible for the system to be assembled in a factory and transported to different locations for installation. Just like other nuclear reactors, nuclear fission is used in SMRs to generate heat and produce energy (International Atomic Energy Agency).

SMRs are prefabricated units, making them able to be shipped to a particular location; additionally, they are more affordable than large reactors. Most large power reactors are custom designed for the location where they are built, making construction delays common. Additionally, SMRs are cost-effective, because construction time is much simpler. Not only do these reactors reduce construction and operational costs, but they also produce much less nuclear waste compared to large reactors (Hillard). According to the Journal of Waste Management and Recycling Technology:

> "SMRs are a compact and versatile form of nuclear reactor that offer several advantages, including reduced construction costs, scalability, and enhanced safety features. SMRs are also well-suited for nuclear waste management and recycling. SMRs can be configured to burn or transmute nuclear waste as part of their fuel cycle, effectively reducing the volume and radiotoxicity of waste. SMRs can provide power to remote locations and support critical infrastructure, reducing the need to transport nuclear waste over long distances. By placing SMRs closer to urban centers, energy demand can be met efficiently, reducing transmission losses and associated risk (Scientific Research and Community 2023)."

Another way that waste management is advancing is through reprocessing technologies, such as PUREX, the Plutonium Uranium Redox Extraction process. This is a widely used chemical method that reprocesses nuclear fuel that has been spent. It allows for the extraction and purification of uranium and plutonium from irradiated fuel. The PUREX essentially recycles the elements of nuclear waste for potential reuse in nuclear reactors (Encyclopedia of Physical Science and Technology). The recycled nuclear waste becomes new fuel. According to the International Atomic Energy Agency, “To manage the nearly 1150 tons of spent fuel it produces every year, France, like several other countries, decided early on to close its national nuclear fuel cycle by recycling or reprocessing spent fuel. In doing so, the French nuclear industry can recover uranium and plutonium from the used fuel for reuse, thereby also reducing the volume of high-level waste,” (International Atomic Energy Agency). For over 30 years, France has successfully developed advanced reprocessing plants and significantly reduced the waste volume from nuclear power plants (World Nuclear Association).

Additionally, not only has reprocessing become more advanced, but deep geological storage for nuclear waste has been successfully demonstrated (World Nuclear Association). Finland’s Onkalo facility is the first nation to bury spent nuclear fuel rods underground for long durations. The fuel is in a stable, isolated environment, making it safe. The “Onkalo,” the Finnish word for cave, is a 1,500-foot-deep grave inside the bedrock of Olkiluoto island. It is now the first permanent storage site in the world to store spent nuclear fuel (Benke). "Everybody knew of the idea of a geological repository for high-level radioactive nuclear waste, but Finland did it," stated Rafael Mariano Grossi, the IAEA director general in 2020 (International Atomic Energy Agency). Though there have been incidents and concerns of radioactive waste leaking, the radioactive waste is stored in extremely highly engineered casks in a vitrified form. The storage solutions are made so that if an earthquake occurred, harmful radiation would not reach the surface (World Nuclear Association). This is a new, advanced waste disposal solution that could spread across the world, solving the problem of storing nuclear waste (World Nuclear Association).

The challenge of nuclear waste disposal is constantly being addressed all over the world through technological advancements, reprocessing advancements, and improved waste storage management. While it is true that waste disposal is a prominent issue associated with nuclear energy, it is not a problem that is undefeatable. With the continuous development of SMRs, the advancement of fuel reprocessing, and realistic geological storage for nuclear waste, safely minimizing waste is significantly attainable. Moreover, when nuclear fuel is recycled, it reduces the need for mining more uranium, making the entire nuclear fuel cycle even more sustainable. (World Nuclear Association).

Another argument that is commonly used to dissuade support of nuclear energy is that it is not possible for nuclear energy to be the main source of energy that a country relies on without national damage occurring (Rhodes). It is universally agreed that for a country to use nuclear energy as its main source of energy, waste disposal must be managed, high construction costs will be evident, and political resistance will occur (Government Accountability Office). While these disruptions can occur when a country relies heavily on nuclear energy, the benefits surpass any barriers that would reduce the amount of nuclear energy generated in a country (Igini).

One country that has transitioned to prominently using nuclear energy is France. About 70% of France's energy is from nuclear energy. Under a former administration, a French government policy was put in place that would reduce the amount of nuclear energy generated in the country to 50% by 2025. However, this was put on hold in 2019 and eventually abandoned in

2023. Interestingly, 17% of the nuclear energy produced in France is spent fuel that has been recycled. According to the World Nuclear Association, “France is the world's largest net exporter of electricity due to its very low cost of generation, and gains over €3 billion per year from this…From being a net electricity importer through most of the 1970s, France has become the world's largest net electricity exporter, with electricity being the fourth largest export.” France has 18 commercial power plants, which are included in 57 operable reactors that run across the country (World Nuclear Association).

Because France relies mainly on nuclear energy, the country has many benefits. First, they have extreme energy security since France is generating its own electricity from nuclear power instead of relying on other fossil fuel markets coming from Russia, making them an energy-independent nation. Second, because nuclear energy is so efficient, they have low electricity costs compared to other European nations. In 2023, the citizens of France paid an average cost of 27.2 cents per kWh, the UK paid 46.5 cents per kWh, Germany 37.9 cents per kWh, and the Netherlands 34.9 cents per kWh. (European Commission). According to President Emmanuel Macron in 2022, “The key to producing this electricity in the most carbon-free, safest and most sovereign way is precisely to have a plural strategy... to develop both renewable and nuclear energies. We have no other choice but to bet on these two pillars at the same time. It is the most relevant choice from an ecological point of view and the most expedient from an economic point of view and finally the least costly from a financial point of view,” (World Nuclear Association). Although President Macron is arguing for the use of both nuclear and renewable sources, such as solar and wind, nuclear energy should be the main clean energy used to substitute because of its efficiency, safety, and dependability. Though the cost of building reactors is a costly investment, the production of nuclear energy is not. As seen above, France is the lowest-paying country compared to similarly occupied European countries.

Because France has such a robust nuclear capacity, the country exports electricity to other European countries, more than any other country in the world. With this exported energy, they make an income of over three billion euros per year (American Nuclear Society). Not only does France rely heavily on nuclear energy, but they are a major component in other European energy markets, making others rely on it for clean energy. Carbon Brief reports that because of France's nuclear capacity, it produces the least amount of electricity from fossil fuels compared to all the other G20 countries.

While some may view transitioning a country to nuclear energy as a dangerous endeavor, France is one country that has proved that a country can rely on nuclear energy as its main energy source and thrive. Though France had to invest in building more reactors, they are now making a revenue of a few billion dollars per year because they distribute energy. Furthermore, they are not reliant on other countries, making them immune to fluctuating energy costs that could occur because of wars. After the Fukushima accident, Germany proceeded to shut down every single nuclear reactor because of radiation and safety concerns. However, the comparison between France and Germany is drastically different in 2024 because of the difference in technology to generate energy. "France's relatively low-CO2 electricity generation contributes to low climate-damaging emissions. The CO2-intensity of electricity generation in France stood at around 57 CO2/kWh in 2020 (Statista). In Germany, the electricity mixes at the same time had a CO2-intensity of 366g CO2/kWh, which was more than six times higher (UBA). The explanation for this high discrepancy lies in the technologies used to generate electricity in the two countries” (Goess). A country that runs on nuclear energy is safer, cleaner, and more energy independent.

“What would happen if someone swam in the pool?” Mr. Lovelock asked, while his eyes were transfixed on the bright glow from the radioactive uranium rods. The guide of the nuclear power plant answered, “Nothing bad, the radiation level at the top of the pool is negligible. Check it with your monitor.” Obliging his invitation, Mr. Lovelock removed his radiation monitor, which showed that the surface water of the pool would be warm and safe. Only the glowing area near the rods would be lethal to humans.

Soon, the guide took Mr. Lovelock and his wife down to an underground chamber where over 25 years of nuclear waste is stored. The radiation reader, which the British scientist held again, read safe radiation levels, indicating the waste as safely buried. After visiting the nuclear power plant and seeing for himself the radiation levels within, Mr. Lovelock wrote that fear of nuclear energy must be stopped. The fear of nuclear reactors must be broken (Lovelock).

We have seen what nuclear energy is. First, the dependability of nuclear energy was examined. The studies done have continually proved that nuclear energy is a clean energy source that releases no greenhouse gases, and if the world desires to reach a goal of no fossil fuels, nuclear energy must be used. This led to the consideration of safety. In examining safety, specifically the Fukushima, Chernobyl, and Three Mile Island accidents, the evidence compellingly showed that nuclear energy is the safest source of energy, despite public opinion. Finally, an analysis of data clearly showed that nuclear energy is the most efficient source of energy. The three arguments that were considered were that nuclear energy surpasses the benefits of wind and solar, the output of energy created by nuclear power plants makes it the greatest renewable source of energy, and because nuclear power is not dependent on weather, it has the highest capacity factor compared to all other energy sources.

Many will question why any of the studies or advantages of nuclear energy matter. They may state that nuclear energy is an energy source that is insignificant in daily life. While nuclear energy may not directly affect everyone, bringing awareness to its incredible abilities and having the public educated is essential to furthering its potential. It is problematic that many gather their opinions from the press and government. Because of this, almost all the world believes misconceptions and falsities relating to nuclear energy. These lies create a crippling fear, turning citizens against supporting nuclear energy. This fear must be stopped. This magnificent source of energy could change countries for the better, but many do not even know how nuclear energy is created or how low the radiation levels truly are. It is time to start speaking about what nuclear energy is and how it has been made into a monster that does not exist.

What does this mean for the average person? The challenge now is to take the next step. There are three crucial things citizens can do to immediately help further nuclear energy in their country. First, they can educate themselves and the people around them on the benefits of nuclear energy. To dispel the fallacies and the widespread nuclear energy anti-movement, accurate information about both the economic and environmental benefits of nuclear energy must be spread. Through better education, broader support for nuclear energy can be effectively built. Next, citizens can contact their elected officials and voice support for an increase and investment in nuclear energy, influencing their politicians to make policies towards advancing nuclear energy. Additionally, participating in grassroots movements and advocating within a community through organizations that further the use of nuclear energy through awareness is extremely influential. Lastly, if able, choosing an electricity provider that prioritizes nuclear energy generation will help support the industry through energy consumption. Will you follow through? Are you going to take small steps to make your country a better one? Nuclear energy use can increase because of actions taken by citizens. Let’s further this incredible energy source.

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