

# The Path to Carbon Neutrality in U.S. Focusing on Energy Sector

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**Abstract.** One of the most important things for human is energy. Literally every physical action by machines requires energy consumption. With the increase of energy consumption, relying solely on fossil fuels is not the right method because fossil fuels have a finite amount, and they are also the main cause of global warming. Therefore, using renewable energies is the best solution. The United States (U.S.) is one of the largest and powerful country worldwide, so the prospects of renewable energies in U.S. can have a great influence in global renewable energies. After full-scaled research and analysis on U.S. renewable energies, two of the most suitable renewable energies for U.S. are nuclear energy and wind energy, which can replace fossil fuels on a large scale. Although both energy sources have their shortages, they are the most applicable solution to achieve carbon neutrality, and they both have a bright future in the U.S.

**Keywords:** Carbon Emission, United States, Nuclear Energy, Wind Energy.

## 1. Introduction

The problem of global warming has raised the awareness of people in the past decades, and the consumption of energy has become a frequently discussed topic recently. There are many types of natural energy sources on Earth, such as fossil fuels, hydropower, nuclear energy, solar energy, wind energy, biomass, geothermal and a lot more.

The usage of fossil fuels contributes significantly to greenhouse gas emission, which is a major factor of global warming. Moreover, fossil fuels will run out one day due to that they take millions of years to form. Interestingly, more than 80% of today's energy consumption are fossil fuels [1], which significantly dominates global energy consumption. Therefore, people need a solution to solve this problem. The term "renewable energy" refers to energy sources other than fossil fuels that won't harm the environment and will not be used up, so it seems that it is the best solution of the concern of overusing fossil fuels.

According to the analysis and prediction by some experts, the current fossil fuels we have will run out before the next century. Thus, it's essential for human to find a solution not only practical, but also promptly. Reasonable and logical estimation for a few decades later can also help human to take action in the right direction and with a high efficiency.

The U.S. is the second largest country in global energy consumption in 2021 with about 93 exajoules [2]. Moreover, the U.S. is the world's largest economy. Its GDP in 2022 exceeds 25 trillion dollars, which shares over 30% in the top 20 nations with the highest GDP that year [3]. Also, the U.S. has the top technologies in a variety of territories. Thus, the U.S. has a great hope getting close to carbon neutrality faster than other countries due to the advantages it has. Actions on renewable the U.S. take in the future will have a significant impact on the path to carbon neutrality globally. Therefore, it's meaningful to conduct a research and analysis on the renewable energy of the U.S.

Most people will only claim that renewable energy should replace all fossil fuels as soon as possible. However, there are also problems with renewable energy that has to solve, including the efficiency of turning natural energy into usable energy, installation, transportation, technology, land using, economic efficiency and even potential harm to human and the environment. These factors are easily neglected and not adequately covered academically. In further sections, these aspects of the U.S. will all be discussed, along with prediction and estimation of the future of the U.S. renewable energy.

## 2. Overview of U.S. Energy Today

As the second largest energy consumption country, the U.S. uses about 97 exajoules in 2021 as mentioned above. As shown in fig. 1, 79% of the energy consumption of U.S. came from fossil fuels, which includes petroleum, natural gas and coal. This number is slightly lower than the average percentage around the world. Around 8% of U.S. energy came from nuclear plants, which is twice as much as the global average. The other renewable energies contribute for nearly 13% of U.S. energy consumption, and this figure is about the same compared to the average worldwide [4]. Although U.S. is one of the most advanced countries worldwide, it does not use a tremendous amount of renewable energy. With the technical resources, financial ability and natural resources, U.S. has a great potential to achieve carbon neutrality in the future.

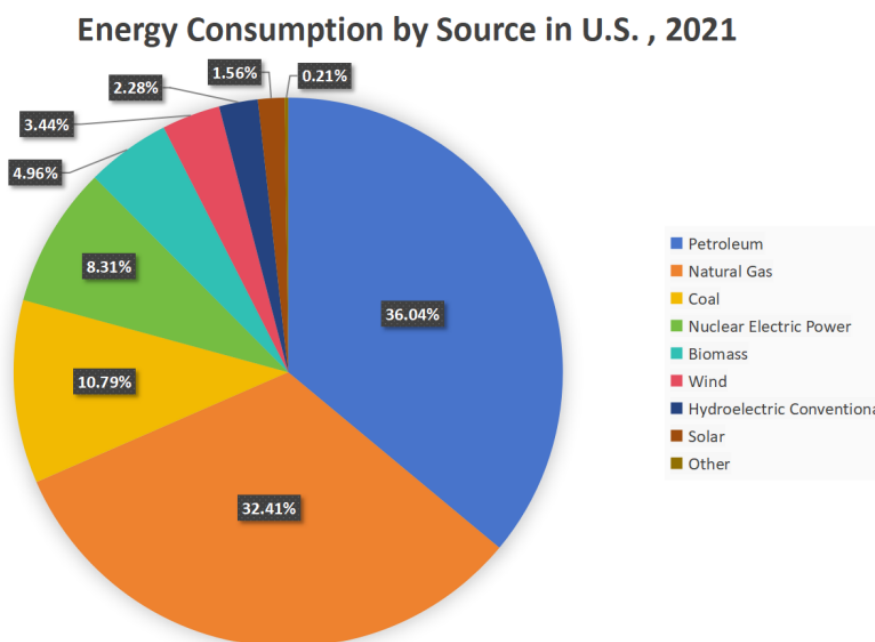


Figure 1. U.S. energy consumption by source in 2021 [4]

## 3. Nuclear Energy

### 3.1. Nuclear Energy Introduction

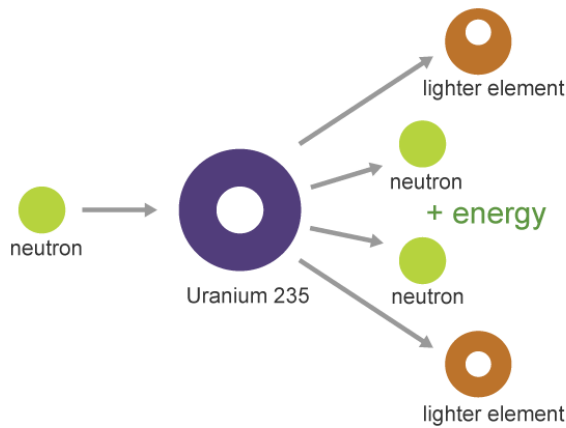
The categorizing of nuclear energy has raised some arguments among people. Despite the fact that it is also sometimes referred to as a fossil fuel, nuclear energy is commonly referred to be a renewable energy source. Nuclear energy should theoretically be viewed as a fossil fuel since uranium, the main ingredient in nuclear fission, cannot regenerate and replenish itself in accordance with the concept of a renewable energy. The quantity of uranium currently existing on Earth, however, is enough to produce energy for billions of years, even without accounting for the potential for nuclear fusion, which necessitates the reaction of other elements. Therefore, uranium could be treated as infinite amount, so nuclear energy is generally categorized as a renewable energy, although it should be called carbon-free energy technically. In later sections, nuclear energy will be referred as a renewable energy.

### 3.2. The Ways Nuclear Reaction Release Energy

Nuclear energy can be used in two different ways: nuclear fusion and nuclear fission. Nuclear power plants all across the world are currently using nuclear fission, which has already been achieved. Nuclear fusion hasn't yet been refined into a reliable and marketable energy source, though. Scientists from all over the world are making great strides on experimental fusion devices to show the viability of nuclear fusion before it is extensively used. Atoms or particles are split or combined in nuclear fusion as well as nuclear fission, as shown in fig. 2 and 3, respectively.

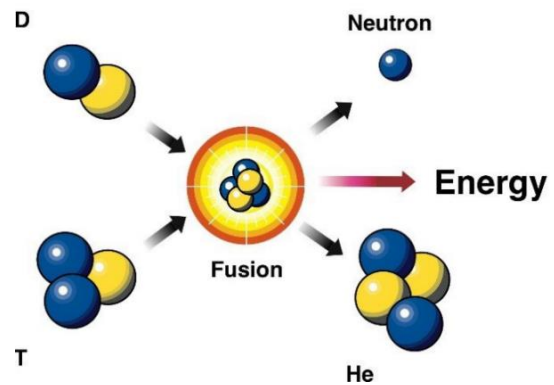
In nuclear fission, the uranium atom breaks into lighter particles when it collides with a neutron. People can utilize the heat and radiation that are emitted during this process, which is significant [5]. On the other hand, a few of the periodic table's components may theoretically carry out nuclear fusion. A heavier nucleus is created when two light nuclei fuse together in a fusion reaction. This process can release energy since the nucleus' mass is smaller than the total mass of the two initial nuclei. The extra mass becomes energy, according to Einstein's equation,  $E = mc^2$ . Researchers working on fusion energy applications are particularly interested in DT fusion reaction, which involves deuterium and tritium. DT fusion produces not only a helium nucleus, but also a neutron. Thus, DT fusion releases much more energy than most fusion reactions do [6].

**How fission splits the uranium atom**



Source: Adapted from National Energy Education Development Project (public domain)

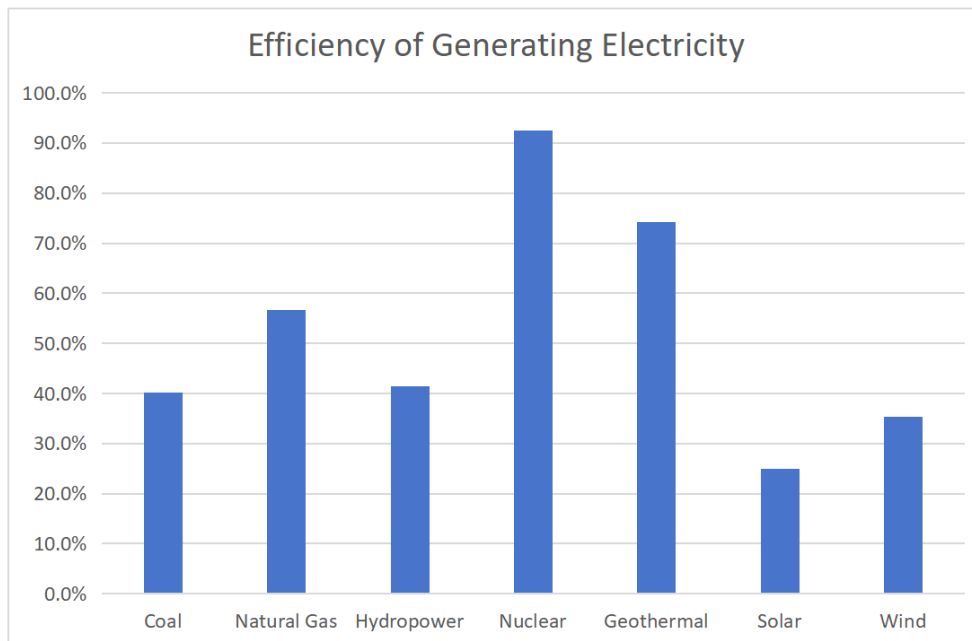
**Figure 2.** nuclear fission process [5]



**Figure 3.** nuclear fusion process [6]

**3.3. The Advantages of Nuclear Energy**

The first advantage of nuclear energy is carbon free, which means nuclear reaction emits absolutely zero greenhouse gases. This is necessary for achieving carbon neutrality. Secondly, the U.S. is one of the most developed countries in nuclear technology economy, and it's also a major consumer of energy worldwide, as mentioned in Introduction. Thus, the U.S. can develop nuclear energy vigorously and also lead the world to use nuclear energy as a main force in achieving carbon neutrality.



**Figure 4.** electricity generation efficiency by source [7]

Nuclear energy has the highest efficiency among all kinds of energies, with a capacity factor of over 90%; while the capacity factor of the other three major renewable energies, which include hydropower, wind and solar, are relatively modest with less than 50% as shown in fig. 4 [7]. Therefore, nuclear reaction can generate two or even three times more energy compared to other renewable energies if the energy input are the same. Furthermore, nuclear energy is one of the densest energy source, only using 0.3 m<sup>2</sup> for generate 1000 kWh of electricity, which mean nuclear energy uses less ground for generating the same amount of energy [8]. The high density of nuclear energy plus its incredibly high efficiency gives it the advantage of generating energy while using much less resources.

### 3.4. Concern and Problems of Nuclear Energy

#### 3.4.1. The most tragic nuclear accident

On the other hand, there are several reasons that result in a bad prospect of nuclear energy. Many countries, including the U.S., do not have their future focus on enhancing the amount of nuclear energy utilized and have no plan to build more nuclear energy plants. The main concern of nuclear energy currently is how secure they are. The major harm that nuclear energy can cause is radiation. During nuclear reaction, certain design was made to make sure nuclear radiation will not spread outside the reactors. Additionally, nuclear waste has to be properly handled too. Nuclear radiation will not decay in a few decades, which means storing nuclear waste is another severe problem. Although people appreciate the high efficiency and other advantages of nuclear energy, nobody wants nuclear waste store near them. Moreover, the consequences of nuclear accidents are also notable.

The most famous nuclear accident in history is at Chernobyl in 1986. The Chernobyl accident was more frightful, which resulted in around 50 deaths. The day after the Chernobyl accident, more than 30 thousand inhabitants began to evacuate, and monitoring systems from Russia, Belarus, France, Italy, Sweden had all reported high levels of wind-transported radioactivity. In addition, some livestock were born deformed, and there were illness and cancer among people that were caused by radiation. Furthermore, over 4000 km<sup>2</sup> of land around the Chernobyl nuclear power plants are occupied as exclusion zone even to this day [9]. This catastrophe was mainly caused by nuclear reactor issues and poor safety management. Thus, the potential accidents of using nuclear energy can bring is unimaginable, which is the major reason that many nations are reluctant to use nuclear energy extensively.

#### 3.4.2. Fukushima nuclear waste water discharge

The other recent popular event is that Japan discharged nuclear waste water from the Fukushima catastrophe in 2011 last month. The design and construction of the Fukushima nuclear reactors are somewhat poor, and due to the strong earthquake and the tsunami that followed the earthquake on March 11, 2011, several reactors in the Fukushima nuclear station were damaged. Although nobody died in the accident, the Japan government used a huge amount of water to cool down the damaged reactors and to prevent radioactive radiation from being released. Water has to be added into the damaged reactors incessantly to cool them down, and the used water were stored in massive tanks. Japan claims they have no more space for storing this water, and they need this land for other uses. Thus, Japan officially started to dump nuclear waste water into the ocean in August 24, 2023. In a survey made in Japan, only 53% of Japanese citizens support the act, while 41% think it's harmful to do so [10]. Although there are other solutions, such as subterranean burial, geosphere injection and hydrogen release, the Japan government decided to discharge them into the sea. The Tokyo Electric Power Company (TEPCO) claims that the radionuclides were already filtered by Advanced Liquid Processing System (ALPS) before discharging, researchers raised suspicions on the safety and quality of the filtering system. Theoretically, ALPS should be able to remove all non-tritium radionuclides, but Science News points out that there are potential non-tritium radionuclides present in the waste water, especially <sup>137</sup>Cs. <sup>137</sup>Cs might have a great impact since it stays radioactive for around 30 years. <sup>137</sup>Cs is the main cause of cancers due to nuclear accidents, and released <sup>137</sup>Cs in open sea may bring dreadful impact on living things. Research simulation shows that although the dose of <sup>137</sup>Cs after

discharging nuclear waste water will be lesser than doses after the Chernobyl accident. If that's the case, then the decision by the Japan government is unqualified for the international law. Thus, marine product in the region where nuclear waste water is dumped will not be edible, and they might transmit  $^{137}\text{Cs}$  into other ocean areas [11]. The safety of nuclear reactors and potential nuclear accidents are not the only concern of nuclear energy usage, but also the way countries deal with nuclear wastes. Nuclear wastes are mainly stored until the radiation decays. If people overuse nuclear energy extensively, the first problem is how to store nuclear wastes safely while using less amount of land. Therefore, the solution for nuclear wastes storage, processing and discharging has to be found before nuclear energy is widely used.

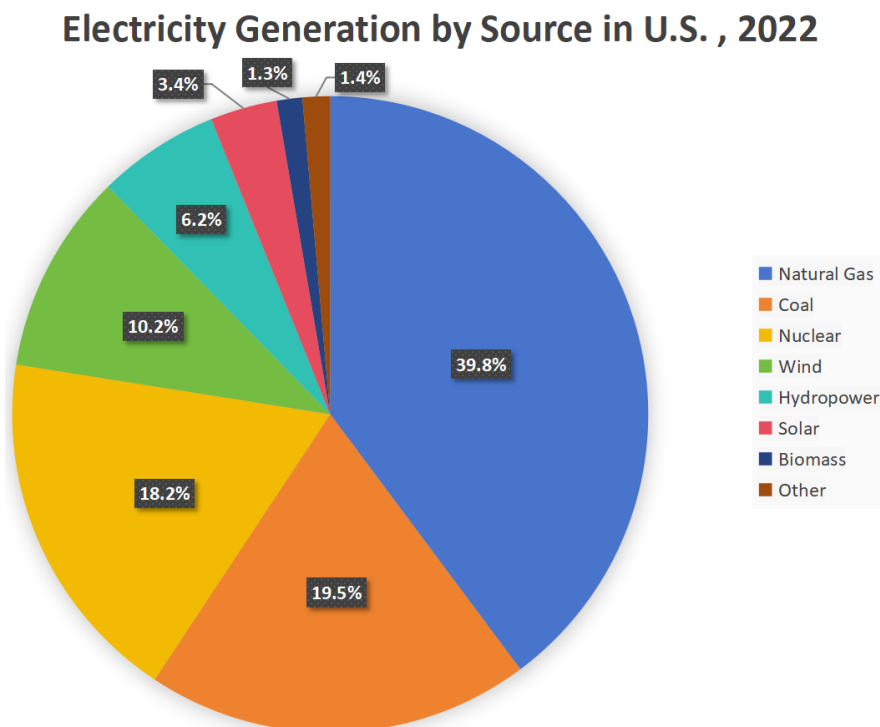
### 3.5. Solutions for Nuclear Energy

The solution for the hazardous of nuclear energy is actually simple: develop nuclear fusion technology so that less radioactive emission will be produced. Most of the radiation of nuclear fission are released from the split atoms, so the broken atoms will release strong radiation. On the other hand, two nuclei in nuclear fusion collide with each other and sort of "stick" together. Nuclear radiation from fusion is not very strong and can decay and reuse within 100 years, while nuclear fission radiation can remain dangerous and radioactive for tens of thousands of years or more. Furthermore, nuclear fusion reaction is not a chain reaction like nuclear fission. If a step of nuclear fission goes wrong, the problem will only get more and more severe and eventually out of control, so nuclear fusion removes the concern of runaway reactivity. It's true that nuclear fusion can also be harmful and it has not yet been used to contribute people, so scientist don't how will nuclear fusion exactly be when it is utilized in daily life. From another angle, all kinds of energy production may cause potential threat to people, and scientist will learn lessons from the previous nuclear accidents. Thus, nuclear energy, especially nuclear fusion, can have an opportunity to contribute greatly to the energy usage worldwide.

## 4. Wind Energy

### 4.1. Wind Energy Introduction

The basic reason that people need to use natural energy resources on Earth is to convert them into usable energy satisfy our daily life needs. There various forms of energy we can use straightforward, such as electricity, gasoline, heat and many more. The most common and multi-purpose energy people can use straightly is electricity. For example, many vehicles are encouraged to use electricity instead of gasoline. As fig. 5 shows, wind was leading electricity generation by renewable energy in U.S. with more than 10%, not including nuclear energy [12]. With the contribution to electricity generation today, wind energy could take a heavy responsibility in the future to generate electricity in a absolute clean way, which is a crucial step towards carbon neutrality. The specific way that wind turbines generate electricity and how they can suck up more wind involves some complicated aerodynamics. However, the general principal of wind turbine is simple: It's just the opposite of a electric fan. Instead of using electricity to spin the blades, wind cause the propeller-like blades of a turbine to rotate around an axis which is connected to a generator, and the spinning of the generator will produce electricity.



**Figure 5.** U.S. electricity generation by source in 2022 [12]

#### 4.2. The Advantages of Wind Energy

The first advantage of wind energy is that it's not only carbon-free, but it does not produce any waste or substance that can cause problems for people. Wind energy is absolutely clean, since wind blowing is a natural phenomenon and wind turbines are just standing in the path of wind. The main competitor of wind energy in the renewable energies is solar energy. However, according to Figure 4, although the efficiency of wind energy is among the lowest of all energies, its efficiency is considerably higher than solar energy [7]. Moreover, the maximum rate of turning the wind kinetic energy into electricity is 59%, according to the Betz limit in fluid mechanics. Therefore, there is a huge room for scientists to improve.

Furthermore, the net land footprint of wind turbines is one of the lowest among all energy resource, occupying only 0.4 for generating 1000 kWh of electricity [8]. This number does not include the land in between wind turbines, but people can utilize this land for other purposes. The U.S. is fourth largest country worldwide in terms of national territory area, so there are a lot of potential land that can be built into wind farms. As Figure 6 shows, the cost of onshore wind is one of the cheapest in all forms of energies, and the cost dropped significantly from 2010 to 2019. Although the current offshore wind cost is still high, the cost is declining at a fast rate [13]. This trend is expected to continue in the future, which makes wind energy very competitive due to its low cost.

Also, wind turbines can be built on the sea, which are called offshore wind. Since 70% of Earth's surface is covered with water, people could utilize this area for offshore wind production. There are also two benefits of offshore wind: the first is it does not occupy any land territory, and the second is wind blown over oceans is typically stronger than windblown on land. The U.S. can strive to develop offshore wind in particular because it also has a long coastal line. Moreover, wind energy is safe since the wind turbines are unlikely to cause any tremendous disaster. Therefore, wind energy can have a great potential in the U.S. for both onshore and offshore.

#### 4.3. Concern and Problems of Wind Energy

Despite the various benefits of wind energy, there are also hinders that can cause problems for the development of wind energy. The first problem is the installation of wind turbines. Typically, the places where wind is abundant and strong are in remote areas, so constructing wind turbines in those

places can be challenging because of the geographic landscape. Furthermore, transporting electricity generate in rural areas to urban cities is an obstacle too. Upgrading transmission network that connects areas with excess wind resource and population centers will increase the expense on using wind energy significantly, thus it might reduce the expand of wind farms.

Wind turbines will also produce noise at some extent and can affect visual scenery. Making noise means that although the net land footprint of wind turbines is the lowest among all energies, it's not practical to utilize spaces between wind turbines for other use. If people build large wind farms with gaps between wind turbines, land occupation will become a severe problem because the land footprint of wind farms will be very high [8]. Additionally, some people have already reflected the effect on visual scenery produced by wind turbines. The best natural landscape are gathered in places far from cities in the nature, which could be ideal for building wind farms. Therefore, constructing wind farms in these ideal places might cause decline in tourism. Offshore wind turbines may also affect scenery on the ocean. Besides, the construction of offshore wind is much more expensive than onshore wind and also the most expensive energy worldwide, as fig. 6 shows [13], which gives offshore wind a drawback.

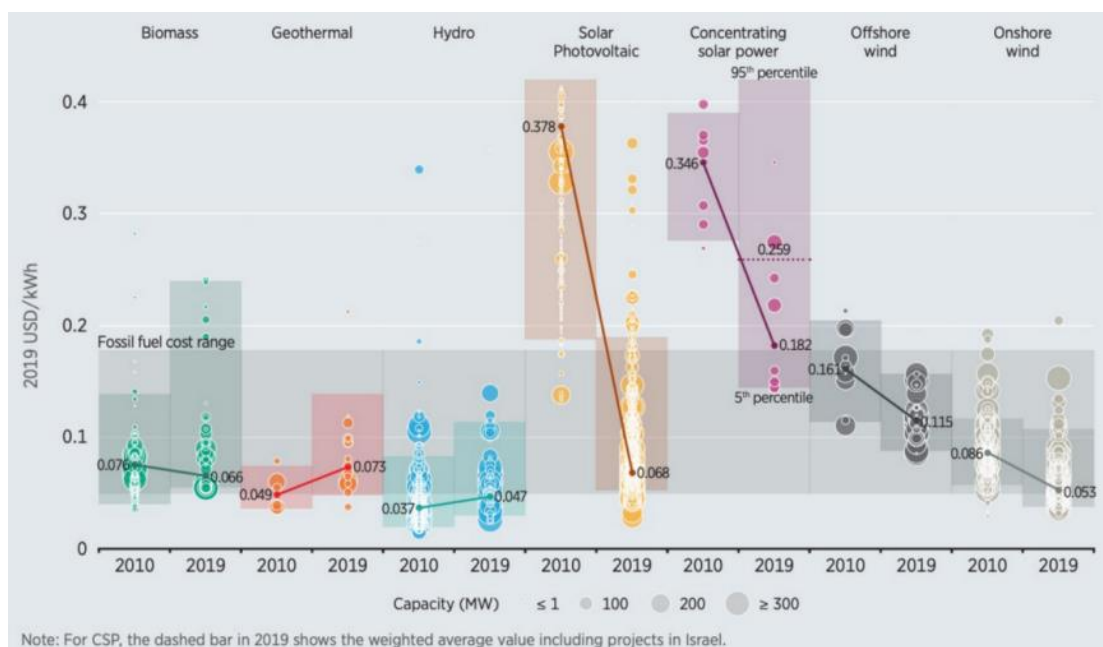


Figure 6. cost of various source of energies in 2010 and 2019 [13]

## 5. Future Prediction

### 5.1. Future Prediction of Nuclear Energy

The future of renewable energies is no doubt clear and hopeful, no matter which form of renewable will be in lead towards the carbon neutral world. Since this essay has been discussing nuclear and wind energy in the U.S., this section will evaluate the future possibilities of these two forms of energies. According to U.S. Energy Information Administration, the projects generation from nuclear power plants will plateau in the future, which means they won't increase significantly [14].

On the other hand, usage of nuclear energy could also increase significantly due to events that happened around the U.S. The first promotion is the U.S. government allocated 700 million dollars to build a supply chain of high-assay low-enriched uranium, which is HALEU in short; while allocating another 150 million dollars for nuclear research and technology development. Additionally, the tax credit of nuclear electricity generation will be \$15 per megawatt-hour, which makes the price of nuclear energy competitive in the market. Moreover, fuel loading is completed at Plant Vogtle in Georgia, which means Unit 3 and 4 will come into service soon, supplying clean, reliable energy to over 1 million Georgia homes and businesses. Energy companies are also preparing to devote for

nuclear energy production. For example, X-energy is willing to dedicate for fueling HALEU-based reactors, and Ultra Safe Nuclear Corporation developed nuclear facilities too. The Department of Energy, which is DOE in short, also awarded 150 million dollars to Centrus Operating Corporation on HALEU programs. Furthermore, there are also breakthroughs in technologies. Idaho National Laboratory in U.S. successfully achieved a prototype of DOE's MARVEL project, which is micro-reactors that are more compact. Internationally, the U.S. will help Poland to build its first nuclear reactor, and the U.S., France and Canada launched plans to increase nuclear capacity in Romania. DOE also announced the achievement of fusion ignition in Lawrence Livermore National Laboratory, which is a significant breakthrough in fusion technology. Most importantly, DOE released a study on coal-nuclear transition, which the report shows that 80% of the U.S. coal power plants could be converted into nuclear plants, which can increase U.S. nuclear capacity by 250 gigawatts [15].

## 5.2. Future prediction of Wind Energy

The future of wind energy seems to be one of the brightest among all energy sources. The growth of wind energy in U.S. was tremendous during the past decade, which the capacity grew from about 94 terawatt-hours in 2010 to about 338 terawatt-hours in 2020, which is more than tripled. Moreover, the wind capacity grew for over 100 terawatt-hours in the past two years, and the new installed capacity was generally growing [16]. The short-term prediction by EIA also indicates that electricity generation from wind energy will increase in the next couple years, replacing some of the electricity generated by natural gas and coal [17]. Additionally, DOE have collected wind energy installment in U.S. in the past and also made some projection for the future. In 2000, the wind capacity of U.S. is only 2.53 gigawatts across a mere 4 states, and obviously with no offshore wind consumption. In 2010, 27 states in U.S. had wind installation and the total capacity increased for nearly 20 times, but the number is still modest with a little over 40 gigawatts, and there was also no offshore wind. In 2020, 113 gigawatts of wind capacity across 36 states were present, and some coastal states started to establish offshore wind. DOE estimated that in 2030, the wind capacity in U.S. will be around 224 gigawatts, which is almost twice as much as 2020, and offshore wind will be enhance dramatically. According to the projection for 2050, over 400 gigawatts of wind energy will be installed across 48 states in U.S., which covers almost the whole country. Furthermore, offshore wind will become dominant in most of the coastal states, which is shown in fig. 7; this could save a significant amount of land for other purposes [18].

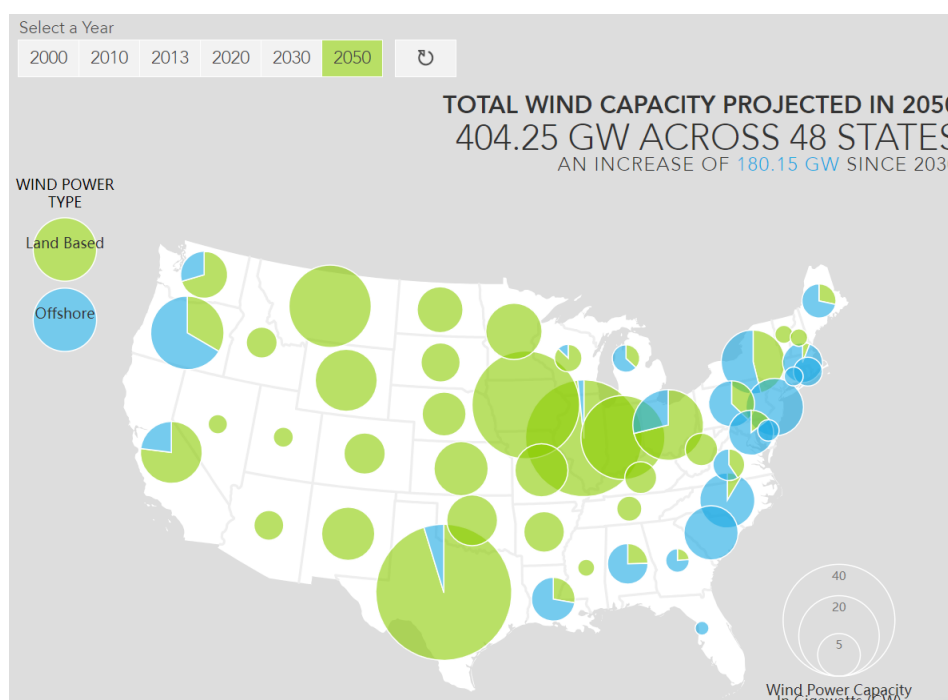


Figure 7. projected wind capacity in U.S. in 2050 [18]

## 6. Conclusion

In summary, both wind and nuclear energy have great potential for contributing to U.S. energy generation and consumption. Although nuclear energy is an unpopular energy source currently, some of the policies and acts from the government and companies are supporting nuclear technology. The greatest advantages of nuclear energy are high efficiency and high density. Nuclear energy has higher technological requirements compared to other energy sources, so if the U.S. can overcome technological difficulties and advertise the positives of nuclear energy, it can become a dominant renewable energy in the future. As for wind energy, it has a better public impression than nuclear energy. It's one of the cleanest energies sources and it has no obvious disadvantage. According to projections from various reliable sources, wind capacity in U.S. will increase significantly in the next decades. If scientists can solve the shortage of land occupation and efficiency, wind energy will certainly become the most dominant energy in U.S. This essay covers some blanks in the research of future potential of U.S. renewable energy, especially nuclear energy and wind energy. This essay has roundly detailed research on all aspects of nuclear energy and wind energy, which could contribute to researchers and governments to develop these two energy sources in a more beneficial way. Nevertheless, this essay does not adequately cover all the renewable energies in U.S., and it also lacks the specific policies on these two energies from the U.S. government. Future researches can be more full-scaled and explore other renewable energies in U.S., which could lead humans to a carbon neutral world in the future.

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