March 2011

Assessment of Alternative Energy Technologies and Recommendations for a National Energy Policy

Alexander S. Hindley
Worcester Polytechnic Institute

Kevin R. Brown
Worcester Polytechnic Institute

Kyle S. Bartosik
Worcester Polytechnic Institute

Repository Citation
Hindley, A. S., Brown, K. R., & Bartosik, K. S. (2011). *Assessment of Alternative Energy Technologies and Recommendations for a National Energy Policy*. Retrieved from https://digitalcommons.wpi.edu/iqp-all/1764

Project Number: MH-1073

Assessment of Alternative Energy Technologies and Recommendations for a National Energy Policy

An Interactive Qualifying Project Report submitted to the faculty
of Worcester Polytechnic Institute, in partial fulfillment of the
requirements for the Degree of Bachelor of Science

Authored by:

Alex Hindley, Kyle Bartosik, and Kevin Brown

Submitted to:

Professor Mayer Humi

March 9, 2011

Abstract

The objective of this IQP is to analyze the current state of energy production by all major energy sources, explore the technical and economic feasibility of individual alternatives, and to develop a set of public policy recommendations that can be implemented at the federal level to address this situation over the next few decades.

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Executive Summary

This project examines the current feasibility of alternative energy resources in general and contains proposals for actions that can be taken by the government to accelerate the rate of alternative energy adoption in the United States.

Several individual alternative energy sources as well as major traditional sources of energy are examined in this report. These traditional sources include coal, oil, natural gas, and nuclear. The main alternatives looked at are photovoltaic solar, wind, geothermal, solar-thermal, tidal, and fusion. Transportation based technologies were also examined such as hydrogen fuel cells, algae biofuel, and electric cars.

For each energy source an analysis of the technical and financial feasibility of large-scale short term implementation was conducted. Based on the research conducted, the most promising technologies from a purely cost effectiveness perspective appear to be wind and solar-thermal farms. However, it is also important to acknowledge that although other technologies such as geothermal and tidal power are slightly more expensive, they are much more reliable in terms of delivering predictable and continuous amounts of energy. It is therefore important to include some amount of these technologies on the basis of providing a stable base load supply of energy.

Most of the technologies considered in this report, with the exception of fusion, photovoltaic farms, and some transportation fuels, all appear to be feasible and ready for immediate large-scale adoption. Therefore, the largest barrier identified seems to be a lack of capital funding for such large-scale projects. Because most of these technologies are competitive with fossil fuels over their whole life-cycle they do not necessarily need to be subsidized in the long term. However, making capital available in the form of loans or through temporary subsidies would have a significant impact on adoption in the short-term.

Because of the urgency to develop these resources in a short time-frame, economic competitiveness will need to be complemented with other incentives and obligations to implement alternatives quickly. Incentives to change might include legal obligations to use certain amounts of renewable energy by specific dates, stricter pollution regulations to ultimately decrease fossil fuel competitiveness, and general transmission infrastructure investments

1 - Introduction

In recent years it has become more apparent that supplies of various fossil fuels such as petroleum, coal, and natural gas are or will become less abundant. Projections have shown that at our current rate of consumption, our resources will be depleted within decades or at best the next century. Additionally, it is becoming more difficult and expensive to obtain these fossil fuels as the more readily accessible wells and mines become depleted. As a result there is incentive to search for and invest in alternative energy sources in order to prepare for the eventual shortage of these traditional resources. The environmental impact of these fuels combined with the economic and political costs of dependence on resource-rich areas only add to the need for alternatives.

In identifying alternatives, both the technical and economic feasibility of each energy technology shall be identified and compared relative to each other. Once acceptable alternatives have been found an energy policy will be produced to advance those technologies for widespread deployment. The energy policy must consider as many viable options as possible in an objective manner with a focus on resources which are renewable, have a low impact on the environment, and the lowest real cost to the consumers.

The comparison of different energy resources will be simplified to some degree by focusing this project primarily on grid-based electrical power. In addition to forming policy suggestions, we shall also seek to determine the impacts of such policies on human health, the economy, and the environment. This impact analysis should consist of both the positive and negative effects and possibly additional suggestions or alternative policies that would reduce those negative effects.

The main focus of this project will be on alternative energies which are reliable and renewable. These might include the capture of kinetic energy from the environment via wind or tides. Some others might include technologies that directly or indirectly use sunlight as a primary source of energy, such as traditional solar power and bio-fuel production from plants. We will also examine geothermal energy production and look into the use of hydrogen and fuel cell technology. All energies considered will be eventual replacements for traditional forms of energy that rely on finite sources like fossil fuels.

2 - Background and Technical Research

2.1 - Traditional Energy Sources

The first component of this project involves an analysis of current and traditional energy technologies. These technologies include primarily fossil fuels such as coal, gas, and oil. Also included in this section is traditional nuclear fission. Nuclear fission is another large part of US energy production and is also looked at in this section.

2.1.1 - Crude Oil

The United States is a crude oil-reliant country. A majority of its consumers use either gasoline or diesel on a daily basis. The extracting, production, and distribution of refined crude oil has gained the largest influence on the economy. Crude oil-based petroleum is the dominant source of energy used, accounting for approximately 37% of energy consumption.[1] Of that consumption about 28% is transportation based. In 2007, there were 249 million vehicles in the United States, more than three cars per four people. 84% of transportation energy usage is in the form of diesel or gasoline.[2] The reliance on crude oil-based products creates a problem in continuing to meet the demands of the population's usage.

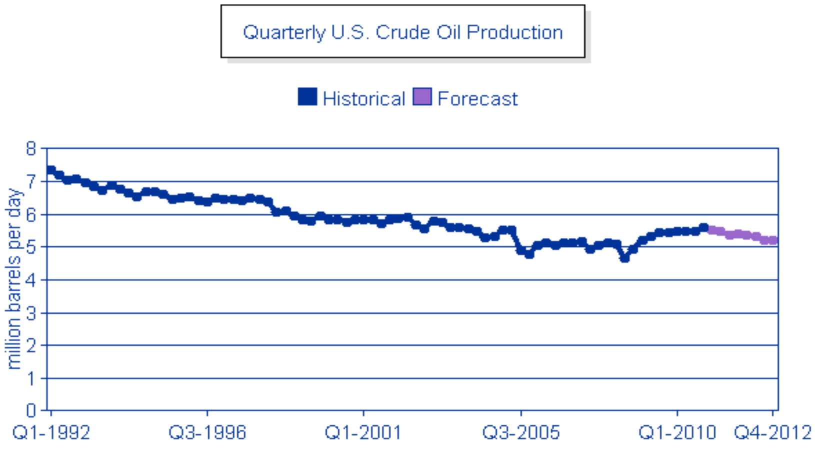


Figure 1- U.S. Crude Oil Production

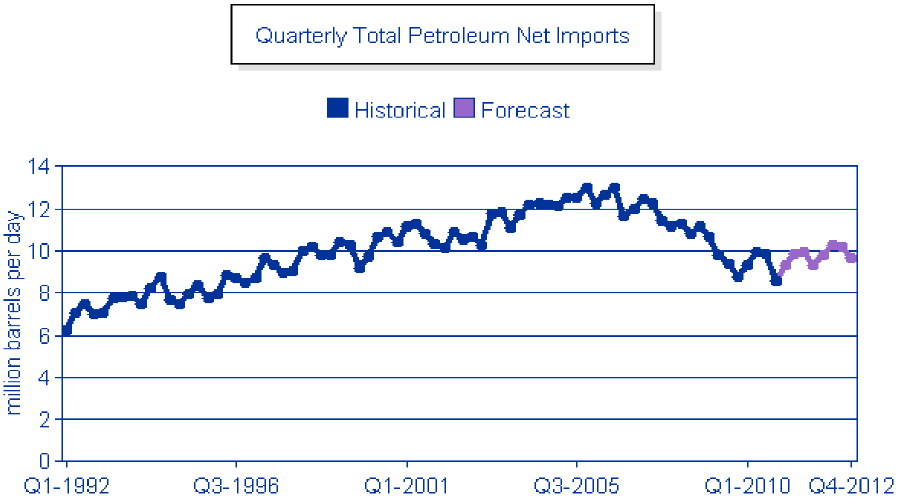


Figure 2 – U.S. Total Petroleum Net Imports
Data and graphical representations from www.eia.doe.gov/steo[3]

The United States lacks the crude oil production to match the rate at which oil is consumed by those who live here. The peak of crude oil production was in 1970, since that time the general trend has been a steady decrease. With the recent technology advances, the drilling for reserves in the Gulf of Mexico increased crude oil production by about 7% from 2008 to 2009.[4] In the 2001 report of the National Energy Policy Development Group to George W. Bush there is an estimated 64 % import of foreign oil to the U.S. within 20 years.[5] From the time this report was submitted to 2009 the percentage of oil net imports did not increase, it remained approximately 52%.[6] This is due in part to a new discovery of oil reserves, infrastructure redesign, and alternative energy usage.

As of February 25, 2011, the U.S. production rate of crude oil is approximately 5.6 million barrels per day. Total imports of crude oil and petroleum based products are approximately 11 million barrels per day. Total exports of mostly finished petroleum based products are approximately 2 million barrels per day. The total product supplied is approximately 20 million barrels per day.[7] Total stock of crude oil and petroleum based products are an estimated 1.8 billion barrels,[8] giving approximately 185 days-worth of supply at the current rate of consumption with no further addition to the stocks.[9] The production rate of crude oil cannot be sustained, as there is a finite amount of reserves, which as of 2008 were proven to be 20 billion barrels of crude oil for the U.S.[10] The estimated total recovery estimate given by the

Energy Information Administration is a range between 3000 billion and 3900 billion barrels of total recoverable crude oil and petroleum based products. Based upon the current consumption rate, oil supplies will be depleted between 2036 and 2070.[11]

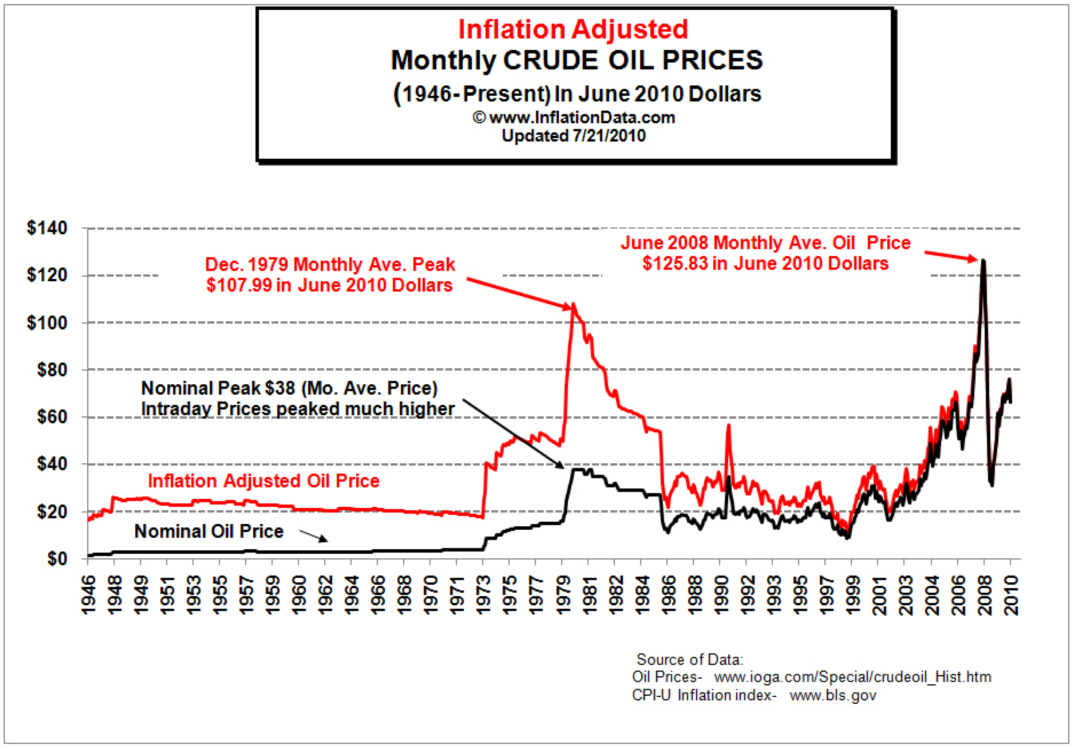
Crude oil is produced by a long process starting with the death and settling of diatoms (algae with cell walls made of silica) to the bottom of the ocean floor. Once buried under layers of sediment and the oxygen depleted from the surrounding, high pressure and temperature along with some chemical reactions converts the sugars and fats stored in the diatoms to a mineral called kerogen.[12] The kerogen is buried deeper over time, pressure and temperature increases convert it into crude oil and possibly natural gas. As this process takes several million years, crude oil is not a renewable energy resource.

Remaining U.S. oil reserves have become more costly to produce as exploration and production costs increase due to the lower-cost oil being mostly recovered. Oil sites like those In the Apline field on Alaska's North Slope use technology to drill horizontally which allows the avoidance of difficult to drill materials. Multilateral drilling is also used at sites like these to drill multiple pockets of crude oil on a single well.[13] These technologies allows for a larger area of exploration into the earth, reducing the amount of drill sites required to reach the oil pockets. Another innovation in the oil drilling industry is 3-D seismic receiving technology, which allows for greater accuracy and in combination with multilateral drilling greatly reduces the impact on the environment. However this does not solve the problem of the limited crude oil reserves nor does it address the ecological impact of production, transportation, and consumption of using crude oil and petroleum products.

The potential risks involved in production, collection, and transportation of crude oil and petroleum based products are far greater than they appear to be. Incidents such as oil-rig damage and spills have the potential to occur on a more regular basis than the general public is aware. A series of design and human errors can easily occur to create another spill in which huge environmental problems arise. As we explore the deeper waters of the Gulf of Mexico the risk for a failure on a drilling platform increases. As the U.S.'s production rate does not match that of the consumption rate of petroleum products, it is only a matter of time before the reserves go dry. This calls for a necessity to search for an alternative means of energy.

As a crude oil/petroleum-reliant country it is not a simple task evaluating the fuel source for further use. As approximately 37% of the current energy usage within the U.S. is crude oil based,[14] the dependence on sources of crude oil to sustain energy consumption is a large portion of the current energy policy. For future considerations, the sustainability, environmental impact, and cost to the consumer must be evaluated to determine viability of remaining a crude oil dependent country. As crude oil is a non-renewable energy resource, at least within the human lifespan, and the goal of this report is to consider a complete replacement of non-renewable resources, crude oil is then not a viable energy resource.

As a current source of energy, crude oil fluctuates in supply and demand, which causes variable cost to the consumer. This can be seen in the following chart, which records a rough estimate of crude oil cost per barrel since 1946, (price is in dollars per billion barrels). Similarly in the table that follows average values per year show the fluctuations in price, which is due to the investment by speculators in stocks, causing a change in value of the product.



Source of Data:
Oil Prices- www.ioga.com/Special/crudeoil_Hist.htm
CPI-U Inflation index- www.bls.gov

Figure 3 – Inflation Adjusted Monthly Crude Oil Prices
Graphical representation from inflationdata.com[15]

Generally we consider crude oil to be transportation energy; however there are certain plants in the U.S. that burn oil instead of coal to produce electricity. The electrical output of these crude oil based burning facilities ends up being roughly 12.37 cents per kilowatt-hour of power as of 2009.[16]

As a result of this fluctuating price, a finite amount of resources, projected to last between 16 and 60 years (previously mentioned), high emissions, and non-renewability of the energy resource. It can be considered that crude oil is a now solution to the problem of energy consumption. With limited resources, within one or two generations our current dependence upon crude oil will no longer be sustainable. This brings about a need to change to alternative fuel sources which are renewable within the human life span.

The environmental impact of crude oil can be determined by calculating the CO_2 output of crude oil based products. The problem then becomes determining individual CO_2 outputs for products produced from crude oil, as of 1995 the amount of products produces from one barrel of crude oil, approximately 159 liters, that passed through U.S. refineries was: [17]

1. Gasoline: 44.1% (70.12 liters)
2. Distillate fuel oil: 20.8% (33.07 liters)
3. Kerosene-type jet fuel: 9.3% (14.79 liters)
4. Residual fuel oil: 5.2% (8.27 liters)

Two assumptions are then made about the conversion of crude oil based products to more refined fuels, i) that all other products produced from crude oil (still gas, coke, asphalt, etc) have alternative uses that do not emit CO_2 into the atmosphere and ii) that production rates of refineries in 1995 are an average value that has not significantly changed within the last 15 years.

The volume of each product per barrel is then multiplied by their respective specific weights[18] to determine a rough weight of product per barrel which in turn will give us the amount of carbon emitted as a weight. The following result is then: [19]

1. Gasoline: 70.12 liters x 0.74 = 51.89 kg
2. Distillate fuel oil: 33.07 liters x 0.88 = 29.10 kg

3. Kerosene-type jet fuel: 14.79 liters x 0.82 = 12.13 kg
4. Residual fuel oil: 8.27 liters x 0.92 = 7.61 kg

"When fuel oil is burned, it is converted to carbon dioxide and water vapor. Combustion of one kilogram of fuel oil yields 3.15 kilograms of carbon dioxide gas. Carbon dioxide emissions are therefore 3.15 times the mass of fuel burned."[20] The combined liquid fuels produced from an average barrel of crude oil yields 100.73 kg and thus when these products are burned they will produce a minimum weight of 317 kg of CO_2. With simple conversions we can then determine the amount of CO_2 emitted by one U.S. gallon of gasoline and diesel. These values come out to be one gallon of gasoline produces 8.824kg of CO_2 and one gallon of diesel produces 10.493 kg of CO_2.

2.1.1.1 - Emissions of Internal Combustion Engines

A large source of carbon emissions from crude oil use is due to the internal combustion engines used to power the approximate 250 million motor vehicles currently registered in the U.S.[21] These carbon emissions stem from the incomplete combustion of the fuel used in the engine. A small amount of fuel is left after the combustion reaction within the engine's cylinders due to a lack of proper oxygen ratio.

In order to completely combust the liquid fuel commonly used in internal combustion engines, gasoline or diesel, it is necessary to maintain a proper stoichiometric ratio of fuel to air in the cylinders. Oxygen sensors are used in modern, made after 1980, gasoline vehicles to determine and adjust the air to fuel ratio such that it is kept at an ideal ratio. For gasoline the ideal air to fuel ratio is 14.7, the mass of the air molecules should weight 14.7 times that of the gasoline molecules used within each cylinder head.[22] This ratio stems from balancing the chemical reaction of the gasoline with the oxygen to allow for ideal combustion, as gasoline is made of primarily hydrocarbons a general equation for hydrocarbon combustion will give an idea of the process occurring. [23]

$$C_xH_y + \left(x + \frac{y}{4}\right) O_2 \rightarrow \; xCO_2 + \left(\frac{y}{2}\right) H_2O$$

As we know combustion will not occur without enough oxygen, and because of the complex formulation of today's gasoline, it is difficult to identify exactly how much oxygen is required to completely burn all the fuel used. The result is an incomplete combustion which leaves additional chemicals in the engines cylinders; these chemicals either remain for the next combustion cycle or are ejected through the exhaust system. To limit the amount of un-ignited fuel a common four stroke internal combustion engine utilizes the aforementioned oxygen sensor or some additional closed loop feedback system to identify the amount of oxygen and correspond it to the exhaust gas composition. Corrections are made via computer controlled fuel injectors to either increase or decrease fuel flow rate depending on the sensor readings.

It is key to maintain the proper stoichiometric ratio of combustion in the cylinders so that the catalytic converter can properly reduce emissions from the exhaust gas. Catalytic converters are a required to comply with EPA regulations. The main process of the catalytic converter involves the use of a catalyst, a precious metal the most common used being platinum, to stimulate chemical reactions that reduce carbon monoxide, hydrocarbons and nitrogen oxides to less harmful gases which can be emitted into the atmosphere. The reduction process eliminates 90% of these harmful gases by producing water, nitrogen, and carbon dioxide.[24] Without the converter in place the average family car would emit 15 tons of toxic gases into the atmosphere over a 10 year span.[25]

A three way catalytic converter is the most commonly used in today's gasoline vehicles. The three processes that it performs on the exhaust gas are: [26]

1. Reduction of nitrogen oxides to nitrogen and oxygen

$$2NO_x \rightarrow xO_2 + N_2$$

2. Oxidation of carbon monoxide to carbon dioxide

$$2CO + O_2 \rightarrow 2CO_2$$

3. Oxidation of hydrocarbons (unburned) to carbon dioxide and water

$$C_xH_{2x+2} + [(3x+1)/2]O_2 \rightarrow xCO_2 + (x+1)H_2O$$

Given approximately the stoichiometric air to fuel ratio of combustion allows for the converter to promote these chemical reactions such that almost all of the toxic emissions are converted to non-toxic gases. Outside of stoichiometric ratio the catalytic converter quickly degrades in performance, with the introduction of more air to the cylinders the catalytic converter reduces nitrogen oxides at the expense of hydrocarbons and carbon monoxide reactions. With less air introduced into the cylinders, excessive fuel is used; the catalytic converter oxidizes carbon monoxide and hydrocarbons at the expense of nitrogen oxide reduction.[27]

2.1.1.2 – Efficiency of Internal Combustion Engines

The output of the standard gasoline vehicle is 12.6% of the total energy put into the system via fuel. A majority of this loss is engine design related, which accounts for about 62.4% of the total energy dispersion.[28] This loss can be explained via several design functionalities of a standard internal combustion engine in place in gasoline vehicles. The excessive loss can be explained by thermal efficiencies, as a byproduct of the combustion process a substantial amount of heat is produced which must be removed from the engine block in order to ensure that the engine materials do not fail due to the thermal loads.

Commonly the radiator hose used for a gasoline engine is around 1.5 inches interior diameter, which leaves approximately 2 square inches of cross sectional area. The water pump circulates water through the system with a speed of around 15 ft/s, multiplying this by the cross sectional area gives 360 in^3/s, or roughly 12 lbs/s. Commonly the water is heated by 15 °F when removing heat from the engine cylinders walls and head, by using the notion that it takes 1 Btu of energy to raise 1 lb of water 1 °F it is possible to calculate the average thermal energy removed in the form of heat. This gives 180 Btu/s of heat taken away from the engine in the form of thermal energy which represents the maximum capacity of the average internal combustion cooling system. There are factors that are not taken into consideration in this calculation that produce the end result of approximately 650,000 Btu/hour or the equivalent of 256 horsepower loss, assuming that there is approximately 2500 Btu/horsepower.[29] Again these values are for maximum possible operation of the cooling system, but as can be seen there is a great deal of energy capacity designed into the system. All the energy is transferring in the form of heat from the combustion cylinder walls and surrounding heads to the radiator via water hoses with the assistance of the water pump. It is then dissipated via the radiator with the assistance of an open grill and fans, returning cooled water to the engine.

The cooling system is not the only source of thermal energy, which translates to overall power loss. There are other factors in engines that account for a significant power loss. Some of these include stop and go idling, air resistance in the form of drag, drive-train friction, rolling resistance between the road and tires, breaking, and powering any accessories within the vehicle. These losses can be approximated by the following diagram.

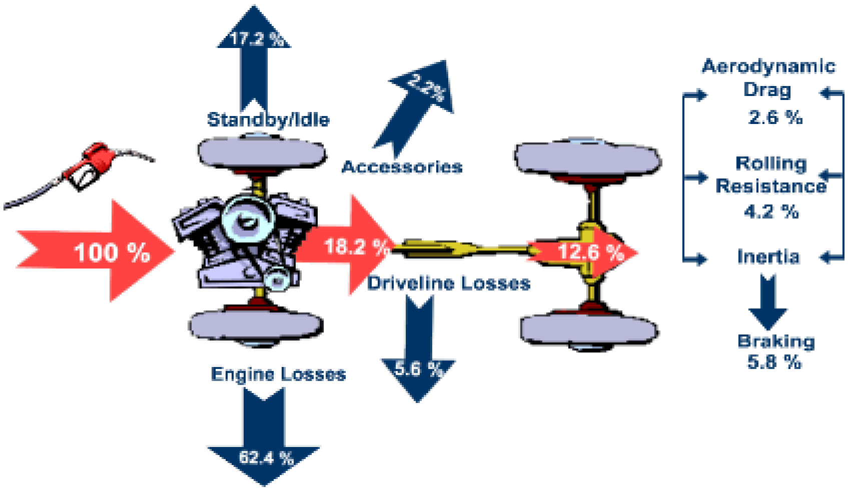
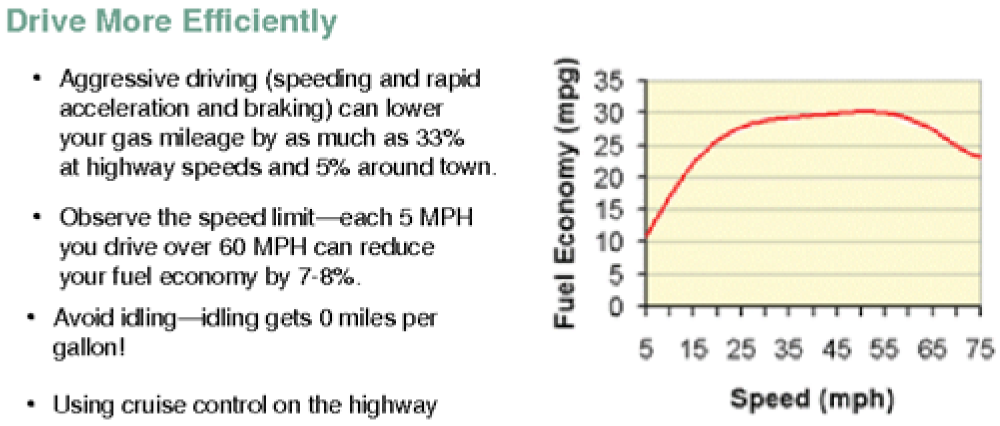


Figure 4 - Energy Losses of Average Vehicle[30]

Given ideal driving conditions of highway travel at 60 MPH, using these values we can approximate the maximum energy translation to be around 25% of the total fuel energy is converted into useable mechanical energy for driving. The problem with drivers today is that they do not travel at the optimal speed/rpm for their engines. As much of travel today is done on a stop and go type of travel the 17.2% idle/standby and 5.8% breaking energy loss shown above reduces the efficiency of fuel use. Additionally heat is lost through the exhaust system due to the expulsion of heat and incomplete combustion products. This accounts for an average of 35% of the total 62.4% of the above mentioned engine losses as can be demonstrated in the below chart. The remainder of these losses is in the form of thermal losses to the cooling system which averages to around 30% and frictional energy losses which are accounted for in all heat expulsions.

Table 1 - **Heat Balance Chart** [31]				
Engine	Brake Load Efficiency	Loss to Cooling Water	Loss to Exhaust	Incomplete combustion and other losses
Gasoline (spark ignition)	21-28%	12-27%	30-55%	3-55% + 0-45%
Diesel (compression ignition)	29-42%	15-35%	25-45%	0-21% + 0-5%

Further efficiency loss when not traveling between 25 and 60 MPH is experienced due to the fact that the cooling system drastically reduces the amount of usable energy being produced from the combustion of the fuel in the cylinders. The problem at low speed becomes low engine temperature, which causes thermal energy to be taken from the combustion within the cylinder due to the high heat capacity of the cooling system. This reduces the amount of mechanical energy produced per combustion as there is less force being delivered to the cam shaft from the pushing down of the piston via the explosion within the each cylinder. At high speed the thermal efficiency of the engine is running at approximately optimal levels, such that a high amount of explosive energy is translated into mechanical energy. However, the problem becomes the aerodynamic design of modern vehicles. At speeds above 60 MPH the aerodynamic drag increases, which requires an increased amount of mechanical energy to push the vehicle through the same amount of air. Past 60 MPH the aerodynamic forces outweigh the possible mechanical forces produced from the combustion process.


Drive More Efficiently

- Aggressive driving (speeding and rapid acceleration and braking) can lower your gas mileage by as much as 33% at highway speeds and 5% around town.
- Observe the speed limit—each 5 MPH you drive over 60 MPH can reduce your fuel economy by 7-8%.
- Avoid idling—idling gets 0 miles per gallon!
- Using cruise control on the highway

Figure 5 - Data and graphical representation from fueleconomy.gov[32]

Given the primary power efficiency loss is through the engine design, an alternative solution to gasoline internal combustion engines would be to use one designed for use with diesel products. The differences between gasoline and diesel fuels are the hydrocarbons during production. Crude oil contains hundreds of types of hydrocarbons mixed together; in order to separate these during the refining process a boiler is used as each hydrocarbon has a different vaporization temperature. Gasoline mixtures contain hydrocarbons C_7H_{16} through $C_{11}H_{24}$ which have a boiling point of 104 to 401 F° while diesel uses $C_{12}H_{23}$ through $C_{15}H_{28}$ which have a boiling point of 382 to 662 F°.[33] There are several hydrocarbons that can be found in both gasoline and diesel products. The advantage to using diesel versus gasoline, in combination with the high cost of refining gasoline products as compared to diesel, is that diesel has high combustion efficiency. This is due in part to diesel having a higher compression ratio which allows for enough heat to be produced for self-combustion when compressed. Gasoline has a compression ratio of is typically 10:1 where diesel can be as high as 25:1.[34] The higher the compression ratio, the more energy is produced which can be translated into rotational power.

Diesel engines differ from gasoline engines in the manner of how the fuel is burned due to the difference in compression ratios. While gasoline engines start ignition with spark plugs, diesel engines do not require a spark to ignite the fuel, the piston instead compresses the air and fuel mixture until the fuel ignites itself. While gasoline is premixed with air before entering the piston, a diesel engine combines the air and fuel in the piston that is that the first stroke of a diesel engine brings air in through the intake manifold, the second stroke compresses the air inside the piston, the fuel is injected under high pressure as the piston approaches the top of the stroke. At this point the air is heated due to compression enough that when the fuel is introduced it is instantly ignited transferring its explosive energy to the piston which transfers that energy to the cam-shaft and eventually the tires.

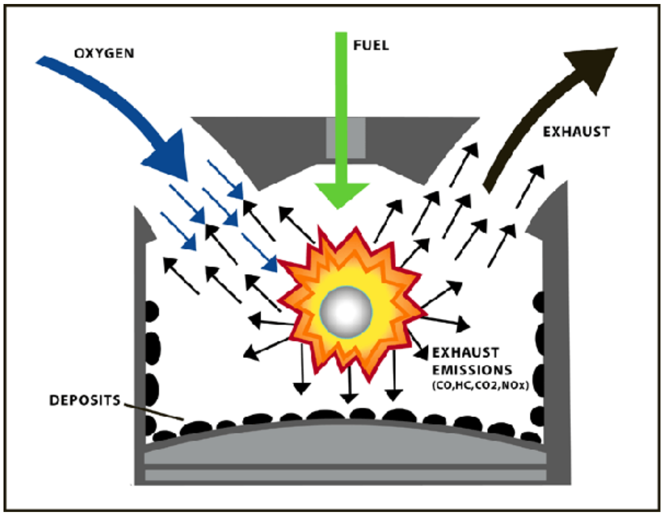


Figure 6 - Diesel Combustion
Graphical representation from www.uniburn.com[35]

Any efficiency advantage gained from gasoline to diesel is the result of the higher compression ratio and higher density which allows for more energy to be produced per gallon. One gallon of diesel fuel contains 1.6×10^8 Joules of energy, while gasoline contains 1.3×10^8 Joules of energy.[36] Additionally diesel fuel is mixed with the heated air at close to maximum piston stroke, which reduces the amount of mechanical energy lost to pushing down the piston into the cam shaft, or working against the rotational force caused by subsequent pistons misfiring. In turn if the spark plug is ignited, causing the fuel to burn, before the piston has passed the top of its stroke additional energy is lost forcing the piston over the top of the cam-shaft in order to progress in its stroke. When the premixed gasoline enters a piston chamber it is subject to the compression reducing the fuel to air mixture as the piston moves along its, which in turn reduces the amount of power available from the mixture.

Diesel on the other hand can be mixed at close to perfect ratio during the piston cycle, which allows for a better power conversion. Unfortunately there is no such thing as a perfect combustion which causes similar effects of gasoline combustion. The fuel is not uniformly burned; the lighter hydrocarbons are ignited first resulting in exhaust gases moving at high pressure which interfere with the oxygen mixing properly with the heavier molecules. This can be observed by the common black smoke emitted from diesel vehicles which are referred to as soot, these unburned heavy hydrocarbons can build up inside the engine and exhaust system which further reduces the power output of the system and should be removed during maintenance to reduce damage to the engine.[37] One solution to create a more uniform combustion is the combination of diesel fuel with an additive to ensure clean fuel injectors, although none of the additives can be proven to work as advertised.

One additional benefit to diesel engines is the ability to detect and control the air to fuel ratio inside each piston. This is made possible by the introduction of the diesel fuel into the piston via electronic control modules combined with an array of temperature, pressure, and speed sensors as well as pedal activation sensors which all run through the vehicles electronic control unit. The ECU also known as a power-train control module (PCM) or engine control module (ECM) gathers and processes all the information from the various sensors and determines the amount of fuel and ignition timing to keep the engine running.[38]

The ECU makes decisions on how much fuel to add based on throttle position and temperature of the engine. If the throttle pedal is pressed down it opens the throttle body allowing for additional air to be taken into the engine, the ECU then calculates the amount of air being passed through the engine in order to calculate the amount of fuel to inject into the pistons. The ambient temperature of the engine caused by the moving of internal parts affects the amount of air that is passing through the engine, on diesels there is a heating element to warm up the engine prior to initial ignition, and the ECU takes this into account and introduces additional fuel to allow for proper combustion. The largest concern with using diesel engines in the United States is the association the general public has of diesel with loud large transport trucks emitting large quantities of black soot.

2.1.2 - Coal Power

One energy source, Coal, which has been used since the very beginning of the industrial revolution itself, is both the cheapest and dirtiest form of energy available within the United States. As a direct consequence of its low cost, coal is currently the nation's number one fuel source for generating electrical energy for the grid. In the year 2000, about 52% of the electricity generated for the grid came from coal-fired power plants. In some states this number was as high as 80%.[39] While the percentage of grid power generated by coal has decreased in recent years, it is still very large and was about 49% in the year 2009. The measured average utility cost of coal energy in 2008 was $2.07 per MMBTU and is estimated to be $2.25 per MMBTU for 2010 and $2.19 in 2011. At this rate, the average end-user price per kilowatt-hour has been about 7.5 cents over the last 2 years.[40]

Coal is basically any readily combustible black or brownish rock whose composition, including moisture, consists of more than 50% by weight and more than 70% by volume of carbon. It is formed from plant remains that have been compacted, hardened, chemically altered, and metamorphosed by heat and pressure over geologic time.[41] The percentage of coal that isn't carbon usually consists of Hydrogen, Sulfur, Oxygen, & Nitrogen. It also contains varying, much smaller, amounts of many other particles and substances depending on where and how the coal was formed. These other substances can span the entire periodic table and include both harmless and harmful elements. The energy density of coal itself is very high, 6,150 kWh/ton (at 100% efficiency). In actuality though, coal power plants usually operate at about 30-40% efficiency. The average US coal-fired plant is around 34.7% efficient, producing 2,134.5 kWh per ton of coal consumed. These figures were calculated using total US coal consumption and total electrical output by coal plants in 2008.[42]

Production and consumption of coal is a huge industry in the US. Each year, about 1.073 billion short tons of coal are mined in the United States. Of that, about 1 billion short tons are consumed by power plants and other institutions annually. A net amount of 59 million short tons are exported, while the remaining production goes towards domestic reserves. Currently there are about 239 million short tons of reserve coal stockpiles (as of 2009).[43] Transporting all that coal is an equally large industry. Coal is primarily transported by rail, especially over long distances.

Rail transportation makes up about 64% of the coal-transport industry. Additionally, 12% is transported by truck, 9% by water-ways, and another 12% is transported by conveyor belt or slurry pipeline in situations where the end-user is on the same site that the coal has been mined from. The current average rate charged for coal transport is about $10 per ton moved, or when distance is taken into consideration, $5 per ton-mile.[44]

A typical, 500 megawatt, coal-fired power station produces, each year, around 10,000 tons of sulfur dioxide emissions (SO2), 10,200 tons of nitrogen-oxide (NOx), 3.7 million tons of carbon-dioxide (CO2), 1300 millicuries of radiation (48 gigabecquerels), 3.5 billion kWh of electricity, and consumes 1,640,000 tons of coal.[45] [46]

The radiation generated by coal power plants comes from coal ash. The amount of that radiation is about 363.3 micro Curies per billion kilowatt-hours of electricity generation. The element Radon contributes the most to this at 331.2 mCi/TWh. Uranium is another 3mCi/TWh, Potassium 5.3mCi/TWh, Lead 10.0 mCi/TWh, and Polonium 13.8 mCi/TWh.[47]

One reason that coal seems so cheap is that the coal industry has largely externalized many of the real-world costs of coal mining and burning. For instance, the process of mining coal isn't always as simple as digging a mine and extracting that coal. In many cases the entire plot of land under which coal is known to be gets completely destroyed as the coal mining operation literally digs up or blasts away an entire mountain or area to get to it. This process is known as open-pit mining and is again very cheap internally because it externalizes all the damage-related cost done to the local environment. This aside, the actual burning of the coal once it reaches the power plant is where even more harm is done. It has been estimated that the emissions and general pollution caused by coal-plants is responsible for about $60 billion worth of damages to human health and agriculture every year. If that were to be included in the market price of coal-power it would be an additional 3.1 cents/kWh (for a total of 10.6 c/kWh).[48]

In an effort to reduce some of the harmful pollutants generated by the burning of coal for energy, several methods and devices have been developed over the years, and especially implemented over the past 2-3 decades. One such invention is the "Scrubber". This is an apparatus installed at coal-fired power plants which remove certain pollutants, such as Sulfur, Mercury, NOx, and general particulate matter, from that facility's exhaust. The process of 'scrubbing' flue gas (plant emissions) usually involves piping those emissions through a special chamber where they are treated with water vapor mixed with a variety of chemical agents. These water-droplets and chemicals stick to or chemically react with (absorb) particulate matter and target pollutants. This specific process in general is usually referred to as wet-scrubbing and is currently the most common way of controlling plant emissions at plants that do control emissions. A modern coal-power flue scrubbing system can trap 88% of NOx, 99% of particulate matter, & 92% of SO2 emissions, compared to an uncontrolled facility.[49] The estimated cost of scrubbing ranges from $60 to $1100 per metric ton, annualized cost per ton per year of pollutant controlled (at 7 grams of pollutant per cubic meter of total emissions).[50]

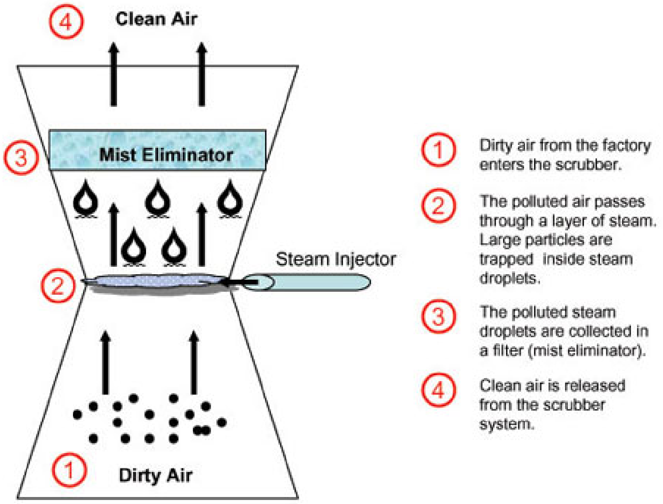


Figure 7 - Simplified Diagram of Wet-Scrubbing[51]

In addition to conventional burning of coal straight as a solid, there exists another product called Syngas, and it is produced from the gasification of that coal. Syngas is a gaseous fuel, created from originally solid coal, which can either be used directly, or separated further into other gases. The creation of syngas from coal involves a gasifier in which oxygen and coal (usually pulverized) are fed into. The gasifier is then heated and in some cases pressurizes the contents. Water vapor is also added to the heated oxygen and coal mixture. The contents of the gasifier undergo chemical reactions to form the desired syngas.[52] The chemical reaction that takes place can be simplified as such, where capital letters represent elements, and (imp) represents other impurities in the mixture: 3C + (imp) + O2 + H2O => H2 + 3CO + (imp). So, syngas is essentially a combination of Hydrogen, Carbon monoxide, and other impurities like sulfur, mercury, etc.

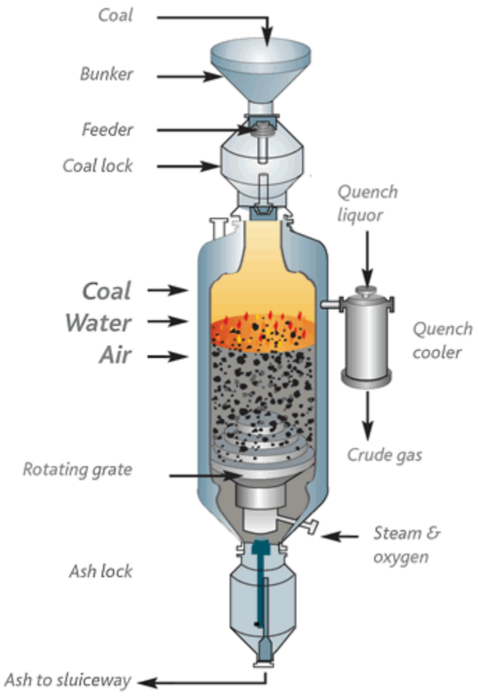
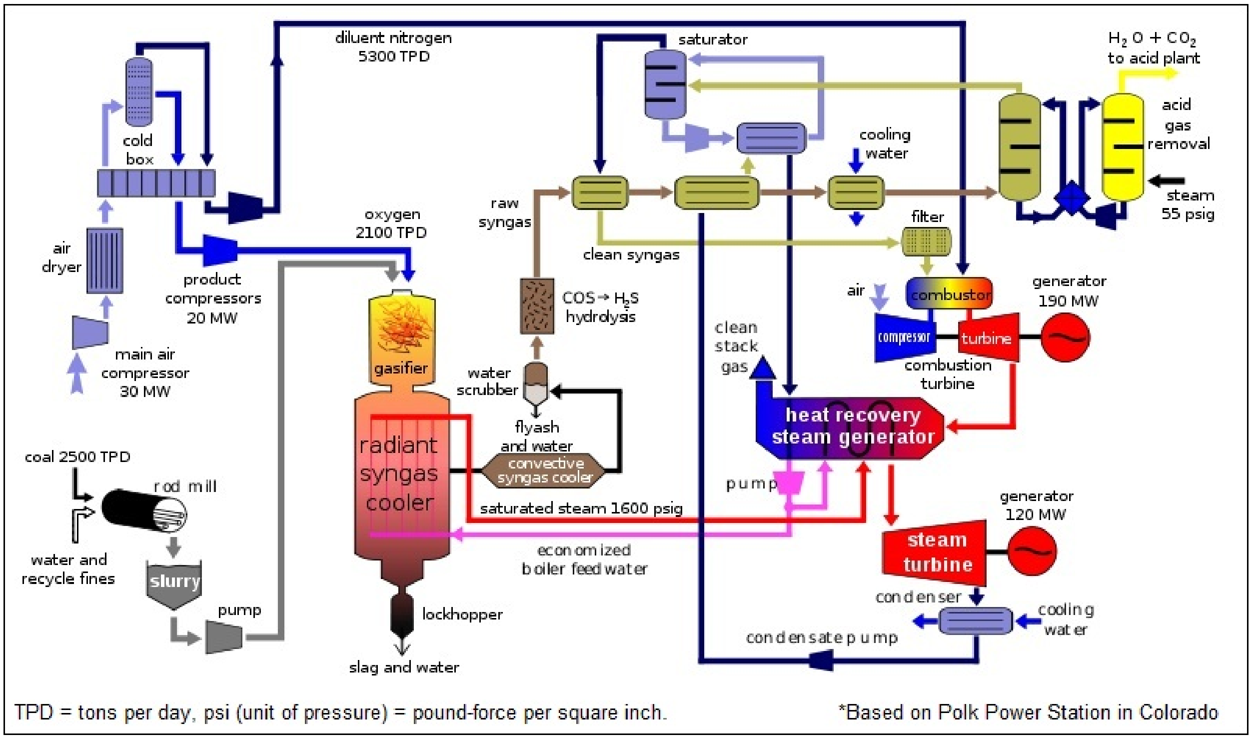


Figure 8 - Coal Gasifier[53]

More recently, a concept referred to as Integrated Gasification Combined cycle (IGCC) which is a larger process of coal gasification, additionally seeks to remove impurities and pollutants from the syngas and/or collect those substance byproducts as usable goods. The entire process starts with air and coal. The air is stripped down to just oxygen and added to the coal in the process of initial gasification. At this stage, slag and ash byproduct are produced and collected. The resulting syngas (comprised mostly of CO + H) is then combined with water (H2O) in a process known as water-gas shift to produce Hydrogen (H2) and Carbon dioxide (CO2). At this stage, sulfur and any other particulate matter byproducts are filtered out and collected from the gas using conventional scrubbing techniques. The now cleaner syngas, composed of Hydrogen and CO2 is separated into the respective gases. The CO2 is collected and either piped to an on-site or off-site carbon-capture facility. Hydrogen being the desired resultant, is at this point ready to be used as a fuel in a range of electric generators (including gas-turbines, combustion, or fuel-cells) or used as feedstock for other industries and institutions.



TPD = tons per day, psi (unit of pressure) = pound-force per square inch.

*Based on Polk Power Station in Colorado

Figure 9 - Diagram of an IGCC (integrated gasification combined cycle) power plant.[54]

Another important aspect of IGCC plant design is the use of heat-energy recovery. As shown in the above diagram, this added system which uses what would otherwise have been waste-heat to power an additional turbine. By utilizing the waste-heat of the coal-gasification system, a power plant can obtain much higher efficiencies of electrical output per unit mass of coal consumed.

Historically, Coal gasification was only used in dire situations when other fuels such as petroleum were scarce. This was the case because of how dirty traditional coal gasification is. For example, the last major use of coal-gasification was by the German government during World War II after the country had run low on gasoline.[55] Even today, the only reason gasification is considered in the US is largely based on the fact that there is a limited supply of oil and a much more abundant supply of coal (relative to petroleum). However, now with the technology and methods in IGCC, it is much more economically and environmentally feasible to create and use syngas.

A key issue with all fossil fuels and especially with coal is the matter of carbon-dioxide emissions which have been shown to play a large role in climate change. In order to address this, any solutions involving coal as the primary fuel must be accompanied by some form of carbon capture and storage technology. CCS is basically any process of capturing CO2 from industrial or power-generating facilities and storing the carbon or CO2 entirely in some form or location. Ideally this would be permanent and the ultimate goal with any CCS is to achieve 100% CO2 emissions capture. Currently there exist two main types of CCS, forced underground storage and biological absorption.

Conventional CCS technologies usually involve converting the captured CO2 into a more transportable form, such as a high-pressure liquid. Then transporting, by pipeline, the CO2 to a well where it is pumped deep into underground geological formations such as porous rock, depleted gas/oil reservoirs, etc. Capturing CO2 from the flue gas of a power station (post-combustion) is commonly achieved through the highly developed acid gas removal process. This process has been refined over many decades and since the early 20th century has been used in many other industries to capture CO2 and/or hydrogen sulfide. Also known as "amine gas treating" the process involves pumping the flue gas into an absorbing chamber where down flowing amine solution absorbs the CO2, and then is transported to a separate "regenerator" chamber where the amine solution is boiled and stripped of the CO2 so it can be re-used.[56] Incremental cost of installing conventional CCS technologies at new IGCC plants are estimated to be between $150 and $200 per ton of captured CO2, and slightly higher - up to $250 per ton to retrofit the technology to existing coal-fired plants.[57] [58]

The other form of CCS not involving underground storage uses green algae to absorb and store the CO2 as biomass. This process involves bubbling the flue-gas (coal plant emissions) into photo bioreactors or ponds. Photo-bioreactors are very simplistic, usually consisting of little more than a clear tube-like chamber filled with water and green algae. In both the bioreactors and open pond systems, the algae absorb the CO2 via regular photosynthesis. Algae-based CCS has more potential than conventional underground-storage CSS due to much lower operating costs, and the fact that the resultant algae is extremely marketable as a byproduct. Even the algae have the potential for being converted into further fuels or petroleum substitutes.

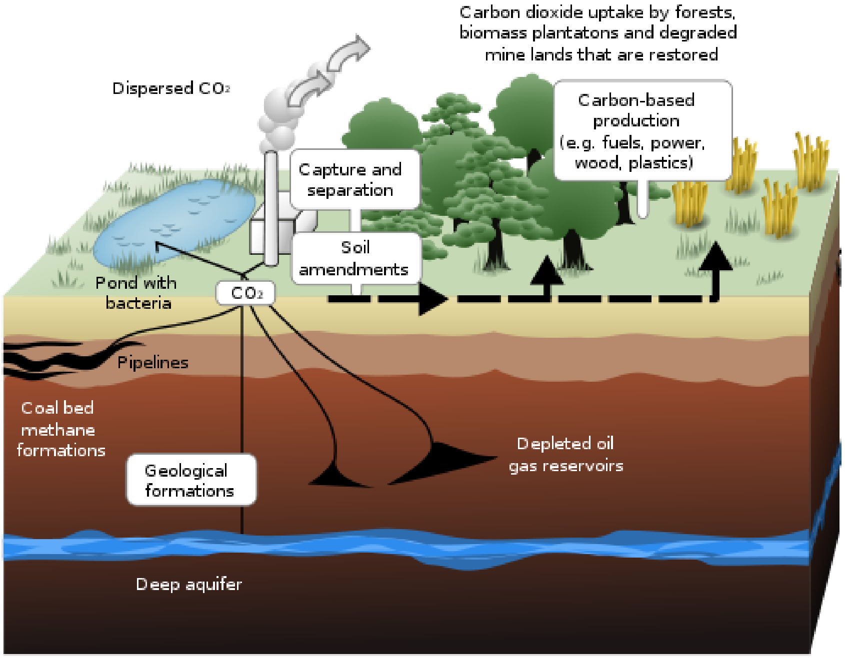


Figure 10 - Schematic of Different CCS Technologies/Methods[59]

The phrase "Clean Coal" is commonly applied to methods, such as these, of harnessing coal energy with mitigated or completely controlled emissions. Coal as an energy source will most likely continue to be under increased scrutiny by environmentalists and the general public, meaning that the coal industry will need to implement these clean-coal technologies if it wishes to remain politically viable. Whether or not this can actually be done in a feasible way will very much depend on other factors such as the price of much cleaner alternatives.

Compared with the price of 7.5 cents per kilowatt-hour for mostly uncontrolled coal-power, an IGCC plant would deliver power at a range of 9-11 cents/kWh. Adding carbon-capture costs of 5 more cents/kWh, the total delivered cost of "clean coal" would be about 15cents/kWh.[60] Even at this much higher cost, existing IGCC plants have only been able demonstrate control of up to 95% of their emissions, meaning that even with all clean coal technology in place, the entire process is still both carbon-positive, and a source of hazardous pollutants in the environment. Additionally, Coal gasification wastewater has an average pH of 9.8. This is much too high to safely be released back into the environment, creating a new and separate problem of waste-water treatment and disposal which will only add to the final cost of clean-coal.[61] A majority of clean-coal projects suffer from outright cost overruns, huge project delays, or total failure to proceed with operations, or to meet set goals. The GAO (government accountability office) for example found that of 13 clean coal projects proposed and started before 2005, 8 had serious delays or financial problems, 6 were behind schedule by 2-7 years, & 2 projects went completely bankrupt.[62] For these reasons, Clean Coal does not appear to be feasible at this time, nor would it be within the next 20 or so years, making such technology at best a costly distraction from the research of other more feasible and long-term alternative energies.

2.1.3 - Natural Gas

While there are many different methods of producing electricity in the United States, natural gas remains one of the primary sources for alternative electricity generation (not just coal, oil or nuclear power). “About 90 percent of all new electricity plants currently under construction will be fueled by natural gas.” Although this seems good as an alternative to oil, a heavy dependency on any one fuel source (especially if foreign acquired) will constantly create an increase in prices for the consumer, among other things. The United States has not been expanding its domestic energy production enough, rather relying on foreign imports (causing the dramatic rise in prices over the past 5 years). This, as stated before, is a result of increased imports, Natural gas imports “rose from 5 percent in 1987 to 15 percent over these past 5 years there has been a real push to heat homes with natural gas. This push is “driven by electricity restructuring and the economics of natural gas power plants. Lower capital costs, shorter construction lead times, higher efficiencies, and lower emissions give has an advantage over coal and other fuels.” As well as being a critical way to produce electricity, natural gas is also used in many other ways, such as industrial fuel, heat for homes, and as a raw material in the manufacturing process. It contributes to such products like rubber, clothing, furniture, paper, chemicals, glass, and other petroleum products.

Our natural gas foreign imports are almost entirely from “Canada, as it has rather large gas supplies and pipeline access to the lower 48 states”. Natural gas prices, unlike oil, are determined regionally rather than global markets. The demand of natural gas is projected to increase 50% between the year 2000 and 2020, which will ultimately lead to higher costs. But this is a double edged sword, where higher prices have adverse effects on consumers and businesses; they do promote the increased development of natural gas plants and more energy efficient technologies. With increased production, however, we will need to locate more deposits of natural gas. Domestically, short-term production is projected in the Rocky Mountains, the Gulf Coast, and the Mid-Continent regions. Long term, however, is dependent on how long domestic supplies last.

There is, however, a new natural gas deposit (that was previously thought to be unobtainable) that contains more than 500 trillion cubic feet of natural gas. It is located under the Appalachian Mountains in the Marcellus Shale rock. It is a low density, organic rich rock that was formed over 359 million years ago during the Paleozoic Era. The reason that this natural gas deposit was believed to be inaccessible is because it is more than 1 mile into the earth. Current natural gas wells in this area, before 2000, had mostly unimpressive results due to the formation of the rock and the vertical drilling. The reason these wells did not have success is because the natural gas in the rock gets trapped within the pore spaces of the shale and within its many vertical fractures. The tiny pores contain most of the gas, but they do not permeate well through the holes, but do travel well through the multiple fractures. Unfortunately, the wells could only drill vertically until recently developed technology that allows the wells to bore horizontally to cross as many vertical fractures as possible. These new wells have had such yields as one million cubic feet of natural gas per day, but such technology is so new that the long term data is not available.

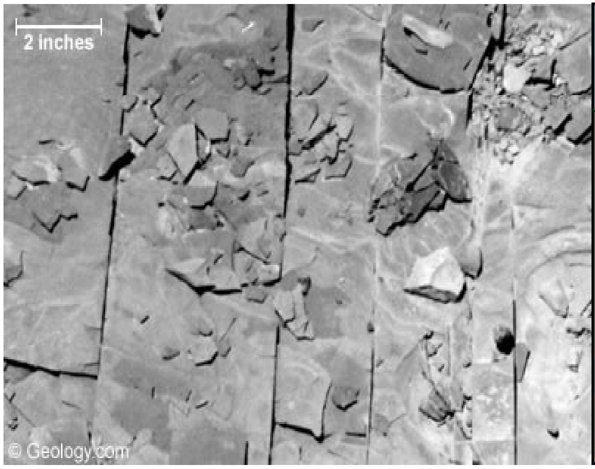


Figure 11 - Highly Fractured Shale[63]

Natural fractures "joints" in Devonian-age shale

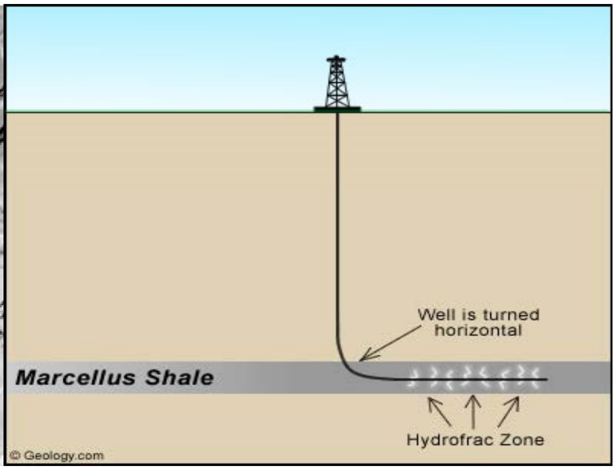


Figure 12 - Horizontal Drilling[64]

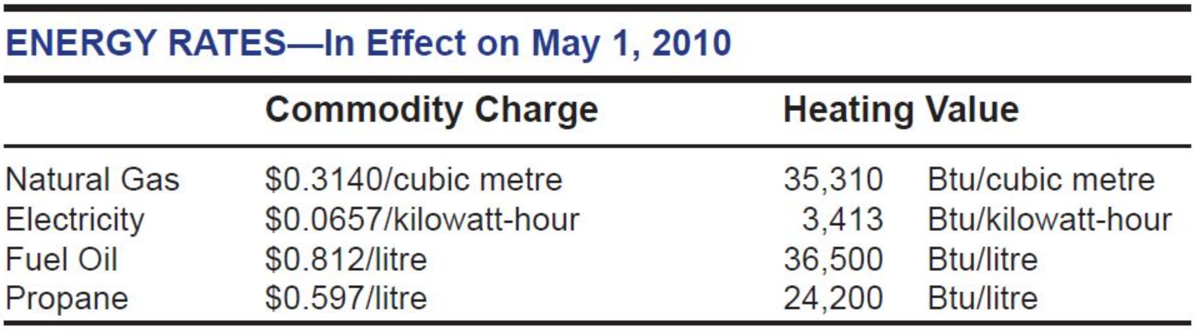
The most promising wells drilled into the Marcellus employ two technologies that are relatively new to Appalachian Basin gas shale production. One is horizontal drilling, in which a vertical well is deviated to horizontal so that it will penetrate a maximum number of vertical rock fractures and penetrate a maximum distance of gas-bearing rock. The second is "hydrofracing" (or hydraulic fracturing). With this technique, a portion of the well is sealed off and water is pumped in to produce a pressure that is high enough to fracture the surrounding rock. The result is a highly fractured reservoir penetrated by a long length of well bore.

This Natural Gas deposit will have great significance to the highly populated areas on the east coast. Lower transportation costs and a steady supply for years will make this a very valuable resource in the near future. Even though the risk of drilling for and using natural gas is lower than other energy sources, there is still a risk of the toxic gas leaking and building up in very large quantities which can lead to very dangerous explosions.

Unfortunately, even though the United States does produce 85% of its natural gas, prices have risen in the past decade. Challenges some people face due to this price rising are:

- Farmers are paying up to twice as much for fertilizer
- Nearly 50% of families heat their home with natural gas, and in some areas heating costs have doubled or even tripled from recent cold winters.
- Small businesses forced to close who cannot keep up with heating bill

Table 2 - Heating Fuel Energy Rates[65]



ENERGY RATES—In Effect on May 1, 2010

	Commodity Charge	Heating Value	
Natural Gas	$0.3140/cubic metre	35,310	Btu/cubic metre
Electricity	$0.0657/kilowatt-hour	3,413	Btu/kilowatt-hour
Fuel Oil	$0.812/litre	36,500	Btu/litre
Propane	$0.597/litre	24,200	Btu/litre

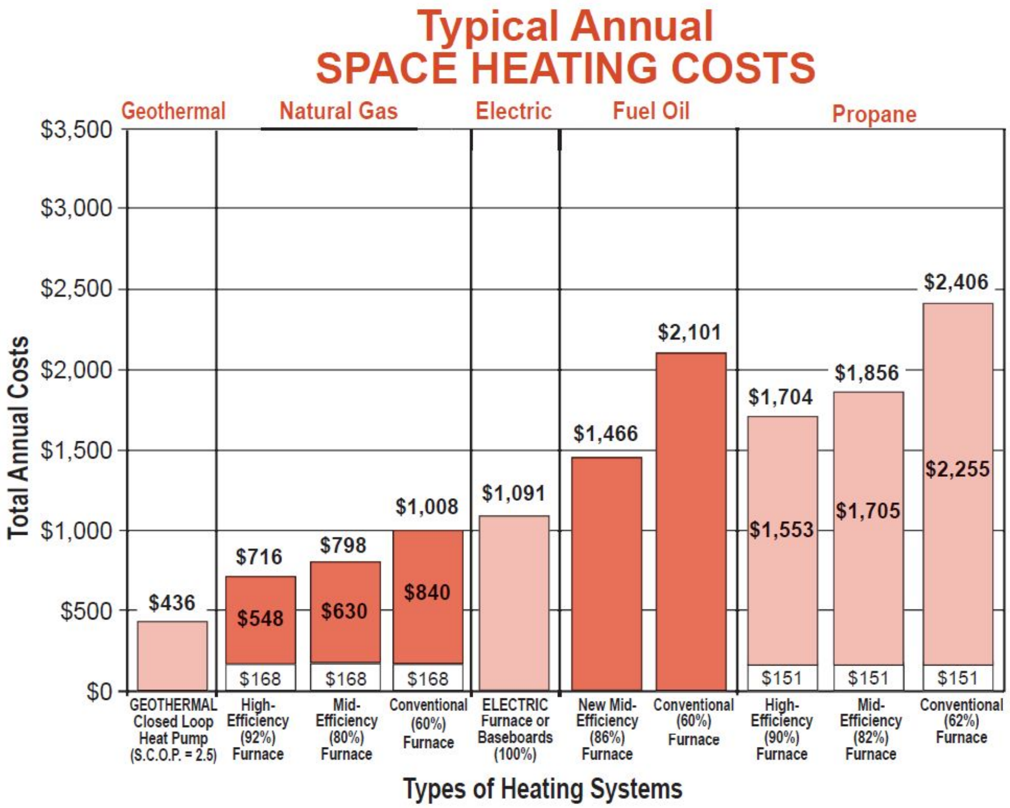


Figure 13 - Typical Annual Space Heating Costs[66]

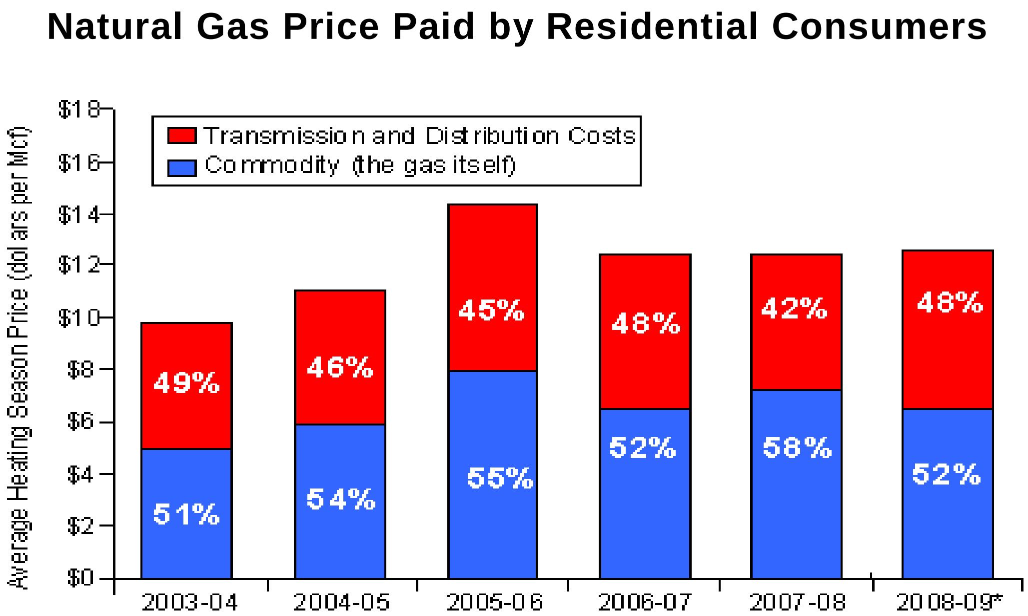


Figure 14 -Breakdown of Natural Gas Price Paid
by Residential Consumers During the Heating Season, 2003-2009[67]

Dry Natural Gas Proved Reserves by Area, 2006

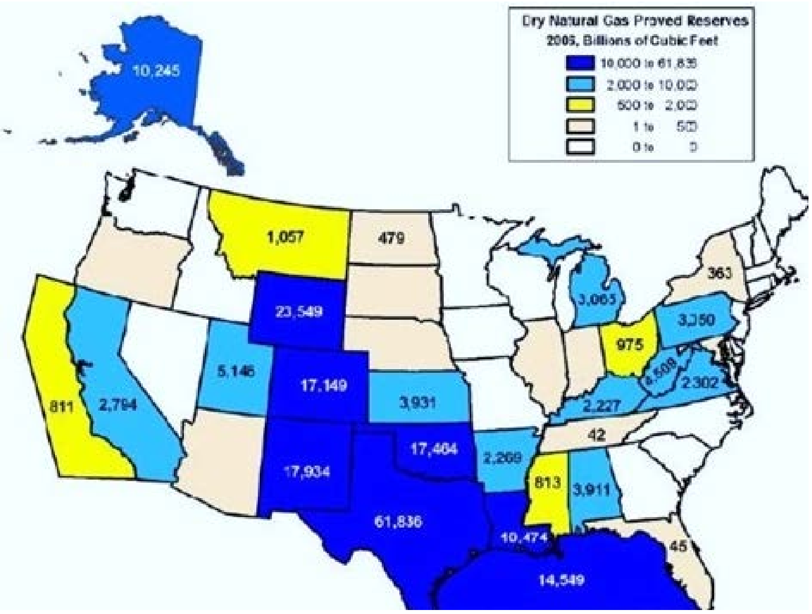


Figure 15 - Natural Gas Reserves[68]

“As of December 31, 2007, estimated proved reserves of "dry natural gas" (consumer-grade natural gas) in the United States were 237.7 trillion cubic feet (Tcf). The United States consumed 23.2 Tcf of natural gas in 2007...As of January 1, 2007, EIA assumes that domestic natural gas undiscovered technically recoverable resources are approximately 1,536 trillion cubic feet.” (www.eia.doe.gov)[69]

2.1.4 - Nuclear Power

The United States has had 104 active nuclear power plants since the 1970s; these reactors produce a consistent amount of energy per year, approximately 800 million kilowatt-hours of electrical energy. As the leading commercial nuclear power provider, this accounts for only 20% of the total electrical generation needs. In comparison France produces 77% of their electricity needs from nuclear power plants.[70] As an energy source, Uranium and Plutonium primarily being used, nuclear power is a clean alternative to coal, natural gas, and oil plants.

Nuclear power, as with natural gas and oil, is a non-renewable energy source. Nuclear energy stems from the fission of atoms, during which a single neutron hits the atom of the material and splits it into two lighter atoms, neutrons, and energy in the form of heat and radiation. The stray neutrons then continue the chain reaction of the fission process to produce additional energy. The most common element used to produce nuclear power is Uranium. Uranium is used as it has an isotope found to be fissile, able to sustain a chain reaction during fission, which is U-235.

The nuclear binding energy is an important concept to understand when discussing nuclear power production via fission. The nuclear binding energy is the amount of energy required to break apart the neutrons and protons of the atom, it can be determined using Einstein's mass energy relation $E = \Delta mc^2$. For U-235, the reaction is as follows: [71]

$$ {}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{140}_{55}Cs + {}^{93}_{37}Rb + 3\,{}^{1}_{0}n + 200\,\text{MeV} $$

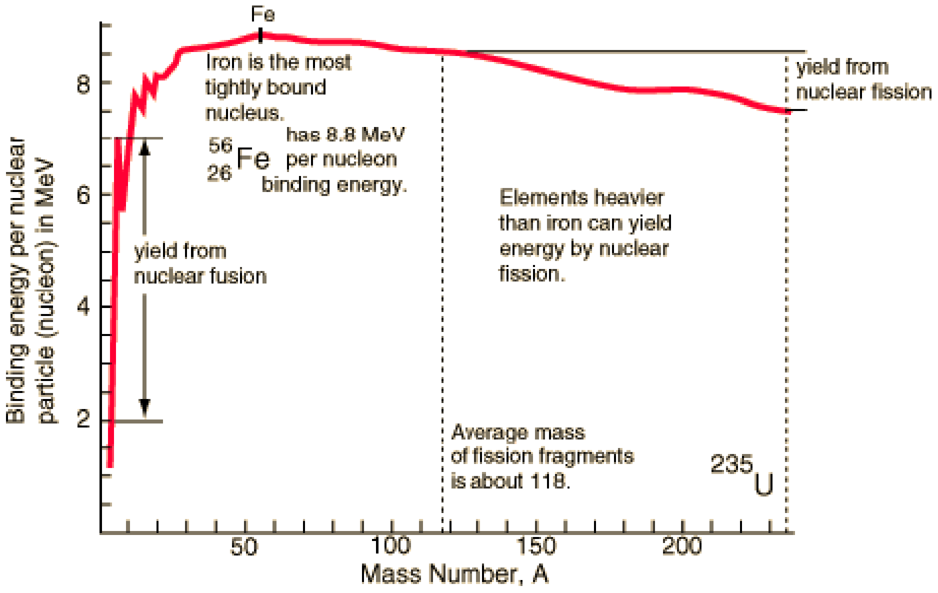


Figure 16 - Binding Energy vs. Mass Number

Graphical representation from www.world-mysteries.com[72]

For a conversion factor, 1 kilowatt-hour is equal to 2.25×10^{19} MeV, so it would take 1.13×10^{17} reactions to produce 1 kilowatt-hour. The fission of 1 kg of U-235 releases 18.7 million kilowatt-hours of heat energy. The following chart describes the yield of a nuclear fission reaction using the binding energy per nucleon, where a nucleon is the total number of protons and neutrons, versus the mass number. We can then extrapolate that the more tightly packed the nucleus is, the more energy will be output through fission. The defining feature that makes U-235 special is its ability to sustain the fission reaction because it releases an average of 2.5 neutrons through the above mentioned chemical reaction of the fission process.

The Uranium that is found in nature is very rarely in U-235 isotope; as such it must be extracted. The following image will display the typical Uranium processing cycle that will be described in greater detail afterwards.

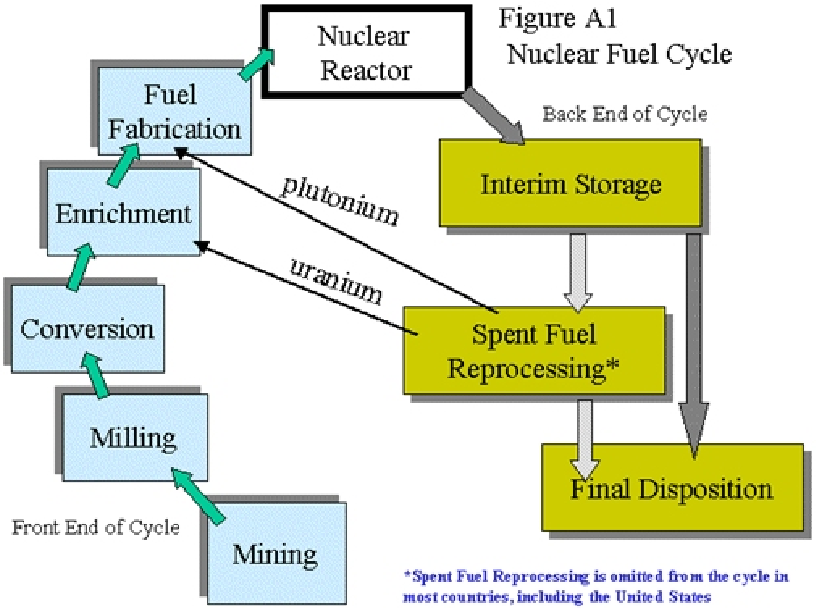


Figure 17 - Nuclear Fuel Cycle

Image from eia.doe.gov/energyexplained[73]

Typical Uranium concentrate is in the form of U_3O_8 commonly known as “yellowcake.” Depending on whether the Uranium is mined in an open pit/underground mine or solution mine there are differing processes for extraction of the yellowcake. If extraction is from a open pit or underground mine, the minerals collected are crushed and reacted chemically to separate the Uranium. In solution mines, uranium is found coating sand particles called conglomerates, or minerals combined with stones in a cement type mixture. The Uranium is separated by means of a creating a slightly elevated pH level water mixture which dissolves the Uranium, which is retrieved through a resin bed at the mill. This is again concentrated to form U_3O_8.

Once the Uranium has been reacted to form the yellowcake it is then converted to Uranium hexafluoride (UF_6) which is a gas. This is a useful compound at this step as it is easy to separate the various isotopes of Uranium. As mentioned above the desired isotope is U-235, as such it is necessary to separate it so it can be properly mixed for nuclear fuel. Once the isotopes are separated they are then combined together in such a manner that the final product is 4% to 5% U-235, this is the optimum range for isotope levels so that control can be maintained when fission is occurring within a nuclear reactor. Any less concentration and fission will occur less frequently, any more concentration and the fission process could go out of control causing a melt-down within the power plant. There are various methods for isotope separation, which involve mass differences between the isotope-gas mixtures, a brief mention of the methods are gas diffusion and gas centrifuge. The "enriched" UF_6 is then placed into canisters, cooled, and allowed to solidify before transported for further conversion.[74]

The Uranium hexafluoride is then reacted to create Uranium dioxide (UO_2), which is used in the nuclear power plants. The UO_2 is placed in small tubes 1 cm in diameter and placed in assemblies that hold 179 to 264 rods; the average reactor core holds 121 to 193 fuel rod assemblies. For a 1000 Megawatt power station, the dimensions of the reactor core are roughly 14 feet high by 12 feet in diameter.[75] At this stage the Uranium is only mildly radioactive, and is mostly contained within the rods, as such it can be handled with no precautions with bare hands.

Once the Uranium has been used in the nuclear reactor until it is deemed as depleted, no longer have the U-235 concentration to undergo fission, the spent fuel rods are placed in on-site water tanks for several years. Even though the Uranium is no longer undergoing fission, it is still emanating heat from the radioactive elements decaying that were created as a result of the fission process. The water pools not only cool the rods, but also protect plant operators from any radiation from the decay occurring. As of 2002, there were 165,000 depleted fuel rod assemblies, stored at 70 locations in the U.S.[76]

This is a major concern in the U.S. as our current nuclear waste policy does not allow for reprocessing/recycling of the spent fuel. In 1977, President Carter announced, "We will defer indefinitely the commercial reprocessing and recycling of plutonium produced in the U.S. nuclear power programs."[77] At the time the rationale was based upon India testing a nuclear weapon made from weapons-grade fuel produced from a civilian energy plant. The movement to eliminate the possibility of further nuclear war was not followed by the rest of the world. Later the Nuclear Waste Policy Act of 1982 would be placed into effect, the result of which is a direct disposal of commercial reactors and government defense waste and research.[78]

As a result of President Carter's decision to no longer recycle/reprocess nuclear waste, the only means of disposal is storage. A majority of depleted nuclear fuel is stored at the nuclear power plant for several years, after which time it could then be moved to a dry cask storage container with air-cooling for further on-site storage, they are typically special concrete or steel containers. The final step in the U.S. is to collect the on-site storage depleted fuel rods and transport them to a permanent underground repository. There is currently no satisfactory location for this within the U.S.

To date there is 60,000 metric tons of commercial used fuel, 13,000 tons of government held used fuel and defense-related high level radioactive waste, and 2000 metric tons produced by the 104 nuclear power plants currently in operation in the U.S.[79] With the primary storage being on-site a permanent storage facility needs to be found, or the policy for reprocessing/recycling needs to be revisited so that future Uranium does not need to be imported. "Owners and operators of U.S. civilian power reactors purchase the equivalent of 53 million pounds [24,000 metric tons] of uranium during 2008."[80]

In 1987 congress amended the Nuclear Waste Policy Act such that the only site for the Department of Energy to conduct a characterization of the geology of Yucca Mountain, Nevada. The site seemed promising as a deep geological repository for high level nuclear waste, as it contains volcanic ash material that is believed to be suitable to store radioactive waste for hundreds of thousands of years required to make radiation levels of the waste projected to be disposed there safe. High opposition in the state of Nevada made any plans to place a facility in the mountains very difficult and as of 2009 the site was deemed unacceptable by the Obama administration,[81] funding was cut to the project in the 2010 budget.

The other nuclear waste management site currently located in the U.S. is the Waste Isolation Pilot Plant. It has been in operation since 1999, and is licensed to dispose of transuranic waste and mixed waste generated from the Department of Defense. Transuranic waste consists of radioactive waste with chemical elements that have atomic numbers past Uranium (92). Waste is placed 2150 feet below the surface of the earth in a 3000 foot thick salt formation which has been stable for 250 million years. The site is located in the Salado and Castile Formations 26 miles east of Carlsbad, New Mexico in Eddy County. The site has a permit to dispose of waste for 10,000 years that has been left from research and the production of nuclear weapons.[82]

As with crude oil, nuclear power is a limited resource with Uranium as the basis of the energy production as opposed to oil. In contrast, Uranium is semi-renewable in that once the Uranium rods have been depleted by the fission they can then be re-enriched or used in a breeder reactor which produces more nuclear fuel than it consumes. As mentioned above the U.S. does not partake in the reusing of nuclear waste due to the concerns for creation of nuclear weapons observed in other countries.

The main issue with nuclear power is the nuclear waste, with which there is currently no offsite permanent disposal in the U.S. Onsite storage is costly to the companies that own individual power plants, and only adds to the costs of ownership. Primary cost for construction of a nuclear power plant is in allocation, development, and community objection to building a new site. Once the power plant is running, maintenance cost and fuel cost is relatively low in comparison.

Compared to oil, coal, and natural gas, nuclear power is all used for electricity. The power plants then cost the consumer roughly 2.03 cents per kilowatt-hour of power.[83] With this low cost for power to the consumer, the main concern then becomes the impact of the radioactive material on the environment and those workers that have daily contact with the materials around the power plant. If the U.S. changed its current policy of not reprocessing nuclear waste, nuclear power could be considered an alternative means to create electricity that has less impact on the environment than coal, oil, or natural gas power plants.

2.2 – Summary of Current Energy Supply and Usage

From the previous overview sections regarding crude oil (petroleum), natural gas, coal, and nuclear power; a greater understanding of these technologies and how they are being utilized to produce the energy which powers the nation’s large demand is hoped to have been passed on to the reader. In this section of the report, a brief overview of the current usage of those technologies will be combined for an easily accessible guide to the current energy production, consumption, and resource management.

U.S. Primary Energy Flow by Source and Sector, 2009

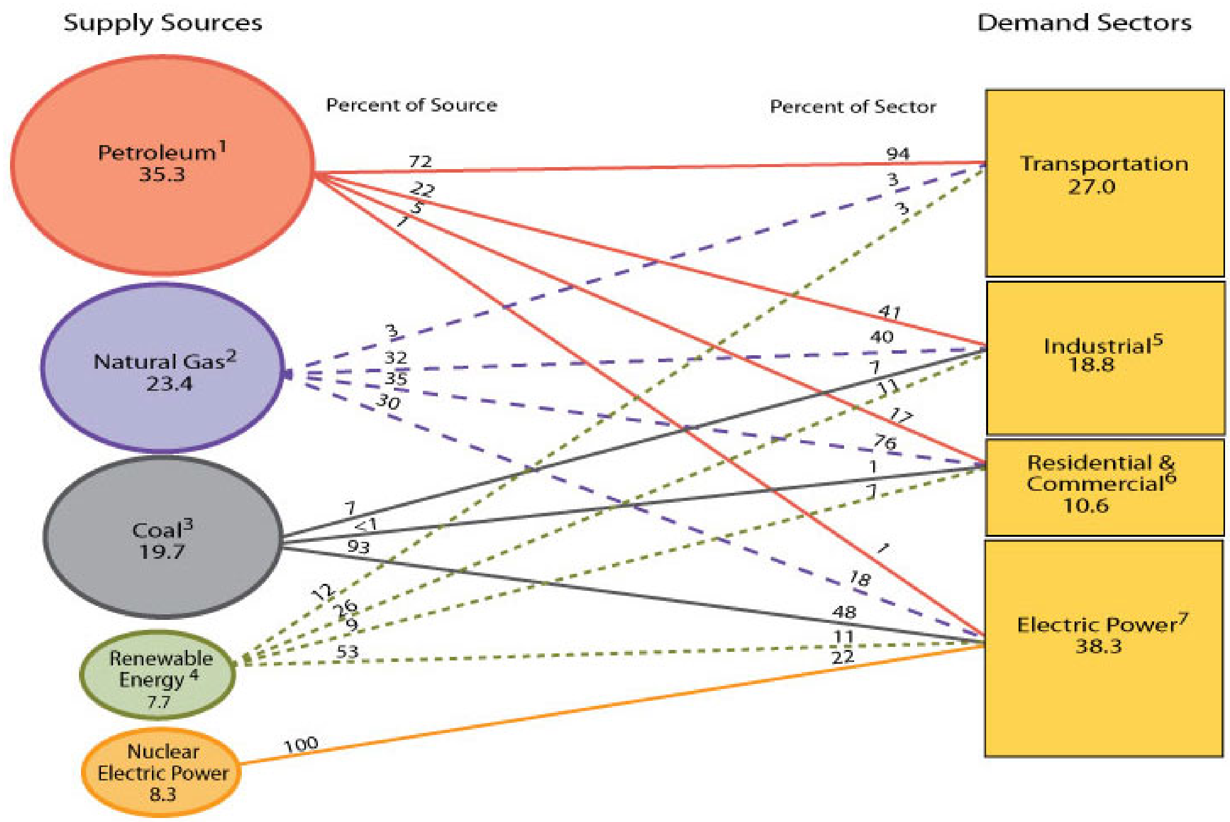
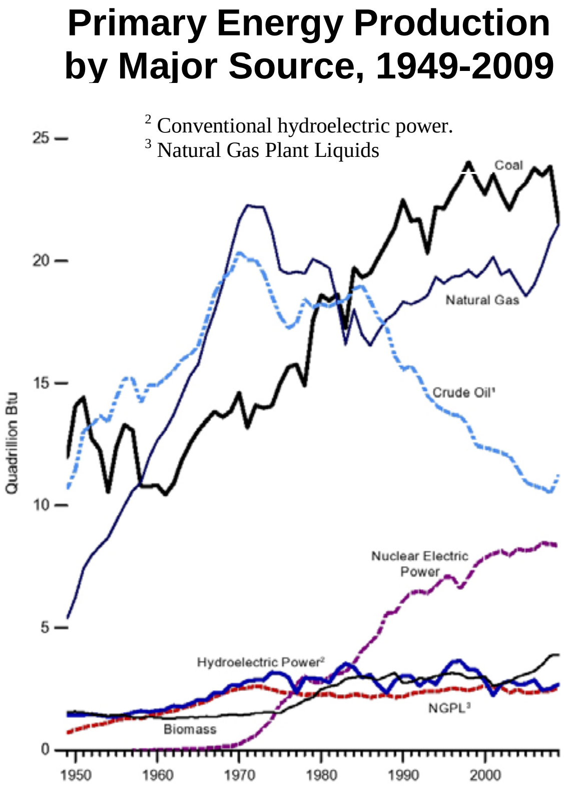


Figure 18 - U.S. Primary Energy Flow (2009)

Graphical representation from www.eia.doe.gov[84]

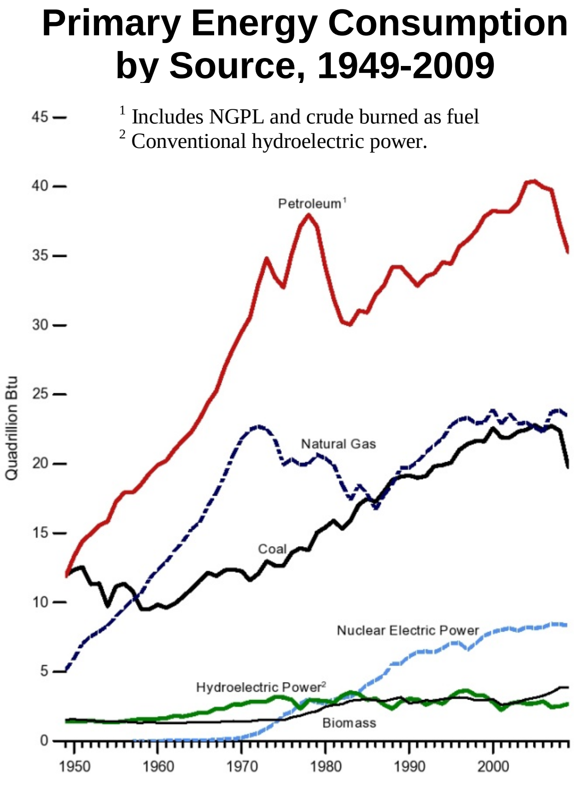
As there is a lot of information contained within this single flow chart, it is important to identify key statistics it provides the reader. It quickly becomes evident that the largest slice of the energy supply and demand pie has been taken by the fossil fuel industry and subsequent support infrastructures. The transportation sector can be seen to have a 94% use of petroleum and petroleum products created from domestic and foreign crude oil. 81% of the industrial sector is split between petroleum and natural gas resources, in combination the industrial and transportation uses of petroleum accounts for 94% being used for the transportation of goods and people. 76% of the residential and commercial sectors demand is met by natural gas usage which is accounted for by the large demand for heating and cooling. And Coal provides 48% of the grid electrical power production needs which accounts for nearly all of the coal energy production (93%). As has been previously mentioned nuclear power is strictly used for electrical power generation to power the needs of the public attached to the electrical grid.

The statistics provided by the U.S. Energy Information Administration on a yearly and quarterly basis displays that the government takes interest in the status of energy supply and demand and provides specific data to the general public. Data provided by the EIA in this section dates back to the late 1940s, and although the values are estimated, they provide a good gauge on the various trends that will be identified.



Primary Energy Production by Major Source, 1949-2009

[2] Conventional hydroelectric power.
[3] Natural Gas Plant Liquids



Primary Energy Consumption by Source, 1949-2009

[1] Includes NGPL and crude burned as fuel
[2] Conventional hydroelectric power.

Figure 19 – Primary Energy Production

Figure 20 – Primary Energy Consumption

Graphical representations from www.eia.doe.gov[85] [86]

Within the last four decades a general trend of increased consumption for producing energy is matched with a general decrease in crude oil production accompanied by an increase in importation of crude oil from abroad. The sudden increase of crude oil and natural gas production in the 1970s region can be accounted for by the rapid expansion into Alaska as well as technological advances which accompanied the economic growth of the period. The increase in crude oil production of the mid-1970s to 1980s is accompanied by an increase in consumption and price associated with the Arab oil embargo of the United States from 1973-74. Additionally the Iranian political upheaval and subsequent fear of Islamic revolution spreading during the late 1970s kept oil prices high until the mid-1980s as well as increasing domestic oil production to match consumption demands.[87]

The sudden drop in petroleum consumption accompanied by coal production and consumption can be linked with the recession starting in fall 2007. Additionally energy costs saw a steep decline due to the economic instabilities associated with the recession. An increase in unemployment as well as a reshaping of the electrical grid power production can explain these sudden drops. Additionally the increase of natural gas from shale gas reserves, previously discussed, helped to reform the production of grid power. Expectations of a Congressional cap on greenhouse gas emissions, the lowest natural gas wellhead prices in seven years, and expansions of the natural gas pipelines capacity allowed for southeastern states to reduce coal use by 11.6% and increase natural gas use by 4.3% for grid power production.[88] A closer look at the crude oil and natural gas prices during the same time frame can better demonstrate these trends.

U.S. Crude Oil Prices 1949-2009

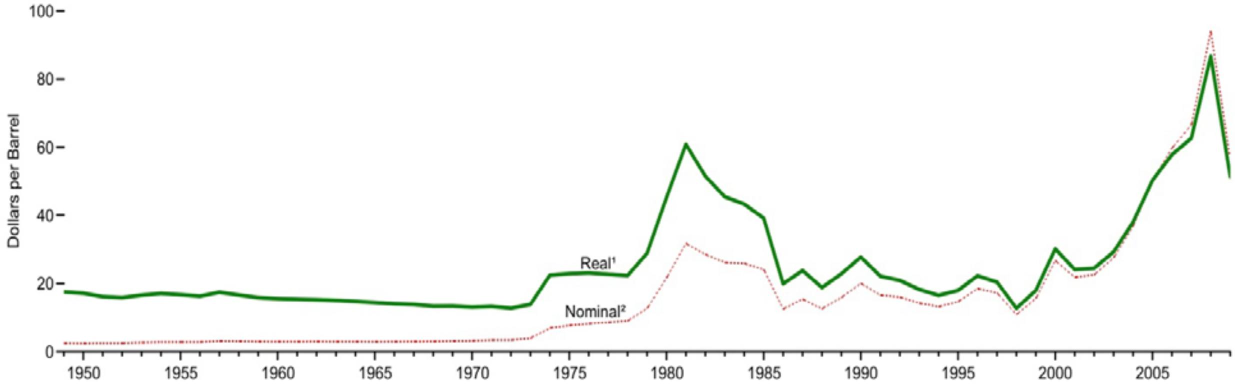


Figure 21 - Crude Oil Prices[89]

U.S Natural Gas Prices 1949-2009

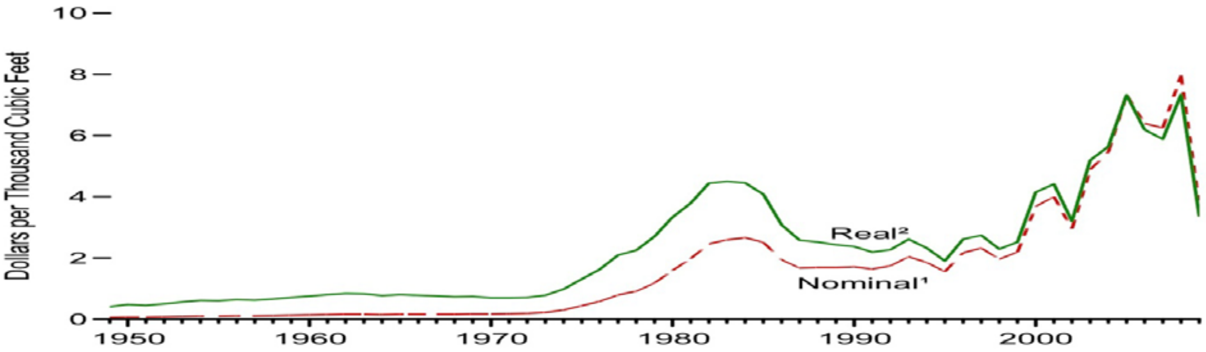


Figure 22 - Natural Gas Prices[90]

The information provided in this section has been general percentages and trends, but what does it all translate to when we look at how the United States produces and consumes energy. The United States relies upon fossil fuels, which are limited in supply, environmentally damaging, and unstable in economic value. Renewable energy accounts for 7.7 quadrillion Btu (8%) of the 94.5 quadrillion Btu worth of energy consumed by the United States in 2009. [91] Out of that 78.4 quadrillion Btu (83%) are fossil fuel and 8.3 quadrillion Btu (9%) is used from Nuclear sources. At the current rate of energy consumption fossil fuels will last somewhere between 50 to 70 years for natural gas[92] and oil and around 90 years for coal.[93] Given that the U.S. is currently consuming roughly 7.6 billion barrels of oil per year[94] and has an estimated 30 billion barrels[95] in reserve. U.S. natural gas reserves total 238 trillion cubic feet[96] and has a consumption rate of 24 trillion cubic feet per year[97]. Taking into account production rates and importation of goods pushes these values from around ten years to closer to fifty to sixty years given current consumption rates. It is therefore necessary to look for alternative resources and sources of energy to accommodate the United States' energy demands.

2.3 - Alternative Energy Sources

Alternative energy resources such as bio-fuels, biomass, hydropower, wind, geothermal, and solar are not only renewable resources but more environmentally friendly. Aside from biomass, all other forms of renewable energy mentioned do not directly emit greenhouse gases. Changing from fossil fuels to renewable energy resources could not only improve our standards of living, but also provide future generations with a cleaner planet. Problems of infrastructure and commercial backing become involved however, making the process of changing our resource management difficult if not impossible.

An alternative to changing to a renewable energy resource would be an increase in efficiency. Even though automobiles use about 60% of the gasoline they did in 1972, the average fuel economy for passenger vehicles has remain relatively flat due to the growth and popularity of low-fuel-economy trucks, vans, and SUVs.[98] With the transportation sector using a large amount of crude oil-based petroleum (84%) there is the potential to reduce demand easily. “A recent analysis indicates that the fuel economy of a typical automobile could be enhanced by 60 percent by increasing engine and transmission efficiency and reducing vehicle mass by about 15 percent.”[99] With the introduction of hybrid electric/gasoline vehicles the automotive industry is making an effort, however there is a distinct lack of immediate change. This is due in part to the collaboration between the oil and automotive industries. It is also due to higher initial production costs on new technology, and the high cost of research to improve design. These new technologies and advancements can only become available with reduced component costs and higher demand.

In recent years there has been a big push for the United States to start using more environmentally friendly and efficient forms of energy. The biggest reason is due to the fact that over 75% of the United States' non-nuclear energy usage is carbon based, which produces many harmful emissions as byproducts. Renewable energy sources (solar, geothermal, biomass and biofuels, wind, and hydropower) generate only 8% of the total energy consumption in the United States. The United States' heavy reliance on fossil fuels (especially imports) is one of the many causes of high electricity costs. Renewable energy sources are domestic and environmentally friendly, which are only two of the many benefits they possess.

2.3.1 - Wind Power

Every homeowner wants to know how they can trim their electricity bill every year. Some turn off the lights more often, some install solar panels on the roof, while others are still unsure of what to do. Residential wind turbines are another way of generating electricity from a free source that is all around us: the wind.

"Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetation."[100] Wind turbines work the opposite of a fan. Instead of using electricity to make wind, they use wind to make electricity by turning the kinetic energy from the wind into mechanical power, and then convert it into usable electricity for a home. Residential wind turbines do not completely replace home utilities, but, like solar panels, they contribute to the total electricity production.

The cost to the consumer is one of the most important questions homeowners always ask. Just like solar panels, wind turbines are not cheap to install. Both solar panels and wind turbines most likely will cost between $5,000 and $20,000 (the more the consumer pays, the more energy they will get out of the turbine or panel). Turbines with greater power producing capacity will cost more than turbines with lower power producing capacity.

Wind turbines are only greatly effective in areas with annual wind speeds averaging 7mph or more. The formula for calculating the power generated by wind turbines is:

Power = 0.5 x Swept Area x Air Density x Velocity[101]

Power(watts), Sweep area (m^2), Air density (kg/m^3), Velocity (m/s) [102]

Every time the air speed doubles, the power generated goes up by a factor of 8. Each wind turbine has a rating that gives the average power generated at a certain wind speed. The reason that that rating is less than that of the calculated power is because of inefficiencies and Betz Limit, which states that "Wind turbines extract energy by slowing down the wind. For a wind turbine to be 100% efficient it would need to stop 100% of the wind - but then the rotor would have to be a solid disk and it would not turn and no kinetic energy would be converted. On the other extreme, if you had a wind turbine with just one rotor blade, most of the wind passing through the area swept by the turbine blade would miss the blade completely and so the kinetic energy would be kept by the wind."[103] You can only convert less than 59% of the kinetic energy of the wind into mechanical power.

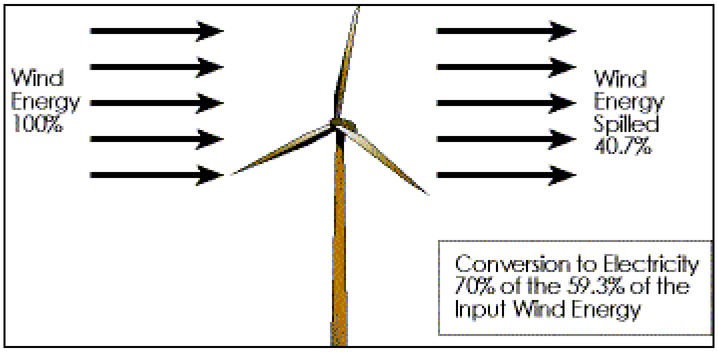


Figure 23 – Wind Energy Conversion[104]

Another factor that goes into wind turbines is the noise that is created mainly from the wind passing through the blades. “Aerodynamic noise is also a function of the tip speed of the blades. Tip speed ratio (TSR) is a term that refers to the speed of the tip of a wind generator blade in relation to wind speed. For example, a wind system that operates with a TSR of 10 means that when the wind speed is 25 mph, the tips of the blades are moving at 250 mph. Increasing tip speed results in more noise. Slow-speed wind generators operating with 7 TSRs of about seven emit noise that is barely discernible from ambient noise.”[105] While the turbines do make noise, there is also a large amount of background noise that also occurs. Background noise includes traffic, lawn mowers, construction work, the wind blowing against the trees, bushes, etc. While the distinct sound of a wind turbine can be distinguished (it does not sound like traffic or construction work), it does not overpower the existing background noise. A study done in 1997 by the Bergy Windpower Company concluded that “a sound test carried out on his company’s 10 kW BWC Excel wind system. At a distance of 300 feet and in 25 mph winds, the BWC Excel generated sound with a 54 dB(A) to 55 dB(A) rating, making the wind generator barely audible over the 52.5 dB(A) rating of the surrounding environment's background noise. At about 500 feet, the BWC Excel sound rating was 53 dB(A), making it just another part of the background sound.”[106] While there is sound generated by these turbines, it gets blended in with the sounds of the environment around it.

Even with these shortcomings wind turbines still provide ample electricity in areas with high annual wind speeds. On average wind turbines ill save from 25% up to 90% on a residential electricity bill (depending on turbine used and wind speeds in the area). The turbines will pay for themselves within 10-20 years (again depending on the initial cost of the turbine).

Also, “over its life, a small residential wind turbine can offset approximately 1.2 tons of air pollutants and 200 tons of greenhouse gas[es].”[107]

Residential wind turbines are designed to power a single home, but to power homes on a national level the turbines need to be much larger and grouped together. These groupings are called wind farms. Currently (as of 2009), there are over 75 large wind farms in the continental United States, which together have an installed capacity of about 35,000 megawatts (35GW) of power. As a comparison, coal powered plants account for about half of the United States energy production and, in 2006, had a total capacity of about 335.8 GW of power (actual generated power around 227.1 GW, which translates to 1.991 trillion kilowatt-hours per year.[108] With wind power only accounting for about 2% of the total electricity generated in the United States, in 2008 it was enough to power about 9 million homes and reduce the carbon emissions by about 2.5% (around 57 million tons of carbon).

Roscoe Wind Farm in Texas is the largest wind farm in the United States with 627 wind turbines and covers almost 400 square kilometers of land (100,000 acres).This wind farm has a total installed capacity of 781.5 MW and provides enough electricity to power over 250,000 homes. As a comparison, the largest solar energy facility in the United States is the Solar Energy Generating Systems in the Mojave Desert. The 9 plants have a total installed capacity of 354 MW and covers over 6.5 square kilometers (1,600 acres) of land. To make the capacities of each plant roughly equal by doubling the size of the Solar Energy Generating Systems, the Roscoe Wind Farm takes up around 31.2 times more area.[109] [110]

Even with this shortcoming of energy density, the United States has been expanding wind power exponentially (see chart below) and, according to a recent report by the U.S. Department of Energy, provided a scenario where 20% of the total electricity used by 2030 would be through wind turbines. By 2030, some benefits would include lowering the national coal consumption by 12%, reducing CO_2 emissions by 825 million metric tons, and also reducing water consumption by 17% (water is used in the electric grid to cool fossil-fuel and nuclear based plants). With these benefits and more, many challenges also arise, including:

- “Investment in the nation's transmission system is needed so that the electricity generated is delivered to urban centers that need the increases supply;

- Continued reduction in wind capital cost and improvement in turbine performance through technology advancement and improved manufacturing capabilities is needed;
- Addressing potential concerns about local sitting, wildlife, and environmental issues within the context of generating electricity is needed."[111]

Table 3 - **Wind Power Capacity from 1999-2010**

Year	U.S. MW	Change	% Change
2010	40,180	5,317	15.25%
2009	34,863	9,453	37.20%
2008	25,410	8,503	50.29%
2007	16,907	5,332	46.06%
2006	11,575	2,428	26.54%
2005	9,147	2,424	36.06%
2004	6,723	373	5.87%
2003	6,350	1,663	35.48%
2002	4,687	455	10.75%
2001	4,232	1,693	66.68%
2000	2,539	67	2.71%
1999	2,472	N/A	N/A

Data from the Office of Energy Efficiency and Renewable Energy.[112]

Energy created from wind power produces no pollutants nor does it use any fuel. The energy used in creating the turbines and transporting them is even paid back within months of completion. The land required for each turbine varies depending on the size of the turbine. Roscoe Wind Farm takes up 0.25 square miles per wind turbine, while the Horse Hollow Wind Energy Center (installed capacity of 735.5 MW with 421 turbines) only requires 0.17 square miles per wind turbine. Fortunately, many large wind farms are located on top of existing farms which allows farmers to grow crops almost right up to the base of the turbine themselves, ultimately not wasting any ground space.

One of the biggest disadvantages of wind farms is noise levels. There is proof that wind farms do produce a distinct “whooshing” sound, but some people are bothered by it while others are not. Wind farms are most often placed where wind speeds are high, thus the wind speed usually blends in with the noise of the turbines themselves. The drawback that comes with this is that the noise isn’t necessarily loud (typically around 40dB at 350 meters away), it’s the low frequency repetitiveness that it often never ending. This poses an annoyance to many people, and is usually the cause of many lawsuits and studies conducted. This low frequency is not always head by all people and cause people to react differently. While it is not considered a disease, it can cause symptoms like headaches, insomnia, anxiety and dizziness. All wind turbine farms are now required to comply with local sound ordinances prior to completion as well as a comparison to the existing environmental noise.[113]

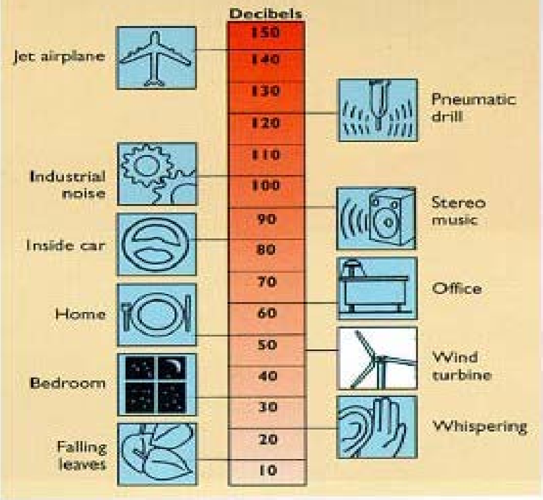


Figure 24 - Typical decibel reading of common sounds[114]

The total energy generated by wind in 2009 was roughly 70,760 GWh. [115] If wind power accounts for roughly 2% of the total energy generated in the United States, that means the total energy generated in 2009 was about 3,538 TWh. If we take the total amount of Greenhouse Gas emissions in the United states to be about 7,052.6 million metric tons in 2008[116] and take 35% of that away (transportation emissions), we are left with about 4,584.2 million metric tons of greenhouse gases produced by the electricity grid. Also, if we say that roughly 5% of the renewable energy sources do not produce emissions that will leave us with 3361.1 TWh that is generated with non-renewable sources. This means that for every terawatt hour of electricity generated, it produces roughly 733 thousand metric tons of greenhouse gases. If we increased the amount of wind power energy so that the total of renewable energy sources was 10% of the total that would mean for every terawatt hour of electricity generated it would produce roughly 694 thousand metric tons of greenhouse gases. That 5% increase of renewable energy sources decreased the emissions by about 6%.

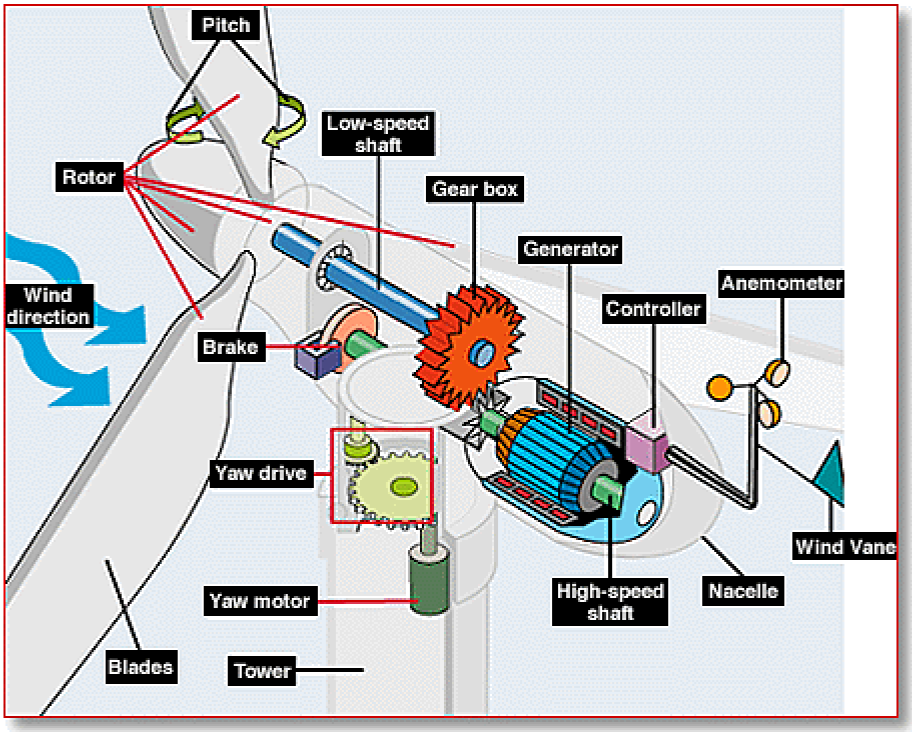


Figure 25 - Wind Turbine Components[117]

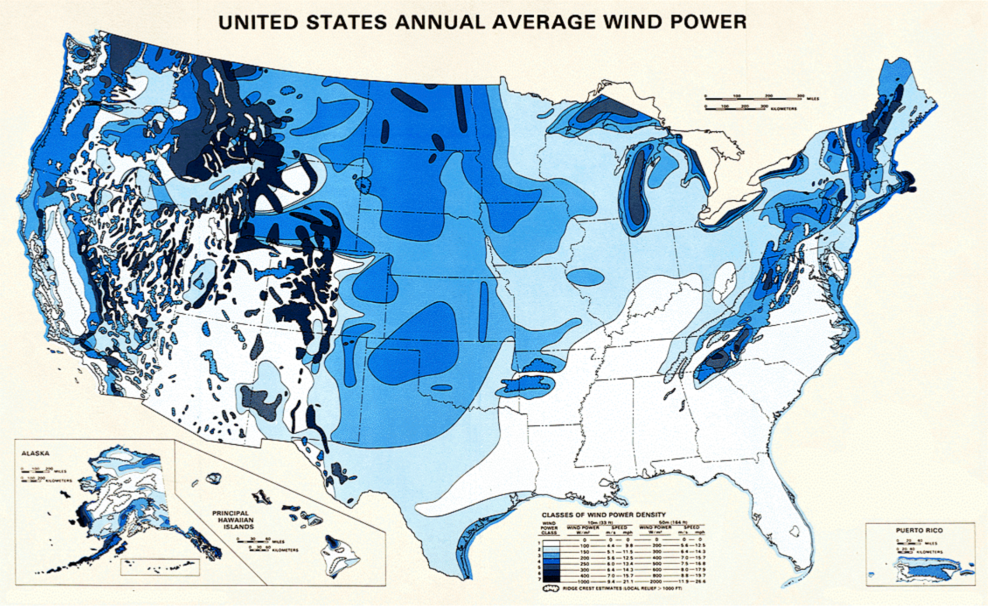


Figure 26 - Topographical Wind Power (Annual Average)[118]

Wind Resources and Power

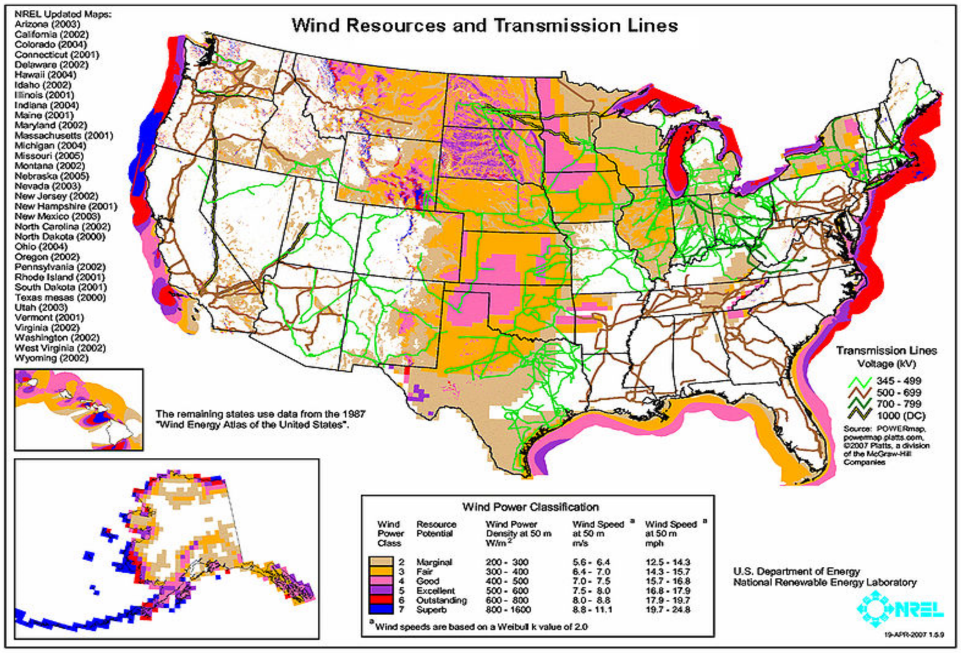


Figure 27 - Wind Resources and Transmission Lines

Image from rredc.nrel.gov[119]

2.3.2 - Tidal-Flow Energy

Harnessing the vast amounts of energy observed in the natural movement of water has been at the center of energy generation since the beginning. Starting with water wheels and eventually progressing to dams of all sizes, most of the focus of hydropower and traditional hydro-electric generation has been on the use of rivers as a source of energy. While this is a great source of energy, we have learned of many of the negative effects associated with creating these dams. Some of the negative effects on local ecosystems have been mitigated over the years by creating complimentary technologies which allow wildlife to navigate around or over these dams. While this addresses one problem it has yet to address the next environmental issue of blocking what was naturally a river. By blocking rivers, standing reservoirs of water are created which can drastically alter the local ecosystem. This must be taken into account when constructing new dams. However, this leads to the final and probably most limiting factor. In the United States, we have essentially reached a point where there are no more viable locations for new hydroelectric dams of substantial size.

Despite having utilized most of our nation's rivers already, there still exists a hugely untapped resource in the hydropower sector. The oceans are the largest and most powerful bodies of water we have. For the most part though their power has not been harnessed or even thought of as useful. However, it has been recognized that certain behaviors of the ocean actually can be harnessed using relatively simple technologies. One of these behaviors that create a great opportunity for energy generation is the continual motion of tides interacting with every coastline. Additionally, waves and the vertical displacement they create can also be harnessed using mostly mechanical solutions.

The first 'new' hydro-electric technology under examination is "Tidal Power". This means of energy generation has actually been studied for quite a few decades in one form or another. The tides themselves are part of a phenomenon that occurs world-wide as a result of the gravitational interaction between the Earth and the Moon. More specifically, as the Earth rotates and the moon revolves around the Earth, the gravity of the Moon acts more strongly on the closest side of the Earth than it does on the other. This force causes the oceans to rise and fall as the Moon passes over them as well as circulates some of the water back and forth. Tidal power works by harnessing either the kinetic energy of water rushing toward or away from coastlines, or the vertical potential energy difference created by the rising or falling tides.

There are several methods of capturing tidal energy. The first and most conventional approach is to use familiar dam-technology to create a "Tidal Barrage". This consists of damming off an area of coastline such as a bay, the mouth of a river, or some other form of geographical indentation in the coast. These dams operate in much the same way traditional river dams do. As the tide rises on one side of the dam, the difference in height causes water to flow through generators in the dam structure thereby producing electricity and balancing out the water on both sides. The only major difference from fiver dams lies in the fact that once the tide falls; the dam operates in the reverse direction to let water out into the ocean again. An optimal tidal power station like this would harness both the inflowing and out flowing water.

Figure 28 - Tidal Barrage Diagram[120]

As with damming a river, the costs associated with creating these tidal barrages are quite large. The technology involved is very simple and already in widespread use; it plays only a small role in the cost of the dam. The majority of costs come from the raw materials needed and civil engineering challenges associated with building something this big in a marine environment. The true cost of a project can vary depending on what pre-existing geography is available on-site, but there are some real-world examples of completed projects. Currently, the largest tidal barrage type power plant is the Rance Tidal Power Station in Brittany, France. The main barrage is about 750 meters long, with a peak output of 240 MW. Its average annual output is about 600 GWh and it has been in operation since 1967.[121] This example shows that the method itself is feasible, but in the interest of analyzing cost, a more modern plant needs to be examined. One such plant is the Incheon Tidal Power Station currently under construction in

South Korea. This plant will be the new largest tidal power facility once completed. It has an expected peak power output of over 1300 MW and an annual capacity of 2.41 TWh. The financial cost of the Incheon station in US dollars is currently about $3.4 billion.[122]

The capital cost for a Tidal Barrage power station is therefore about $2,600/kW installed. Because of the similarity in technology involved it is safe to assume tidal power stations like this also have a similar operational cost to that of traditional hydroelectric dams. This puts the O&M cost at about 2% of the original investment cost, or just under 3 cents/kWh.[123] Because dams can theoretically be maintained forever at this rate, it becomes necessary to arbitrarily choose either a payback date or have it determined by the sale price of the energy. So, assuming the energy is sold at the current US average retail price of 10.5 cents/kWh, the plant would fully pay for itself after 16 years in operation.[124]

Figure 29 - Rance Tidal Power Station (240 MW)[125]

Aside from ecological considerations there are also some challenges and opportunities presented in regard to the human impacts of these dams. Like the Rance power station, many tidal energy plants will need to accommodate boat crossings. This can be accomplished by adding a lock system which can bring boats to the other side of the dam. One of the opportunities that are presented is that the dam can also serve as a bridge for regular road or rail traffic. From a financial standpoint, and with the aid of tolls, the transportation across the dam can be used as an additional source of income for the power station.[126]

A second method of directly harnessing tidal energy also exists. This other method is very comparable in operation to how wind turbines work. Basically, instead of building a dam which channels the water through a small number of high-power turbines, the tidal energy is captured by a larger number of small power stations. These power stations usually consist of a structural column with one or more open turbines with long blades. Because the system is open and not confined like with dams, these turbines individually produce much less power. However the advantage is that they are substantially less costly to produce and are much less of an obstruction than a full sized dam. Many of these power stations can be placed together to form a farm, just like with wind turbines. In addition to tide movement, this technology is also ideal for harnessing underwater currents in general. For deeper-water applications the column section is usually removed from the design of the units, leaving only the turbine with some sort of housing.

As with the barrage-type tidal power stations, these compact tidal power units have a low maintenance cost and a higher capital cost. Investment cost in the experimentation phase is slightly higher, but commercial-scale investment cost is estimated to be $2,300/kW installed.[129] There is no fuel involved in operation because the turbines are harnessing tidal currents, but because these turbines are underwater, they need to be regularly maintained and cleared of any debris that might get caught in them. This puts the O&M cost somewhere around 8 cents/kWh for these types of systems.[130] Some of the things that could damage the system include wildlife such as fish or plant species such as weeds which can wrap around the moving parts of the turbine. With regard to the environment, these smaller tidal power units spin very slowly and usually don't have a very complex gearbox so there is basically a negligible physical or auditory impact on marine life nearby. [131]

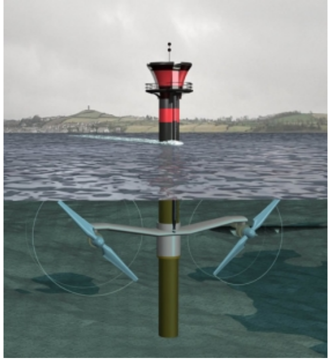


Figure 30 - Shallow Tidal Power Unit[127]

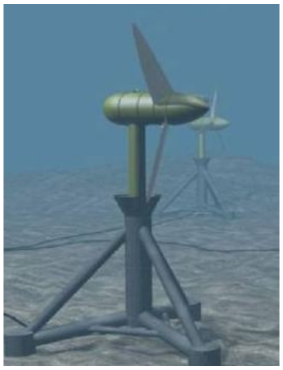


Figure 31 - Underwater Turbine[128]

The various tidal power technologies represent a clear opportunity to harness sizable amounts of predictable energy. The predictability of tidal flow is something that really gives this type of power generation a lot of advantage over other renewables. Solar and wind power for example can sometimes be unreliable if it is not windy or if there is a dense cloud cover. With both forms of tidal power, the payback time for the investment cost is fairly reasonable. And, because there are two very structurally different approaches tidal power is very scalable and can be fitted to either large or small need.

In addition to tidal power, Wave Power is another untapped hydro-electric resource which is widely available. Wave energy is an irregular and oscillating low-frequency energy source that can be converted to a 60-Hertz frequency and can then be added to the electric utility grid. The energy in waves comes from the movement of the ocean and the changing heights and speed of the swells. Kinetic energy, the energy of motion, in waves is tremendous. An average 4-foot, 10-second wave striking a coast puts out more than 35,000 horsepower per mile of coast. [132]

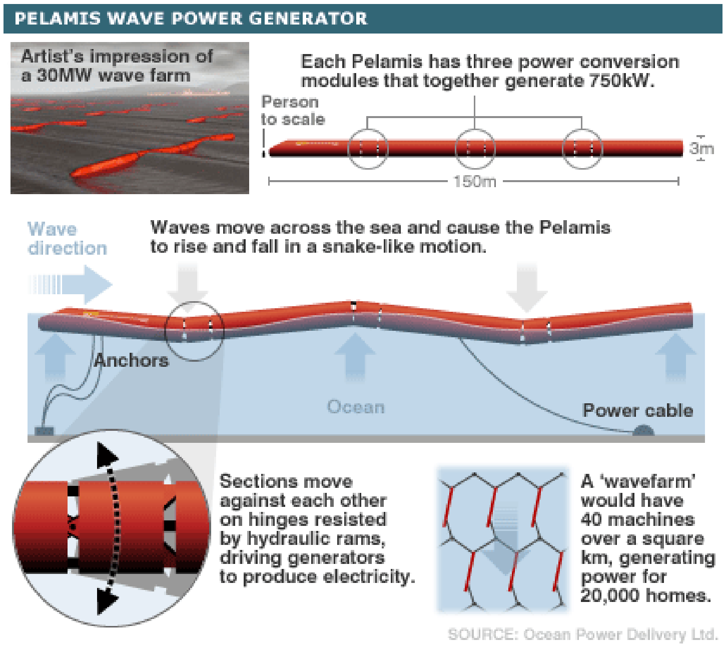
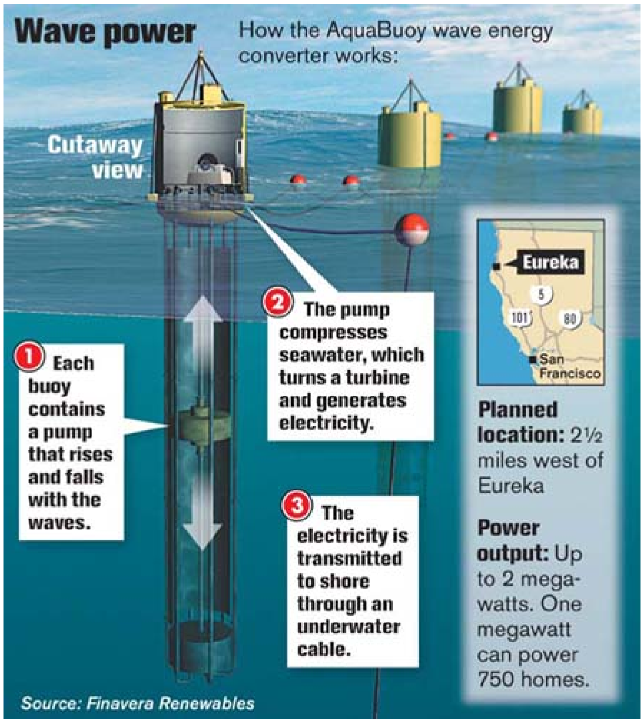


Figure 32 - Pelamis Wave-Power Operational Diagram[133]

To harness wave energy, there are a few basic methods. The first method, as depicted in the above figure, involves capturing the mechanical work done to a snake-like mechanism floating on top of waves. This is accomplished with hydraulic rams connected to generators linking the various sections of the device. One Company which currently produces these types of machines is Pelamis Wave Power. Each of their units is rated at 750kW, and currently has a typical capital cost of about $2000/kW installed.[134] The O&M cost for such a device is in the range of 5 cents/kWh.[135]

A second approach to generating wave power is through the use of underwater pressure differences created by moving waves. This is accomplished with an array of buoyant devices tethered to pumping mechanisms on the sea-floor. These pumping mechanisms are driven by the up and down motion or constant swaying of the device and force water into a pipeline. This pressurized water pipeline is connected to a facility on the shoreline which takes that pressurized water and uses it to operate a water turbine. In addition to electrical energy, this type of power system has the capacity to desalinate the incoming seawater for use as freshwater and salt byproduct.



Source: Finavera Renewables

Figure 33 - Submerged Wave Power & Desalination Plant[136]

Wave energy, despite being a newer renewable energy source, contains roughly one thousand times the kinetic energy of wind. This allows for much smaller and less conspicuous devices to produce the same amount of power in a fraction of the space. In all, wave energy is an excellent, high-density renewable energy source that is able to generate electricity much more reliably than solar or wind. The only drawback to this technology at the moment is that it is a much newer technology and so does not have very much data to analyze in terms of operational costs and potential issues. These will hopefully be resolved as further research is done into this type of power and economies of scale drive down the capital costs of ever larger 'wave farms'. [137]

Table 4 - Hydroelectric Power Comparison[138]

	Capital Cost	Energy Cost	Advantage	Disadvantage
Tidal Barrage	$2600 / kW	3 cents /kWh	Low O&M cost & high power density	High capital cost & environmental impact
Tidal Flow	$2300 / kW	8 cents /kWh	Scalable, low impact on water traffic	Higher operating costs, hard to maintain
Wave Power	$2000 /kW	5 cents /kWh	Scalable, low cost, Easy to maintain	Potential hazard to water traffic / shipping.

2.3.3 Photovoltaic Solar Power (PV)

Solar panels come in two forms, either a photovoltaic module or a solar thermal collector. This section will focus on photovoltaic panels which are used for home energy use. Thermal panels will be considered in a later section. Solar panels convert light into electrical energy using a solar cell, the efficiency of which ranges from 5% to 18% in commercial production. Infrared photovoltaic cells can be used can be used to collect light at night.[139] The solar cells that make up the solar panel are solid state devices, devices comprised of only solid materials to create the electronic portions of the apparatus.

The solar cells can be compromised of various photovoltaic materials, the most common of which are made out of monocrystalline silicon (c-Si, as a group crystalline silicon) in bulk and cut into wafers, circular discs between 180 and 240 micrometers thick.[140] However, since solar cells a less demanding than microelectronics on structural imperfections the c-Si is often replaced with polycrystalline or multicystalline silicon which is cheaper to produce.[141]

The photovoltaic effect that allows for electrical energy to be produced from light is a process in which light hits the semiconducting material in the solar cell and knocks electrons from the atoms, which allows them to flow through the material in one direction due to the composition. The flow of electrons in one direction creates a direct current form of electricity. For home use, a solar panel, charge regulator, battery and inverter are required to provide electricity that is not tied into the grid power, for grid power you then need a phase shift to match the incoming electricity. A third option is a multi-inverter that connects to both a battery bank and the grid power, it is a smart system that identifies when there is solar available, battery power available, and if neither are draws from the grid. This is obviously expensive.

Solar electricity costs about $10 to $12 per watt installed without government incentives.[142] Often if your solar system is connected to the grid power you can receive government financing and tax rebates[143] ". Grid inter-tied solar energy systems make up 70% of the world's solar voltaic market.[144] Depending on the desired load of the solar system, "a rough range for upfront costs, including installation, for solar panels, inverter box, wiring[, and batteries]… is approximately $30-40,000 for a single family house, if you are looking to entire replace grid based-electricity with solar energy."[145] The efficiency of which can be improved with solar tracking apparatuses, which then increase the cost further.

Energy loss is the primary concern with all energy resources. Solar power is no different, there is a great deal of energy loss from the start, at approximately 20% average efficiency solar panel technology is no better than fossil fuel engines. After collection efficiency, a standard solar panel must then be inverted, further reducing the amount of electricity gained. It is then placed into a battery, which stores the energy and returns a portion of the energy placed into the capacitor, as batteries have chemical reactions that occur there is an energy loss in the form of heat and gas. The energy then passes through the wiring of your house, which has some resistance value; by the time it reaches its destination a great deal of energy has been lost. Replacement/improvement of any of the parts of this system can improve energy cost reduction, and further green energy production.

The replacement of deep-cycle, or sealed deep-cycle batteries with fuel cells can increase efficiency with similar dangers. Deep-cycle batteries require addition of water, potential acid handling, and ventilation of hydrogen/oxygen, where fuel cells require storage of hydrogen. Both technologies are potentially dangerous and hazardous to the consumer as a means of energy storage.

Inventive Research has patented a way to generate AC power directly from a solar panel. An ingenious design that has never before been accomplished takes the currently used solar cells and places then in such a way that they create a sinusoidal electrical current (AC). This is accomplished through the mechanical manipulation of alternate banks of cells such that the electrons pass in opposite directions, reducing the total energy collected at a time, but increasing the total usable energy. The main energy loss in a conventional solar panel is in conversion to AC from DC.

Inventive Research has also introduced a simple way to phase shift the current, as the collection method is mechanically regulated the speed of the spinning apparatus can be changed, which changes the phase eliminating the need for a phase shifter if connecting to the grid.

Figure 34 – Inventive Research Alternating Current Solar Panel

Image from acsolargenerator.com[146]

Solar power is certainly environmentally friendly, as it has no emissions. However, the current technology that is used is expensive, inefficient and takes a lot of consideration before installing panels. The high up-front cost and efficiency of the panels is the main concern when considering the use of solar power in a country wide energy policy. There are grants and incentives that can reduce this cost considerably, however the energy loss from conversion to AC power from DC, phase differentials, and other processes that are needed to result in usable energy cause concern.

With this new technology of integrated mechanical phase lag, along with no need to convert to AC power from DC leaves little to be considered when questioning if solar power should be in a nationwide energy policy. The concern then becomes that of the individual willingness to spend a certain amount of money on these panels, as depending on the needs of the consumer, these packages can be individualized for both cost and energy use. The average American household would require a current cost of $20,000 system to use only solar power for their electrical needs. That is not in the budget of a majority of the residents. If there were more incentives, or lower production/installation costs then this technology would be certainly viable for replacement or supplement of grid power.

There is only one large capacity solar photovoltaic farm in use in the U.S. It is the DeSoto Next Generation Solar Energy Center located in Arcadia, DeSoto County, Florida. The plant, constructed in under a year, from fourth quarter 2008 to October 2009, is on a 180 acre plot of land and has a 25 MW solar capacity.[147] It produces 42,000 MWh annually, which provides 3,000 homes with electricity, roughly 20% of DeSoto County. The price to the consumer however is still the grid power cost, between 0.13 and 0.15 $/kWh and between 0.06 and 0.08 $/kWh to businesses.[148]

There are plans for additional facilities in the U.S. with the earliest being operational in 2011. The Copper Mountain Solar is the earliest large scale solar photovoltaic farm scheduled to be operational at this time. The facility will total 58-60 MW of solar capacity when completed. The project involves an expansion of the 10 MW facilities already in place in a location El Dorado, near Boulder City, Nevada .The facility will produce an average of 100 GWh annually, equal to the consumption of 14,000 homes.[149] An analyst said that the “cost/watt is probably closer to $3.30/W than the $3.17 we reported on Dec. 16, when we also suggested an installed cost/watt of $0.075/kWh. A more refined LCOE estimate would be closer to $0.12/kWh, while we believe the output was sold to PG&E under a PPA at roughly $0.14/kWh.”[150]

Figure 35 - 10 MW facility at El Dorado, Nevada. [151]

Another farm that is projected to be built in the California region is that of the High Plains Ranch II which is proposed to use 2,000 acres and built in San Luis Obispo County's California Valley. The facility will have a solar capacity of 250 MW and produce 550 GWh annually of renewable energy. The facility will be constructed with Sun Power's technology, which they claim can generate up to 50 percent more power than conventional crystalline cells.[152] Also tracking technology allows for approximately 30% increased energy capture. This facility in combination with another larger facility is being constructed to meet the 20% energy consumption in the form of renewable energy required by California laws by this year. The project is expected to begin this year and be fully operational by 2012.

The last large photovoltaic farm that will be mentioned in this section is the Topaz Solar Farm which will be built in the Carrizo Plain, NW of California Valley and cost over one billion dollars. Its capacity is planned to be 550 MW and produce 1100 GWh annually of renewable energy.[153] The facility will be constructed by OptiSolar and use "relatively low-cost, thin film PV panels designed by Optisolar."[154] This project is expected to begin in 2011 and be fully operational by 2013.

With several small scales, those of 10 MW and under capacity, photovoltaic farms in use by various local power companies and NASA, the desire to expand these current facilities is growing as our technology improves. I have only mentioned three of the many plans for additional solar farms utilizing this photovoltaic technology, currently there are five additional large scale farms in planning phases all of which have a projected capacity of 200 MW or more.

Additionally there are four more farms planned to be constructed that can hold between 20 and 80 MW of power generation capabilities.[155] The problem with these facilities is that the technology is not efficient. As has been stated previously, peak performance of a photovoltaic solar panel is approximately 20 % efficient at collecting solar light and transforming it into electrical energy through a chemical process in the collection material. That efficiency is then further reduced by the conversion of DC to AC, overall efficiency of each panel then is approximately 14-16% efficient in collecting the energy available from solar rays. According to California Photon, the peak efficiency of the High Plains Ranch II photovoltaic apparatus based on the footprint and peak storage capacity is roughly 27.58 W/m^2 with a net efficiency of 2.78%.[156] Similarly for the Topaz Solar Farm the peak efficiency is 22.35 W/m^2 with a net efficiency of 2.24%.[157]

The increase in solar photovoltaic farms in California suggests that these facilities are low upfront cost, low maintenance, and effective at producing energy. Given the technology has room for improvement and the wealth of new facilities projected to be coming online with several years, it seems that photovoltaic solar farms are a viable means of clean energy creation/production as an alternative to traditional energy production facilities.

With an average of less than 20% efficiency for collection of solar rays, photovoltaic technology does not seem like a smart business decision when compared to alternatives. Even with a theoretical efficiency rate of 31%[158], the amount of energy loss is still unacceptable. One of the explanations of the energy loss is that light energy contains high level energies that photovoltaic cells cannot collect. When lights hits a photovoltaic cell, a fraction of the energy is absorbed, which excites the electrons in the material and allows them to escape their atoms. An electric field forces the electrons in one direction, which makes a current, and can be used as DC power.

The energy that is unable to be absorbed is then high-energy electrons that disperse the remaining energy as heat. The key to improving efficiency then is capturing that heat. One means of accomplishing this is by capturing the high-energy electrons using a quantum dot. A quantum dot is a superconducting nanocrystal that can confine a high-energy electron within its structure. One means of accomplishing these tasks is to use lead selenium quantum dot crystals in combination with a titanium oxide in order to remove the electrons from the quantum dot.

“PbSe was chosen because it has an extremely large Bohr radius of 46 nm. This means that charge carriers in PbSe quantum dots (which are less than 10 nm in size) are strongly confined in the dots and that their electron wave functions extend well beyond the nanocrystal surface. This ‘delocalization’ allows electron transfer from the nanocrystals to an electron-accepting material placed nearby, such as TiO_2. TiO_2 was chosen because it is readily available as single crystals and can accept electrons easily.”[159]

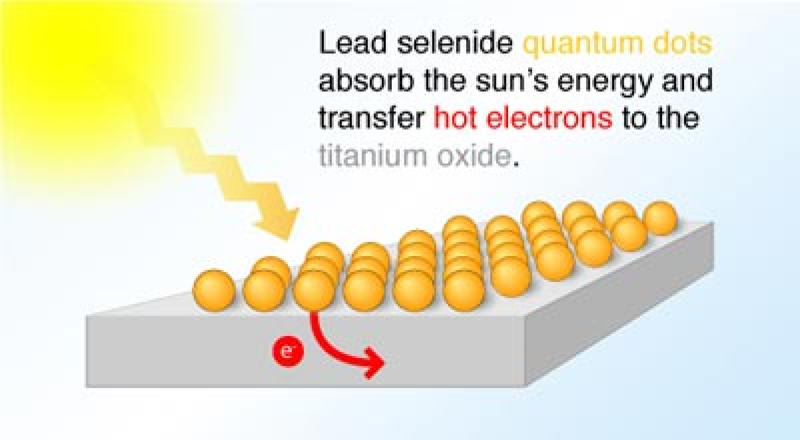


Figure 36 - Hot Electron Transfer with Quantum Dots[160]

Titanium oxide is an electron receiving compound, when used in combination with the quantum dot allows for the collection of more energy from the sun’s light. An estimate of this technology is that it is potentially 66% efficient in collecting energy from the sun’s light.[161]

Given the means of producing quantum dots and the associated conducting materials, via “simple” chemical reactions and the ease of integration to the current production method of photovoltaic cells, quantum dots need to be considered as a means of further inquiry of the scientific community for integration into solar photovoltaic technologies by those companies producing them. With no additional equipment needs, no procedural change, there is no down side to the addition of this technology for the low increase in cost, the efficiency level is increased by approximately 10%.[162] “In other words, the extra conversion efficiency, the extra watts produced, are obtained at nominally the same processing cost.” [163]

2.3.4 - Concentrated Solar Thermal Power (CSP)

Solar Thermal plants utilize mirror based heat collection to heat synthetic oil which is then used to heat water and run turbines. The US currently has two large facilities one in the Mojave Desert which is named Solar Energy Generating Systems (SEGS), the largest facility in the world, it has a capacity of 354MW and consists of 9 facilities over 1600 acres. The panels are made of materials that allow it to be 94% efficient for heat recovery from reflection. Wind is the greatest source of breaking of these panels, which are rotatable by the facility operators to reduce breakage during wind storms. The 9 plants vary in turbine output due to the facilities being dated. Only the two latest facilities output an average of 80 MW of power. This facility was built in a range from 1984 to 1990. The price of production varies at the SEGS facility, ranging from 0.24 $/kWh to 0.08 $/kWh, the newer the facility the lower the cost.[164]

Table 5 - SEGS Facilities

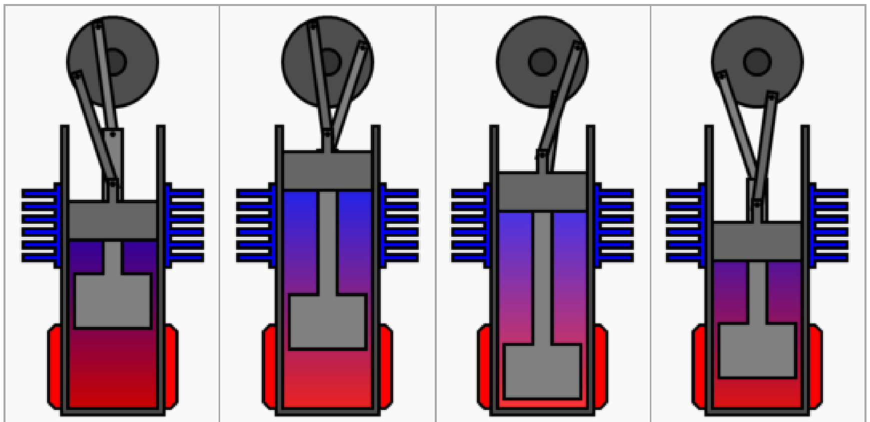
SEGS plant history and operational data [165] [166] [167] [168]

Plant	**Year built**	**Location**	**Net turbine capacity**	**Field area**	**Oil temperature**	**Gross solar production of electricity (MWh)**
			(MW)	(m²)	(°C)	average 1998–2002
SEGS I	1984	Daggett	14	82,960	307	16,500
SEGS II	1985	Daggett	30	165,376	316	32,500
SEGS III	1986	Kramer Jct.	30	230,300	349	68,555
SEGS IV	1986	Kramer Jct.	30	230,300	349	68,278
SEGS V	1987	Kramer Jct.	30	250,500	349	72,879
SEGS VI	1988	Kramer Jct.	30	188,000	391	67,758

SEGS VII	1988	Kramer Jct.	30	194,280	391	65,048
SEGS VIII	1989	Harper Lake	80	464,340	391	137,990
SEGS IX	1990	Harper Lake	80	483,960		125,036

The other facility is Nevada Solar One with a nominal capacity of 64 MW, and a max output of 75 MW. This project required 255 million dollars to construct. It is estimated to produce 134 MWh per year. It was built in 2006, and took 16 months to construct. The facility utilizes about 400 acres, 300 of which are solar panels. It uses 760 parabolic troughs with more than 180,000 mirrors that concentrate the sun's rays onto a pipe with a heat transfer liquid, which is heated to 735 degrees F which is then exchanged to water which drives a turbine. The price to the consumer is no lower, as the local power company still owns the facility, so the average cost is around 0.11 $/kWh to 0.13 $/kWh.[169]

Another form of thermal solar power that has been developed fairly recently is known as the Stirling dish. Stirling dishes are a combination of Stirling engine and parabolic solar collector dish. Stirling engines are basic heat-engines that derive mechanical power from a heat differential using the laws of thermodynamics. These types of engines have had very little practical use in modern history due to their size and lower power output in comparison to direct steam turbines and internal combustion engines. However, these engines have been found to be a perfect fit for concentrated solar-thermal applications as they are usually more efficient at converting heat into mechanical energy than some steam-turbine systems.



1. Power piston (dark grey) has compressed the gas, the displacer piston (light grey) has moved so that most of the gas is adjacent to the hot heat exchanger.

2. The heated gas increases in pressure and pushes the power piston to the farthest limit of the **power stroke**.

3. The displacer piston now moves, shunting the gas to the cold end of the cylinder.

4. The cooled gas is now compressed by the flywheel momentum. This takes less energy, since when it is cooled its pressure drops.

Figure 37 - Stirling Engine Cycle[170]

The majority of Stirling dishes use an array of mirrors arranged in a parabolic shape to create the "dish" part of the device. The parabolic shape of the dish directs all of the nearly parallel rays of energy coming from the sun towards one central location at the focal length of the dish. This point is where the Stirling engine is located. The engine is typically supported by an arm that is mounted to the bottom edge of the collector dish so that it can remain at the focal point regardless of which direction the dish is pointing. The reason that it is mounted to the dish is that the dish is usually rigged to slowly move with the location of the sun in the sky so as to harness the maximum amount of energy.

Figure 38 - Stirling Dish[171]

These Stirling dishes have been constructed by a handful of small developers, but the largest application by far is the 500MW farm under construction in the Mojave Desert of California. Each dish with a diameter just under 40ft would produce about 25kW of peak output.

The manufacturing costs for Stirling dish units, which are made of inexpensive and common materials, are much lower than that of photovoltaic panels which are heavily based on the price of silicon. Standard manufacturing methods such as robotics and assembly lines can also be used as these dishes require far less precision and cheaper base materials, so as production increases, the costs of production will dramatically decrease for this technology.

Given the technology has the potential to be a cheap resource which is cheaper than that of photovoltaic as it is more efficient and has a wider range of uses, possible home heating applications etc…, and solar thermal technology seems like a viable solution to renewable energy production. Similar problems to those of the photovoltaic farms come about, in that large stretches of open land are required, with limited interference between the sun and collection mirrors. Wind concerns arise in these flat areas as the primary locations for these farms are in the mid-western states of the U.S., which are then prone to wind storms. Changing orientation designs could then feasibly be controlled by an onsite operator during hazardous weather to limit damage to the facilities many mirrors. Low maintenance cost, with replacement of broken mirrors and water for cleaning being primary expenditures, solar thermal farms appear to be a good alternative to the less efficient collection of solar rays via photovoltaic technologies.

2.3.5 - Geothermal Power

Not only can you get energy from the wind, the sun, or the water, but energy can also be harnessed from the heat from the earth. Geothermal energy has been used to centuries as bathing in hot springs, but today is being used to produce electricity and heat homes. In the world today, there is about 10,715 megawatts of geothermal power (around 67,000 GWh being produced).[172] In the United States there are 77 geothermal plants having a total installed capacity of 3,086 megawatts. The largest of these plants are the Geysers in California; a group of 22 plants with more than 350 wells. It has an installed capacity of 1517 Megawatts and an average production of 955 megawatts (around 63%)[173].

There are three main types of geothermal power plants; Dry steam, Flash steam, and Binary cycle power plants. Dry steam plants are the oldest type in existence. They directly use the geothermal steam to drive turbines to produce electricity. The most common type of geothermal plant is the flash steam power plant which uses deeper, higher pressure water and channels it into lower pressure tanks. This causes the lower pressure tank to turn into steam very quickly. The resulting “flashed” steam is used to turn the turbines. The problem with these plants is that the temperature required of the steam is 150°C (302°F) or more. The only places where you can get this kind of heat are very deep into the earth or near tectonic plate boundaries. For the United States, that creates realistic limits to the west coast. But there is a third and final type of power plant recently developed that can be used with steam temperatures as low as 60°C (140°F). It is called a binary cycle power plant. It operates by pumping the hot water from the ground through a heat exchanger. This exchanger passes the hot water by another fluid with a low boiling point temperature, like butane, where the flash steam is created and used to turn turbines. This type of plant can allow places other than around tectonic plate boundaries to realistically harness geothermal energy with minimal cost.

Three types of geothermal plants[174]

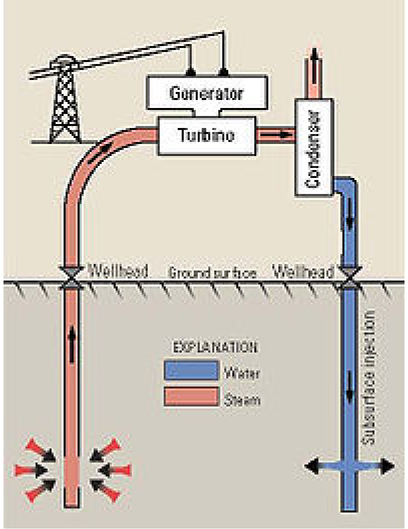


Figure 39 - Dry Steam

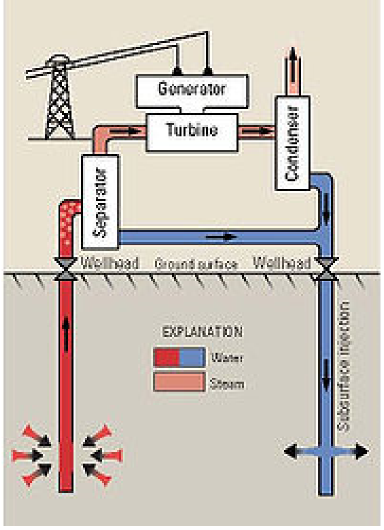


Figure 40 - Binary Cycle[175]

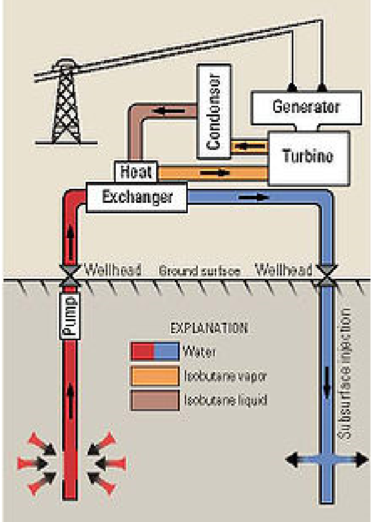


Figure 41 - Flash Steam

Geothermal power plants require no fuel to operate, but does produce greenhouse gases as a result from exhaust heat created to the limits of efficiency of the heat engines (engines that produce power and cooled air from steam). The fluids from the earth contain not only water, but also other gases like carbon dioxide, methane and ammonia. Geothermal power plants emit an average of 122 kg of carbon dioxide per megawatt-hour (MWh) of electricity or around 12,000 tons of greenhouse gases per year.[176] This is the same amount a coal plant will produce in 5 days.

Another large problem is the cost. It does not cost much to maintain, like wind farms or solar farms, but the cost of drilling deep into the earth and establishing a plant is quite excessive. On average it costs about 2.2 million dollars to drill for every megawatt of electrical capacity. So a 4.5 megawatt power plant would cost 10 million dollars to drill.

On the positive side of geothermal plants, they take up little land and require very little fresh water to operate. Coal and nuclear plants require around 1000 liters of freshwater per MWh while geothermal plants only require about 20 liters per MWh. They take up about 3.5 square kilometers per gigawatt of electricity produced versus 32 for coal plants and 12 for wind farms. The cost to the consumer ranges from around \$0.08 to \$0.11 per KWh.

Residents also can have their own home heated by geothermal heat. Known as ground source geothermal, this is done by placing a long winding tube filled with a type of antifreeze liquid under the earth about 8 feet below the surface of the earth where the air is a steady cool temperature, usually between 10-24°C (50-75°F). This fluid then flows through the tubing by a small electric pump. During the summer months it carries the hot temperatures away from the home and brings cooler temperatures in, while in the winter the ground warms the liquid up, thus heating the home. With minimal cost to use the pump, the only real cost is the installation, which runs about 5,000 to 15,000 dollars depending on the size. This is repaid within 3 to 10 years with a lifetime of around 25 to 50 years.

2.3.6 - Nuclear Fusion

Often coined as the holy grail of energy production, nuclear fusion has long been looked at as the ultimate high-power renewable energy source. A very real and daily reminder of the power of fusion can be found in our own sun. Stars, through their intense gravity, continually fuse together elements of all kinds to create vast amounts of energy. Our sun's output alone is so high that we can feel the effects of it 92 million miles away here on earth. However, because we don't have the same advantage of gravity here on earth to naturally create fusion we have had to come up with other ways. Some of the earliest examples of humans inducing fusion here on earth are in the form of Hydrogen Bombs, first developed in the early 1950s. Both of these forms of fusion, either by gravity or in a nuclear explosion, are completely uncontrolled and so are not very useful in terms of generating electricity.

Since the 40s, scientists and engineers have been devising controllable methods of inducing nuclear fusion, and have come up with several types of reactors in the process. The first challenge to overcome was of course simply initiating a reaction small enough to be contained. This was the main focus of most of the earliest types of reactors and the purpose of many reactors currently in operation today. These reactors usually consist of two general types; either toroidal (donut-shaped) or consisting of a central ignition chamber.

The fuel for most of these reactors is typically a combination of hydrogen isotopes. The particular fuel used is a combination of Hydrogen-2, Deuterium, and Hydrogen-3, Tritium. These two isotopes combine to create Helium, a free neutron, and about 17.6 MeV of energy per reaction. Deuterium is fairly abundant here on earth, and can most readily be found in a percentage of water molecules. About 1 in every 6,400 hydrogen atoms contained in water are Hydrogen-2. To get these types of elements from nature, scientists isolate and purify "heavy water" which contains these "heavy hydrogen" atoms, and then through electrolysis separate the oxygen and hydrogen atoms in the water. This process has been in use since the 40s.[177] Tritium is also naturally occurring, but is so rare that it is more economical to manufacture it. This is done most commonly by exposing Lithium to the neutron radiation within nuclear reactors. Since the 1950s, about 225kg of tritium has been produced in the United States usually with the intent of being used in thermo-nuclear weapons or "H-bombs".

The first problem in attaining fusion is that at least with hydrogen isotopes, the process requires a substantial temperature to take place in. In the Hydrogen bombs developed in the 50s, this high temperature was achieved by first triggering a separate fission reaction (A-bomb) within the device. Because detonating an atomic bomb inside a power plant is not safe or practical, other methods for achieving such high temperatures were developed.

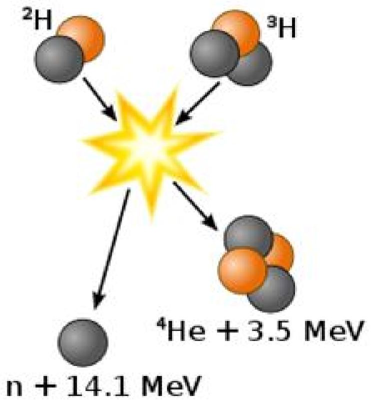


Figure 42 - D-T Reaction[178]

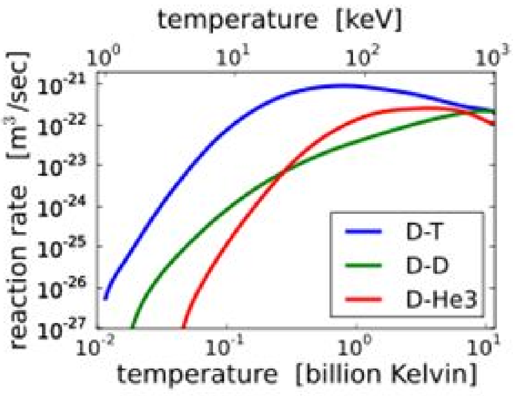


Figure 43 - Fusion Reaction Temperatures[179]

The most studied method for inducing nuclear fusion has been magnetic confinement in donut-shaped tokomak reactors. With these types of reactors, the hydrogen gas is confined and compressed as plasma by magnetic forces. This magnetic force is created electromagnetically by a solenoid wrapping around the sections of the reaction chamber. The plasma is also heated in a similar way by inducing an electrical current into it via separate electromagnetic coils. Through this process of compression and heating, plasma reacts with itself and releases high-energy neutron particles. To create power, a reactor must capture the energy in these ejected neutrons.

In the late 1970s, several European nations pooled their resources to create an experimental reactor to further research the capabilities of tokomak-type nuclear fusion. The resulting reactor, the Joint European Tokomak (JET) is the largest and most powerful tokomak in the world and currently the only machine capable of operating with the deuterium-tritium fuel mix of future commercial reactors. In operation since 1983, JET was explicitly designed to study plasma behavior in conditions and dimensions approaching those required in a fusion reactor. In the center of the machine is a vacuum-sealed reaction chamber where the fusion plasma is confined by means of strong magnetic fields and plasma currents which reach up to 4 teslas and 5 million amps. Currently JET is configured for an outer plasma torroid radius of 3 meters and inner radius of 0.9 meters. The total plasma volume occupies 80 cubic meters. A diverter at the bottom of the vacuum vessel allows escaping heat and gas to be exhausted in a controlled way. The whole device stands at 11.5 meters tall. Today, the primary task of JET is to prepare scientists for the construction and operation of its successor, acting as a test bed for the larger reactor's technologies and operating scenarios.[180]

Figure 44 - Inside-View of the Vacuum Vessel (Reaction Chamber) of JET[181]

As a successor to JET, there is another Tokamak fusion reactor facility currently under development which will serve as a full-sized testing facility for fusion-energy research and when completed will be the largest Tokamak reactor ever built. This new facility, "ITER" (International Thermonuclear Experimental Reactor), was designed to produce 500 MW of output while consuming 50 MW of input energy and a deuterium-tritium fuel mixture. Work already began in 2008 on site preparation while excavation for the Tokamak Complex and construction of the first buildings began in 2010. The facility will occupy about 400 by 1000 meters of land and is scheduled to be completed by 2019. Between 2019 and 2027 the facility's main purpose will be to conduct a series of plasma-based experiments for research purposes, after which the facility will begin full ignition testing and operation until 2038, the planned end of the project.[182]

Building on information gained through the ITER project, there are plans to build a third Tokamak called "DEMO". This is intended to be the first prototype of a commercial-scale fusion power plant which will create usable electricity. Currently, ITER is designed only for testing purposes in energy production to be dissipated rather than captured. DEMO will have linear dimensions 15% larger than ITER, and create a 30% denser plasma in the hopes that such a reactor will produce at least 2.5 times more output energy and between 2 to 4 gigawatts of usable electricity continually. The project will remain in the design phase until after the completion of ITER, so that the design can be modified accordingly. It is expected that assuming ITER remains on schedule, initial design could be complete by 2024, allowing construction to be completed in 2033.[183] The actual financial costs associated with these projects cannot be known for sure, but the best estimates can be made using the current budget for the ITER project. The ITER reactor facility is currently at about 15 billion US dollars in terms of investment cost, and is expected to accrue yearly costs of about half a million USD. This yearly cost reflects parts replacement, general plant maintenance, both professional and supporting labor, and fuel consumption. Because of its high energy density and how common it is, the fuel for such reactors is one of the least expensive components of operating cost. In total, DEMO, using figures proportional to ITER, would generate electricity at a rate of just under 2.5 cents/kWh plus the initial investment cost of about $6,000 per installed kW capacity.[184]

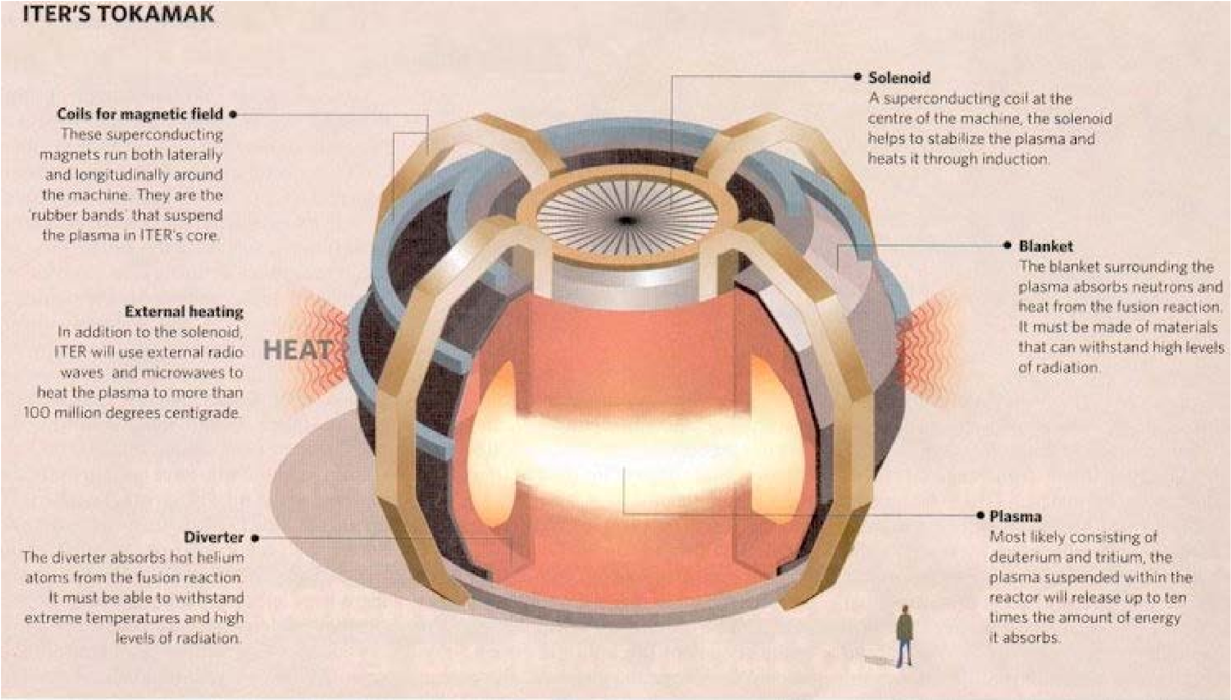


Figure 45 - Simplified ITER Tokamak with Person for Scale[185]

The safety (compared to nuclear fission) and lack of environmental impact associated with nuclear fusion are very promising aspects of this technology. One feature of fusion that differs from the traditional nuclear fission is that the reactor has no ability to start a runaway-reaction. The reason for this is that fission power plants typically use uranium fuel rods holding months or even years of stored energy within the reactor at any given time, where-as a fusion reactor only holds several grams of gaseous fuel which could at most only sustain the reactor for less than one hour, and only if the magnetic field around the reactor is maintained. Another difference is in the waste-products associated with each process. Fusion of hydrogen isotopes yields only helium and neutrons as byproducts. While the helium is inherently safe, the neutrons do have the capacity to irradiate the inside walls of the reactor. However, this only presents a problem when decommissioning a reactor rather than at any point during its operation. Also, the half-life of the types of radioactive materials created in the reactor is on the order of decades rather than the thousands of years associated with fission byproducts. This means that any contaminated sections only have to be stored for about 50 years before they are safe.[186] The environmental benefits of fusion power are that it is generally safe, produces no emissions or waste-products (other than helium), and utilizes an abundant source of fuel that can be safely obtained from water.

The only remaining questions and points of contention with fusion power are its economic and scientific feasibility, at least within a reasonable time-frame. Currently there is very limited knowledge about the behavior of plasma, suitable materials that would not degrade inside the reactor, or the process by which heat can be efficiently collected from fusion reactors and converted into electricity. Many scientists within the field of fusion research believe that it is through the construction of large scale test-bed devices such as ITER that we will be able to answer many of these questions or confront through practice any likely engineering problems. Taking this into consideration, optimistic estimates put feasible commercial fusion power at 40 years from now, and any large scale adoption of the technology at 80 or more years, assuming all the known technological challenges are overcome by then.

In the context of an energy policy mainly focusing on the short term of the next 25 years, fusion power would not practically play any role in meeting actual short-term energy demand. However, it would be important to continue to invest into its research as a very promising long-term solution to growing energy demand.

2.4 - Transportation Applications

Transportation and especially personal vehicles such as automobiles are a huge part of the American way of life. Because of this fact, the energy demand of the transportation sector is quite large and needs to be considered in any comprehensive energy policy. For almost a century, gasoline and diesel powered vehicles have been the dominant form of transportation across the United States. However, recently there have been many developments in the area of alternative fuels and engine types. The types of cars and fuels focused on in this report include the following: Hydrogen-powered fuel cells, Bio-fuel powered internal combustion engines, Hybrids of different types, and Battery-Electric vehicles. Each of these options examined rely on or can rely on sources of energy which are fully renewable.

2.4.1 - Algae Biofuel

There has been a growing amount of interest and subsequent research over the past few years in the field of algae-based bio fuels. Algae are organisms that can range in appearance from being a collection of disorganized cells to varying colors and sizes of underwater plant-like structures. Particularly, some strains of green algae known as "Dunaliella", or colloquially as 'Pond Scum' have yielded very promising results as both an energy source and as a substitute for petroleum in many other industries.[187] Raw algae can be processed to make "biocrude", the renewable equivalent of petroleum, and refined to make gasoline, diesel, jet fuel, and chemical feedstock for plastics and pharmaceuticals. This algae requires CO2, sunlight, and water to grow and since these are all fairly abundant resources that can be found almost anywhere, algae has a tendency to do just that. Even saline or certain types of waste-water are fertile breeding grounds for algae. In fact some waste water actually has the types of nutrients algae thrive on.

Figure 46 - "Pond Scum" [188]

Algae production, unlike most other crops, can run year-round and in a broader range of environments not suited for those other types of crops. Traditional corn or sugar based ethanol inherently competes with food industries for common resources such as land and the actual corn or sugar itself. Algae on the other hand used nutrients derived from waste products or common in the environment and the algae itself isn't a food crop so it doesn't compete with or cause the same financial problems in the agricultural sector that corn-ethanol has shown to cause. The energy density for this technology is also very promising. Potential yields in ideal conditions, based on laboratory results, for 1 acre of land are as much as 20,000 gallons of algae oil per year, using existing technologies and known strains.[189] Currently, the average real-world production is about 2 or 3 thousand gallons of usable fuel per acre of land per year of production in "open-pond" growing systems. Even at this much lower level, present real-world comparisons to traditional biomass and ethanol crops show that farming algae consumes far less resources per unit of usable output.[190] Traditional biofuel and ethanol crops also use a large amount of water. For instance, almost 10,000 liters of water are needed for each liter of crop-based biofuel and only 1.5 liters of water are needed for a comparable liter of algae biofuel.[191]

Table 6 - **Biofuel Yield Comparisons**[192]

Crop	Oil yield (L/ha)	Land area* needed (M ha)	Percent of existing US cropping area*
Corn	172	1540	846%
Soybean	446	594	326%
Canola	1190	223	122%
Jatropha	1892	140	77%
Coconut	2689	99	54%
Oil palm	5950	45	24%
Microalgae (70% oil)	136,900	2	1.1%
Microalgae (30% oil)	58,700	4.5	2.5%

*area required to meet 50% of transportation fuel demand

Although the end-result is still releasing CO2 into the atmosphere by the fuel's combustion, the life-cycle of algae fuel is carbon-neutral since all of that CO2 being released was taken from the atmosphere or other sources only a few months before-hand in the growing process. This is in contrast to fossil fuels which introduce a net increase of CO2 into the environment, released from underground stores. In addition to being life-cycle carbon-neutral, the exhaust from burning bio-fuel does not contain any sulfur, which is commonly found in traditional petroleum products. This, combined with a lack in many other toxic substances that are found in fossilized fuels makes algae based bio fuel much safer when burned and even in the event of a spill. Unlike petroleum, most biofuels are actually biodegradable and pose a much lower risk to the environment.[193]

There are 2 major methods and a few less common methods for growing Algae. Open ponds and closed bioreactors are the most common, and special laboratory or greenhouse environments are a less common approach. The Open Pond system has several economic advantages since the ponds are simple to construct and require very little building material (other than the land itself). Another particular advantage to open-pond farming is that it can use ambient CO2 from the air without any special CO2 collection or transport technology. Right now, this is the most economically feasible of the available algae production technologies since there is very little specialized infrastructure needed. One disadvantage to operating an open-pond algae farm is that the pH must constantly be monitored and kept at the right level despite being susceptible to environmental changes. There is also the constant threat of environmental contaminants or other factors such as weather that might kill or damage some of the unprotected algae. The open pond system tends to take up a lot of land but is actually fairly dense relative to the energy density of other renewable energies.

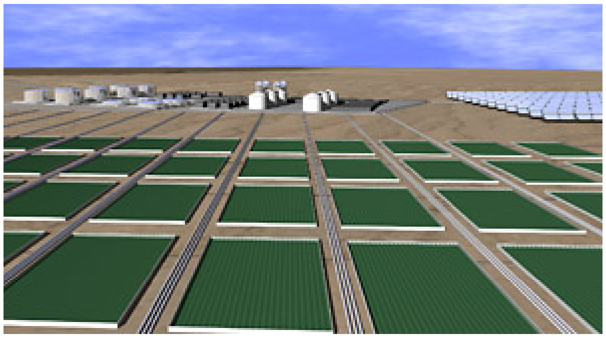


Figure 47 - Artistic Rendering of an Open-Pond Algae farm[194]

The second method of growing algae is in Bioreactors. Bioreactors come at a higher initial cost because the entire system is housed within special containers or tubes connected together with various piping and physical support infrastructure. The advantage however is that the system can operate year-round and can be located almost anywhere since the algae is protected from the elements and harmful contamination. Bio-reactors, being part of a closed system, are far easier to control and monitor and are actually much denser than pond systems since they can be arranged for optimal sunlight collection in a given area of land. Typically, a bioreactor consists of clear, tubular containment vessels that can be filled with water and algae. These vessels are arranged in such a way that they get the maximum amount of sunlight throughout the day while, simultaneously, pipes connected to the vessels feed a stream of nutrients and bubbles of concentrated CO2 into the reactors. This combination of concentrated nutrients, CO2, and sunlight enable the algae to grow extremely quickly using regular photosynthesis.[195]

Figure 48 - Tubular Photo Bioreactors[196]

Growing algae in small pools, containers, or bioreactors within a greenhouse can also successfully produce algae. However, both the initial and general operating cost are slightly higher (per unit volume output) than other methods. This method is usually only reserved for research and laboratory situations that call for specialized control of the overall growing process or development of various growing techniques.[197]

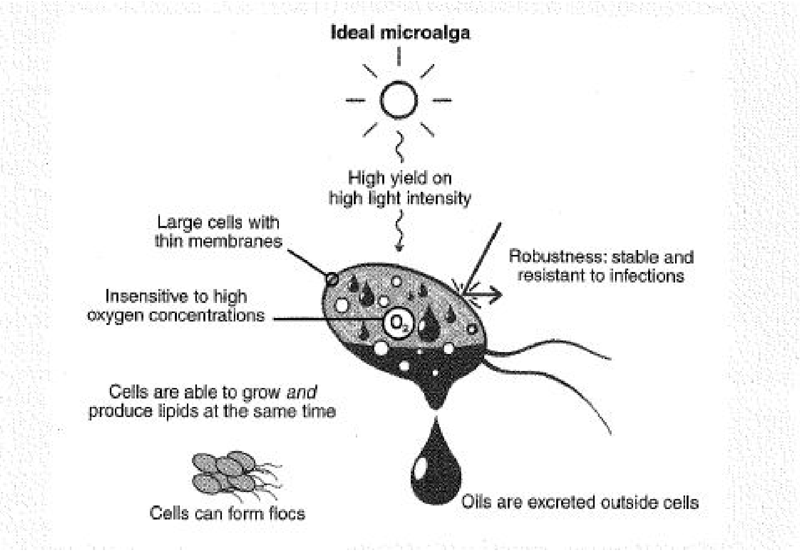


Figure 49 - Microalgae producing oil[198]

Once the algae has grown and matured to a point where it can be harvested, it is collected from storage areas (either ponds or bioreactors) and filtered from the water it had been growing in. The water is typically fed back into the system for use in growing another yield of algae. The collected algae is dried and starved of nutrients to break it apart at the cellular level. At this stage, solvents are used to chemically separate the resulting sugars and fatty oils. Once separated, the solvents are evaporated from the mixture leaving just the fatty oils which can be further refined into biodiesel and other specialized forms of Biofuel.[199] Algae can also be harvested in other ways and in some cases produce other fuels such as ethanol or hydrogen, and the leftover mass converted into biogases or nutrient feedstock.[200] The ideal microalgae, which biotechnology firms are searching for and selectively breeding, are not only capable of producing a high yield of algae oil but are also capable of excreting this oil rather than retaining it. Such strains make it much easier to collect the oil as there is no need to break apart the algae to get it.

Algae based fuels have an almost identical chemical composition to many petroleum based fuels. This is extremely advantageous as it means that there are almost zero new infrastructures that society would need to invest in to utilize this type of fuel. Depending on how the algae are refined, final products can include: Biodiesel, Biobutanol, Biogasoline, and Biologically-derived Jet fuel. These liquid fuel products with properties identical to that of petroleum fuels can be transported and stored in very similar if not already existent infrastructure. For example, this type of fuel can easily be transported in the same trucks and containers designed for conventional gasoline and oil, and delivered to consumers through the already existing network of gas stations. Because the infrastructure for a liquid hydrocarbon fuel industry already exists in areas of transport, storage, and end-use the costs associated with implementing biofuels lie only in the initial production and are therefore much lower than some other renewable energy sources which rely more on comprehensive infrastructure changes.

There are 4 basic applications for this technology which are capable of directly mirroring the applications and scope of the modern-day petroleum industry. The first 2 which are not the focus of this report, but worth mentioning, are the use of these algae-derived oils in food-grade or pharmaceutical applications and then secondly as substitute chemical feedstock for materials currently only produced by the petro-chemical industry. These include various plastics and other synthetic materials that rely on the complex hydrocarbon polymers found in both crude petroleum oil and this new biocrude algae oil. The 3rd application, and by far most focused on, is the use of these biofuels for transportation. This includes but is not limited to the powering of cars, buses, trucks, trains, ships, and aircraft. The final application for these biofuels is in stationary power generation in everything from personal generators to commercial-scale power plants that supply energy to the grid.

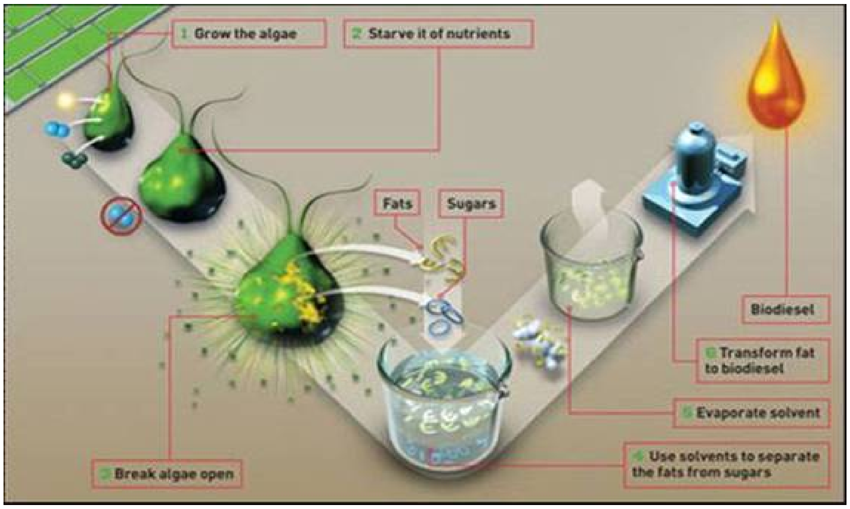


Figure 50 - Algae Biodiesel Production Process[201]

Currently, biodiesel is the easiest recognizable fuel that can be created using algae-based technology. This is in of itself very useful because it has been demonstrated to be a fairly simple and low-cost process to adjust current diesel engines to run on such fuel as a mixture with petroleum diesel or in its pure form.[202] Many individual truck and diesel-powered car owners have demonstrated this ease of conversion by personally converting their own cars to run on this type of fuel. Producing biodiesel has traditionally been very expensive, but since 80% of the cost of biodiesel is based on the cost of the feedstock rather than the extraction process itself, low-cost algae can bring the cost of biodiesel down to basically the same price as conventional petroleum-based diesel.[203] The main difference in cost is then just in changes to engine design to accommodate the more viscous fuel. There are already several makes and models of vehicles in the US that are fully capable of running on certain forms of bio-diesel or ethanol without modification.[204] GM has estimated the cost to be about 100 extra dollars per car to make such changes and has demonstrated this in their production of several "flex-fuel" cars and trucks.

Ultimately, a lot of research is focusing on the production of Biogasoline and Aviation-grade biofuel that are more effective and match more closely the chemical properties of petroleum-based gasoline and aviation fuel. Biogasoline therefore would ideally be fully interchangeable with conventional gasoline in every way without any modification of engine technology and in addition to the standard automotive gasoline; the same research focuses on the matter of aviation fuel. Several major airliners such as Air New Zealand, Continental Airlines, and Virgin Airlines have already carried out initial testing of aviation biofuels in commercial aircraft. The initial tests usually aim at blending biofuel with regular fuel but ultimately will move toward being entirely bio-fuel powered.[205] Another project, sponsored by DARPA, run as a joint venture by the Defense R&D firm SIAC and General Atomics, is expected to yield a large initial output of crude Biofuel oil at a cost of $2 per gallon, with refined jet-fuel at $3 per gallon. The current plan for this particular operation is to scale up to 50 million gallons (of final product) per year, by 2013 while hopefully reducing cost per gallon with the larger production scale and advances in the technology.[206]

Chevron, ExxonMobil, Shell, and few other Corporations in the petro-chemical industry are making huge investments in the technology particularly because of its potential as a long-term renewable substitute for the goods these companies already produce and work with. Many of these companies therefore are working with partner companies which have used the capital to construct initial test-production farms and laboratories dedicated to discovering or breeding algae with higher oil yields per mass. Currently, the best algae are approximately 50% usable oil by volume.[207] ExxonMobil in particular has been very outspoken about their involvement in algae fuel research. Their commercial partner, Synthetic Genomics has been working with ExxonMobil to test and refine various growing strategies and different species of algae to find and ultimately implement the most optimal algae-growing techniques. Another biotech firm, Solazyme, has been working in conjunction with Chevron for capital funds, and has recently been working on mass production of naval fuel. In 2009, the US Navy signed a deal with the company for 20,000 gallons of the biofuel and this year has increased that number to 150,000 gallons.[208]

The cultivation of algae as a renewable substitute for petroleum has the potential to be very successful and is very useful in that it directly addresses the matter of our hydrocarbon-based modern society. It would appear that the process as a whole seems quite feasible depending on what types of growing methods are used and if larger scale production of this type of fuel can be executed successfully. Even in the near-term this seems very likely as the technology mostly builds on existing infrastructure and other already proven technologies. There aren't many drawbacks to this technology and the idea of using algae as a fuel and power source, other than the use of land to grow the algae. On the whole however this compares favorably to other alternatives in both energy density and cost. The feasibility of large scale mass production is estimated to be only on the order of about 10 years away with the current amount of advancement and is capable of smaller but still 'commercial-scale' production even now.[209]

2.4.2 - Hydrogen Fuel Cells

Fuel cells are electrochemical devices that convert the chemical energy of a fuel (hydrogen, natural gas, gasoline, etc.) and an oxidant (air or oxygen) into water or carbon dioxide and electricity. The fuel cell is similar to a battery in that it has three parts, the anode, cathode and an ion-conducting material (electrolyte). Fuel cells are classified by the electrolyte material used in the device.

The chemical processes that occur generally start with the introduction of hydrogen into the anode (fuel electrode) side of the cell where it is separated into a hydrogen ion and an electron. The anode catalyst is normally comprised of very fine platinum powder, which increases the cost of the unit. The ions then pass through the electrolyte which is designed such that no electrons can flow through it; instead they are forced along a wire so that current can be created. The electrolyte varies depending upon the fuel cell. On the other side of the electrolyte is the cathode (oxidant electrode), often made of nickel. A second reaction takes place when the electrons rejoin the ions with a third chemical, normally oxygen, to produce water or carbon dioxide.

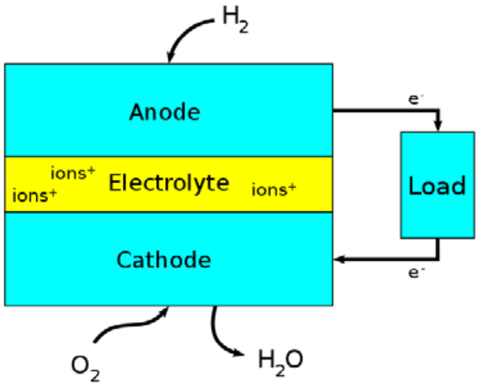


Figure 51 - Block diagram of fuel cell[210]

Fuel cells use hydrogen as the primary fuel source, due to the lack of hydrogen delivery infrastructure a short-term solution of using fossil fuels to create hydrogen can be implemented. This process is called fuel reforming and is accomplished by several methods. One such way to transform fossil fuels into hydrogen is that of steam reforming, during which steam is mixed with the fuel at temperatures around 760°C.[211] This process is generally done with methane (CH_4), the reaction for this is;

$$CH_4 + 2\ H_2O \Rightarrow CO_2 + 4\ H_2$$

For high temperature fuel cells, carbon monoxide in the fuel stream acts as a fuel. It is likely that this is instead another reaction with steam to create hydrogen, whose reaction looks like;

$$CO + H_2O \Rightarrow CO_2 + H_2$$

These reforming processes can be accomplished at differing scales, from a large chemical plant, gasoline station or an on-board fuel processor in any vehicle before introduction of hydrogen-rich steam to the fuel cell.

Fuel cells can be severely degraded in performance by the introduction of different types of molecules into the system, because of the different types of electrolytes, operation temperature, catalyst and other factors the amount of performance loss is variable and depends upon these conditions. The major contributor to the degradation of fuel cells is hydrogen sulfide and carbonyl sulfide; these originate from the inherence of sulfur in fossil fuels. Small amounts are left after fossil fuels are processed and must be removed before any fuel which could contain them is used in a fuel cell.

There are various different types of fuel cells which differ in the chemical used as the electrolyte used in the chemical process to create electricity. As previously mentioned, fuel cells are generally classified by the operating temperature and the type of electrolyte used. A brief overview of the various types of fuel cells is useful in identifying possible uses for the technology.

The Department of Energy primarily focuses on the development of the Polymer exchange membrane fuel cell (PEMFC) as it is the most likely to be used for transportation applications. This type of fuel cell has a high power density and a relatively low operating temperature range of 60 to 80 degrees Celsius.[212] This low operating temperature means that it doesn’t take long for the cell to come to temperature and produce electricity. This type of fuel cell uses the simplest chemical reaction of any of the fuel cells with an electrolyte of the device is the proton exchange membrane (PEM). The PEM is a semipermeable membrane generally made from ionomers which is designed to conduct protons while being impermeable to gases. An ionomer is a polymer that has physical properties of electrical conductivity and isoviscosity with an increase in isoviscosity at higher temperatures.[213] One of the most common and commercially available PEM materials is Nafion, made by DuPont.[214] PEMFC utilizing Nafion have an operating temperature of 50 to 120 degrees Celsius, with somewhere between 50 and 70% efficiency for the fuel cell at a cost of 30 to 35 dollars per watt of power generated.[215]

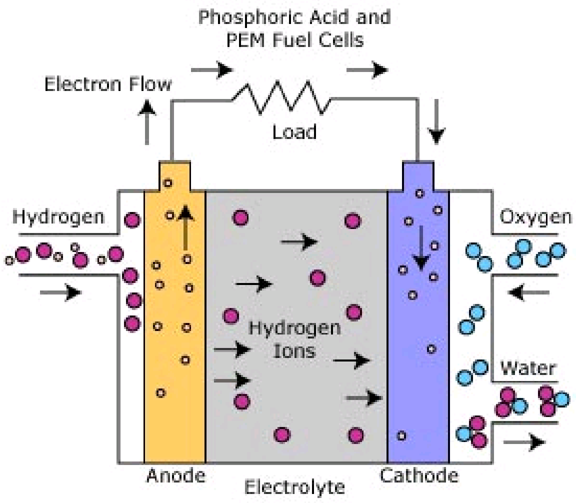


Figure 52 - Polymer Exchange Membrane Fuel Cell Diagram[216]

From a chemical standpoint there are two reactions occurring with the fuel cell, that at the anode side and that at the cathode side. These reactions are such that;

Anode side:	Cathode side:	Net reaction:
$2H_2 => 4H^+ + 4e^-$	$O_2 + 4H^+ + 4e^- => 2H_2O$	$2H_2 + O_2 => 2H_2O$

The reaction in a single fuel cell produces about 0.7 volts of electricity.[217] In order to produce a reasonable voltage a combination of fuel cells to create a stack using bipolar plates connecting the fuel cells. These bipolar plates are subject to oxidation and stability problems, the metallic bipolar plates can corrode and the products of this corrosion can interact with the membrane and electrodes reducing the efficiency of the cell reactions. The most common materials for this type of plate are lightweight metals, graphite and carbon or thermoset composites (plastic that remains rigid at high temperatures).

Compared to other types of fuel cells, PEMFC generate more power for a given volume of weight. The high power density makes them compact and lightweight. Production is less expensive as sealing of the anode and cathode gases is simpler with a solid electrolyte. The cell and stack life is longer than other fuel cells due to the less corrosion problems.[218] The electrolyte is required to be saturated with water to operate optimally, so moisture control at the anode and cathode is important. These factors make this type of fuel cell ideal for automotive power applications.

Solid Oxide fuel cells (SOFC) are high temperature operating fuel cells with a range of operation between 500 and 1000 degrees Celsius.[219] This type of fuel cell has a solid oxide or ceramic electrolyte which has the characteristics of high efficiency, long-term stability, fuel flexibility, low emissions and relatively low cost.[220] The largest problem with the SOFC is the high operating temperature which results in longer start up as well as mechanical and chemical compatibility issues. The difference between this fuel cell and that of the PEMFC is instead of conducting positive hydrogen ions through the electrolyte, the SOFC uses the solid oxide electrolyte to conduct negative oxygen ions. The electrochemical oxidation of these oxygen ions occurs at the anode side as opposed to the cathode in the PEMFC.

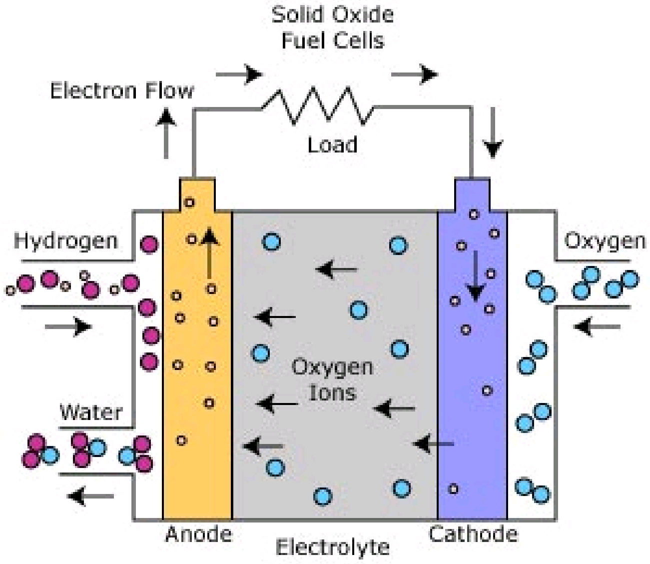


Figure 53 - Sold Oxide Fuel Cell diagram[221]

As a solid electrolyte, it does not allow for gas cross-over from one electrode to the other. At the cathode the oxygen molecules from the air are split into oxygen ions with the addition of four electrons, these ions are conducted through the electrolyte and combined with the hydrogen at the anode, which releases the electrons that follow an external circuit producing electricity and heat. From a chemical standpoint there are two reactions occurring with the fuel cell, that at the anode side and that at the cathode side. These reactions are such that;

Anode side: $2\ H_2 + 2\ O^{2-} \Rightarrow 2\ H_2O + 4\ e^-$	Cathode side: $O_2 + 4\ e^- \Rightarrow 2\ O^{2-}$	Net reaction: $2\ H_2 + O_2 \Rightarrow 2\ H_2O$

One advantage of this type of fuel cell is the lack of platinum catalyst material required in the PEMFC which increases the cost significantly. Additionally these fuel cells are not subject to carbon monoxide hindering the chemical reactions, however they are subject to sulfur impeding the process, as such as previously discussed all sulfur must be removed before entering the cell. A wide range of uses of these fuel cells, from vehicles to stationary power generation with outputs varying from 100 W to 2 MW[222] and a 60% theoretical efficiency make these fuel cells a good candidate for high-power industrial applications as well as electrical power stations.[223]

Molten Carbonate fuel cells (MCFC) are high temperature fuel cells that operate at temperatures above 600 degrees Celsius.[224] They use an electrolyte composed of molten carbonate salt mixture suspended in a porous, chemically inert ceramic matrix of beta-alumina solid electrolyte (BASE). BASE material is a fast ion conductor material used as a membrane; this material was first developed by Ford Motor Company in the search for a storage device for electric vehicles.[225] Two mixtures of the molten carbonate electrolyte are currently used; lithium carbonate and potassium carbonate, or lithium carbonate and sodium carbonate. In order to melt the carbonate salts and achieve high ion mobility high operating temperatures are required.

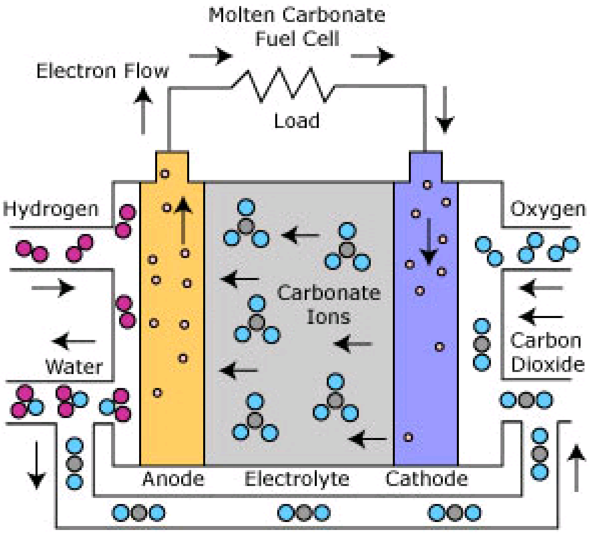


Figure 54 - Molten Carbonate Fuel Cell Diagram[226]

When heated to temperature the salts melt and become conductive to the carbonate ions. These ions flow from the cathode to the anode where they combine with the hydrogen to give water, carbon dioxide and electrons resulting in electricity and heat. From a chemical standpoint there are two reactions occurring with the fuel cell, that at the anode side and that at the cathode side. These reactions are such that;

Anode side: $CO_3^{2-} + H_2 \Rightarrow H_2O + CO_2 + 2e^-$	Cathode side: $CO_2 + 1/2O_2 + 2e^- \Rightarrow CO_3^{2-}$
Net reaction: $H_2(g) + ½O_2(g) + CO_2$ (cathode) $\Rightarrow H_2O(g) + CO_2$ (anode)	

At the higher operating temperatures fuel reforming of natural gas can occur internally, eliminating the need for an external fuel processor. Because of the high operating temperature, non-precious metals can be used at the anode and cathode as catalysts instead of the high cost platinum. As such standard materials can be used for construction and a nickel-based catalyst can be used at the electrodes. The by-product heat from the MCFC can be utilized to generate high-pressure steam to be used in industrial applications. Again these fuel cells are not prone to carbon monoxide or dioxide hindering the chemical processes, but are subject to sulfur impeding the reactions. The carbonate electrolyte can also cause electrode corrosion problems as well as control of the CO_2 introduced at the anode. The benefits of these fuel cells are the high electrical capacity of up to 100 MW, but high temperatures and lower efficiency, around 55%, cause for higher maintenance costs.[227] Main uses for these types of fuel cells are industrial and grid power production.

In 2003, President Bush proposed the Hydrogen Fuel Initiative which was implemented by the 2005 Energy Policy Act and 2006 Advanced Energy Initiative.[228] This legislation aimed to develop hydrogen fuel use, fuel cells, and the infrastructure required to make fuel cells viable for transportation use and cost-effective by 2020. The United States dedicated more than a billion dollars to fuel cell research and development to work towards these goals. More recently however, President Obama cut off funds for the development of fuel cell hydrogen vehicles due to other technologies reducing emissions more quickly. The US Secretary of Energy explained that hydrogen vehicles “will not be practical over the next 10 to 20 years,” this is due to the difficulty in the change of fuel delivery infrastructure. The US government will continue to fund research related to stationary fuel cells.[229]

Fuel cells as an alternative energy resource are lacking in the infrastructure and competitive pricing to be featured in any energy policy that this report will compile. Due to the large cost of platinum in PEMFC type fuel cells which would be primarily used for transportation purposes, it is not reasonable at this time for fuel cell transportation to be much more than a novelty. At the same cost a hybrid electric car or pure electric car would be much easier to integrate into the infrastructure, and some of this technology has already surfaced on the commercial level.

There are various problems with fuel cells, those of efficiency reduction by corrosion, introduction of foreign elements into the system, and durability concerns regarding any materials used to construct the devices. High operating temperature fuel cells have a major concern when it comes to the durability of construction materials, the longer the cell is active the more strain and stress is place on the material, chemically changing its structure and reducing the strength.

Further considerations for storing of the highly dangerous gaseous fuels must be taken into account. Oxygen and hydrogen being highly combustible require a high strength storage means, and upon introduction of these kinds of tanks into a transportation vehicle can cause further hazards in automotive accidents, general wear and tear on vehicles due to weather, and other considerations.

2.4.3 - Electric Cars and Hybrids

One of the biggest challenges of many alternative forms of energy such as solar and wind power, is that they produce pure electrical energy rather than a transportable fuel such as with gasoline or other forms of fossil energy. This limitation has no bearing on immobile consumers such as households and industries, but without a storage medium, this clean energy can't be used for powering the millions of cars on the roads today. As most people know, in portable devices this pure electric energy can be stored in batteries.

In the past decade there has been a new wave of interest in the idea of electric cars. This has mostly arisen from two major factors. The first has been the steady increase in the price of gasoline and knowledge about its negative effects on the environment. The second factor is the continuing development of higher efficiency lithium based as well as more traditional high-energy battery technologies. These two factors have simultaneously lowered the cost of production for electric vehicles and also raised the cost of owning traditional non-electric vehicles.

Initially, only a few small companies and individuals were able and willing to produce fully electric cars because of their expensive batteries. In the 1990's a few auto manufacturers began to create hybrid-electric vehicles. Hybrids are a great compromise as they have all the benefits of a gasoline-powered car, but at the same time have larger onboard battery. This combination allows hybrids to still run on gasoline, but operate at a significantly higher energy-efficiency. This efficiency is partially derived from the fact that electric motors can deliver power much more quickly and efficiently than a piston-driven engine. Because hybrids have a battery bank acting as a buffer between the engine and this drive motor, they can run a much smaller gasoline engine at the most efficient speed. The battery bank then makes up the difference in power when it’s needed or charges itself when there is more power than needed. In a conventional car with no energy buffer, a huge engine must deliver whatever power is needed in real-time regardless of if it is optimal.[230]

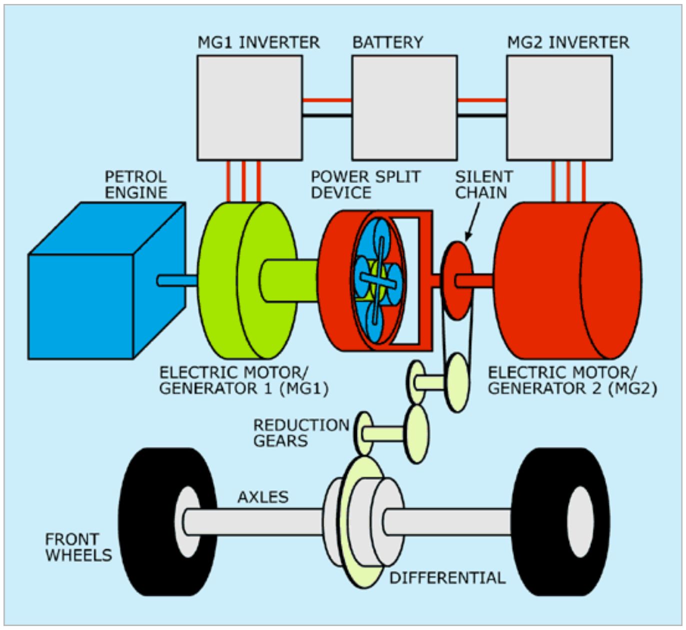


Figure 55 - Diagram of a Hybrid Power train[231]

Another key feature in improving the energy efficiency of a vehicle is regenerative breaking. Traditionally, breaking technology consists of dissipating all the kinetic energy of a moving vehicle into heat or noise. In cars, this is accomplished with a spinning disk on the wheels which is clamped down on when the breaks are applied. The friction eventually stops the car, but all of that energy is completely lost in the process. With regenerative breaking, a car can convert a significant part of the kinetic energy directly into usable potential. This is done in hybrids already and is a fairly simple process. When the breaks are applied, the rotation of the wheels turns the drive motor, effectively acting like a generator, which sends that energy back into a hybrid's battery.[232]

Over the past few years, hybrids have become a fast growing part of the auto industry. Right now, every major car manufacturer has at least one hybrid model, and many even have several. Toyota and their subsidiary Lexus have been leading in this market, offering 7 different models including the very popular Prius. The Prius by itself accounts for over 2 million of the global hybrid sales since 2000, or 814,000 just in the United States. As of 2010, about three percent of all cars currently on the road in the US are hybrid vehicles.[233] Currently, hybrid cars can go much further than traditional cars on the same amount of fuel, with mid-sized hybrid cars getting about 40mpg and compact cars like the Prius getting 50mpg. This market is expected to grow substantially over the next decade as stricter pollution and efficiency regulations go into effect and consumers demand higher gas-mileage from their cars.

As a direct result of the research developments and mass production of hybrid-electric vehicles as well as advancements in the smaller lithium-ion batteries found in electronic devices, battery technology has progressed to a point where it has become more economically feasible to build purely electric cars, sometimes referred to as BEVs (for Battery Electric Vehicle). Certain companies like Nissan are hoping to capitalize on this and have just released or plan to release new electric cars that are not only intended for mass production, but are already being mass produced. Unlike electric cars in the past, these new cars through the improvements in battery technology and mass production are becoming more cost-competitive with traditional vehicles.

Table 7 - New Electric Cars

Make	**Model**	**Range (electric +ex)**	**Charge Time* (@ 120v, 240v, QC)****	**Top Speed**	**Price (consumer)**	**Initial Sales**
Tesla[234]	Roadster	227mi	30h, 6h, 3h	125mph	$101,500[235]	2008
Nissan[236]	Leaf	100mi	20h, 8h, 0.5h	87mph	$25,280	2010
Mitsubishi[237]	i MiEV	75 mi	14h, 7h, 0.5h	81mph	$22,500	2011
BYD[238]	E6	205mi	20h, 7h, 0.8h	100mph	$32,000	2011
Ford[239]	Focus EV	100mi	8h, 3.5h,	84mph	$26,000	2012
Tesla[240]	Model S	160 or 300mi	15h, 3.5h, 0.5h	120mph	$49K or 58K	2012

*charge time reflects fully charging a depleted (empty) battery

** QC refers to specialized, high-voltage "quick-charging" stations

Although the average American drives less than about 40 miles each day, there has been a reluctance to adopt battery-powered cars because of their range limits compared to gasoline. This is known as "Range-anxiety" and has been a key reason for the slow development of the electric car market. By increasing the efficiency of electric vehicles and the capacity of their batteries, companies have been trying to reduce this range anxiety by pushing the range out to and sometimes above a hundred miles on average. Others, like General Motors and Toyota have taken a different approach. Instead of only increasing the range of the battery, they have invested in Plug-in Hybrid Electric Vehicles (PHEVs). These cars are similar to hybrids in that they have small gasoline-powered engines, but differ in that these engines only supply power once a pre-charged battery has been depleted. In a hybrid the engine is always running, but in PHEVs the car will operate completely on battery power, not burning any gas, for the range of the battery's initial charge. This approach eliminates the range anxiety of owning an electric car by allowing it to act like a hybrid if it needs to go further than the range of the battery alone. Two examples of mass-market vehicles using this technology are the 2011 Chevy Volt and the 2012 Toyota Prius.

Table 8 - Mass-market Plug-In Hybrid Vehicles

Make	**Model**	**Electric Range**	**Charge Time (@ 120v, 240v)**	**Fuel Economy**	**Price (consumer)**	**Initial Sales**
Chevy[241]	Volt	35mi	10h, 4h	37mpg	$32,780	2011
Toyota[242]	Prius PHEV	13mi	3h, 1.5h	50mpg	$33,000[243]	2012

Despite range anxiety, typical electric cars which run completely off of a battery are fully capable of meeting the needs of a majority of car owners, and especially in households with more than one car. Many households today, with two job holders, have a need for a second car anyway, and so an electric car would meet the daily needs of one person, where as an alternative hybrid or traditional car can be used for long-distance road trips or in emergencies when the battery of the electric car is not sufficiently charged.

The problem of range has been a big focus of the electric car industry for a while now, and there have been many suggested solutions generated in the process. One very obvious solution is the concept of wide-spread public charging stations. The idea with this is that people can park their electric car in parking garages or in locations that have been fitted with specially designed high-power charging stations or at the very least standard 120-volt outlets. Technologically this is a very simple idea and is only a matter of implementation. Because the implementation would have an associated cost, and at least right now there are not many electric cars to merit the stations anyway, it has not taken place. By mass-producing the electric cars first, this will hopefully create the demand for these stations, and thus allow the new electric car owners to charge their vehicles while they are away from home. One way that the cost of such stations can be mitigated is by metering them and having the users pay a fee for the energy they use from the station, just as one would pay for fuel at a gas station.

Assuming batteries retain their inability to be charged too quickly over the next few years, electric cars will continue to present an issue of time consumption. Typically it takes an electric car at least an hour to charge if not several. This can be reduced by charging the car frequently at charging stations, but it is a very real problem for long-distance trips. There is however a possible solution to this problem. It is possible to transfer power through induction and so it is therefore possible to charge an electric car via induction lines embedded in a road-surface. At least initially such an idea would not be feasible or necessary for all roads, but might be a practical option for highways. A "charging lane" could be setup on major interstate highways which would allow electric cars to travel long distances without having to stop to charge. As the technology becomes more main-stream, it could eventually be expanded to other highways, and eventually certain high-traffic roads. Funding for such an idea might be gotten through the increased use of tolls on highways. Tolls in general might also serve as an alternative means for states to generate revenue for use in general road maintenance as fewer drivers are paying traditional gasoline taxes. A more sophisticated approach might also be to build devices into cars which meter the power flowing into the vehicle and communicate that information with the highway at certain checkpoints along the route, or along the entire route if feasible.

Figure 56 - Electric car charging via induction loops in the road[244]

At this point in time, many people have indicated that they would like to own an electric car or hybrid but have generally been turned away by the price of such vehicles. Hybrids have come down in cost significantly over the past decade and companies like Nissan and Ford believe this same process of cost reduction through mass production can be applied to electric cars. The Leaf, Nissan's first mass-market electric car, has received the company's full support and will hopefully show that it is possible to own an electric car at a competitive price. Nissan is even hoping to reach a production capacity of 500,000 Leafs over the next 2-3 years.[245] Ford has yet to develop an independent electric brand, but has committed to all-electric versions of their existing line of vehicles. The Ford Focus EV will be the first of these and is slated for public release in late 2011 for the 2012 model year.

Figure 57 - 2011 Nissan Leaf[246]

Figure 58 - 2011 Chevy Volt[247]

Most of the running cost of an electric vehicle can be attributed to the maintenance and replacement of the battery pack because an electric vehicle has only around 5 moving parts in its engine, compared to a gasoline car that has hundreds of parts in its internal combustion engine. This is why electric cars were not economically feasible before the recent breakthroughs in battery production which resulted from hybrid development over the past decade.[248] Electric cars being sold today often come with warranties guaranteeing them for at least 100,000 miles and between 8 and 10 years depending on the manufacturer. These types of warranties can re-assure buyers of such vehicles that they no longer have to worry about the battery replacement costs of the past, as these new batteries have been designed to last for the lifespan of the vehicle.

With the cost of battery technology slowly coming down, it makes a lot of sense to incorporate it into vehicles, and especially individual cars. In the next 10-20 years, the percentage of vehicles sold being hybrids will most definitely increase, followed by electrics and partially electric vehicles. This transition will be good for the environment in the long-run as it will reduce each cars gasoline consumption and emissions or eliminate them completely in the case of electric cars. Taking the task of power-generation out of vehicles and placing that burden on the grid instead, allows for much more flexible energy-sources such as renewables that have lower energy density or are not available 24 hours. It will also allow Americans to continue to experience the freedom and mobility they are accustomed to while tackling those environmental problems. By allowing people the same freedom of owning and driving cars, and simply changing how those cars are powered, it creates the least impact on those users. It also means that they can use the existing roads and highways with little or no modification, which in of itself reduces overall costs associated with such a transition.

3 - Existing Energy Legislation

Alternative fuel and fuel economy legislation dates back to the Clean Air Act (CAA) of 1963.[249] In an attempt to better the environment and limit the amount of carbon emissions legislation is necessary in order to institute and enforce laws/regulations centered on pollution produced by the daily use of energy. In 1963 the act was passed in order to develop a national program in which air pollution was minimized in order to address environmental problems associated with air pollution. The Amendments to the Clean Air Act (CAAA) culminating in 1990 established standards and procedures for reducing human and environmental exposure to a range of pollutants generated by industry and transportation. Four major regulatory programs were initiated by the 1970 amendments which include national emission standards, new energy resource performance standards, national ambient air quality standards, and the implementation of state air pollution reduction plans. Further revisions to the CAA were put in place in 1977, these amendments addressed concerns regarding deterioration of air quality in areas meeting the air quality standards, defining of areas which do not meet one or more of federal air quality standards as non-attainment areas, and adjustments to the permit review policy to ensure attainment and maintenance of the national air quality standards. In 1990, further revisions to the CAA increased the enforcement authority and responsibility of the federal government, initiated programs to regulate acid rain and other toxic air pollutants, the reduction of chemicals shown to deplete the ozone layer, and the initiation of additional research programs.

At the same time as the 1970 amendments, Congress established the Environmental Protection Agency (EPA) whose purpose was to implement and enforce the requirements of the CAA. One of the responsibilities of the EPA is to set limits on the amount of air pollution anywhere in the U.S. Under the CAA the EPA is responsible for creating regulations limiting the emission of air pollutants around Chemical plants, utilities, and mills.[250] States or tribes are allowed to have stronger air pollution regulations than those set by the EPA, but not weaker. All state, tribal, and local agency air pollution plans must be approved by the EPA. If the plan does not meet the requirements set by the EPA, sanctions can be issued and if necessary the EPA can enforce the CAA in the area. The EPA assists in the research, study, and funding of state, tribal, and local agencies to further the protection of the quality of air.

State, local, and tribal governments are responsible for monitoring of air quality and inspecting facilities under their jurisdiction.[251] States are required to develop implementation plans that outline how the air pollution will be controlled under the CAA. These plans are a collection of regulations, programs and policies that the state will use to clean up polluted areas, public and industries must be involved through hearings and are allowed to comment on the plan.

After the Arab oil embargo and petroleum shortages of the 1970's, congress enacted the Energy Policy and Conservation Act of 1975 which created the Corporate Average Fuel Economy (CAFE) program through which mandatory fuel economy standards are set based on studies done by the EPA. This act also introduced a credit system for CAFEs in which a manufacturer is given a credit should they exceed the CAFE for the model year, these credits go towards shortfalls in standards for three years forward or back.

In 1988, the Alternative Motor Fuels Act (AMFA) established vehicle manufacturer incentives in the form of CAFE credits for production of vehicles utilizing alcohol and natural gas based fuels as either a petroleum replacement or to be used in conjunction with petroleum. Vehicle manufacturers are required to meet average fuel economy and greenhouse gas emissions standards for passenger cars, light-duty trucks, and medium-duty passenger vehicles sold in the United States. Manufacturers are required to improve fuel economy and reduce greenhouse gas emissions by 5% per year for the vehicles produced between 2012 and 2016. By 2016, vehicles must meet average emissions level not higher than 250 grams of carbon dioxide per mile, equivalent to 35.5 miles per gallon through fuel economy improvements to meet the carbon dioxide emission standards.[252]

The Energy Policy Act of 1992 (EPA-92) is an important law passed in the identification of important components this report's final policy. EPA-92's goal was to reduce the reliance of the U.S. on foreign oil by utilizing alternative fuels, alternative fuel vehicles (AFV), and other methods by which the petroleum dependence could be displaced. Specifically, The EPA-92 regulations require that federal, state, and alternative energy providers use AFVs in their fleets. Meeting these requirements is done through Standard Compliance, where 75% of newly purchased vehicles of a covered state's light-duty fleet use AFVs, and 90% of newly purchased alternative fuel provider's light fleet use AFVs. This act encourages alternative fuel use through voluntary and regulatory means. EPA-92 defines alternative fuels as methanol, ethanol, alcohols, fuels that use 85% or more alcohol with gasoline (E85), natural gas as well as the liquid fuels produced from natural gas, liquefied petroleum gas, hydrogen, electricity, biodiesel, coal-derived liquid fuels, non-alcohol biological fuels, and P-series fuels (added in 1999).[253] Under this act the DOE has the authority to add more alternative fuels to the list if certain criteria are met.

The Energy Policy Act (EPA) of 2005 amends the previous act to include articles that regulate the use of alternative energies for transportation and incentives/credits for those businesses/individuals who select alternative energy vehicles. $25 million was authorized by this act form 2006-2009 for the use of fuel cells in school buses. $5 million per year from 2006-2010 was authorized for the use of testing biodiesel in engines and to determine the impact of these fuels on emissions. Alternative motor vehicle credits were also established with this act, which are to equal 50% of the incremental cost of the vehicle as well 30% of the incremental cost with near zero emissions.[254] This credit is available on the purchase of alternative motor vehicles and awards the following amounts dependent on the gross vehicle weight rating (GVWR):

- $5,000: 8,500 GVWR or lighter
- $10,000: 8,501 - 14,000 GVWR
- $25,000: 14,001 - 26,000 GVWR
- $40,000: 26,001 GVWR and heavier[255]

Similarly for fuel cell and hybrid motor vehicles, a $4,000 credit of light-duty fuel cell vehicles is available on purchase. For hybrid light-duty vehicles and trucks with missions <8,501 GVWR the credit award is based on the efficiency gains over 2002 baselines:

- 125%-149%: $400
- 150% -174%: $800
- 175%-199%: $1,200
- 200%-224%: $1,600
- 225%-249%: $2,000
- 250%+: $2,400[256]

A tax credit equaling up to 30% of the cost of alternative refueling property, up to $30,000 for a business is available based on the use of natural gas, propane, hydrogen, E85, or biodiesel. Residential refueling equipment is eligible for a $1,000 tax credit.

The Energy Independence and Security Act of 2007 (EISA) is another law passed that is important to the research on creating an effective energy policy. The goal of EISA was to improve vehicle fuel economy and reduce domestic dependence on petroleum based fuels. EISA set various regulatory standards to achieve this result. One of which was the creation of a Renewable Fuel Standard, which sets a required amount of renewable energy sold in 2022 for the purpose of transportation uses be a minimum of 36 billion barrels, to include bio-fuels and biomass diesels.[257] Additionally it sets CAFE standards for passenger cars and light trucks to be 35 MPG by 2020, and includes grant programs which encourage the development of bio-fuel, hybrid, and various electric vehicles.

In 2009, President Obama enacted the American Recovery and Reinvestment Act (ARRA) which appropriated numerous legislative provisions and funding for the improvement of renewable, alternative, and self-sufficient energy use in the U.S. The ARRA appropriated $800 billion to be used in part towards renewable energy technologies and the furthering of energy independence for the U.S. Among the provisions there are a few key sections involving alternative fuels, advanced vehicles, fuel economy, and engine idle reduction; these sections provide funding for the research and construction of alternative energy technologies as well as create/modify tax credits for the use of such technologies. $2.5 billion was appointed through the ARRA for U.S. Department of Energy research and development as well as other projects through the Office of Energy Efficiency and Renewable Energy, $2 billion was appointed for the manufacture of lithium batteries and hybrid electric systems for use in the transportation sector, $400 million was appointed for electric vehicle production, and $3 billion was appointed for the purchase of alternative fuel vehicles for federal usage.[258] There are various other appointments of funding via the ARRA whose goals are to increase fuel efficiency, decrease toxic emissions, and stimulate the growth of the market for alternative energy vehicles and their technologies for use in the transportation sector.

These are brief overviews of the important portions of the alternative energy legislature that has been enacted and is enforced today in the U.S. It is important to realize that the appropriation of funding via these legislative acts allows the furthering of research, development, and implementation of new emerging technologies or the integration of existing technologies to be used to lighten the fossil fuel burden on the transportation sector. The acts reviewed do not reflect upon grid power production directly, however the regulation of carbon emissions and air quality standards set by the EPA are not directly enforced by the EPA, unless otherwise deemed necessary, and are therefore suspect to an inherent flaw by which information can be altered to meet the necessary requirements set by the EPA. Data collected for the EPA at various sites for chemical emissions are supplied by the companies, facilities, and areas by their own scientists, it is therefore a difficult task to identify when standards are truly being met, and not simply a fabrication of industrialized science. Legislature and regulations are necessary to maintain a sense of order, but there is a gap in the enforcing of the laws due to a lack of standardization of testing which is not performed by the EPA directly. Certainly legislation is required to distribute funding for national projects and policies; however the enforcement of specific standards/regulations cannot be guaranteed due to the lack of power and resources the EPA has to enforce them.

3.1 - Renewable Portfolio Standards

A renewable portfolio standard or "RPS" is a type of state-imposed regulation that requires that electric utilities increase their production of energy from renewable energy sources. RPS mechanisms generally obligate those electricity supply companies to produce a specified fraction of their electricity from renewable energy sources over a given amount of time. In the United States, certified renewable energy suppliers earn certificates for each unit of electricity they produce. They can then sell these along with their electricity to electric utility companies. The utility companies then pass on those certificates back to the regulatory body to demonstrate their compliance with the regulations.

The RPS system is what's known as a market mandate and so relies almost entirely on the private sector for implementation. Because it is market-based in terms of how the renewable energy is generated, RPS programs tend to allow more price competition between different types of renewable energy. This market implementation of renewable energy supply therefore should result in the most efficient and innovative solutions, through the act of competition, delivering renewable energy at the lowest possible cost to both the utility and the end-user.

Currently the majority of states have some form of RPS in place and some states have had such regulation in place for up to a decade now. Typically these RPS mandates have only suggested a growth rate of 0.5% annually. However, after several years of a program being in place this number usually gets adjusted to require higher renewable energy growth rates. The chart below illustrates the states which have or do not have such programs in place.

States With Renewable Portfolio Standards

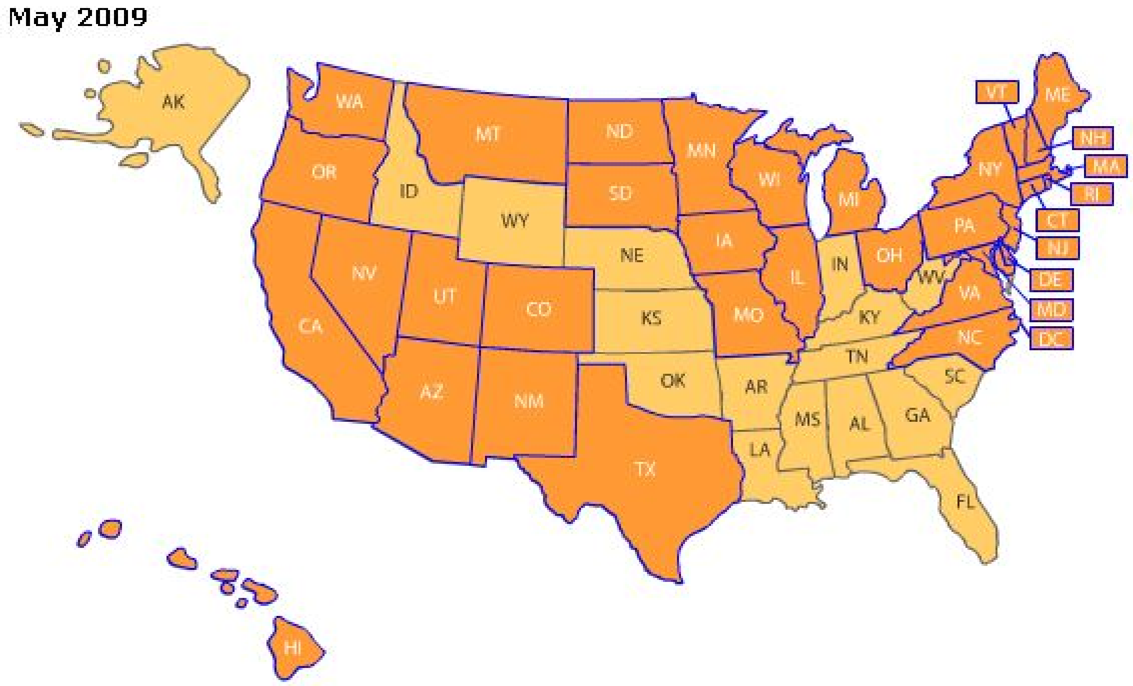


Figure 59 - RPS programs[259]

As of 2009, the states colored in the darker orange currently have some sort of RPS program or system in place. States that are colored in a lighter shade of yellow do not have any RPS system in place or are states that have only a voluntary RPS system. Voluntary or goal-oriented RPS policies rather than mandates so far appear to be an insufficient means of promoting renewable energy adoption. So for the purposes of this project states having such nonbinding policies will be considered part of the share of states which do not have a full RPS system in place.

The states in which binding RPS systems already exist serve as a good model for other states that do not have these programs in place but may soon adopt them either through federal policy or individual will to do so. These types of mandates put a concrete deadline on renewable energy adoption and so an RPS program implemented at the federal level would be a very useful and central part of an overall national energy policy.

4 - Analysis and Summary of Data

4.1 - Energy Cost Comparisons

Throughout the course of this project, cost data was collected or estimated and has been summarized in the table below. The first table represents grid-based energy sources compared at wholesale electricity costs experienced by the utility company. Capital and annual cost figures are based on the nameplate generating capacity. Lifetime costs incorporate the capital and annual cost figures over the expected service life and adjusted for the capacity factor of each resource.

Table 9 - **Cost Estimates for Grid-Power Sources**[260]

Energy Source	Capital Cost ($/kW)	Annual O&M ($/kW)	Service Life (years)	Lifetime Cost (cents/kWh)
Wind Turbine	2145	76	20	7.7
Solar (Photovoltaic) [261]	4400	47	25	12.7
Solar (Thermal) [262]	2024	61	30	10.9
Tidal Turbine	2300	189	20	12.8
Geothermal [263]	4655	170	40	4.9
Hydrogen Fusion	6000	130	40	3.5
*Uranium Fission	3900	300	40	6.7
*Coal Power	3400	320	40	7.5
*Natural Gas[264]	1400	-	25	11.5
*Petroleum Oil	1800	-	25	13.5

Because it is useful to compare the costs of new or alternative energy sources with existing technologies and fuel sources, non-renewable energies are also included in the tables. These mainly consist of fossil fuels and nuclear power, each denoted by asterisks before their name. The prices reflected in the table as well as the following table are based on the research conducted by members of this project between quarters Q3 of 2010 and Q1 of 2011. The fuels below are compared at their retail price, which is what the consumers of each fuel would expect to pay for them. These prices, especially for calculated equivalents, assume that the fuels are primarily used for personal generators or as transportation fuel and are based on the national average prices of each fuel.

Table 10 - **Transportation Fuel Costs**[265]

Fuel	**Cost (cent/kWh)**	**Cost ($/gal) *equivalent**	**Power Density (kW/m^2)**	**Power Density (*gal/acre)**
Crop-Based Ethanol	23	3.7	0.8	250
Algae Oil (Bio-Crude)	12.5	2.1	19.8	5000
Processed Algae Fuel	19.5	3.1	19.3	4875
*Traditional Gasoline	18.5	2.8	-	-
*Petroleum (Crude Oil)	13.5	2.2	-	-

Comparing the final product costs for grid-based energy is rather simple because they all produce the same final product of electricity, but comparing transportation fuels is a bit more complex. Fuels can come in a variety of forms and each has their own energy density and consumption rate. To overcome these differences and make comparing these fuels with each other easier they are all listed in units of equivalent gallons. What this means is that the energy content of each type of fuel per given volumes of that fuel were taken into consideration and compared with the energy content of 1 gallon of conventional gasoline. So, cost per gallon equivalent in the table represents the actual cost of obtaining 115,400 BTUs worth of a given fuel.[266] The energy content used for those calculations as well as of a variety of other fuels is listed in the next table below.[267], [268]

Table 11 - **Fuel Energy Content & Waste CO2**

Fuel	**Energy per Volume BTUs / gal (US)**	**Energy per Mass MJ / kg**	**CO2 Released grams / MJ**
Biodiesel	117,100	40.0	0 (net)
*Conventional gasoline	115,400	45.0	
*Crude petroleum	131,800	43.0	73
*Diesel	128,700	45.0	
*E85 (Ethanol + Gasoline)	81,600	32.4	
E100 (Pure Ethanol)	75,700	29.8	0 (net)
Hydrogen	n/a	121	0
*Natural Gas	n/a	54.0	51
*Uranium (standard fission)	n/a	650,000	0
Tritium + Deuterium (fusion)	n/a	337,899,016	0
*Black Coal (Anthracite)	n/a	25.5	90

Several energy sources (mostly renewables) are absent from the table above as they do not for all practical purposes consume a fuel to generate power. These types of energy sources derive their energy directly or indirectly from the sun or via natural processes, and so cannot be calculated in a meaningful equivalent way. Additionally, there are a few fuels in the table that are either virtually unlimited in supply or completely renewable within the lifetime of the Sun. The fuels with an asterisk are nonrenewable and have a significantly finite supply here on earth. Fuels producing zero carbon-dioxide, according to the table, are those which either do not contain carbon at all or in the case of bio fuels have a life-cycle, or "net", CO2 output of zero. Using this lifecycle value of zero for non-fossil fuels is more practical since the quantity of CO2 released by combustion for those fuels was previously removed from the atmosphere within a significantly short amount of time, compared to the millions of years for fossil fuels.

4.2 - Energy Demand and Infrastructure Growth

The next step in devising an energy policy, after understanding each of the energy sources, was to quantify the current state of renewable energy use. In addition to getting a current capacity, it is also important to look at the current growth trends of both the demand for power in general, and the rate at which renewable energy sources are being utilized to meet demand. The following table represents a summary of the growth and current domestic capacity (within the United States) of each of the energy sources that were looked at during the course of this project.

Table 12 - **Installed US Capacity & Growth (as of 2010)** [269]				
Energy Source	**Nameplate Capacity (MW)**	**Capacity Factor**	**Real Output (GWh/year)**	**Annual Growth (5-year average)**
Solar (Photovoltaic)	1,256	20%	2,201	98%
Solar (Thermal)	431	26%	960	15%
Wind Turbines[270]	40,200	25%	88,098	31%
Hydro (Traditional)	79,511	44%	250,600	0%
Tidal Turbines[271]	0.2	27%	0.47	n/a
Geothermal[272]	3,086	85%	22,980	12%
*Nuclear (fission)	107,194	91%	798,855	0.5%
*Coal	292,849	72%	1,755,904	- 2%
*Natural Gas	264,527	42%	920,797	1%

The nameplate capacity of each source represents the peak capacity that can be generated, but because renewable energy sources do not always operate at peak capacity a capacity factor is taken into account. This capacity factor represents the percentage of the nameplate capacity that is actually generated on average and can be used to calculate the real output of a given resource. The calculation for annual output is simply the product of the installed nameplate capacity, the capacity factor, and the number of hours in a year:

$$\text{Annual Energy Output} = 365.25*24*F*N$$

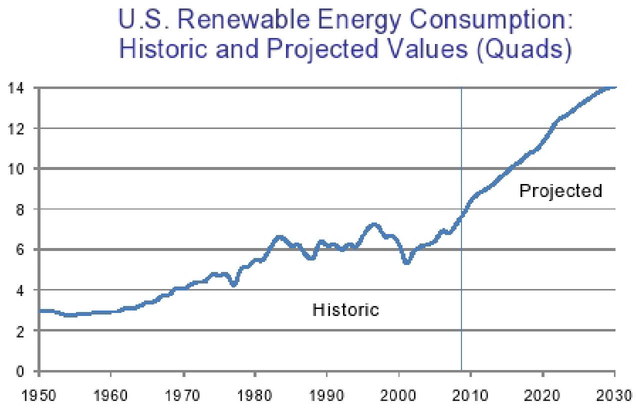


Figure 60 - U.S. Renewable Consumption[273]

In 2008, wind power provided roughly 42% of newly installed capacity for United States energy production which totaled 8545 MW brought online for the year accounting for a 43% increase in wind energy capacitance in operation.[274] In 2009, an additional 9453 MW of wind power was installed totaling 34,863 MW of capacitance in operation.[275] The potential for wind energy growth is large, “It is not a question of lack of resources,” said Tim Stephure, an analyst at Emerging Energy Research, a consulting firm in Cambridge, Mass, “by 2020, wind’s installed capacity could be five times higher than it is today, reaching about 180,000 megawatts.” [276]

311 MW of grid connected Photovoltaic capacity was installed in 2008 a growth of 61% with an installed cost reduction of 4.6% to $7.6/Watt due to a reduction in wholesale module costs.[277] An additional 429 MW was brought online for 2009 accounting for an increase of 52% in solar photovoltaic energy capacitance in operation, bringing the total U.S. photovoltaic farm grid-connected power generation to 1256 MW.[278]

Six geothermal power plants, totaling 177 MW came online in 2009 which accounted for an overall increase of 6% of the U.S. geothermal energy capacity.[279] As of August 2009, the U.S. total geothermal capacity was 3152 MW according to the Geothermal Energy Association with an additional 6443 MW of power plant capacity in construction or planning. 125 MW worth of that is already under facility construction and has begun drilling which include two facilities in California accounting for 85 MW and three in Nevada totaling 39 MW.[280]

Estimates by the United States Energy Information Administration show total domestic electricity demand rising about 1.2% each year over the next few decades. As of 2010, the total

US electric demand was about 4,101 annual terawatt-hours. The estimate of demand growth over the next few decades is based on fairly conservative assumptions that energy consumption per capita will remain fairly constant, and so does not take into account large-scale changes such as electric car adoption, personal energy conservation, and significant increases in energy-efficiency. The following graph represents the percentage of this EIA-estimated demand that will be generated by renewable sources, assuming hydro-electric sources remain constant and non-hydroelectric renewable energy sources continue to grow at the current rate. The "conservative" growth of 6.4% is based on the 15-year average, while the more optimistic growth rate of 13% is based on the past 5 years' average.[281]

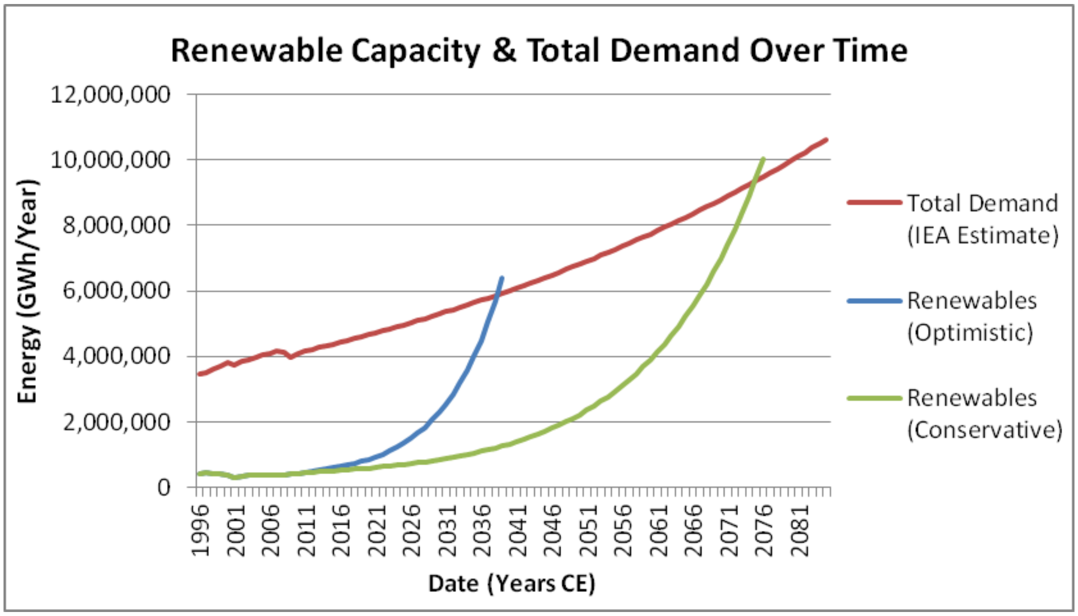


Figure 61 - Renewable Capacity and Demand[282]

As previously stated, the graph above assumes that demand per capita will remain generally the same over time. To get a better picture of demand however, we need to look at some other changes in lifestyle that can affect this estimated demand over time. The changes that are believed to have the biggest impact on demand include: an increase in distributed power generation, such as with residential solar panels and small wind-turbines; widespread adoption of partially or fully electric vehicles; and increased energy efficiency of consumers in general.

The easiest of these three to calculate is the adoption of plug-in hybrids and electric cars in the marketplace. Even this estimate however assumes that electric and plug-in-hybrid car adoption will follow a similar trend as traditional hybrid adoption. Hybrid car sales currently represent about 3% of the new car market and are generally expected to continue doubling every 5 years. Based on this trend, the combination of electric and plug-in-hybrid car markets could very likely represent 3% of new car sales by 2020, and possibly 12% by 2030 if the trend continues. Another important point to bring up is that these figures also assume that the government continues to offer similar incentives for buying these types of cars as it did with hybrids through the 2000s.

One of the effects of all these electric cars will be an increase in electrical demand on the grid, which can be found by estimating the amount of power each car will need per day and multiplying this by the percentage of the total number of plug-in cars. Using the assumption once again that the average American typically drives 40 or 50 miles per day and electric drivetrains can usually deliver this 50-mile range on 12 or 15 kWh of energy, that come out to 5480 kWh per year per car. These numbers are all based on the specifications of mass-market EVs produced or in production in 2010 and so are probably conservative figures as these are essentially using first-generation technology. Using these assumptions and the assumption that each car stays on the road for about 8 years, it can be roughly calculated the cumulative amount of energy being used by electric cars each year. This estimate is shown in the following graph.

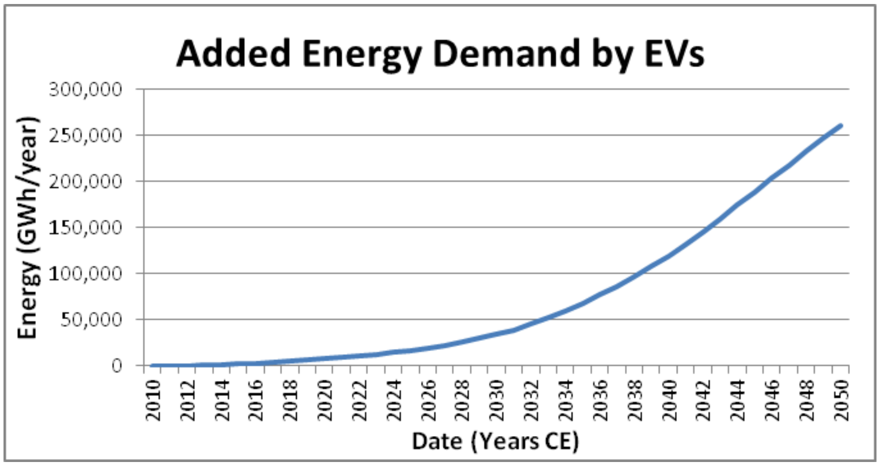


Figure 62 - Added Energy Demand by EVs[283]

Although these plug-in vehicles represent one challenge of further increasing our electrical energy demand, the advantage they provide is that they similarly reduce the consumption of fossil fuels such as gasoline and diesel fuel. Even where the electricity being delivered by the grid is based on other fossil fuels such as coal or natural gas, the much greater energy efficiency of electric drive trains still constitutes a net decrease in fossil fuel usage. Additionally, by shifting the energy demand of vehicular transportation from gasoline to grid-based electricity it indirectly allows for the use of renewable energy sources in powering those vehicles. To power any vehicle in real-time requires a level of portability and energy-density that most renewable energy sources cannot deliver on a small scale, but because of the energy redistribution ability of the grid, low-density power plants and energy farms can collectively contribute to charging EV batteries.

The next major contributor to changes in energy demand on the grid will be the continued expansion of distributed power generation in the United States. "Distributed Generation" is an umbrella term to denote any means of electrical power generation by residential and commercial suppliers rather than centralized power plants or energy farms. “Distributed Generation” can include any fuel source. Usually fossil-fuel based generators are used in industrial and commercial applications and residential consumers use renewable energy sources that require far less maintenance and do not impact home-owners' health and local environment.

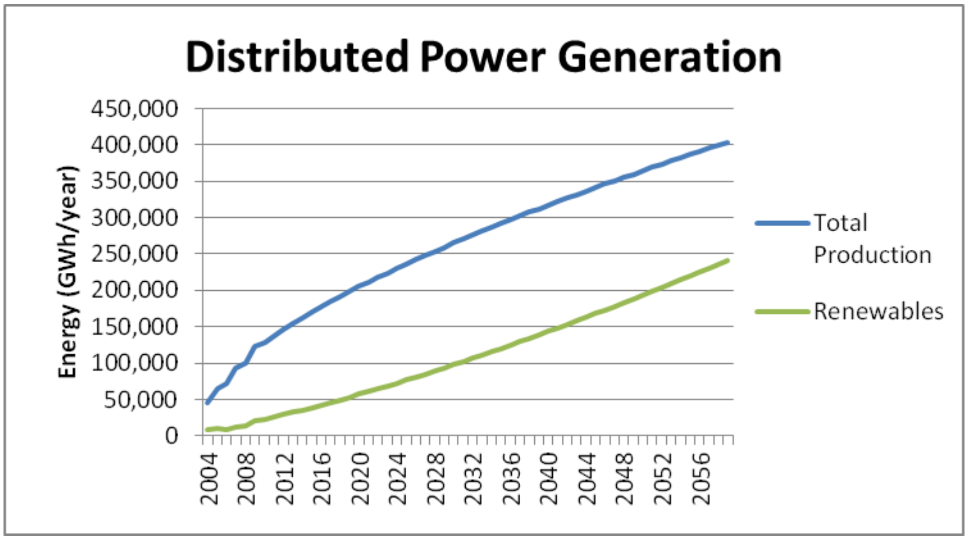


Figure 63 - Distributed Power Generation[284]

For the percentage of total distributed generation that is based on renewables, photovoltaic solar panels are becoming the most popular source. This is partly due to their unobtrusive nature as an easily installed low-profile roof fixture, and also because of their low maintenance. In rural areas and especially on farmland, wind turbines are another popular choice. In either case or even using other methods, distributed energy generation has the effect of significantly reducing the total energy demand placed on the grid and in some cases can providing additional power to the grid.

Energy is provided back to the grid when an individual household or business uses less energy than what is produced by their own system. Distributed generation systems that have the ability to exchange excess power supplied or demanded between the local supply and the overall grid network are known as "grid-tied" systems. Grid-tied systems can cost slightly more to install than off-grid systems, but can provide an extra level of practicality that the user would otherwise not have. If an individual has a certain installed capacity but is not tied to the grid, they are fundamentally limited in how much energy they can use and if they increase their capacity they will likely end up with a surplus of energy during off-peak hours. One solution to this problem of uneven energy demand is to have a battery bank installed. Batteries serve as a buffer between the constant energy production and the variable energy consumption. However, battery systems having the capacity needed to serve as an effective buffer usually cost much more than the hardware needed to tie a system to the grid.

Because energy being transferred through the grid is usually subject to market energy rates, it only makes sense then that utility companies compensate individuals for energy they provide to the grid. Technically speaking this is as simple as installing a two-way electrical meter at the individual's property. These meters work in just the same way a regular one-way power meter does in that they measures the flow of electricity in kWh and are different only in that they have the ability to register negative changes in power consumption. These negative changes represent times when the individual customer is producing more energy than they consume and so the meter simply turns backwards.

Currently the rates utility companies’ offer individuals for selling back their surplus energy differs widely by state and even by district in some cases. As part of a new national energy policy, this discrepancy should be addressed and ideally normalized for all suppliers of distributed generating capacity throughout the nation as a whole.

5 - Conclusions and Policy Recommendations

From the research data collected in this report it is clear that there are many feasible options available in terms of energy source technologies that can be implemented in both short term and long-term scenarios. However, some technologies require upfront investments that serve to deter the use of that technology despite a lifetime savings. Additionally, the inherent incentives for private sector adoption of renewable energy are not always clear or quantifiable on a case-by-case basis. Therefore, it is believed that government programs and policies can and should be created to assist or direct the adoption of these cleaner, renewable sources of energy in the interest of long-term stability, public health, and environmental protection.

5.1 - A Federal Renewable Portfolio Standard.

The current RPS mechanisms in place in some states have met with a degree of success that could easily be implemented in other states. A federal minimum RPS would ensure that the entire country would begin the process of installing and utilizing renewable energy resources. Based on the rate of adoption in states with existing RPS programs, a reasonable schedule for the federal minimum might look like this:

Table 13 - RPS Schedule

Date Range	**Increase (per year)**	**Increase (during interval)**	**% of total energy supply at end date**
2011 - 2014	0%	n/a	0%
2014 - 2020	0.5%	3%	3%
2020 - 2025	1%	5%	8%
2025 - 2030	2%	10%	18%
2035 - 2040	4%	20%	37%

The schedule above includes a grace period that allows companies and states to prepare for the program before any requirements go into effect. The program could also continue into more years than are shown or be adjusted at future dates to reflect changes in energy demand and feasibility of renewable energy implementation.

Because renewable sources are not always equally distributed among geographic regions, a certificate exchange system could also be implemented in conjunction with this RPS mechanism. RPS certificates in this model would be issued by a government agency such as the Department of Energy to producers of renewable energy such as hydro-electric dam operators, geothermal plants, solar, and wind farms. Energy producers could then pass on those certificates to the utility companies that they supply to. To complete the cycle, the utility companies would then provide the certificates back to the government as evidence of their adherence to the RPS policy. Because this would be a federal program, the certificates would be interchangeable between utility companies redistributing power across state lines. States with existing RPS programs that meet or exceed the federal standard would be allowed to continue their own programs if they chose to.

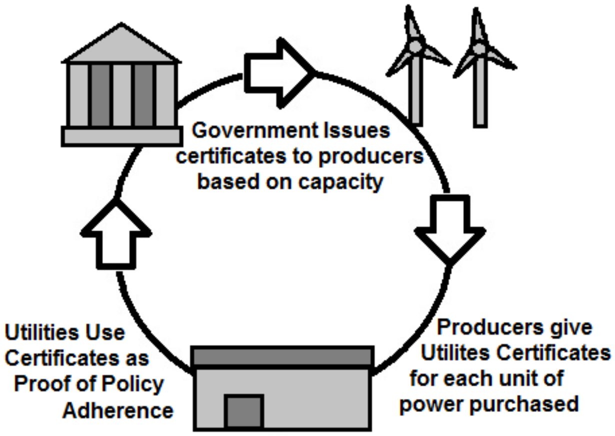


Figure 64 - RPS program cycle[285]

As a mandate based policy component, the RPS program would not constitute any significant amount of spending aside from administrative costs to implement within the DOE. If the program in general and energy certificates within the program are both managed electronically it will drastically reduce the amount of spending related to administration.

5.2 - Low Interest Renewable Energy Loans.

There are many individuals and business entities that wish to deploy or harness renewable energy for themselves or as suppliers to the grid, but it is very rare that they have the capital on hand to do it. It is also apparent that many financial institutions will not accept the risks associated with funding individuals or startup companies' renewable energy investments. This problem can be easily solved with the issuance of government sponsored loans specifically used for these types of infrastructure investments.

Because these are loans and not credits or grants, they would not add any significant amount of long-term spending burden to the government's budget. Ideally, these loans would be issued at close to zero-percent interest in order to encourage companies and individuals to use them. In a worst case scenario where administrative costs become significant and further external funding cannot be obtained, the interest rate on new loans can be adjusted higher to cover costs. In a best-case scenario, an interest rate could be chosen which is both sufficiently low enough to spur development and also sufficiently high enough to result in a net profit. This additional revenue could be used for other renewable-energy activities or re-invested in the programs discussed in this project.

5.3 - Tax Credits and Rebates

An important part of a continued policy toward promoting a relatively new technology is that incentives of every kind be considered or given. Tax credits and rebates have been very successful at promoting certain technologies already and make early adoption much more affordable. It is for these reasons that as part of the policy suggestions of this report, these types of incentives be seriously considered.

Specifically, credits are already awarded to homeowners to reduce the cost of installing solar panels, or to purchase an electric car. These two programs in particular should be continued. They can eventually be phased out, once it is clear that the market does not need them in place. This can happen either after a set amount of time or customers, such as with the similar tax credit awarded to hybrid car buyers a decade ago, or it can be evaluated after certain intervals to assess its effectiveness so far.

One final recommendation on the subject of tax credits is that replacing them with tax rebates creates the same amount of financial impact, but can be much more effective at convincing individuals to use them.

5.4 - Disincentives and Pollution Accountability

The United States IRS is currently utilizing a “gas guzzler tax” which is issued to the manufacturer or importer of vehicles in the United States. These taxes have been in effect since 1991 and require that the manufacturer/importer pay the United States government for every vehicle that does not meet the minimum fuel economy rate of 22.5 miles per gallon.[286] The tax costs are as follows:

Table 14 - Gas Guzzler Tax values

Fuel Economy (MPG)	Tax cost ($)
At least 22.5	N/A
21.5≤ x < 22.5	1000
20.5≤ x < 21.5	1300
19.5≤ x < 20.5	1700
18.5≤ x < 19.5	2100
17.5≤ x < 18.5	2600
16.5≤ x < 17.5	3000
15.5≤ x < 16.5	3700
14.5≤ x < 15.5	4500
13.5≤ x < 14.5	5400
12.5≤ x < 13.5	6400
x < 12.5	7700

One suggestion for the reduced energy consumption of the United States is to increase the amount of taxation on such standards, or alter the tax to be paid by the consumer instead of the manufacturer/importer. In order to effectively reduce the amount of low fuel economy vehicles on the road the better suggestion would be to transfer the tax onto the consumer, such that at purchase a significant cost is instilled for knowingly purchasing the vehicle, such as up to 50% of the purchasing cost. Alternatively a yearly tax could be instilled that would account for up to 40% of the car’s blue book value depending upon its fuel economy below the standard.

One such taxation change that was instituted recently was that of registration fees and road taxes based not upon the engines size, but rather its carbon dioxide emissions. The introduction of this change instilled an increase in purchasing low carbon dioxide emitting, and thusly smaller, vehicles.[287] A similar taxation and registration fee could be instilled here in the United States such that:

Table 15 - Carbon Dioxide Emission Registration and Road Taxes

CO_2 Emissions (grams/mile)	Vehicle Registration Tax (% of Blue Book)	Road Tax ($/year)
$x < 200$	12%	150
$200 < x \leq 225$	16%	300
$225 < x \leq 250$	20%	450
$250 < x \leq 275$	24%	600
$275 < x \leq 300$	28%	1000
$300 < x \leq 325$	32%	1500
$325 < x \leq 350$	36%	2100

A supply side approach to this pollution problem is to institute stricter regulation of fossil-fuel burning power stations. A critical piece of this approach however is that there be actual accountability for adherence to these regulations. As such, the government needs to make a somewhat larger investment into either the EPA or DOE in regard to the hiring of inspectors, and scheduling of more thorough and frequent inspections.

These inspectors would be responsible for measuring the actual emissions of power stations and in combination with tighter regulations of the amount of material being exhausted, fines can and should be imposed for facilities polluting. Since the EPA has recently classified CO2 as a pollutant, this emission rate is also very important and is especially important in the context of global climate change.

Carbon reduction at existing fossil-burning plants is something that is a bit more difficult to accomplish than the reduction of other toxins but is equally important for different reasons. The two ways this can be accomplished from a disincentive perspective are to either allow this to continue and tax the entity emitting, or to impose fines for emitting at all and not using carbon capture technology.

It is the recommendation of this report that as an introduction to this idea of capping carbon emissions it would be more practical to first introduce a general tax, before any sort of ultimate cap. The most practical tax scheme would be progressive in that it focuses on the largest emitters of CO2 such as power plants and large industry, while not penalizing smaller entities or individuals who are only releasing a reasonable amount on a per-capita basis.

6 – Hypothetical Energy Crisis Solutions

The energy crisis is an ongoing problem in the United States and the world, the human population relies on this planet to fuel our daily activities. Right now this report is being compiled with on grid power, produced at some distant power plant probably being generated by coal or possibly from the local wind turbine. Eventually fossil fuels will be completely consumed, estimates range from 100 to 250 years for complete energy future reserve consumption. At what point then do we as human beings need to say, “I’m not satisfied with how my power is being produced.” If gasoline prices were 6 dollars per gallon when you went to fill up your car to get to work, would you change your power consumption? Hypothetically this scenario is not far off and the general answer to would you pay x amount of money to continue to use fuels as we do? “Yes, I’m not happy about it but what else can I do?” It’s a legitimate argument, what can you as a single person do to change the way the world operates, let alone the country that we live in. It’s a difficult process to change the way power is utilized, there is a vast amount of petroleum-based energy transfer infrastructure in the United States and to replace that infrastructure with something completely different would take time and large investments by the government. So what then do we do about our primary source of energy being finite in quantity?

One solution that this report has suggested is the introduction of alternative energy resources. Solar power, wind power, geothermal power, hydroelectric power, Nuclear Fusion, Bio-fuels, hydrogen fuel cells, and electric cars have all been explored throughout this report as alternative means of energy production or consumption. The problem then becomes how to utilize these technologies to eliminate the need for fossil and finite supply fuels. As has been discussed in the previous sections solar cells are limitless in their capacity for energy production only limited by the lifespan of our Sun. Wind power is regionally similar as long as the Earth’s climate allows for temperature and weather changes. Geothermal and hydropower technologies are more isolated in their effective placement, and as such are not as commonly used. Fusion power production is a feasible producer of electricity given that all of the energy transferred into explosive energy is collected. Out of all the technologies bio-fuels have the most easily integrated solution to our reliance on fossil fuels. Bio-fuels can be utilized with the same engines, infrastructures, and distribution means as gasoline and diesel.

One proven technology that is as of yet unexplored in the implementation is Solar Space Panels. The same technologies used for land based solar photovoltaic energy production, creating direct current electricity, are utilized to power and charge satellites orbiting the planet. Coupled with the transmission of power through radio waves to an on-Earth power transfer station, the amount of energy attainable with this technology is far greater than could be achieved with on-Earth solar farms. Pacific Gas and Electric, based in California, would purchase the use of 200 MW of solar power from Solaren Corp. to power its local residential and commercial customers as early as 2016. [288] The radio wave transmission technology was proven over the distance of 92 miles between Hawaiian Islands over the course of a four month experiment in 2008. Translating this technology to be a usable, feasible, limitless means of solar energy collection in space simply requires a rocket and a satellite accompanied by investment.

But do these technologies solve the problem of our ever growing energy demand? No. The United States has the largest energy demand in the world, 94.6 quadrillion Btus worth of total energy was consumed in 2009.[289] A large portion of that energy provided the transportation industry with power accounting for 27 quadrillion Btus (29%), 94% of which was petroleum based. The problem becomes the need for Americans to use that much fuel for travel, be it to get to work, school, or in the transportation of goods to a centralized location where further travel is done to procure the goods for use. It all becomes a problem of traveling out of necessity. Why not then remove that necessity to solve the problem. Instead of having a decentralized community in which each individual family unit has a home wherever the home is and requiring travel of a half an hour to get to the centralized shopping complex, office building, or school, why not centralize life. With the introduction of a large self-contained community tower to replace a suburb and city juxtaposition, it is possible to greatly reduce if not eliminate travel needs and costs. Similar to the way any city operates, such a tower can contain all necessary structures in order to carry out the same lifestyles that we have today. The actual structure would have to be large in size, and thus require a significant amount of investment and planning. But the introduction of such an idea could drastically alter the way society is structured. Instead of being spread across the country, people would be located in specific tower communities with airports located conveniently located such that travel is limited. This type of structure would also open up a large quantity of landscape which was previously occupied by housing, office buildings, and state infrastructure including many roadways.

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