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Spring 2018

Alternative Energy: An Examination of Costs, Safety, and Potential

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Alternative Energy

An Examination of Costs, Safety, and Potential

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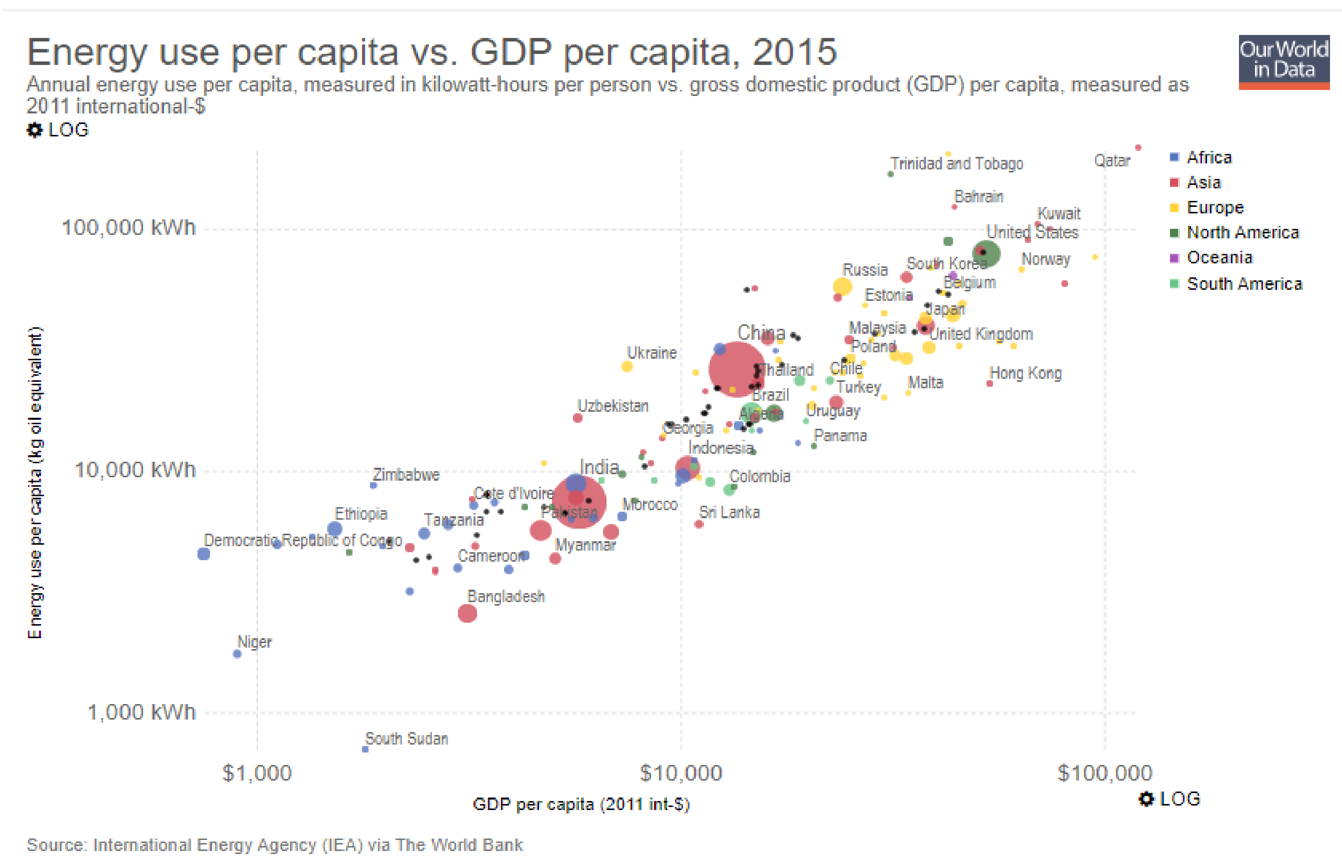
5-24-2018

Importance of Energy:

In the modern world few things are more important than energy. Energy is the lifeblood that powers everything and has a hand in virtually all aspects of human life. Whether it is powering machines in hospitals, transporting products around the world, assisting scientific discovery, or making modern agriculture possible, energy is everywhere. Unfortunately, there are over 1 billion people on the planet who have no electricity and another 3 billion who have almost no electricity by western standards (*Epstein 42*). The lack of energy can be deadly to people living in parts of the world without electricity and without energy. With energy lifesaving surgeries are possible, without them people die needlessly in the third world. Energy powers modern agriculture so it can grow enough food for a larger population to eat while without energy mass food production is impossible. In parts of the world without energy people go hungry and malnutrition due to insufficient diets are common place. The importance of energy to human life is often ignored when thinking about energy issues.

Energy use correlates strongly with the GDP, as can be seen by the graph below from the International Energy Agency. This illustrates the importance of energy to people's standard of living and overall quality of life. Few people appreciate how much the modern world depends on energy to maintain this standard. The fact that a person can get on a flight from New York City to Los Angeles is not appreciated by most people. That it is possible to transfer food and supplies to areas during natural disasters or bad crop years to avoid famines is seen as a given. The reality is that for most of human history these things were not possible and a bad crop meant starvation. It is no coincidence that virtually every measure of quality of life has risen exponentially since the industrial revolution (*Epstein 77*). Energy is the driving factor behind the vast majority of the growth in the past several hundred years. In light of this information it is important to be careful when coming to decisions about what energy sources humans should be using. After careful examination of alternative energy sources, it is clear that nuclear energy is the best option and has the greatest potential to become the world's leading energy source in the future.

Table 1.1:



Terminology and Technicalities of Energy:

Below is a list of important terms and definitions taken from Guild Energy (*Energy Terms*).

- Energy: a measure of how much fuel is contained in or used by something over a period of time.
- Power: the rate at which energy is used or generated.
- Kilowatt (kW): Unit of power equal to 1,000 watts.
- Kilowatt-Hour (kWh): The electricity produced by 1 kilowatt acting for one hour. Amount of electricity consumed in one hour by ten 100-watt light bulbs. Electricity meters use kilowatt-hours as the standard measurement.
- Megawatt: Unit of power that is equal to 100 kilowatts.
- Watt (W): The unit of electrical measurement.
- Watthour (Wh): The work done by a watt in an hour.

Current Energy Landscape:

The worldwide energy landscape is dominated by fossil fuels, which consist of oil, natural gas and coal. In 2013 fossil fuels made up 86% of world energy consumption, nuclear was 4.5%, and hydro made up 6.7% (*Epstein 44*). Wind and Solar combined made up less than 1% of the worlds energy at this same point in time. The energy consumption makeup of the United States is similar with 81.5% of it coming from fossil fuels in 2015 (*Pisupati*). Coal use has been dropping in recent years in the United States, decreasing by 13% in 2015 (*Pisupati*). This is due to cheap natural gas prices and more renewable energy. The graphs below shows the breakdown of worldwide energy consumption and where U.S energy comes from and where it goes. By looking at table 1.2 it shows that fossil fuels make up the vast majority of global energy consumption and have for a long time. Biofuels, which primarily consists of burning wood, make up fraction of energy consumption globally at the bottom of the graph. This is primarily done in the third world, where more advanced energy sources are not widely used. Wind and solar energy are the tiny sections towards the top of the graph and make up very little of global energy consumption. Table 1.3 shows where the energy comes from and goes in the United States. It shows that oil is the largest energy source in the U.S, followed by natural gas and coal. Roughly 40% of U.S energy goes towards producing electricity and 28% is used for transportation. Industrial energy usage makes up about 22% of the energy usage in the U.S and the remainder is used in residential and commercial sectors.

Table 1.2:

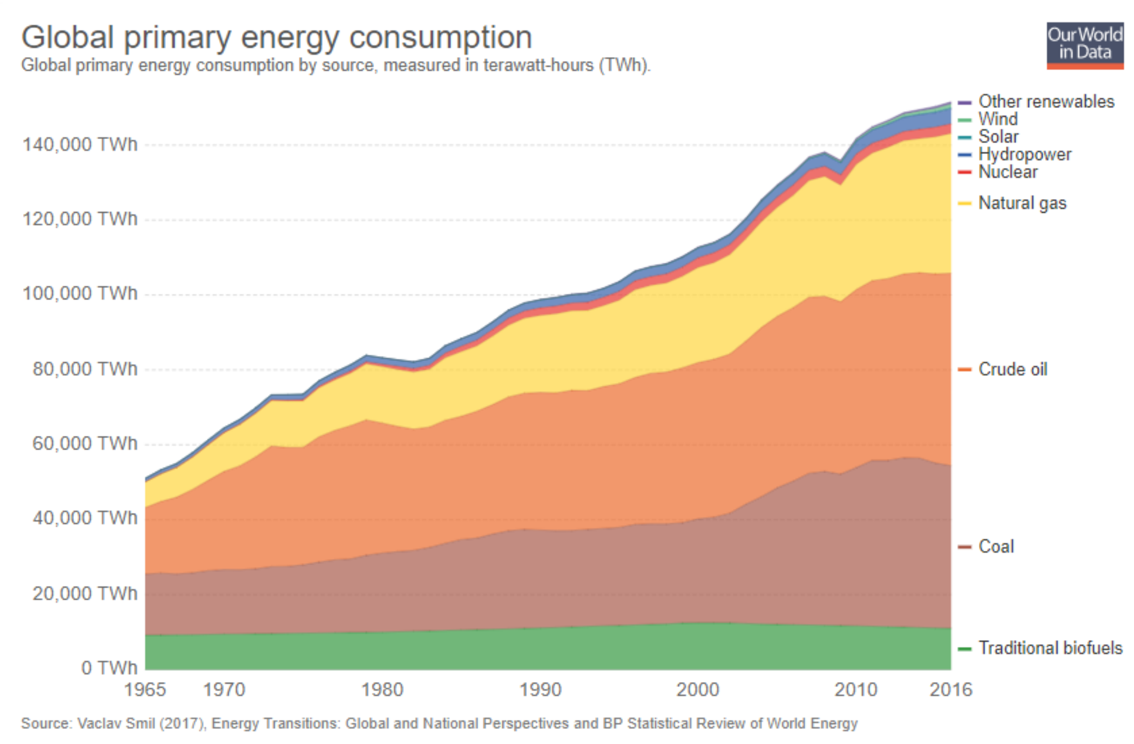
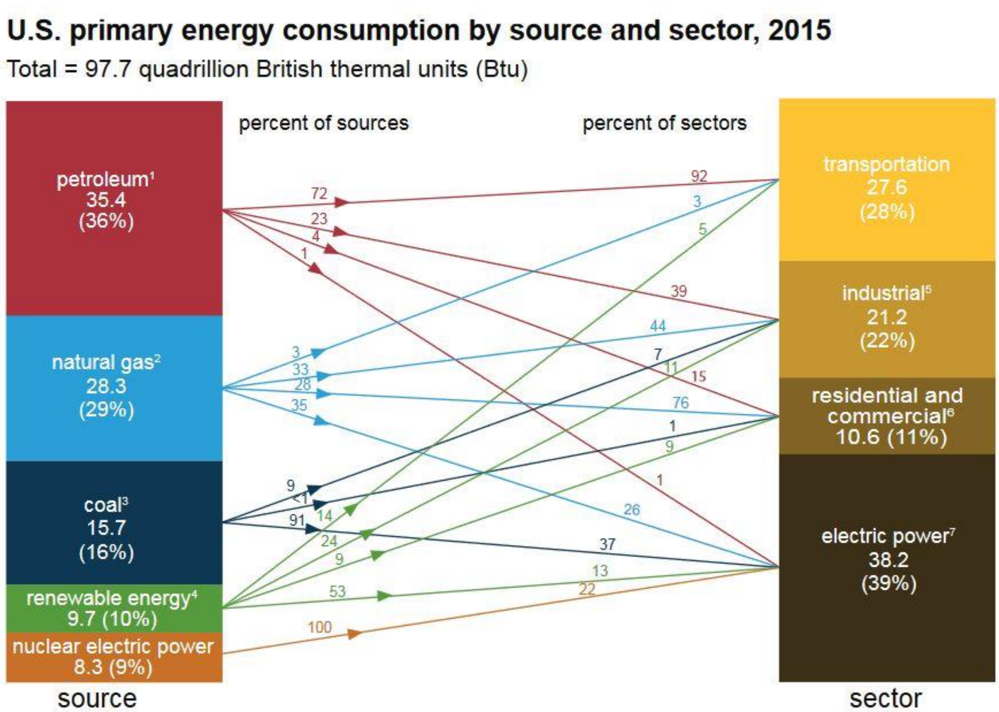


Table 1.3 (*Pisupati*):



Fossil Fuels:

Fossil fuels are called that because it is theorized that they are the condensed concentrations of energy from plants over millions of years. These condensed forms of plant energy are made up of carbon and hydrogen atoms, attached by chemical bonds. As these bonds are burned and used, the bonds break and release energy (*Epstein 66*). Over the course of millions of years dead plants pile up and get piled under layers of earth. During this process, the energy is condensed over the course of millions of years (*Epstein 66*). This leads to the extreme density of fossil fuel energy, meaning a lot of energy is stored in a very small space. Fossil fuels come in three different forms, solid (coal), liquid (oil), and gas (natural gas). The main advantage of fossil fuel energy from a cost perspective is that it is highly concentrated and reliable energy (*Epstein 66*). Other forms of energy, such as wind or solar, can vary in their production but fossil fuels always give you a reliable amount of energy. The other advantage is that there are large amounts of fossil fuels on the planet even today. For example, according to current usage rates, there is over 3,000 years of recoverable coal reserves (*Epstein 66*). Each of these forms of fossil fuel energy have specific uses and pros and cons, which is why they each are used in different ways.

Coal is the world's leader in electricity production, particularly in the developing world (*Epstein 67*). The primary reasons it is used so frequently are that it is a solid and is fairly abundant around the world. Coal is also not spread extremely thinly in the earth, meaning it can be mined easier because minors do not need to mine large land areas to get usable amounts of coal (*Epstein 67*). The levelized cost of energy for coal, according to the Wall Street firm Lazard, is $102/kWh in 2017 (*Levelized cost of Energy 2017*). This is more expensive than some energy sources but due to the abundance and reliability of coal it still makes up a large portion of the worlds electricity generation. Coal use is expected to rise in the coming decades due to developing countries industrializing over that time period.

Natural gas is used frequently for peak load electricity, which is the electricity demand that has to be dialed up and down to meet changing demand. There is base-load power of electricity that is the amount that will always be required no matter what for an area. Peak-load electricity varies more based upon specific daily circumstances and require the energy source to scale up and down very frequently (*Epstein 69*). Extreme heat is often what requires peak load electricity since people use air conditioners in those situations, which drives electricity demand up for relatively short periods of time. Natural gas is particularly good at scaling up or down, which is why it is used primarily for peak load electricity. Coal, nuclear, and hydroelectric power all specialize in base load power, on the other hand. The cost of natural gas according to the Lazard study varies depending on the process used. It ranges from a cost of $42/MWh to $210/MWh depending on the method used to produce electricity with natural gas (*Levelized Cost of Electricity 2017*).

Oil is the final form of fossil fuel energy and is primarily used for transportation. In 2015 oil accounted for 92% of all transportation fuel used in the United States (*Pisupati*). Currently the price for a barrel of oil is hovering around $60, according to Bloomberg, and is relatively cheap. Most transportation vehicles, including cars, trucks, trains and planes, use oil as their primary energy source. One major reason oil is so good for transportation is because it is highly concentrated, as well as being a liquid. Liquid fuels are best for transportation because they can be moved very easily, and since all portable power sources need to carry their own fuel, this is a big important (*Epstein 71*). Other energy sources have struggled to meet this challenge form a competitive standpoint. Electric cars, powered by batteries, are the only true competitor yet are extremely expensive. Specifically, battery technology has not advanced very quickly over time due to technical restraints and hurdles that must be overcome. This can be seen clearly by examining the energy density of batteries. The Tesla Roadster battery has an energy density that is 107 times less than gasoline, meaning the amount of energy that can be stored in the battery is 107 times less than what is stored in gasoline. This factor decreases to 35 times less because the electric motor is more efficient at using the energy than a gasoline powered motor is (*Epstein 72*). Even after that though, it is still an enormous difference in terms of performance capability. Electric cars have been around longer than gasoline powered cars, contrary to popular belief, so it may take a long time for them to become competitive.

Solar:

Solar power is produced by converting the sun's solar rays into energy. The sun releases energy particles called photons, which travel to the earth and can be converted into solar power. The number of photons that reach the earth in an hour would be enough to power the whole planet for a whole year in theory (*SunPower*). Solar energy is produced by using solar panels, which can be put on rooftops or on large solar farms. Solar panels, also called photovoltaic (PV) solar panels, are made up of solar cells. The cells are made of silicon and have both a positive and a negative layer, which combine to create an electric field in the vain of a battery (*SunPower*). Solar panels work by stripping the photons of their electrons when they hit the panel. The electrons then flow through the electrical field created by the positive and negative layers of the cells, creating electricity.

Solar power has a cost to install it at first and then a continuous cost afterwards such as maintenance costs. According to EnergySage, a solar energy equipment supplier, the homeowners are paying between $2.71 and $3.57 per watt to install solar power. This comes out to a cost of $18,840 before tax credits or $11,380 - $14,990 after the tax credit (*Matasci*). The cost is done by using the U.S average system size of 6 kilowatts (kW). The tax credit decreases the cost by about 30% and many states and localities offer further incentives that make it cheaper. The price to install a solar panel also varies by state, with a per watt cost of about $3.50 in Massachusetts and $2.65 per watt in Florida (*Matasci*). EnergySage also lists the amount of savings people can get over the course of twenty years by installing solar panels on their homes. This ranges from $63,000 for someone living in Boston to about $35,000 for someone living in Austin (*Matasci*). If this is calculated on a per year basis someone living in Boston would save about $3,150 a year, compared to about $1,750 in Austin.

The other cost is the continual cost of operating after the solar panels are installed. One way to measure this cost is to use the levelized cost of energy (LCOE). This is when you take the total expected lifetime costs of the technology and divide it by the total expected costs over its lifetime (*Sendy*). The result is a cost for different energy sources that can be compared to each other. It works very similar to what the Net Present Value (NPV) is in the financial world. According to a recent 2017 analysis by the financial company Lazard, in some scenarios solar energy is cheaper according to this metric than conventional sources of energy such as coal or nuclear. The analysis also notes that the Levelized Cost of Energy declined 6% from 2016 for utility-scale solar photovoltaic (PV) energy (*Levelized Cost of Energy 2017*). The LCOE for utility scale solar energy has declined 86% from 2009 to 2017, from a mean rate of $359 per megawatt hour to $50/MWh. The current cost of $50/MWh is much less than the $102/MWh price for coal in 2017 (*Levelized Cost of Electricity 2017*). It also notes, however, that the cost decline seems to be slowing down so it may not continue to drop in price nearly as fast in the future. Despite that, the decrease in cost should lead to more solar capacity being installed in the years to come, according to this analysis (*Levelized Cost of Electricity 2017*).

According to the Institute for Energy Research, in 2015 solar energy made up less than 1% of the total energy production in the United States (*Solar*). Europe has pushed a lot harder for solar energy, as well as wind energy, than the United States. The countries that are often cited as being the leaders in both wind and solar energy are Germany and Denmark. As a result, they will be used for purposes of comparison to the United States and as a benchmark for the success of these energy sources as well as costs. In Germany, 6.1% of the electricity produced in 2017 came from solar energy according to a non-partisan German research organization (*Germany's energy consumption)*. If solar energy is cheaper than conventional sources of energy such as nuclear and coal one would expect it to make up a much larger percentage of the energy market. One reason for this is that solar energy is very intermittent, meaning it varies in its availability (*Solar*). The sun does not shine at night, so right away solar energy is only available for half the day in the best case scenario. Even during the day the sun does not shine all the time due to cloud cover, which can be more common in different parts of the world. Producing solar energy in Seattle is very different from doing so in Southern California. Also, the sun does not shine with the same intensity at all points when it is out due to its position in the sky. This means solar energy produces the most during the times closest to noon, when the sun reaches its maximum intensity. Places such as Alaska or northern Scandinavia get very little sunlight during certain times of the year due to their distance away from the equator. Another problem solar energy faces is that it is diluted compared to conventional forms of energy (*Epstein 49*). This means that it is not a very dense energy source and it requires many solar panels to equal one nuclear or coal plant. Coal can store a lot of energy into a very compact space whereas the sun is spread very thin when it comes to concentrating its rays into usable energy for people.

By looking at the two charts below you can see the wind and solar electricity production in Germany over the course of the year and a month (*Epstein 51-52*). The two energy sources together are never able to meet Germany's electricity demand. The intermittency problem is evident from the charts, which shows how the overall electricity provided is very inconsistent and fluctuates constantly. At nighttime the solar energy goes down to zero because the sun is not out and wind energy tends to be correlated with solar energy. As a result, there are brief moments where they both can combine to provide perhaps 40%-80% of the electricity Germany needs. These are only brief moments and do not last long or happen frequently enough. At other points in time, particularly at night and in the evening, they both provide almost no energy. Conventional energy sources, such as coal, then have to make up for the lack of production from wind and solar energy (*Solar*). This means coal and nuclear plants have to constantly scale their production up and down over the course of a month, leading to increased costs in the same way that stop and go traffic uses up more gas (*Epstein 53*).

Table 1.4: Germany Electrical Production
Source: The Moral Case for Fossil Fuels page 51

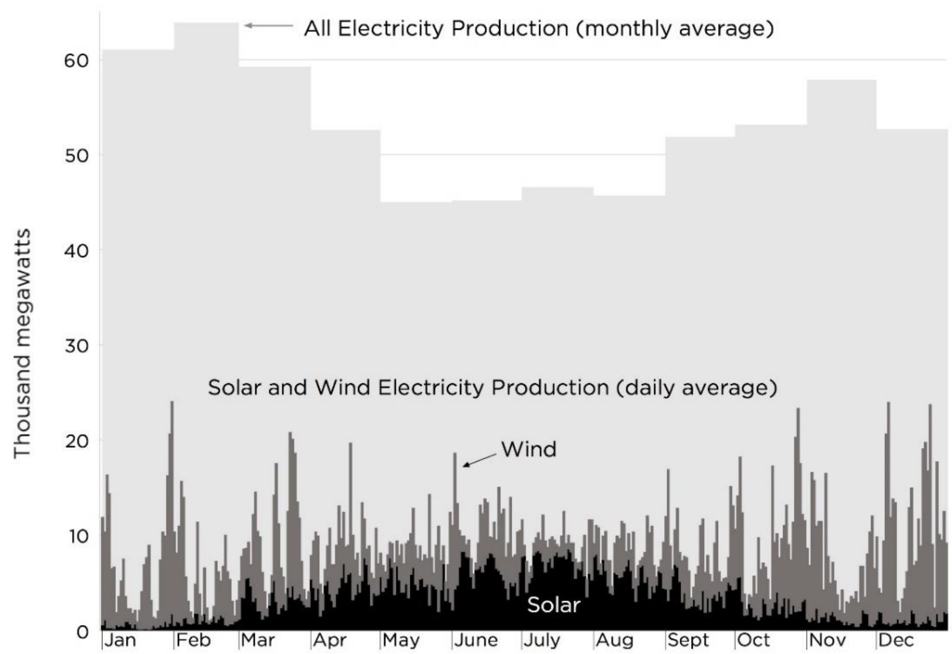
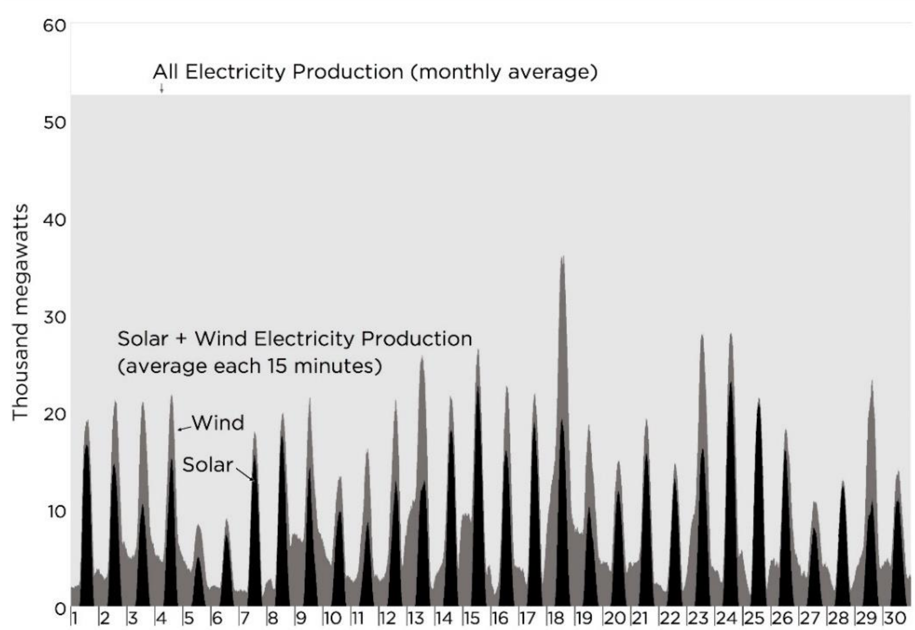


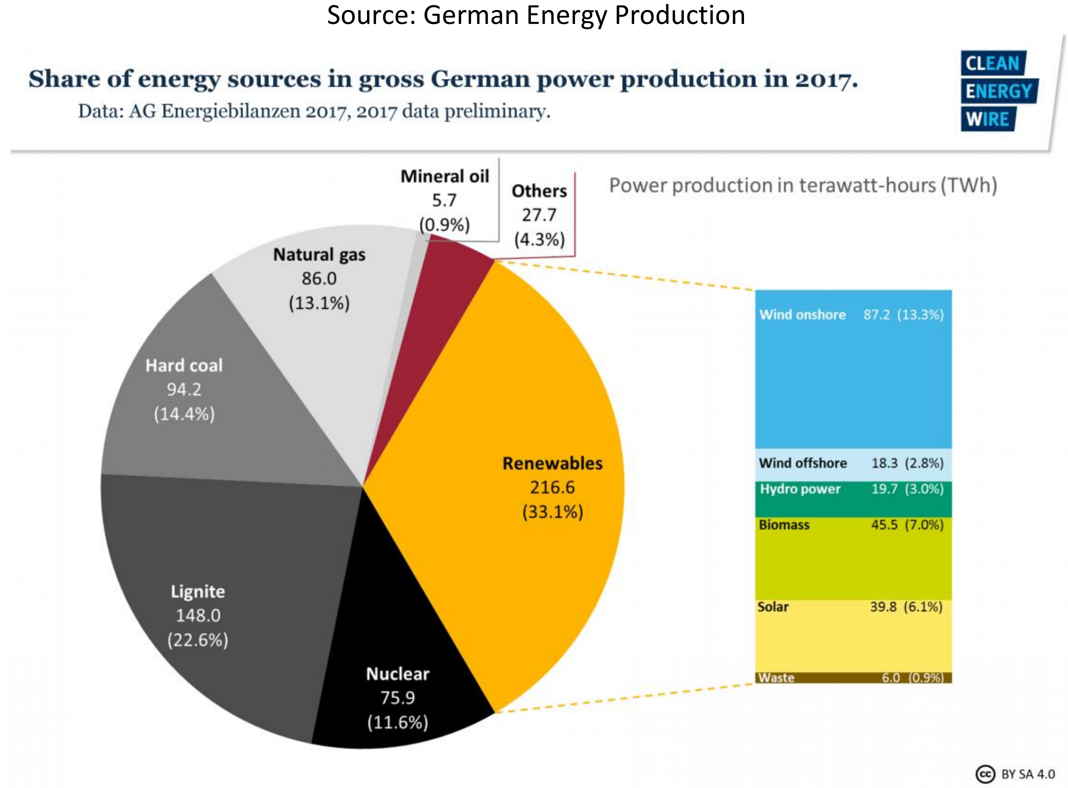
Table 1.5: Germany Electrical Production in a month
Source: The Moral Case for Fossil Fuels page 52



The downsides of varying electricity production and the problems this creates are the main reasons that wind and solar make up such a small percentage of the market in Germany and Denmark. It is also a testament to the difficulty in providing electricity without using conventional, reliable sources that can consistently produce a certain amount of electricity on a daily basis. It is also important to note that these charts only include electricity, not total energy in Germany that is used. Things such as transportation fuel for vehicles or heating fuels for buildings and homes are not included. Right now, the vast majority of transportation is done with conventional energy sources, namely oil. While electric cars have made some progress they are still quite expensive and unlikely in the near future to be widely used (*Epstein 72*). In addition, airplanes, trains, large trucks, and boats would also have to be electricity based to be powered by solar or wind energy. This further magnifies the problems with using alternative energy to power a civilization at the moment, and will likely remain problems for quite some time.

The other problem that both solar and wind energy have is that there is no way to store the energy. Since both of these sources of energy are intermittent, they provide very little energy most of the time and then sometimes there is too much energy. The only solution to this problem is to develop a mass storage system that can collect enough energy during peak production to use when it is low. This is not included in the Levelized Cost of Electricity calculations and is a massive cost. As of 2018 there is still no mass energy storage system in the world that is in development or even any concrete ideas on how it can be done. The only way right now that electricity can be stored in any amount is some sort of battery technology. Battery technology has not developed very much over time and to provide energy for billions of people on demand will require massive improvements (*Epstein 72*). It is possible that there could be a breakthrough in technology that will solve this problem but with little evidence to date that this can be done it may be a long time off. This is another reason that wind and solar do not make up much larger proportions of energy production. Without a reliable source of energy or anywhere to store massive quantities of it, any industrialized world will not be able to run on it. Everything from hospitals, food production, and transportation all rely on energy to keep going. Any shortage of this will result in massive reductions in living standards all around the world so it is important to consider this when deciding on the energy of the future and crafting public policy.

Table 1.6
Source: German Energy Production



Wind:

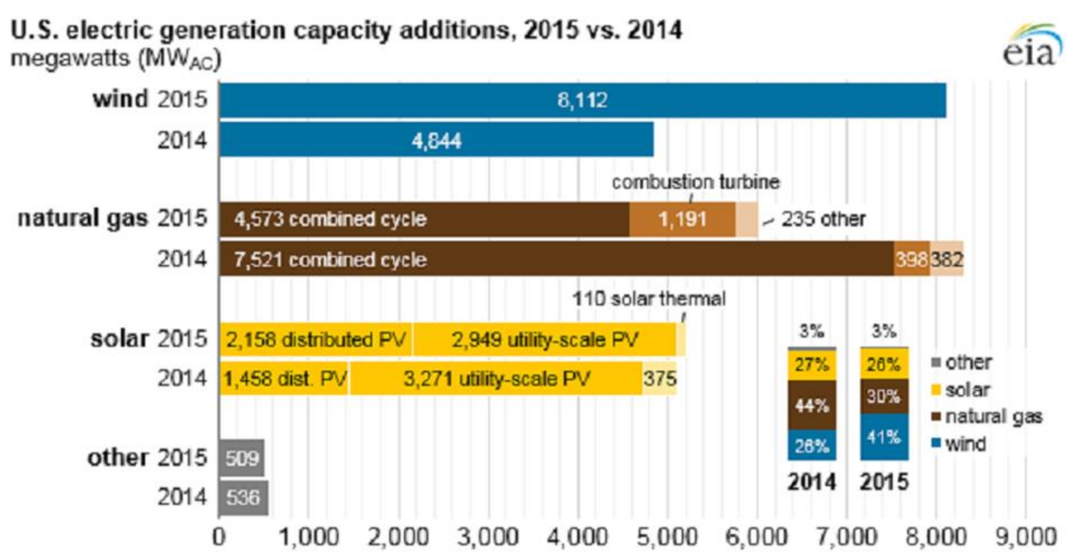
Wind power is a form of energy created by using the wind to turn a turbine in order to create electricity. It is another form of solar energy because the wind is caused by different temperatures of pockets of air in the atmosphere (*Wind Energy Basics*). Wind turbines turn the kinetic energy of the wind into mechanical energy which is then turned into electricity by a generator. This is done with wind turbines built on top of metal towers, where lightweight blades are attached to the top and spin due to the wind, powering a generator which creates electricity (*Wind Energy Basics*). Numerous wind turbines are grouped together on wind farms to produce large amounts of power to be used.

Wind energy is similar to solar energy in that there are a lot of installation costs but much lower maintenance costs afterwards. The initial cost of installing a 5 kW pole-mounted wind turbine is about $32,000 according to The Renewable Energy Hub. Wind power installation also benefits from the 30% tax credit as well as additional incentives and tax breaks for different states and localities (*How much does a wind turbine cost?)*. The cost of wind energy varies by state, similar to how solar energy installation costs do. The center of the United States tends to have the cheapest costs due to high and consistent wind speeds. The western states have historically had the most expensive wind energy production costs, according to the Energy Information Administration. The cost of the wind turbine itself is the single greatest cost factor, accounting for over 70% of the total cost for a land-based wind project (*The Cost of Wind Energy*). The capacity of a wind mill installation will be determined by the location, however, wind power technology is improving with lighter blades and taller towers. Once installed, wind mills will produce energy for roughly 20-25 years with some maintenance required (*The Cost of Wind Energy*). The reason that it only lasts for 20-25 years is due to normal wear and tear, eventually resulting in maintenance costs rising as it ages in the same way they do for cars. The blades, electric converter, and many other parts have to be replaced and eventually it is more financially beneficial to use a new windmill. The maintenance is relatively cheap until the later years when they start to increase as it approaches the average lifespan of a wind mill.

Looking at the same Lazard 2017 study used previously for solar energy costs, wind power has a competitive LCOE. It is even cheaper on the low end than solar energy. The study found that the LCOE for wind power is between $30/MWh - $60/MWh in 2017, which is cheaper than the cost of cost of coal and nuclear (*Levelized Cost of Energy 2017*). The U.S Department of Energy states that the cost of wind energy has declined by over 90% since the early 1980s. Despite all of these declines in cost and studies of the LCOE, wind power only produced 4.7% of all electricity generated in the United States in 2015 (*Wind*). Germany is often cited as the leader in renewable energy, particularly wind and solar, yet it only produced 16% of Germany's electricity in 2017 (*German Energy Production*). The reasons behind this are largely similar to the problems that solar energy faces. Wind energy is very intermittent and does not produce at a consistent rate, a key trait of what keeps the power grid stable. Wind varies throughout the day and by region of the country, with the Great Plains region in the middle of the country having the most wind (*The Cost of Wind Energy*).

The lack of consideration of the intermittency of wind energy, as well as solar, lead many people to make common mistakes in regards to energy statistics. Many claims are made about how wind energy (as well as solar) have added the most capacity in any given year. For example, in 2015 the Energy Information released a graph (which can be found below) showing that wind, solar, and natural gas contributed nearly all of the electricity capacity additions in the previous year (*The Myth of Wind and Solar 'Capacity'*). A simple misunderstanding of terminology leads to statements like this being interpreted wrongly. Electrical generation capacity is not the same thing as an ability to provide consistent energy. Capacity is simply a technical term that is the maximum ability to provide electricity, but it says nothing about the consistency over time to provide energy. A more important point to consider is the capacity that an energy source can run at on a day to day basis. A nuclear plant may be able to run at 80%-90% of its capacity factor on a consistent basis whereas wind or solar energy may run at an average of 20% (*The Myth of Wind and Solar 'Capacity'*). During times where it is very windy and the sun is out they may operate at high capacity levels but this is not a consistent phenomenon.

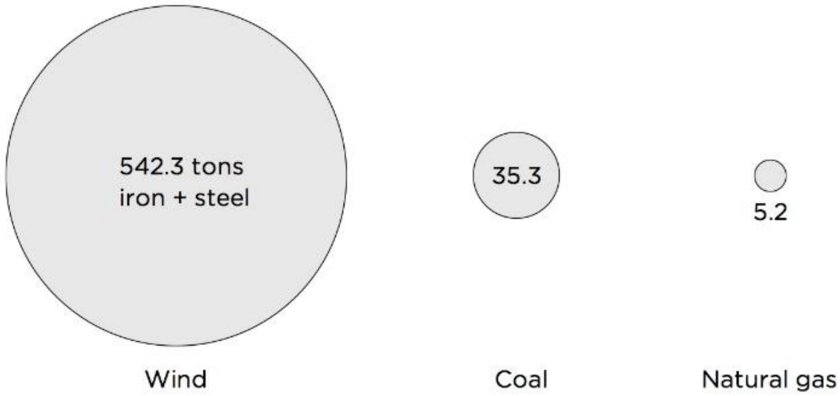
Table 1.7:
Source: Department of Energy, Energy Information Administration



A significant portion of the reason conventional energy sources are used is because they are reliable, which is often taken for granted by many people. When someone goes to the hospital to get a lifesaving treatment that requires technology, they need an energy source that will be available to them. The ability to flip on a light switch and have a light turn on immediately is not appreciated by most people but it is probably the most amazing aspect of modern electrical grids. A good analogy to understand the important of reliability to a power grid would be that of a cell phone plan. Any particular phone plan may be extremely cheap, but if it only provides service 20-30% of the time and the specific times are not very predicable it becomes less valuable. As a result, few would wonder why these phone plans do not make up a larger portion of overall plans even though they may appear to be cheaper.

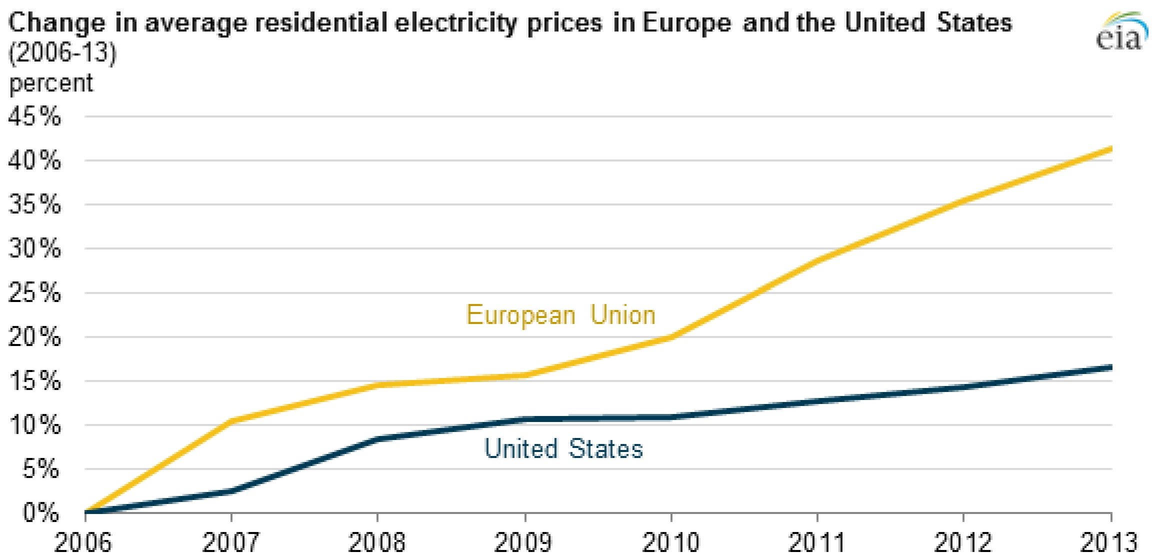
Wind power also suffers from being a fairly dilute energy source in the same way that solar power does. The easiest way to understand this is to see the amount of resources required to produce a given unit of energy for wind compared to other forms of energy. In order to produce one Megawatt of wind energy it requires about 542.5 tons of iron and steel (*Epstein 49*). This is a resource heavy process because it takes a lot of effort to get a lot of wind energy since it is not a dense energy source like oil is. Compare those numbers to 35.3 tons of iron and steel for coal and 5.2 tons for natural gas. This paints a clear picture that getting energy from wind energy takes many more resources than conventional forms of energy. The fact that in different parts of the country wind energy is even more resource intensive and in some cases economically infeasible, explains the lack of production from the energy source.

Figure 1.8:
Source: The Moral Case for Fossil Fuels page 49



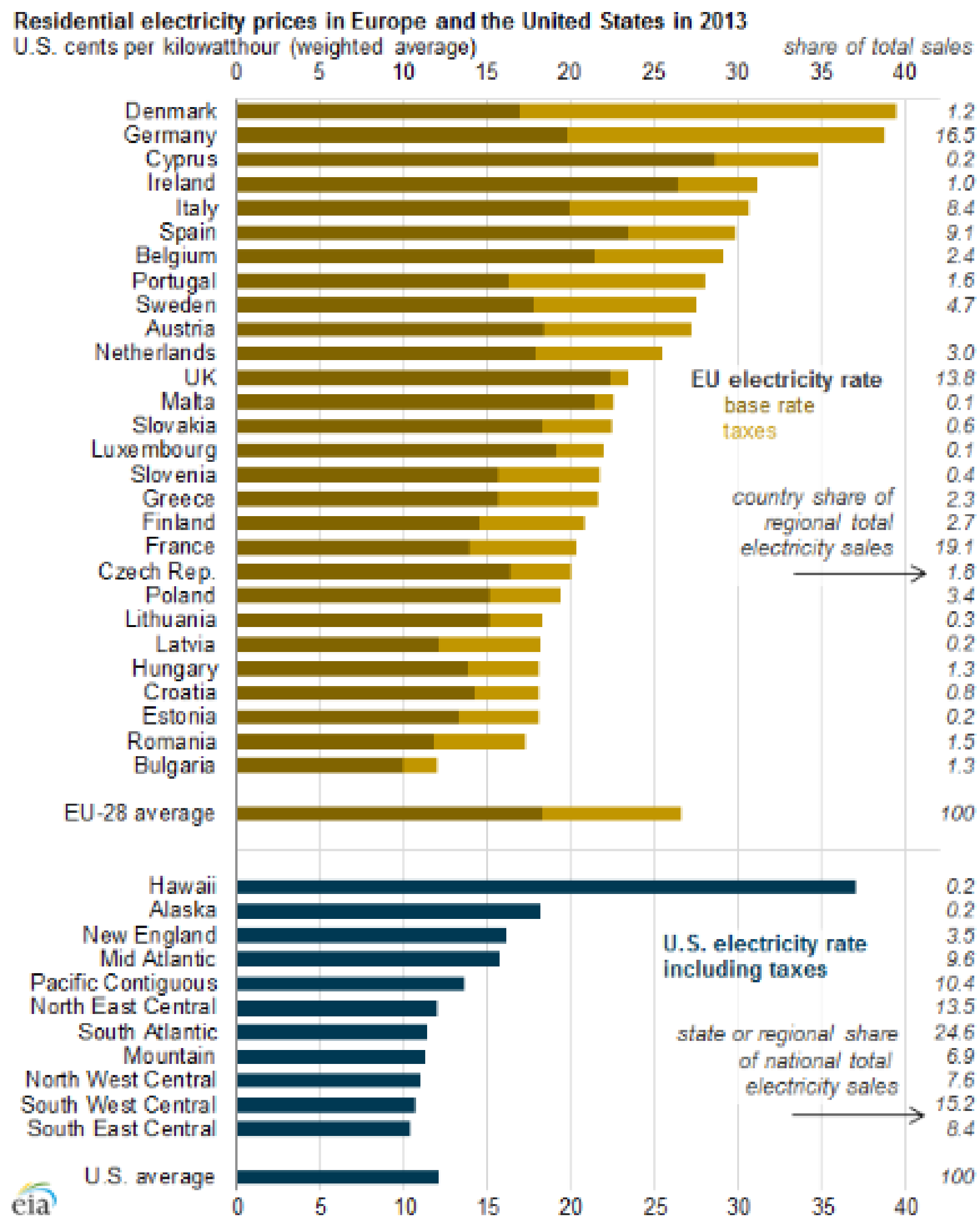
Now that both solar and wind have been examined from a cost perspective according to LCOE analysists, it is important to look at real world examples. While both energy sources are intermittent and dilute, surely they are still going to be cheaper than conventional forms of energy if these LCOE studies are correct. According to the Department of Energy in 2014, Europe has seen a faster increase in the cost of their electricity from 2006 until 2014 when this was looked at (*Marcy & Metelitsa*). During that time Europe saw more than a 40% increase in the average residential electricity costs. When you compare this to the 16% increase in the United States over that same timeframe, it looks all the more alarming. Most European countries produce a larger portion of their electricity from wind and solar energy than the United States. This is a result of governments throughout Europe pushing hard to promote these energy sources and provide numerous subsidies and incentives to invest in them. Since the United States has not done this to nearly the same degree it is concerning to see the rapid increase in electricity costs in Europe compared to the U.S.

Figure 1.9:



Germany and Denmark, which are typically cited as large scale success stories for wind and solar, will be the benchmarks to study how wind and solar impact costs on an electrical grid. Looking at the data from the department of energy Germany and Denmark have the most expensive residential electricity costs in all of Europe. The costs for both countries is roughly 3-4 times as expensive as residential electricity costs in the U.S, depending on the exchange rate. In Germany it costs roughly 38 U.S cents per kilowatt hour for electricity production and 39 U.S cents per kilowatt hour for Denmark (*Marcy & Metelitsa*). The price in the U.S is roughly 13 U.S cents per kilowatt hour, as seen in figure 1.10 below, although it can vary by state. It can be as cheap as 8.67 cents/kWh in Washington to 18.84 cents/kWh in New York and 36.99 cents/kWh in Hawaii due to transportation costs. A significant portion of the additional costs throughout Europe is due to taxes and levies. Residential electricity taxes range from 5% in the U.K to as high as 57% in Denmark (*Marcy & Metelitsa*). Taxes on residential electricity are typically used for subsidies towards wind and solar energy to help pay for the investment in these energy sources. So even if these taxes were to be abolished it would not solve the problem of increased costs due to greater usage of wind and solar energy.

Figure 1.10:



Source: U.S. Energy Information Administration, Electric Power Monthly; Eurostat
Note: A conversion factor of 1.328 Euros/USD was used. Percent share of residential sales are 2012 values.

If wind and solar energy are cheaper than conventional sources the cost trends in Europe are hard to understand. The problem is that the metric of using Levelized Cost of Energy does not capture everything and is a flawed way of measuring energy costs. Some LCOE measurements do not properly account for the cost of subsidies when making calculations. The biggest problem is that the Levelized Cost of Energy does not factor in the costs of grid integration or storage costs (*Deign*). This is usually mentioned in the text of the study, although it is often ignored when people use LCOE to claim wind and solar are much cheaper than they actually are. The grid integration is extremely important because of the intermittency problem that wind and solar energy have. The inconsistent nature of both energy sources cause serious problems with integrating them into a grid system on a large scale. The electricity supply and demand need to be close to the same at all times to avoid blowing the grid up or blackouts due to shortages. Since the intermittency means the energy production will vary widely over the course of the month, or even days, this becomes hard to avoid. Thus, it increases the cost dramatically to try and utilize any large amount of unreliable energy.

Hydroelectric:

Hydroelectric energy is created by using the kinetic energy of water to spin a turbine, similar to wind power, in order to generate electricity (*How Hydroelectric Energy Works*). The water needs to be moving at a fast speed in order to turn the turbine fast enough. In order to do this a dam is built on a river with a steep drop in elevation. The dam collects water and a pipe called a penstock is used to drop water down to spin the turbine, which is connected to a generator to produce electricity. Hydropower works best on larger rivers with big changes in elevation (*Hydroelectric power: How it works*). Hydroelectric power is typically used to provide peak electricity, when demand is highest for electricity. Demand for power is not flat but shifts over the course of the day. Electricity demand is higher during the day and lower at night. Hydro power is typically used during peak demand during the day (*Hydroelectric power: How it works*). At the end of the day water is pumped back up to be stored for the next day so the dam is ready to meet peak electricity demand again.

Hydroelectric energy is the cheapest type of energy, according to an analysis done by Navigant Consulting and the American Council on Renewable Energy (ACORE). It found that hydro power LCOE is about 2 cents per kWh, compared to 7.5 cents for coal and 6 cents for natural gas (*Affordable*). Another major advantage of hydroelectric power is that it is far more controllable than wind and solar energy. While droughts can lead to problems in production, these are relatively rare and easier to predict than the sun and wind. Dams also have the ability to store water for later use so it can be scaled up or down whenever needed (*Hydroelectric power water use*). This means that hydroelectric power can be used for both base load power and peak load power. Hydro dams tend to last around 50 years according to one study, which means the costs are spread out over a long period of time as well. They also need relatively little repairs and maintenance over the course of those 50 years, which is another reason the cost is so low (*Affordable*).

Hydroelectric energy makes up about 17% of the worlds electricity production (*Hydroelectric power water use*). In the United States hydro produces roughly 6% of the electricity, varying by region of the country (*Hydroelectric*). Hydro power is used significantly more than wind and solar are worldwide. Since wind and solar appeared to be much cheaper according to LCOE methods it is important to look at real world examples when examining costs. States that use high amounts of hydro energy tend to have the cheapest electricity bills in the U.S. Some examples include Idaho, Oregon, and Washington, all of which get over 80% of their electricity using hydro (*Hydroelectric power water use*). The electric bills in these states are amount the lowest in the country, proving that this is not just something that can be shown in a study. Looking outside of the United States, there are many countries that get a large portion of their electricity from hydro power. According to The World Bank, Norway gets over 95% of its electricity from hydro power and Iceland gets 73%. This indicates that hydroelectric energy can provide large amounts of electricity to countries at a cheap cost, since both of these countries have relatively cheap electricity costs.

The main problem that prevents hydropower from being used more frequently and becoming a global energy source is that the locations are limited. While hydropower has an advantage on wind and solar by being much more controllable and far less dilute, it can only be done in certain bodies of water. Most of the rivers in the United States that are suitable for dams have already been taken advantage of (*Hydroelectric power water use*). While places like the Pacific Northwest are great for hydro power, Arizona or Nebraska are not nearly as good. This means hydro power is unlikely to ever become the leading source of electricity in most countries around the world. That does not mean, however, that it cannot be expanded in many parts of the world. According to the International Energy Agency, hydroelectricity has the potential to grow by 80% in Asia and 92% in Africa. The agency also estimates that hydro could produce up to twice as much energy globally as it does now, at 6% of the current global energy makeup. Only time will tell if this will actually occur but it is certainly not the price of hydro power that will ultimately hold it back, but rather the limited locations where it can be utilized.

One area of potential in the field of hydroelectric power is the usage of micro hydroelectric power plants. This is something that some companies have experimented with to help individuals and isolated communities get power at a good cost. This is where submerged turbines are placed in small rivers of streams that have very small changes in elevation (*Micro Hydro*). As long as there is moving water and a small drop, even just centimeters, power can be generated for an individual or a small group of people. These turbines do not block the flow of water and as a result there is no increased risk of flooding as a result of it. Also, they are designed to avoid harming fish and so that fish that swim into the turbines will emerge unharmed (*Micro Hydro*). These micro hydroelectric power turbines are capable of generating cheap electricity for a small number of people and can be built far more widely than a traditional hydroelectric dam can be. This could potentially open up the possibilities of hydroelectric energy in the future if micro hydro turbines become more common in the future.

Nuclear Energy:

Nuclear power is created by either splitting or combining atoms, which gives off a byproduct of energy every time this is done (*Nuclear Explained*). Atoms are small particles that make up everything and are made up of protons, electrons, and neutrons. The core of an atom is called a nucleus and has protons and neutrons in it and the electrons surround it. The bonds that hold the nucleus together contain a huge amount of energy. The first process of creating nuclear power is called nuclear fission and is when a heavier atom is split to release energy (*Nuclear Explained*). This is the process that is used in every nuclear plant in the world right now and is usually done using uranium atoms. A neutron is used to split an atom, which releases more neutrons and continues the process in what is called a nuclear chain reaction. The other process is called nuclear fusion and is when two lighter atoms are combined in order of create a larger atom, which produces energy as a byproduct (*Nuclear Explained*). Nuclear fusion is the process that every star, such as the sun, uses to produce energy. Fusion energy is not used in any nuclear power plants right now and is in a research phase to try and make it useful to produce electricity. The reason is because it is difficult to use fusion at a cheap cost right now because it takes more energy to produce the energy than it produces (*Epstein 196*). It is also very difficult to control the fusion process, which has limited research.

Nuclear energy is one of the most fascinating prospects for a large scale energy source to many in the energy field. There are several reasons for this, including the concentration of the energy and the scalability it can provide. The importance of having dense, concentrated energy can be seen by contrasting oil with wind and solar energy. Oil can store a lot of energy in a small space, making it ideal for transportation vehicles that have to carry their own fuel with limited space. Wind and solar, as discussed prior, are both very dilute energy sources and therefore require a lot of work to produce energy. Uranium, which is what nuclear power plants use, has an energy concentration of over a million times that of oil and 2 million times coal. The current state of nuclear technology, however, only allows us to get thousands of times the energy per unit of output (*Epstein 61*). Having an ultra-concentrated form of energy is very important if the goal is to use it to power a civilization. There is enough uranium on the planet to power the whole world for thousands of years, even at increased rates of energy usage (*Epstein 61*). Scalability is another major advantage that nuclear energy has compared to other alternative energy sources. Fossil fuels are used to widely because they are scalable for billions of people at a cheap cost. It can be used anywhere at any time without having to worry about cost or reliability problems due to intermittency. Hydroelectric power is great where it can be used but is extremely limited due to the number of rivers or bodies of water that can be dammed.

A nuclear power plant is not limited by the location of a river or by how much sunlight or wind is present at any given point in time. This means that it is extremely reliable, as well as being much denser compared to other sources of energy. All of this leads to the ability to scale for large numbers of people in the way that fossil fuels can. Other alternative energy sources may work in small amounts in the right places but as of right now are not capable of providing energy for the entire globe. This is a problem that must be solved to provide cheap, abundant, and reliable energy for billions of people. The concerns of nuclear critics are the cost of the process, as well as the perceived danger of it due to concerns of terrorism and radiation, among others.

Understanding how many resources there are remaining for different types of energy showcases the great potential of nuclear power. There are often concerns over how much fossil fuels are left in the earth by supporters of alternative energy sources. The table below shows the size and per capita cash value of numerous resources relating to energy (*Zubrin 139*). It is also divided into two sections, with the one on the top being resources that are usable now and the bottom part being resources that could potentially be useful in the future. The energy column is listed in terawatt years (TW-Years) and the right column is in 1000s of dollars per capita (*Zubrin 138*). A terawatt year is a trillion watt years, which is a standard unit of energy. A 50 watt year light bulb uses 50 watt years of energy in a year, to give some context. In the United States the per capita use of energy is about 11,000 watt years in 2010. According to this table there is 1,197 terawatt-years of fossil fuel resources left on Earth. Roughly 15 terawatt-years of energy are used every single year by humans, meaning there are roughly 80 years of fossil fuel energy resources remaining and many more for nuclear energy (*Zubrin 138*). It is important to note, however, that this is at current usage rates, which are subject to change. Also, almost every year new technology allows more of them to be recovered without losing money or energy. Estimates of how much of a resource are on the planet only include those that can financially be recovered. This is why the number always expands even though more of the resource is used each year, new ways of using and acquiring resources change the math.

Figure 1.11
The Earth's Energy Resources
Source: Merchants of Despair, page 139

Currently Usable Resources	**Energy (TW-Years)**	**Value Per Capita (1000s of Dollars)**
Oil (known reserves)	202	18
Coal (known reserves)	790	69
Natural Gas (known conventional reserves)	205	18
Nuclear Fission (Uranium fuel, without reprocessing)	685	60
Nuclear Fission (Uranium fuel, with reprocessing)	50,000	4,400
Nuclear Fission (Thorium fuel, with reprocessing)	200,000	17,500
Resources Potentially Usable in the Future		
Natural Gas (including sub-sea methane hydrates)	24,000	2,100
Nuclear Fusion	100,000,000,000	8,800,000,000

The current known reserves of uranium and thorium fuel for nuclear energy totals about 250,000 terawatt-years of energy, which is significantly more than the current fossil fuel reserves. With that much energy the globe could be powered at our current usage rates for roughly 16,000 years (*Zubrin 138*). Even with the increased usage of energy around the globe during the next few decades, it will still come out to thousands of years' worth of energy for the whole globe. All of the concerns of energy supply in the future due to fossil fuel shortages are ignoring the potential of nuclear energy. By looking at the per capita dollar value of each resource it becomes even clearer. All of these numbers are obtained by taking the total value of each resource converted into electricity at a price of 7 cents per kilowatt hour. This number is then divided equally among the total human population on Earth, presently about 7 billion (*Zubrin 139*). The per capita values of fossil fuels is $69,000 for coal, $18,000 for oil, and $18,000 natural gas. By comparison, the value of nuclear fuel (uranium fuel with reprocessing and thorium fuel with reprocessing) would come out to nearly 22 million dollars for every person on the planet (*Zubrin 140*). The opportunity this provides for massive amounts of energy is something that people have been overlooking due to concerns about nuclear power. The two main concerns are that it costs too much and safety concerns, including radiation, waste storage, terrorism, nuclear proliferation, and nuclear accidents that have occurred.

The Lazard analysis done in 2017 found that nuclear energy has a Levelized Cost of Electricity ranging from $112/kWh-$183/kWh (*Levelized Cost of Energy 2017*). This is more expensive than many other forms of energy, such as coal or wind energy, according to this analysis. The Energy Information Agency did another study recently looking at the LCOE for plants and energy sources that would be up in running in the future. The LCOE for new nuclear plants that would be running in 2022, according to expected capacity additions, is about $90.2/MWh (*Levelized Cost and Levelized Avoided Cost*). The implication is that nuclear energy will continue to get cheaper over time, although other energy sources will likely do the same as well. As mentioned before, there are limitations to the Levelized Cost of Energy method of determining energy prices.

It is important first to understand how widely used nuclear power is and what the results have been. According to the World Nuclear Association, nuclear power made up 20% of the electricity production in the United States in 2016. The world leader in nuclear power in terms of proportionality is France with roughly 72% of their electricity coming from nuclear plants in 2016 (*Nuclear Power in the World Today*). This is as a result of a major push in the 1970s and 1980s to use less fossil fuels in France. Other countries include Belgium, which gets 52% of their electricity from nuclear power, and South Korea, which got 30% from nuclear in 2016 (*Nuclear Power in the World Today*). This indicates that several industrialized countries deprive a large portion of their electricity from nuclear power. China and India both use small amounts of nuclear power in terms of proportions of their electricity supply but both governments are planning on expanding the usage a lot over the next few decades (*Ferguson 64*). There is almost no nuclear power being utilized in Africa, South America, or Australia, although there is some interest by many governments in developing some. Each nuclear power plant is capable of providing enough electricity for about 600,000 people, which is roughly the population of a mid-sized city (*Ferguson 41*). So many more plants would have to be built in order to provide electricity for entire countries. In addition, technological improvements will likely make future plants better able to provide electricity to larger amounts of people.

In the United States nuclear energy has gotten more expensive over time rather than less so. In the 1970s nuclear energy was becoming more prominent and cheap, even replacing some coal plants at the time due to costs. Since it is clear that the input products, like uranium, are abundant and relatively cheap, this is hard fact to make sense of. Proponents of nuclear power have argued that the problem is not the cost of the process but rather a political one. In the 1970s there was a large anti-nuclear movement that opposed nuclear power due to fears of safety, partly due to hysteria of nuclear weapons (*Zubrin 136*). This movement was led by people such as Ralph Nader, and led to a massive resistance of nuclear power among environmentalists. Groups such as the Sierra Club and Greenpeace made opposing nuclear energy top priorities and still do so today. Many "Green" politicians, activists, and political parties worked to protest the construction or proposed construction of nuclear power plants all over the country (*Zubrin 137*).

The results were very effective just by looking at the rate of new nuclear plants being built and ordered. From 1970 to 1974 a total of 115 orders for new nuclear plants were placed in the United States, averaging 23 each year (*Zubrin 136*). After the anti-nuclear movement gained steam these numbers fell drastically to less than 3 per year from 1975 to 1979. Since 1979, there have been zero construction orders for new plants to be built in the United States, which showcases the power this movement has had at achieving its goals. If the nuclear industry continued to expand at the same rate it did during the early 1970s, nearly all fossil fuel electrical generation would have been replaced by nuclear energy by today (*Zubrin 137*). The movement made it harder to build nuclear plants not just in terms of the number of plants but by increasing the length of time it took to build one. The first commercial nuclear power plant in the United States was the Shippingport nuclear power plant in Pennsylvania in 1958 (*Shippingport Nuclear Power Plant*). The plant took 4 years to build whereas today it can take anywhere from 15 to over 20 years to build a nuclear plant. Fixed costs make up the vast majority of the costs of nuclear energy. As a result, anything that drives up these costs will make it hard to produce cheap energy with nuclear fission. The only main fixed cost for nuclear plants is the actual plant itself so when it takes decades to complete one it dramatically raises that costs. Decades of investment with no return and paying interest on loans makes it very difficult to succeed. When you add in local communities bringing the owners of the plant to court complaining about the construction based on misconceptions, it makes the investment a tough sell for most companies.

As a result of this movement, the industry was demonized by many environmentalists. This created numerous regulations that crippled the industry's ability to expand due to over exaggerated safety concerns. This is what has led to the construction length increasing so much over time. Towns do not want nuclear plants to be built nearby and they oppose any new nuclear plants due to misconceptions related to safety. People also bring the company building the plant to court frequently, which halts construction and this makes it more expensive to build. Since the construction process takes up the majority of the cost, this drove the price up over time and is preventing nuclear energy from competing cheaply, not because of an inability to compete. This is not necessarily a phenomenon limited to the United States, as many other industrialized countries have had similar concerns and regulations. A good example of this would be how Japan has been making in nearly impossible to use nuclear energy after the Fukushima accident in 2011. This has nothing to do with other forms of energy out competing it but irrational fears that are making it harder to develop nuclear power.

The main driver of the anti-nuclear movement was concerns over safety. One of the main claims made in the 70s by this movement, and still believed by some people today, is that nuclear power plants could be blown up in a nuclear explosion. That is simply not true, a nuclear power plant cannot blow up like a nuclear bomb, it is physically impossible for this to happen because the Uranium fuel must be enriched properly. Enrichment is when isotopes are separated in order to concentrate, or enrich, one isotope over others. Isotopes are simply different variations of an element with the same number of protons but different neutrons, lead to a different atomic mass but otherwise similar qualities. In nature isotope U 235 is less than 1% of the concentration of Uranium and to use for energy or a bomb it must be a higher concentration, or enrichment level. Uranium must be enriched to over 90% in order to be used in a nuclear bomb effectively. A nuclear power plant uses uranium that is only enriched to 3% of the isotope U 235 (*Zubrin 147*). It is simply not capable of creating a nuclear bomb and would be a violation of the laws of physics for it to occur. Fear over nuclear explosions is one of the main factors that have been utilized in order to limit the growth of nuclear power. Nuclear energy expert Petr Beckmann put it best when he said "the media keep playing on the the psychological association of "nuclear" and "bomb," which makes as much sense as the association of "electric" and "chair"." (*Beckmann 13*).

Another fear of nuclear power is of terrorist organizations using it to develop nuclear weapons. First, it is almost impossible for an individual to build, steal, or obtain sufficient materials to develop a bomb (*Beckmann 135*). Even if someone could get their hands on enriched Uranium or plutonium capable of being used to build a bomb, the odds that they would ever figure out how to do so are extremely low. It requires a lot of expertise and to create a working nuclear bomb (*Ferguson 135*). In addition, there are many ways to kill large numbers of people that would be far more realistic for someone looking to cause harm. Even for a well-funded terrorist organization this would be supremely hard to accomplish. In the unlikely scenario that a terrorist organization decided to try and get a nuclear weapon, it would make far more sense to try to acquire a ready-made weapon or partly completed weapon instead of making one (*Beckmann 136*). It is highly unlikely that a group of terrorists would possess the knowledge to create their own bomb. There are numerous nuclear weapons in the United States military stockpile, even with the numbers dropping dramatically since the cold war. Many U.S military bases in foreign countries may already have some stored for use in case of war. Any terrorist would have far more success trying to take on of these in an attack rather than using materials from a nuclear plant to try and develop one over a lengthy process.

The other concern regarding terrorism is that a nuclear plant could be attacked in order to release large amounts of radiation on a nearby population. In order for this to happen an explosion would have to blow a hole in the containment building at a nuclear power facility. The containment buildings have extremely thick walls that would be extremely difficult to properly make large holes in it. Even if it were to happen it would still need the right weather conditions for the radioactivity to not simply disperse in the atmosphere with little, if any, harm done. Finally, even if the weather did keep the radiation bunched together it would still need a favorable wind that would blow it right into a major city or population center to cause damage (*Beckmann 67)*. This is an extraordinary set of circumstances that would have to be met and planned out, accounting for unpredictable weather conditions in addition to actually attacking the plant itself. It would be far easier to attack an oil pipeline or a ship storing natural gas at a harbor to cause mass destruction and deaths (*Beckmann 149*). Similarly to the idea of a terrorist organization creating a nuclear weapon, there are far better targets than nuclear plants for causing a lot of deaths.

Radiation is one of the main concerns cited as a reason to avoid nuclear power. What radiation is are particles that move as electromagnetic waves and have high energy levels. It is measured in units called rems, or millirems (one thousandth of a rem). If a person receives high doses over short time periods it can lead to cancer or radiation poisoning (*Zubrin 146*). However, the U.S Nuclear Regulatory Commission has acknowledged that there is, “no data to establish unequivocally the occurrence of cancer following exposure to low doses and does rates – below 10,000 mrem”. This is extremely important because the average nuclear power plant only gives about 0.01 millirems per year. So the concern of nuclear power plants giving everyone cancer in the local area is not something that people should be extremely worried about. The table below shows radiation doses from numerous sources, giving context to how much radiation people come into contact with on an annual basis (*Zubrin 146*). At the very bottom it shows that the average amount of radiation people are exposed to each year is roughly 270 millirems per year. That is well below the threshold that can lead to danger and cause people harm. Nuclear plants may even reduce radiation because they usually replace fossil fuel plants, which often give off more radiation from emissions into the air (*Zubrin 147*).

Figure 1.12

Radiation Doses from Natural and Artificial Sources

Blood	20 mrem/year
Building Materials	35 mrem/year
Food	25 mrem/year
Soil	11 mrem/year
Cosmic Rays (sea level)	35 mrem/year
Cosmic Rays (Denver altitude)	70 mrem/year
Medical X-Rays	100 mrem/year
Air travel (New York to LA round trip)	5 mrem
Nuclear power plant (limit, at property line)	5 mrem/year
Nuclear power plants (dose to general public)	0.01 mrem/year
Average annual dose (general public)	270 mrem/year

Source: Merchants of Despair, page 146

The risks and hazards of nuclear waste disposal are another major concern of activists and environmentalists opposing nuclear power. During the process of releasing the energy from uranium or plutonium through a fission process a certain amount of waste is created. This needs to be stored somewhere safely until it is no longer dangerous, which can take a long time. In 1982 The Nuclear Waste Policy Act of 1982 (NWPA) said the Department of Energy needed to find a location to store nuclear waste. In 2002 Congress and the President approved Yucca Mountain, located in Nevada, as the site for this waste but in 2010 the Department of Energy shut down the Yucca Mountain project without explanation (*Used Nuclear Fuel*). The plan meets the safety standards, such as the requirement for the radiation to be below a dosage of 15 millirems of radiation per year for 10,000 years. The actual amount of radiation that would be released, according to estimates, is about 0.0001 millirems per year for 10,000 years (*Zubrin 145*). Most experts on the subject of nuclear waste disposal have indicated that the Yucca Mountain project would work and in order for the project to continue it simply needs funding. So it is not very difficult to deal with nuclear waste and if it would only get funded the Yucca Mountain plan would be more than adequate in providing a solution to the problem.

Nuclear proliferation is another major concern that people have with nuclear energy. This is the idea that nuclear weapons might become more widespread because the process of creating nuclear energy could be used by foreign governments to create bombs (*Ferguson 103*). This presents a greater challenge than terrorists making a bomb because foreign governments have greater access to scientists who may be able to succeed where terrorist organizations cannot. Natural uranium itself only contains 0.7% uranium-235, capable of fission, whereas the remaining 99.3% is uranium-238, which cannot be used for fission (*Zubrin 147*). This uranium is enriched for usage in a nuclear power plant, to about 3% uranium-235. The enrichment facilities where this occurs could be used to enrich it further to 93% uranium-235 concentrated, making it now usable in bombs. Additionally, plutonium-239 can be created during a controlled reaction and is also capable of fission and being used for a bomb. So it is not outside the realm of possibility that a determined government could use this process to try and make a nuclear bomb in the future and it is a legitimate concern. If governments wanted to make a nuclear bomb they are likely already doing it so it does not make sense to argue that commercial nuclear plants should not be used around the world.

The danger is not with the nuclear plants themselves but at the enrichment and reprocessing centers. This could be managed by forbidding certain countries from having these facilities within their borders. Countries that sponsor terrorism, like Iran, or have destabilized countries and social fabrics could also be prohibited from having these facilities (*Zubrin 147*). The idea that nuclear power is needed for the creation of atomic weapons fails on its own logic. Nuclear energy was not used commercially until the 1950s, at which point the United States and Soviet Union already had nuclear weapons during the Cold War. Some countries may not be fully prepared for nuclear power due to unstable, corrupt governments, among many other problems. As Robert Zubrin put it in his book *Merchants of Despair*, "The issue is not one of "inappropriate technology," but of inappropriate social conditions" (*Zubrin 148*). Many parts of the world, such as western, industrialized countries, have the conditions to utilize nuclear energy and avoid the risks some parts of the world would have. The world needs to be made safer in order to allow nuclear energy to thrive, but this does not mean that some countries are not ready now.

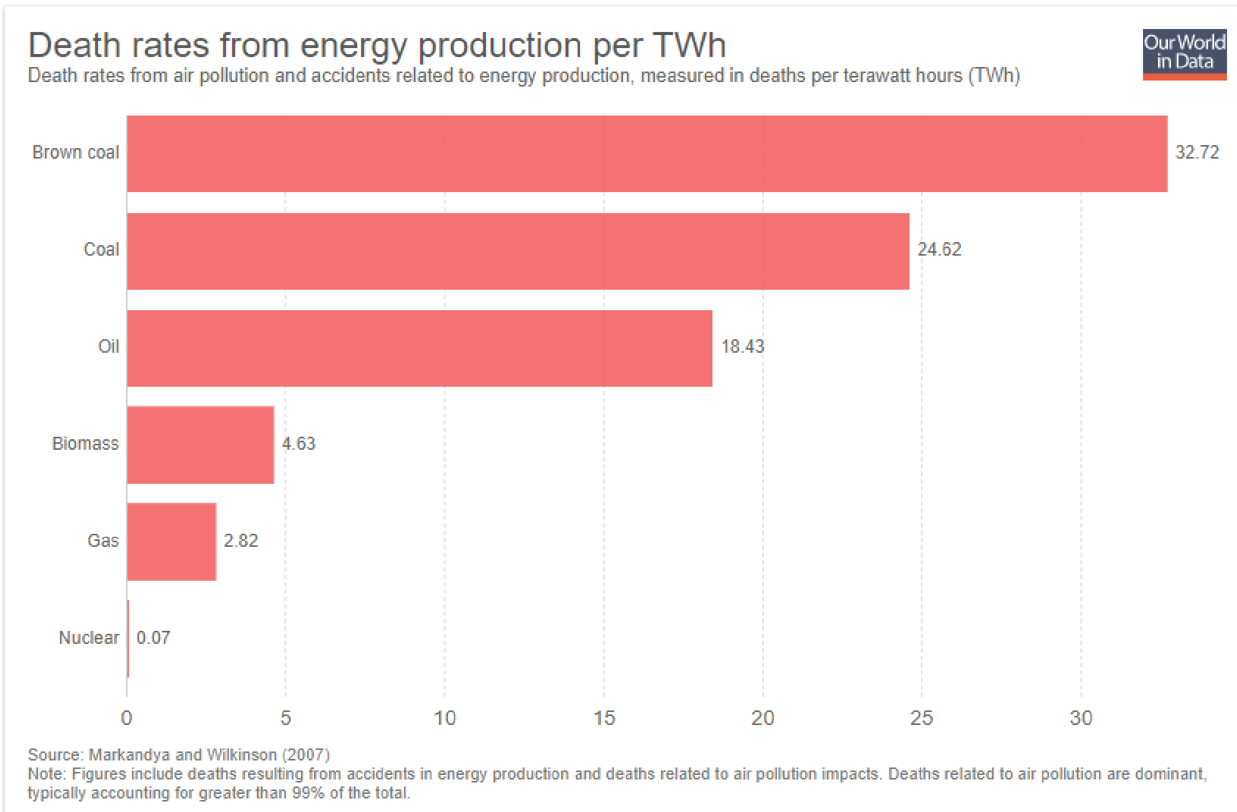
The next concern people have about nuclear energy is the possibility of nuclear accidents. While accidents at nuclear power plants are possible, they are also incredibly rare. Three specific incidents in the nuclear industry over the last 50 years have scared people away from the technology. The first is the Three Mile Island accident in Pennsylvania in 1979, the second is Chernobyl in the Ukraine in 1986, and the third is the accident in Fukushima, Japan, in 2011 (*Ferguson 143*). The accident at Three Mile Island was the result of the failure of the cooling system, which resulted in a core meltdown. The lost reactor cost about a billion dollars but there were no human deaths due to the accident (*Zubrin 141*). Numerous studies into the Three Mile Island accident have found that there have been no significant environmental impacts.

The Chernobyl accident was the most series accident of the three, particularly in terms of radiation released. The amount of radiation released was the equivalent to the amount released by a nuclear bomb (*Zubrin 142*). Roughly 50 people were killed during the accident itself and during the immediate aftermath. A study by International Atomic Energy Agency and World Health Organization found that close to 4,000 people will end up dying due to delayed effects of the accident. This may seem like a large number, but it is only relevant in context to the alternatives. A more important indicator of the dangers of a nuclear accident are to compare them to deaths from other energy sources. Pollution from fossil fuel plants causes more deaths by far than nuclear energy ever has each and every year (*Zubrin 142*). A runaway chain reaction in the reactor is what led to the accident and containment breach. This was the result of a badly designed reactor that was used specifically in the Soviet Union at the time. A proper reactor is designed so that as the temperature goes up it actually powers down. This prevents a runaway reaction where the temperature keeps getting higher and cannot be contained. Most nuclear power plants use water to pump into cooling channels throughout the reactor. This design is so the reaction cannot occur unless the water is present because it slows down the nuclei enough to interact with surrounding nuclei. This design makes it impossible for a runaway reaction to occur because once the reactor begins to heat up the water boils off and the reaction slows down, reducing the power level until it stops. The reactor used at Chernobyl did not utilize water in its cooling system. Instead, it used graphite, which cannot boil and this led to a runaway reaction that could not be contained. The system actually led to an increase in the reactions, which made the situation worse (*Zubrin 143*). A reactor like the one in Chernobyl would never be used in the United States or any other advanced country again.

The last and most recent nuclear disaster was the one at Fukushima, Japan in March 2011. The accident was the result of a tsunami caused by an undersea earthquake. This led to 50 foot waves hitting the nuclear plant, flooding the facilities and a meltdown of 3 of the six reactors (*Ferguson 164*). Deaths due to the earthquake and tsunami totaled around 20,000 people whereas no one died due to radiation. In many ways, this shows how safe nuclear power is rather than how dangerous. All of the casualties were caused by the earthquake and tsunami rather than the nuclear accident, yet people still focus far more on the later over the former. The U.S navy was instructed to stay 100 miles away from the site, which stranded people at sea or under trapped buildings (*Zubrin 141*). This was due to fears of nuclear radiation without much evidence that there was anything to fear. Ironically, this caused far more deaths than any radiation danger ever did.

There is no such thing as safe energy because energy is inherently dangerous and risky. Converting raw materials into large amounts of energy always carries risks, which in the right circumstances, can lead to significant harm for humans. The way to think about safety is to compare it to the best alternative and see which option is the safest. Looking at the statistics of energy deaths it becomes clear that nuclear energy, while having some risks, is by far the safest energy source at the moment. The graph below shows the death rates of energy production per a terawatt hour for numerous energy sources. This includes pollution and deaths resulting from accidents during the production process. Coal has a death rate of 24.62/TWh while the rate for nuclear energy is just 0.07/TWh (*Energy Production & Changing Energy Sources*). So nuclear energy is not only a safer form of energy, it is *much* safer according to this data. According to another data set that measures deaths per trillion kilowatt hours, nuclear is even safer than wind and solar. Solar has a rate of 440 deaths/kWhr while the rate for wind energy is 150 and for nuclear it is 0.1 deaths/KWhr (*Conca*). In this comparison, nuclear energy is safer than even wind or solar and by a large margin. The fear over nuclear energy does not seem to match up with real world data or science.

Figure 1.13



The greatest opportunity that nuclear energy provides is the possibility of nuclear fusion. All commercial nuclear plants that exist today use nuclear fission, which as mentioned prior, take heavier elements like uranium and split the atoms to release energy. Fusion energy is the opposite, where two lighter atoms are brought together and produce energy as a byproduct (*Epstein 196*). This is the process that the sun uses in its core to produce energy. The potential of fusion energy is enormous and would provide more energy than all other energy resources combined could many times over. By looking at the table that shows the amount of each resource, fusion energy has 100 million times more than all fossil fuels resources combined and half a million times great than the fission resources. The per capita value of nuclear fusion resources is in the billions of dollars. Even in the scenario where energy usage increases by a factor of 10, there would be enough energy for close to a billion years (*Zubrin 149*). Another major advantage is that in addition to producing no greenhouse gases, fusion energy would produce very little radioactive waste compared to fission. A successful fusion reactor would only produce about 0.1 percent of the waste that a fission reactor produces. If the reactor is made from carbon-carbon graphite it would produce no waste at all (*Zubrin 149*).

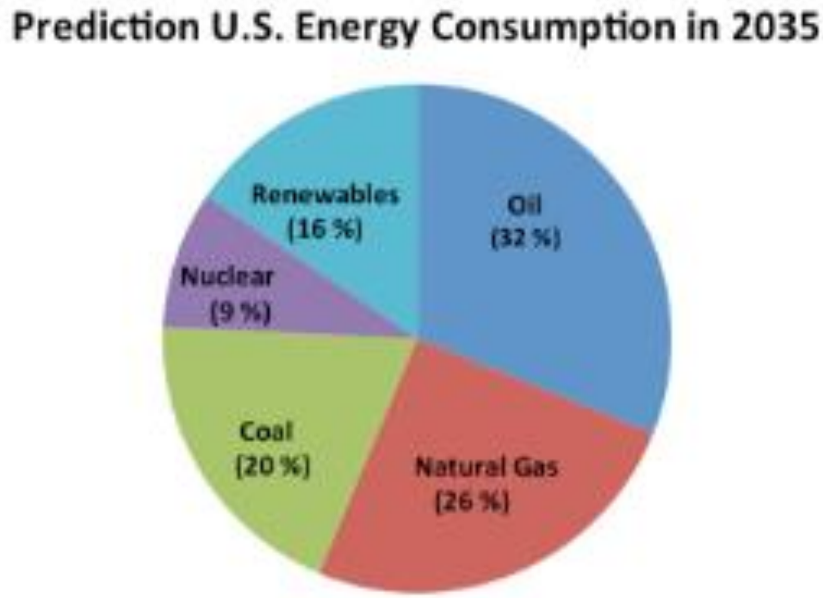
Nuclear fusion is difficult to do commercially because it requires very hot temperatures and a high degree of pressure to work properly. The research for fusion energy has been mostly experimental and conducted by scientists, often with the support of government funding. At very high temperatures, the kind required for fusion, matter exists as plasma. This simply means the atoms of the elements being used to produce the energy are so hot that they exist as plasma instead of the three typical states of matter; solid, liquid, and gas (*Zubrin 150*). Since plasma moves extremely fast at high temperatures it can escape and leak out, meaning it can lose energy. The problem with fusion development is containing the plasma and preventing it from cooling too much and losing energy. There are three factors that determine fusion performance; temperature, plasma density, and the particle confinement time. Together these three factors are simplified into the Lawson parameter (*Zubrin 151*). A more simply way to put it is that the reaction needs to create more energy than is required to heat the plasma. This is called the breakeven point and is the point that researchers need to get to in order to produce net energy. The final threshold would be the ignition point, which is where the heat from the fusion reactions is so great that it heats itself and eternal heating is no longer required. Reaching this point would make nuclear fusion commercially viable and the immense potential of fusion energy could finally be used (*Zubrin 152*). Over the last 35 years fusion technology has made dramatic improvements and the Lawson factor has been increased significantly over this time span. It only needs to go up little bit farther in order to finally reach the ignition point, where no external heating would be needed to keep the reaction going. This just may be possible in the years to come if people have the desire to do so (*Zubrin 153*).

Fusion not only provides more energy than anyone could imagine, but it offers new potential uses of energy due to its nature. As Robert Zubrin mentions in *Merchants of Despair*, “we will be able to use the superhot plasma that fusion reactors create as a torch to flash any kind of rock, scrap, or waste into its constituent elements, which could then be separated and turned into useful materials” (*Zubrin 149*). This would open up the possibility of taking advantage of resources that do not even exist right now or are currently not usable. Lastly, fusion technology could improve the prospect of space travel by opening up the possibility of propulsion methods that are much greater than current methods. Thus, long distance space travel may be within the realm of possibility (*Zubrin 149*).

The Future of Energy:

After examining all of the data for current energy sources it is also necessary to look towards the future. Right now fossil fuels make up the vast majority of the world's energy supply and this is likely to continue for the foreseeable future. The graph below shows a prediction by the Energy Information Administration of what the energy distribution will be in 2035 in the United States. It indicates that fossil fuels will make up 78% of total energy consumption in the United States in 2035 (*Pisupati*). This is only a slight decrease in terms of fossil fuel usage from where it is currently. This indicates that there will not be any energy technology that will be able to replace fossil fuels for quite some time. Renewable energy will be about 16% of U.S energy consumption according to this prediction, which includes hydroelectric energy in the number (*Pisupati*). As a result, wind and solar probably only make up 10% or less of that number. This fits in with the data examined above indicating that there are serious problems with wind and solar energy that are holding them back, namely their unreliability. Unless a mass storage system is devised wind and solar will remain difficult to scale up for a whole society.

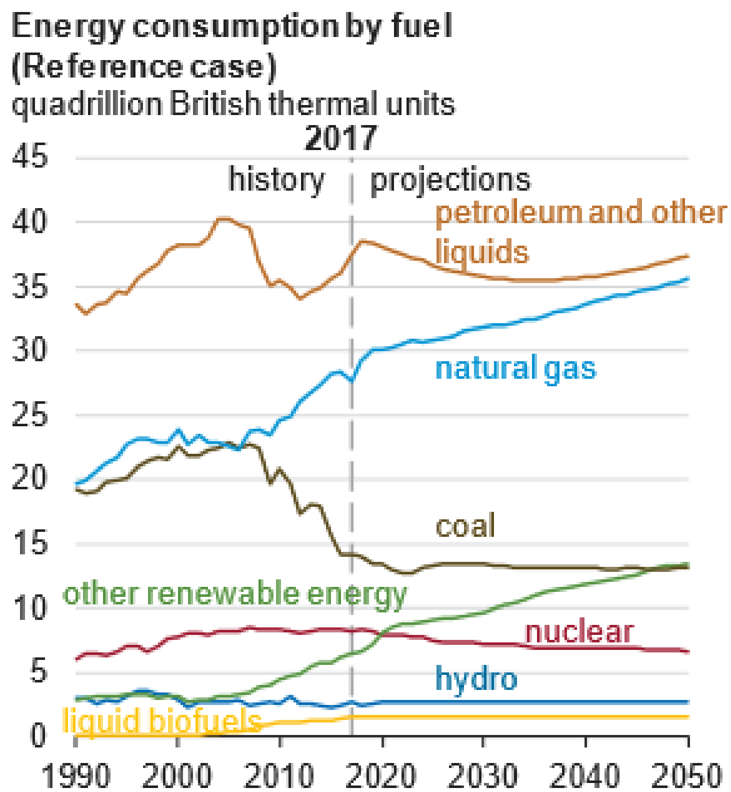
Figure 1.14



Source: Pisupati

The second chart below is also from the Energy Information Administration and projects energy usage out to the year 2050. According to this projection by 2050 fossil fuels will still make up a large majority of all energy usage. This is in line with the first chart's predictions that fossil fuels will remain the dominant energy source well into the future. This chart projects renewable energy other than hydroelectric energy, specifically wind and solar, will match coal consumption (*Annual Energy Outlook 2018*). While this is certainly an increase from where wind and solar consumption levels are today, it is still a lot lower than what fossil fuel consumption is projected to be. Natural gas is projected to increase by a large degree as well while oil levels will remain constant through 2050. Both the first and second chart show that nuclear energy is likely to remain at the consumption level that it is at now. That is an indication that people are still skeptical of nuclear energy and will remain so into the distant future. These charts each showcase that our current energy landscape will largely remain unchanged during the next few decades.

Table 1.15:



Source: Annual Energy Outlook 2018

Now that it is clear what the future energy sources will be in the United States it is important to think about what they should be. After examining each energy source it is clear that nuclear energy has the greatest potential to replace fossil fuels, with a small amount of hydroelectric power where it can be done. People often focus on wind and solar energy but due to serious intermittency problems it is extremely difficult utilize on a large scale. Real world examples in Germany and Denmark have shown that large investments in wind and solar energy increase the costs of electricity noticeably. Nuclear energy is the safest energy source of all time, with the lowest death date per unit of energy of any source that can be measured. This goes against what most people think when nuclear energy is brought up, people think it is uniquely dangerous. The evidence simply does not support this claim in any way that can be measured. On the contrary, all the data indicates that nuclear energy is exceptionally safe, especially when compared to the alternatives. Claims to the contrary are not based on facts and rely on fear mongering and anti-nuclear hysteria.

In regards to the costs and potential of nuclear it is would be dramatically cheaper if it was allowed to compete on a free market. Since the 1970s the nuclear industry has been demonized and highly regulated due to safety concerns that do not exist. This resulted in the number of new nuclear plant order decreasing from dramatically from the early 70s to the late 70s. If nuclear energy is allowed to compete without restrictions it will continue to expand the way it did prior to the 1970s and eventually replace the fossil fuels as the leading energy source. The amount of nuclear energy resources dwarfs that of fossil fuels and would power the world for thousands of years. If nuclear fusion is ever commercialized then it would be the greatest energy source of all time and could power the planet for literally millions of years. It would also be the cleanest and safest energy source ever developed and could be produced at a cheap rate. Hydroelectric energy is also extremely cheap and is very useful where it can be done but cannot power an entire society. It works best as a supplement to another power source wherever and whenever it is possible to do it. Renewable energy, particularly wind and solar, is what most people think will be the energy of the future. After a close analysis of the data nuclear energy comes out as the best source of energy for civilization, with a small amount of hydroelectric energy where possible. If this future is embraced and allowed to exist the world will have nearly unlimited energy for millions of years to come.

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