Toward a Cleaner America

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I. Abstract

Our world has become more polluted and more dependent on oil throughout the past century. A quarter of the world's global warming emissions come from one country: the United States. Many scientists and politicians have endeavored to decrease the amount of pollutants by switching to cleaner, alternative energy. This report finds that there are many options studied but not yet available and should become commercialized and compete against each other.

II. Introduction

Our nation and world have reached an increased interest in saving the environment and creating energy independence. Within the past 150 years, the level of carbon dioxide in the air has increased from 280 to 370 parts per million. The United States, as well as many other countries, depends on foreign oil, importing 60%, mainly for transportation. Thus, a widely discussed solution to this problem is alternative fuels and alternative fuel vehicles. However, now that options other than oil are recognized by both the federal government and the public, there exists a controversy over which ones to use. Hybrid vehicles and ethanol-fueled vehicles are already on the road. In addition, other ideas proposed include vehicles powered by biomass, biodiesel, liquid hydrogen, hydrogen fuel cells, natural gas, coal-to-liquid fuels, and even solar cars. Also, a large debate has sprung between supporters of one specific fuel, ethanol, and those that oppose it. This report summarizes all alternative fuel and alternative fuel vehicle options, investigates the validity of ethanol as a good transportation fuel, and concludes the best options for the environment and security of our nation.

III. Background

A. Cleanliness

The United States' motor vehicles supply 27% of the global warming pollution. Gasoline emits carbon dioxide, carbon monoxide, volatile organic compounds, unburned hydrocarbons, and nitrous oxides. These pollutants can cause health problems, destroy wildlife habitats, and contaminate our air, water, and land.

B. Dependence on Foreign Oil

Throughout the 1970s, the United States went through an oil crisis due to the Arab Oil Embargo in 1973 and the Iranian Revolution in 1979. This resulted in a 30% cut of oil imports to the United States. However, U.S. oil imports continued to grow to around 60% in 2005, according to David W. Monsma and John A. Riggs in their report, "A High Growth Strategy for Ethanol" by the Aspen Institute. Currently, 97% of all the oil used in the United States is utilized for transportation.

C. Government Regulations

With the increasing awareness and potential of alternative fuels, federal and state governments have taken action to curb greenhouse gas emissions and foreign oil imports. In 1970, a major bill was passed in the United States called The Clean Air Act. This legalizes the Environmental Protection Agency (EPA) to mandate emissions standards in order to curb regular vehicle pollutants such as sulfur dioxides, carbon monoxide, and nitrogen dioxides. The Clean Air Act was later amended in 1990 introducing restrictions such as more oxygen in gasoline in order to diminish carbon monoxide emissions.

IV. Discussion

The following section provides descriptions, advantages, and disadvantages of the many alternative fuels and alternative fuel vehicles already invented and proposed as a solution to the environmental crisis.

A. Biofuels

1. *General Information*

All biofuels such as ethanol are derived from biomass, which refers to all plant and animal matter. This can include trees, algae, switchgrass, crops, and even waste. Since the most common U.S. biofuel is corn-based ethanol, it will be discussed by itself in a later section of this report. Arguments against most biofuels such as "food vs. fuel" debates and land debates will be discussed under the ethanol section as well.

2. *Types of Biofuels*

a. ***Forest Biomass***

i. **General Information**

Forest biomass is derived from what is called "ummerchantable" biomass. This includes wood waste, tree tops, branches, and low quality trees. According to Texas A &

M Research News, about 3.5 millions tons of woody biomass is burned or left over at tree harvest sites. 65% of this, or almost 2.3 million tons, could be recovered for alternative energy.

ii. Cost-Effective and Environmentally-friendly

Woody biomass is seen as both cheaper and environmentally friendly than other types of ethanols. Wood ethanol costs around thirty cents worth of wood to produce a gallon, while corn ethanol requires $1.50 worth of corn. The production of wood ethanol is very eco-friendly as it uses much less fossil fuel than corn-based ethanol plants.

b. ***Biodiesel***

i. General Information

Biodiesel can be produced from vegetable oils or animal fats, although the U.S. mostly utilizes soybean oil. It can be used alone (100% biofuel, known as neat fuel or B100) or as a blend (usually around 20% biodiesel and 80% regular diesel, a mixture called B20).

ii. Cleanliness

Biodiesel produces about 78% less carbon dioxide running on B100 than a regular engine running on gasoline. This is due to a "closed carbon cycle": although the fuel produces carbon dioxide when used in a combustion engine, the plants used to create the biofuel use carbon dioxide to grow, thus decreasing the net amount of carbon dioxide released during combustion. This does not, however, completely eliminate carbon dioxide 100%, since fossil fuels are required to produce the biofuel itself.

Not only does biodiesel reduce carbon dioxide emissions, but it also drastically reduces unburned hydrocarbon, carbon monoxide, sulfate, and sulfur oxide emissions compared to regular diesel. However nitrogen oxide emissions are only slightly reduced or may even be slightly increased depending on engine testing methods.

iii. <u>Lubricity</u>

Biodiesel is an excellent solvent. It increases the lubricity of an engine and leaves no deposit, which increases the engine life. According to the U.S. D.O.E. Office of Transportation Technology, only a 1% biodiesel blend could increase the lubricity by up to 65%.

However, since biodiesel is a better solvent than other fuels, blends particularly higher than B20 can remove deposits in the fuel lines. This can block the fuel injectors in the engine. These blends can also degrade rubber parts within the fuel system as well.

iv. <u>Gelling</u>

Biodiesel also tends to gel quicker at cooler temperatures. Depending on the type of oil from which the biodiesel was derived and on the blend of biodiesel, biodiesel has a range of gelling points. The higher the biodiesel blend, the faster the rate at which the fuel will gel (100%, or neat, biodiesel will blend quicker than a 20% blend).

v. <u>Energy</u>

The energy balance of growing crops, producing the fuel, and emitting the fuel shows that soybean production utilizes more efficient energy than corn production, since soybeans do not require nitrogen fertilizer. The Department of Energy (DOE) reports that each unit of fossil fuel required to produce biodiesel results in a net 3.2 unit of energy gain for biodiesel.

However, some tend to disagree. Dr. Pimental, an entomologist from Cornell University and an avid opponent of all ethanol fuels, conducted a report along with Tad Patzek of University of California-Berkley in order to show the net negative energy of biofuels. In biodiesel's case, Pimental and Patzek found that soy oil had a -32% net energy.

c. ***<u>Biobutanol</u>***

i. Efficiency and Cost

Biobutanol, a fuel produced from crops like sugarcane, corn, and sugar beet, is as efficient as gasoline and contains more energy per gallon than ethanol, which is less efficient than gasoline. Although efficient, the main inhibition in the promotion of biobutanol is cost. Production of biobutanol is similar to that of ethanol, but the enzyme in biobutanol is different and costly.

ii. Attractive to Consumers

Unlike ethanol, biobutanol does not absorb water. This eliminates the need to be blended with gasoline closer to the gas station and fulfills the better option of blending biobutanol and gasoline at the refiner.

d. ***Switchgrass***

i. **General Information**

Switchgrass is a perennial grass that can grow in harsh conditions. Irrigation is not required and fertilizers can be severely reduced. Also, it is mowed once a year, so there is no tillage, which reduces erosion.

However, Dr. Pimental's position presents different evidence. He states that the energy input to produce switchgrass is 3.8 million kcal per year. Converting switchgrass to ethanol provides a negative return of 50% higher than corn ethanol production.

B. Hydrogen

1. *General Information*

Hydrogen can be used in automobiles in either the liquid or gaseous form. To be converted to a liquid, however, hydrogen must be cooled to -423ºF (-253ºC), which requires much energy. Liquid hydrogen has a higher density and therefore less space requirements than gaseous hydrogen.

2. *Methods of Production*

a. ***Steam Reforming***

The most common method is called steam reforming, which is about 85% efficient. During this process, natural gas is vaporized and then mixed with steam. Catalysts strip the methane in natural gas of its hydrogen (which then creates carbon monoxide and carbon dioxide). Finally, a filter cleans the hydrogen gas of any impurities.

However, the carbon dioxide produced during the process amounts to about 350 million tons generated per year at steam-reforming plants. Also, this process costs $4-$8 per kilo. Below is a picture of the process.

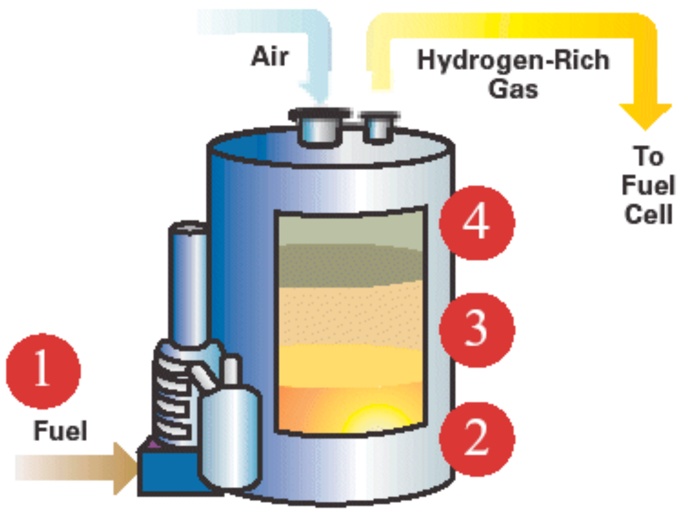

Figure 1: Steam Reforming

http://www.facstaff.bucknell.edu/mvigeant/univ_270_03/John/sources.htm

b. ***Electrolysis***

This process separates water into hydrogen and oxygen molecules and must occur at temperatures greater than 2000ºC (3632ºF). Two electrodes are placed in a solution containing an electrolyte. Current is then run through each electrode. As the current pass through, the water molecules separate and bubbles of hydrogen and oxygen form on separate electrodes.

The amount of water required for electrolysis is about 100 billion gallons/year. Domestic water use in the United States adds up to about 4,800 billion gallons/year. Finally, the United States utilizes about 300 billion gallons/year to produce gasoline.

Thus, the amount of water required for electrolysis is significantly lower than domestic water use and gasoline water use.

A disadvantage of electrolysis is that the price of hydrogen depends on the price of electricity; hydrogen usually costs around $6 per gallon. Another disadvantage comes from the power required to produce the hydrogen. The fossil fuels necessary to create electricity would essentially cancel out the reduced greenhouse gas emissions that hydrogen-powered cars would eliminate. In addition, the amount of power from electricity needed to power our nation's vehicles would not be able to match that provided by fossil fuels today.

c. ***Nuclear Power***

Nuclear power plants emit little or no pollutants and can supply large quantities of power. Also, there is an abundant amount of fuel available to power nuclear plants.

However, nuclear power plants can be very dangerous. Nuclear explosions can emit radiation and harm the public. Also, disposal of nuclear waste is still not yet handled as efficient as possible.

d. ***Renewable Energy***

Renewable energy includes solar, wind, water, and geothermal power. No harmful emissions would be produced, but the hydrogen would have to be transferred to its destination after production. Also, hydrogen production via renewable power is much more expensive than other methods; electricity generated by a solar power plant is ten times more expensive than that generated by a coal plant.

e. ***Aluminum and Gallium Alloy***

Another option recently discovered by Purdue University's Jerry Woodall is a process involving an aluminum alloy. When water is added to an aluminum and gallium alloy, hydrogen is produced. The aluminum is strongly attracted to the oxygen in the water molecule and splits the water molecule, thus releasing hydrogen. The gallium is necessary, because without it, aluminum would form a protective skin after combining with oxygen. Gallium thus inhibits this skin from forming. This is because gallium "melts at low temperature and readily dissolves aluminum," says Woodall.

However, cost is an issue. Gallium is more expensive than aluminum, around $500/kg ($227.27/lb), while aluminum is around $1.20/lb. Also, aluminum is very energy intensive, producing over two kilowatt hours/pound of energy during the hydrogen combustion process and over two kilowatt hours/pound of heat when aluminum reacts with water. Gasoline can get six kilowatt hours/pound of energy.

f. ***Coal Gasification***

Yet another option is coal gasification. This process produces much hydrogen *and* electricity due to the high availability of coal deposits. Coal is also very cheap, and thus it would be cheap to produce hydrogen. However, since carbon dioxide is produced as a result of this process, it is necessary to "capture" the carbon dioxide in order to keep it from being released into the air. Unfortunately, this sequestration requires energy as well.

3. ***Distribution***

Barges, railcars, and truck trailers transport liquid hydrogen in pressurized and insulated tanks which can hold 3,500-70,000 kg. These tanks would have to be kept at or below -423ºF. As for distribution of gaseous hydrogen, distribution of hydrogen via pipeline does not have a positive outlook, since the hydrogen pipeline network is very small (only 460 miles). Even if the pipeline system was expanded, hydrogen can cause pipes to crack and become brittle. Gaseous hydrogen can be transported by trucks, but this poses some obstacles as well; since gaseous hydrogen takes up so much space, about twenty-one trucks would be needed to transport the same energy content of hydrogen as that in one tanker truck carrying gasoline.

4. *Storage*

Storage of liquid hydrogen must be in extremely cold, vacuum-insulated tanks with up to 6,000 psi of pressure. Tanks can vary in size from the tens to hundreds of thousands of gallons of hydrogen in one tank. For gaseous hydrogen, underground caverns have been considered as places to store hydrogen. However, the energy required to pump the gas in and out of these underground natural storage facilities may require an ample amount of energy.

5. *Cleanliness*

During regular hydrocarbon combustion, carbon dioxide, water, carbon monoxide, nitrogen, nitrogen oxides, and unburned hydrocarbons are produced. However, with the combustion of hydrogen, only water and heat are produced.

6. ***Energy and Efficiency***

Hydrogen is only 25-40% efficient when used in an internal combustion engine. Liquid hydrogen does have three times as much energy during combustion as gasoline, but three times the volume is needed in order to achieve the same amount of energy that gasoline reaches.

Hydrogen takes an immense amount of energy to convert it into a fuel. Because of this, according to the EPA, gaseous hydrogen reduces greenhouse gas emissions by 41.4%, while liquid hydrogen *increases* emissions by 3.7%. This is because most of the hydrogen found on Earth exists with other elements in molecules. Energy is required to remove the hydrogen from molecules. Also, while hydrogen carries a large amount of energy/kg, it carries much less energy per volume. It is estimated that gaseous hydrogen takes up 3,000 times as much space as an equivalent amount of gasoline with the same energy content. Finally, while liquid hydrogen would carry more energy per volume than gaseous hydrogen, in order to liquefy hydrogen, 30% of energy in hydrogen is required.

7. ***Safety***

A hydrogen tank consumes a lot of space, but it is less penetrable than a gasoline tank, which can rupture quite easily. In the event of a fire in a hydrogen-powered car, a hydrogen fire would be less dangerous than a gasoline fire; hydrogen is less flammable than gasoline, with an ignition temperature of 550º C (1022º F). Gasoline, on the other hand, has an ignition temperature of anywhere from 228-501ºC (442-934ºF). Hydrogen flames would disperse quickly since hydrogen is very light. The hydrogen molecules would disperse so quickly and so far apart that they would not be close enough to burn.

Although hydrogen is safe in some aspects, it still has a dangerous side. Since hydrogen is so light, it can escape easily through tiny holes. Hydrogen also burns with an invisible flame.

8. *Cost*

Hydrogen is incredibly expensive to produce compared to other alternative fuels. Production costs between \$4-\$8/kilogram through steam reforming and \$6/gallon through electrolysis. It has been estimated that in order to fuel 40% of our nation's motor vehicles, \$500 billion would have to be spent on the creation of an efficient hydrogen infrastructure.

C. Electric

1. *All-Electric Vehicles*

a. ***<u>General Information</u>***

In electric vehicles, a controller is connected between the batteries and the motor. When the driver presses on the accelerator, the battery delivers the amount of current it's capable of delivering. When the accelerator is released, no current is passed to the motor. Any force on the pedal in between zero and maximum force will provide an average of the highest voltage the battery can supply. This process is described as regenerative braking, which captures energy usually lost when easing pressure on the accelerator.

2. *Hybrid Vehicles*

a. ***<u>General Information</u>***

Hybrid vehicles contain both a gasoline engine and an electric motor powered by a battery. Currently, most hybrids operate as "full hybrids," in which the gas engine and electric motor do not depend on each other. Usually, the electric motor is used until the car reaches high speeds. Below is a model of what a hybrid would look like.

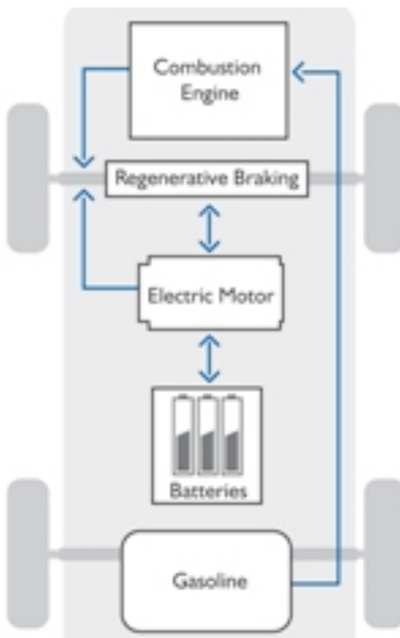

Figure 2: Hybrid Diagram

http://www.electricdrive.org/index.php?tg=articles&topics=132&new=0&newc=0

b. *Cost*

The cost of producing a hybrid vehicle is greater than that of the production of a regular gasoline-powered vehicle. Hybrid vehicles usually run between $25,000 and $35,000. The increased cost is due to the large battery, the electric motor, and the electric control module required to power a hybrid.

c. *Fuel Economy*

Hybrids are most efficient at slow speeds. Also, with the help of an electric motor, consumers can see a 20-50% improvement in the gas mileage on their cars. With the regenerative braking process as described above, energy usually lost in a regular vehicle is saved. The captured energy from regenerative braking powers the motor.

3. *Plug-In Hybrid Vehicles*

a. ***General Information***

Plug-in hybrids work in a similar fashion as regular hybrids, but plug-in hybrids utilize larger batteries in order to make the electric motor the main source of power. These larger batteries are lithium-ion batteries which provide greater energy and power. The gasoline engine serves only to recharge the battery. At night, the owner of the vehicle can plug the car into a regular outlet and recharge the battery. The car usually drives 20-50 miles on pure electricity before it switches to regular hybrid mode, utilizing the gasoline engine when needed (high speeds or no more electricity left in the battery). Below is a diagram of a plug-in electric hybrid.

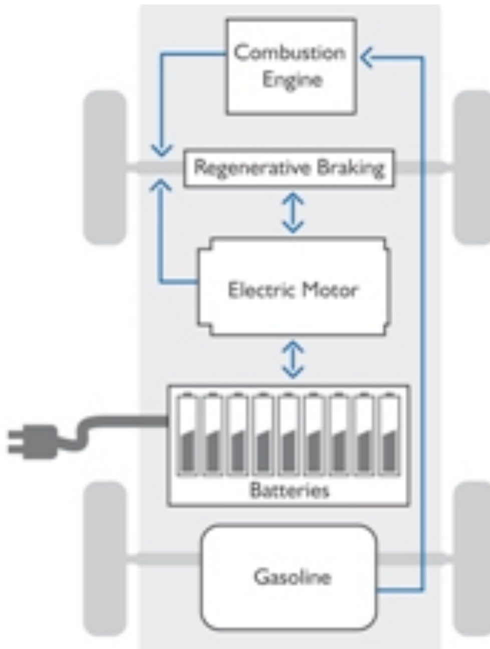

Figure 3: Plug-in Hybrid Diagram

http://www.electricdrive.org/index.php?tg=articles&topics=131&new=0&newc=0

b. *Cost*

Cost is already a dissuading factor in buying a regular hybrid. This factor exists in greater magnitude with plug-in hybrids. The expensive yet energy-efficient lithium-ion batteries cost around $15,000-$20,000. Regular hybrid batteries cost between $25,000 and $35,000. Plug-ins usually has a premium of about $3,000 more than regular hybrids. In the end, the cost of a plug-in hybrid could be around $50,000. Luckily, legislation has been proposed in order to provide tax credits to consumers and providers of electricity in order to spread the potential popularity of a plug-in hybrid.

c. *Fuel Economy*

Plug-in hybrids can actually be as efficient as 100 miles per gallon. This is due to the constant recharging of the battery back by the gasoline engine.

D. Fuel Cells

1. *General Information*

Fuel cells are devices that generate electricity. This is accomplished with fuel supplied at the negatively charged anode electrode of the fuel cell and an oxidant supplied at the positively charged cathode of the fuel cell. The fuel and oxidant come together and react in an electrolyte in the cell. Hydrogen is predominantly used as the fuel and oxygen as the oxidant.

2. *Types of Fuel Cells*

a. ***Proton Exchange Membrane (PEM) Fuel Cell***

i. How it Works

Also known as a Polymer Electrolyte Membrane fuel cell, this type of fuel cell uses hydrogen and oxygen as fuels. The electrolyte used is usually a solid polymer and includes carbon electrodes containing a noble metal catalyst, typically platinum. On the anode side, hydrogen flows in and is separated into protons and electrons. The protons can pass straight through the polymer electrolyte membrane, but the negative electrons must travel through a circuit to get to the cathode. This journey of electrons through the circuit generates electricity. Meanwhile, oxygen flows in at the cathode side and combines with the hydrogen electrons and protons to form water. In addition to heat, this is the only product of the reaction.

ii. Low Operating Temperature

The PEM fuel cell requires little start-up time, since it can operate at temperatures as low as 80ºC (176ºF). The low operating temperature also reduces the wear on the fuel cell. Because of the low operating temperature, this fuel cell would be suitable for motor vehicles.

iii. Vulnerability

The platinum catalyst is easily poisoned by carbon monoxide when CO attaches to the platinum catalyst. CO can exist in small amounts in the hydrogen used if the hydrogen was produced from alcohol or hydrocarbons.

iv. Cost

Cost is also a big issue in commercialization and usage of fuel cells. First of all, the metal catalysts in the membrane add to the cost. Second, if carbon monoxide is present after hydrogen production, this gas would need to be eliminated since the fuel cell is quite sensitive to CO. The reactor needed to carry out this process would add to the cost.

v. Hydration

In order to operate correctly, the PEM fuel cell must be properly hydrated. The fuel cell requires water to be evaporated at the same time it is produced. If the evaporation occurs too rapidly, the membrane will dry and hydrogen and oxygen will combine directly, ultimately creating too much heat and ruining the fuel cell. However, if the evaporation of water occurs too slowly, than the carbon cathodes will flood. Below is a diagram of a PEM Cell.

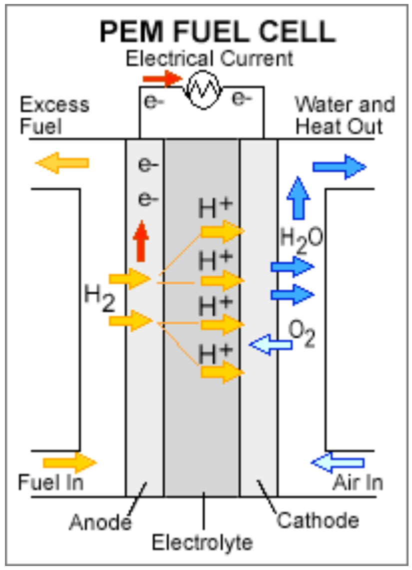

Figure 4: PEM Cell

http://fuelcellsworks.com/Typesoffuelcells.html

b. ***Phosphoric Acid Fuel Cell (PAFC)***

i. How it Works

Phosphoric Acid Fuel Cells use liquid phosphoric acid as the electrolyte and hydrogen and oxygen as fuels. Like the PEM cells, these fuel cells use porous carbon electrodes that contain a platinum (or other noble metal) catalyst. This specific type of fuel cell is primarily used for stationary power. Currently, PAFCs are the most common and commercialized fuel cell.

iii. Efficiency and Vulnerability

These fuel cells are very efficient when it comes to producing both electricity and heat (85%). However, when it comes to generating solely electricity, the efficiency rating drops to 37-42%. Although relatively efficient, these fuel cells are not as powerful as other fuel cells, even with the same dimensions and weight. This results in a very large and weighty fuel cell. Finally, although very weighty, PAFCs are less sensitive to impurities like CO. Below is a diagram of a Phosphoric Acid Fuel Cell.

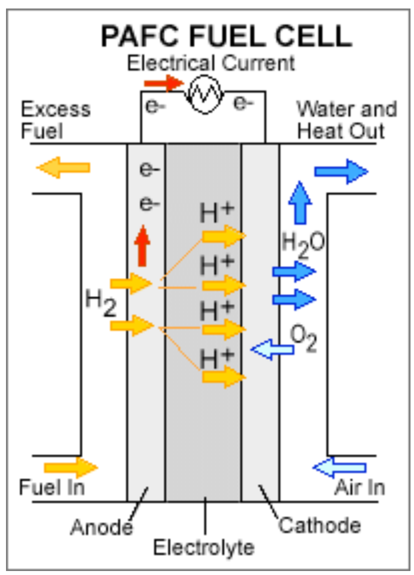

Figure 5: PAFC Fuel Cell

http://fuelcellsworks.com/Typesoffuelcells.html

c. *Alkaline Fuel Cell (AFC)*

i. How it Works

Alkaline Fuel Cells utilize potassium hydroxide (KOH) as the electrolyte with hydrogen and oxygen as the fuels. These cells can also use non-precious metals as the catalyst. Although AFCs previously operated at temperatures between 100ºC and 250ºC (212ºF and 482ºF), newer designs have been developed so AFCs operate around 23ºC to 70ºC (74ºF to 158ºF).

ii. <u>Efficiency</u>

AFCs can perform at 60% efficiency. AFCs perform very well due to the high rate of reaction that takes place within the cell. A typical AFC can remain stable for approximately 8,000 operating hours. However, this is not enough to become commercialized. Since this fuel cell is mostly used in utility applications, AFCs need to surpass 40,000 operating hours.

iii. <u>Vulnerability</u>

This fuel cell is sensitive to impurities as well, but in this case, AFCs are easily poisoned (even by the slightest amount) by carbon dioxide. Therefore, purification of hydrogen and oxygen is necessary, which adds to the cost of the cell. Below is a diagram of an Alkaline Fuel Cell.

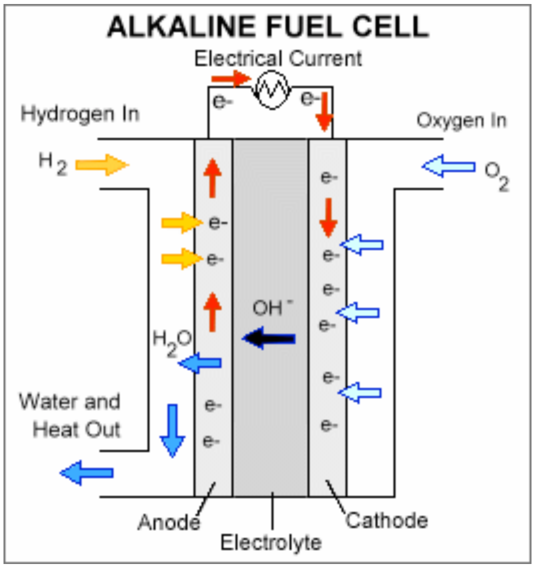

Figure 6: AFC

http://fuelcellsworks.com/Typesoffuelcells.html

d. ***Molten Carbonate Fuel Cell (MCFC)***

i. **How it Works**

Molten Carbonate Fuel Cells (MCFC) use hydrogen and oxygen like other fuel cells, but this cell uses molten carbonate in inert lithium aluminum oxide as its electrolyte. MCFCs operate at a relatively high temperature, usually around 650ºC (1,200ºF). These cells are mostly developed for usage in large power plants.

ii. **High Operating Temperature**

Since MCFCs have such a high operating temperature, non-precious metals can be used, which decreases the cost of the fuel cell. However, at such a temperature, the wear on the fuel cell increases, and therefore the life of the fuel cell is lower than that of other fuel cells.

iii. <u>Cost and Efficiency</u>

As previously mentioned, cost is lower because of the use of non precious metals as catalysts. Cost is further reduced since MCFCs have such high efficiencies, usually around 60%. With the heat captured and reused, the efficiency climbs to around 85%. Cost is also reduced by a process called internal reforming. If another fuel is used to be produce hydrogen, the fuel cell reforms the fuel itself.

iv. <u>Vulnerability</u>

MCFCs are also very resistant to impurities, especially carbon monoxide and carbon dioxide. It is worth noting that carbon monoxide and carbon dioxide can even be utilized as a fuel as well. Below is a diagram of the Molten Carbonate Fuel Cell.

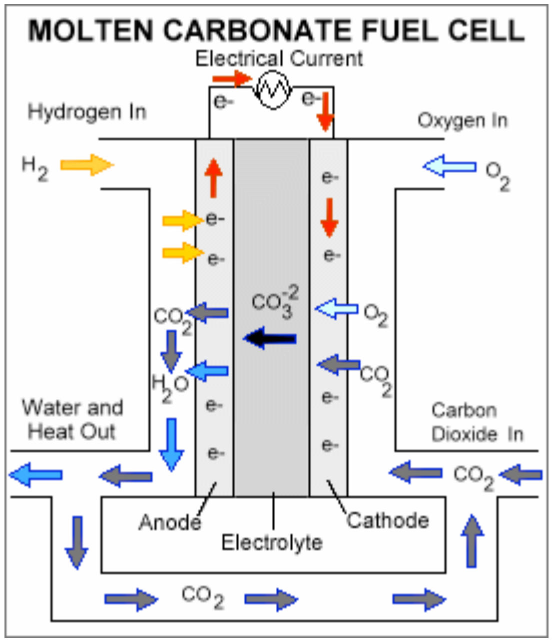

Figure 7: MCFC

http://fuelcellsworks.com/Typesoffuelcells.html

e. ***Solid Oxide Fuel Cell (SOFC)***

i. How it Works

Solid Oxide Fuel Cells (SOFC) utilize hydrogen and oxygen as fuels. For its electrolyte, a hard, ceramic compound is used. These fuel cells operate at relatively high temperatures, usually around 1,000ºC (1,830ºF). However, some SOFCs have been developed called Intermediate-Temperature (IT) SOFCs. These IT-SOFCs usually perform at temperatures around 700ºC-800ºC (1292ºF-1472ºF).

ii. High Operating Temperature

Like Molten Carbonate Fuel Cells, the high operating temperature allows the use of non-precious metals as catalysts. The high temperature also allows for internal reformation of fuels into hydrogen. However, the high operating temperature increases the wear of the fuel cell. Yet the IT-SOFCs can decrease these problems since they operate at a lower temperature range.

iii. Cost and Efficiency

Use of non-precious metals as catalysts reduces the costs of SOFCs. With the flexibility of choosing any type of fuel and no need to purchase a reformer, the costs of Solid Oxide Fuel Cells are also greatly reduced. In addition, SOFCs are relatively efficient, operating at 50%-60% for the generation of electricity. In the co-generation of electricity and heat, efficiencies can reach up to 85%.

v. Vulnerability

SOFCs are very resistant to impurities. SOFCs are particularly resistant to sulfur, unlike other fuel cells. Solid Oxide Fuel Cells can also tolerate carbon monoxide. Carbon monoxide can even be used as a fuel. Below is a diagram of the Solid Oxide Fuel Cell.

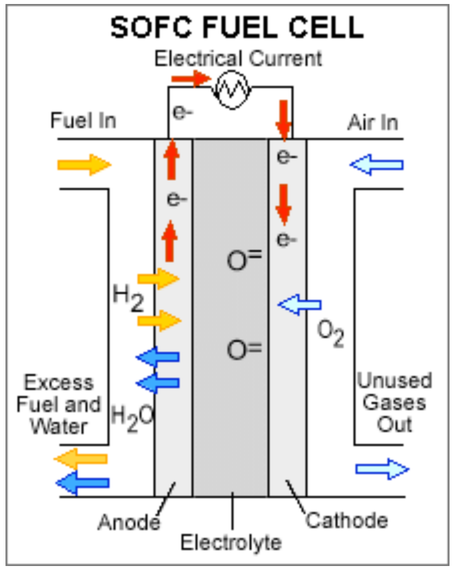

Figure 8: SOFC

http://fuelcellsworks.com/Typesoffuelcells.html

E. Solar Powered Vehicles

1. *General Information*

Solar vehicles are powered by solar or photovoltaic cells. These cells capture light energy from photons in sunlight and then convert this energy into electricity. The materials usually used in solar cells are semi conductive materials, like silicon. The biggest advantage to using solar powered vehicles is that no greenhouse gases are emitted.

2. *Size and Structure*

Most solar vehicles are designed as light as possible. Not only does the small size of the vehicle helps to reduce weight, but the material used to construct the vehicle alleviates the weight as well (ex: some cars are made of aluminum). However, since the vehicle is light, all solar cars are made incredibly small so only one person can fit into them. Also, the solar car is extremely fragile, since the solar cells are extremely delicate.

3. ***Energy & Cost***

The efficiency of solar-powered cars is only around 20%. Also, these cells can be quite expensive. For the solar panel alone, it usually costs round $20 for a single cell. Even for the small size of a solar-powered car, a solar vehicle usually requires *at least* 600 cells. So the cost just for the solar cells would be around $12,000.

F. Coal-to Liquid (CTL) Fuel

1. ***General Information***

Coal-to-liquid fuel is believed to reduce greenhouse gas emissions through "carbon capture and sequestration." During this process, when carbon dioxide is emitted from the plants creating this fuel, the carbon dioxide will be taken and placed underground.

For the most part, however, there is a general consensus that CTL fuel poses serious threats to the environment. Not only is it harmful to the environment during the process of coal extraction (through mountain top removal and mining), but it is especially harmful during the conversion of solid coal to liquid fuel; since coal requires a vast amount of energy in order to be converted from solid to liquid, costs and emissions increase.

G. Natural Gas

1. ***General Information***

There are about 4.7 million Natural Gas Vehicles (NGVs) used in the world today, most of them in Europe. Natural gas is advocated as one of the cleanest combustion fuels and is known to have around a 60 year supply.

2. *Cleanliness*

Natural gas can reduce greenhouse gas emissions by 20%-25%. Carbon dioxide emissions are reduced by about 25%. Nitrous oxides can be reduced by up to 95%, while carbon monoxide can be reduced by up to 90%. Unfortunately, although natural gas consists of multiple gases, it primarily consists of methane. Therefore, upon combustion of natural gas, an increase in methane emissions is released.

3. *Cost and Supply*

Natural gas usually costs around $2.55 per gallon. The cost of a purchase of a new NGV can be alleviated since the government offers tax credits to consumers.

Natural gas is also very plentiful. Currently, there is a 60 year supply left, with 98% of this supply in North America. The location of the majority of natural gas will allow the United States to remove its dependence from foreign fuels.

H. Ethanol

Of all of the alternative fuel options, ethanol, a biofuel, is one of the most heavily debated. The following information will describe *only* corn-based ethanol, unless otherwise specified in order to compare corn ethanol with another type of ethanol.

1. ***Current Ethanol Use***

Corn-based ethanol is the most used biofuel in the U.S.; in fact, 99% of all biofuel usage is from corn ethanol. The number of refineries has just surpassed 100 this past summer, and these facilities produce around anywhere from 4.6-5.4 billion gallons per year.

Around 13% of the United States corn production is used to produce ethanol. In 2005, for example, an average of 148 bushels of corn was cultivated. To achieve this much, about 8 million acres of corn fields were necessary. However, while the United States is producing plenty of ethanol, it is using very little: the United States only depends on ethanol for 3% of its transportation needs.

2. ***The Process***

Once corn is ready to be picked from the fields, the corn is shipped to the ethanol plants via truck and rail. Ethanol is created by fermenting the starches in the corn (or any plant). Excess water is removed and finally, gasoline is added. Below is a diagram of ethanol production.

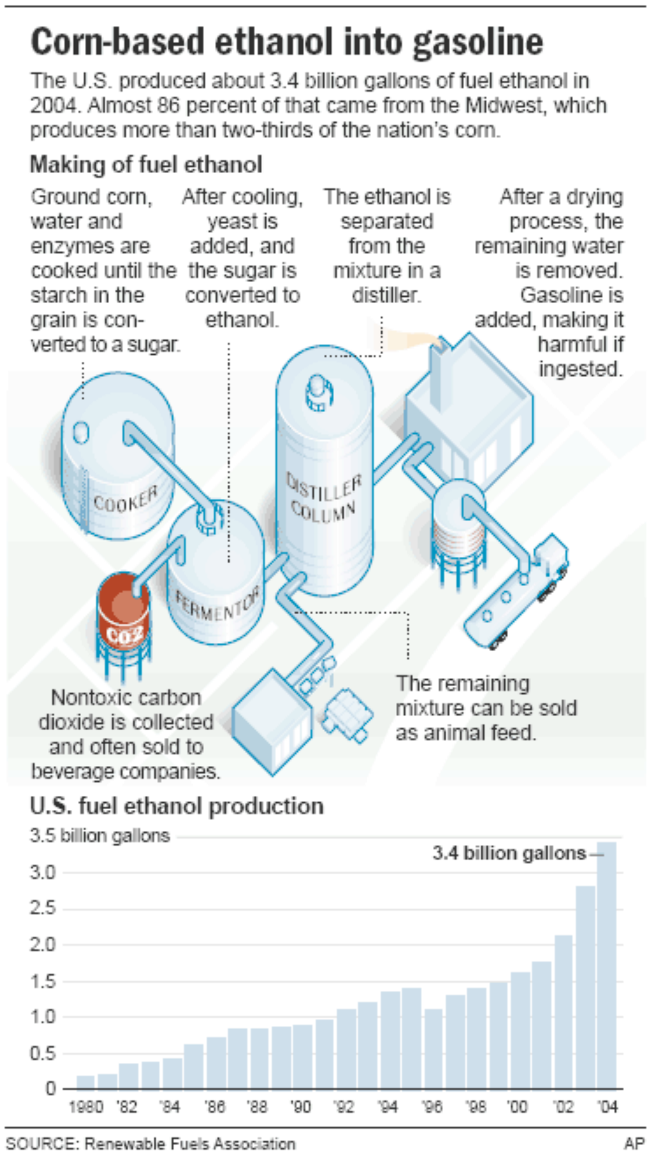

Figure 9: Ethanol Production

http://www.ethanol-news.de/articles/35-Speeding_Right_Past_100.htm

3. *The Fuel*

Ethanol used to be blended only in 10% amounts with 90% gasoline (a mixture called gasohol). Now, most ethanol blends consist of 85% ethanol with 15% gasoline, otherwise known as E85.

4. ***Cellulosic Ethanol Advantages***

Cellulosic ethanol is derived from cellulose in leaves, stalks, trees, agricultural waste and stems of plants, while corn-based ethanol uses the starches in the kernels. It has been concluded by many scientists that fermentation of cellulosic ethanol can yield higher amounts of fuel than the amounts from corn-based ethanol.

The reason why cellulosic ethanol is a cleaner fuel than corn-based ethanol is due to the closed carbon cycle. Upon combustion of cellulosic ethanol, emissions such as carbon dioxide released upon their combustion are simply reused again by the plants being used for ethanol production. All of the carbon dioxide is not reduced to a net zero amount, but much of it is offset by this cycle. Also, cellulosic ethanol has a higher energy value than corn-based ethanol. The cellulose in the biomass used for ethanol production contains a component called lignin. Lignin cannot be fermented into fuel, but it has a very high energy content.

5. ***Fuel Independence***

Like other alternative fuels, ethanol is a way to remove America's independence on foreign oil. America's Midwest is a major producer of corn, so little imports for the fuel would be necessary.

6. ***Choice***

Ethanol in blends over 10% should be run by a Flex Fuel Vehicle (FFV). These vehicles can be powered by gasoline or any blend of gasoline and ethanol between 0%-

85% ethanol. However, this requires the purchase of a new vehicle, which some consumers might not enjoy. Currently, only 1% of gas stations sell ethanol. Therefore, until ethanol increases in popularity, consumers won't have to worry about finding a gas station that sells ethanol.

7. *Cost*

FFVs are not much more expensive than regular gasoline-powered vehicle. FFVs usually cost only about $150 more to manufacture. So, the consumer will not have to invest his or her money considerably in a new car.

Although the vehicles that run on ethanol are not significantly more expensive than gasoline-powered automobiles, the production costs for ethanol are higher for ethanol that gasoline. According to Everythingbiomass.org, "Ethanol from corn costs about $1.74 per gallon to produce compared with about 95 cents to produce a gallon of gasoline."

8. *Emissions and Cleanliness*

Greenhouse gas emissions have been calculated to be reduced by 18%-28% per gallon. Cellulosic ethanol can reduce greenhouse gas emissions by up to 87%. E85 reduces the amount of toxic chemicals, such as benzene, a carcinogen. Any blend with ethanol will reduce carbon monoxide emissions, as well.

Surprisingly, if ethanol is used in low blends instead of E85, it can actually increase the amount of greenhouse gases currently present, according to Nathanael Greene, contributing researcher of "A High Growth Strategy for Ethanol," a report of an

Aspen Institute Policy Dialogue. Specifically, it will increase the amount of nitrogen oxides and volatile organic compounds. Nitrogen oxides (NOx) are emitted at a higher rate, because low ethanol blends have higher oxygen content. Next, volatile organic compounds increase because of increased vapor pressure and increased permeation (when hydrocarbons travel through the parts of the fuel system and eventually evaporate into the air).

9. *Not Enough Fueling Stations*

Today, only around 1,100 stations out of 170,000 stations provide E85. Most of these stations are located in the Midwest, as well, since this is where a good portion of the nation's corn is grown.

10. *Big Business*

Many venture capitalists and big businesses are investing in ethanol. According to Ethanol Industry News, Mike Bryan, CEO of BBI International, stated that about ten years ago, no more than ten banks would be willing to lend money for ethanol production. Now, there is no problem obtaining the proper funding. With enough money to start projects, it has appeared that there are too many money-chasers for too few projects. Some have to wait as long as 18 months before construction of a plant can get started.

11. *Other Parts of the Environment Affected*

According to the National Academy of Sciences in 2003, United States corn production erodes the soil more than any other crop. Not only does it cause soil erosion, but it also utilizes more pesticides than any other crop, which causes water pollution. Finally, corn uses more nitrogen fertilizer than other crops and therefore causes water pollution, as well. Not only is this toxic for humans, but the increased levels of nitrogen in water leads to the deaths of plants and animals that live in affected waters.

12. *Fuel Economy*

Although ethanol may have a greater net energy than gasoline, its energy *content* is lower than that of gasoline. It has been reported that ethanol only has two-thirds the energy that gasoline contains. The U.S. Department of Energy says that using E85 would require 1.4 times more fuel as opposed to gasoline. Consumers would have to make more frequent trips to the gas station because of this.

13. *Not Enough Energy Crop*

Pimental and Patzek, among others, claim that the approximately 4-5 billion gallons of ethanol currently in use only eliminates 1% of America's oil consumption. They even claim that if *all* corn production was devoted to energy production, it would only replace 6%.

14. *Food vs. Fuel Debate*

It is estimated that 3.7 billion people in the world are malnourished. Biofuels (ethanol in particular) have caused concern among scientists and human rights organizations due to the fact that a large portion of crops will be used as fuel instead of food. The following paragraphs address this issue by observing views from those against biofuels and those for biofuels.

a. ***No Impact on Food***

Bruce Dale, contributing researcher in the Aspen research project, concluded that population growth rates are declining which will help to ease the potential burden of using food for fuel. Also, he stated that ethanol producers usually co-produce animal feed. EU Energy Commissioner Andris Piebalgs goes further to state that the co-production of animal feed will make food cheaper.

Nathanael Greene, colleague of Dale, suggested producing energy crops on "marginal land." Rich farmland should be utilized only for food production, but energy crops could be grown on land that is dry or of poor quality so that competition with food production does not occur.

b. ***Impact on Food***

Since ethanol production is heavily subsidized by both federal and state governments, many opponents of ethanol see the high demand for biofuels increasing prices of foods other than corn, such as meat, milk, and eggs. The U.N. Food and Agriculture Organization said that vegetable oils and coarse grains are most heavily used in biofuel production. Their prices will increase the most by the end of this year, supposedly by 13% since 2006. Also, according to Dr. David Pimental, prices are rising because 70% of corn grain is used for animal feed. Finally, many people in impoverished countries are being pushed off of their land so big businesses can create biofuel plants. As mentioned, already 3.7 billion people are malnourished, and it is important that they are able to affordably receive a daily staple.

15. *American Farmer Debate*

a. ***Farmers Can Benefit***

Bruce Dale of the Aspen research group describes massive incentives from the federal government to farmers for energy crop production. According to Dale, farmers received "payments for agricultural price supports between 1995 and 2004" that "averaged $14 billion annually, providing six percent of gross and almost one quarter of net farm income. Payments in 2005 were about $24 billion."

b. ***Farmers Cannot Benefit***

Although farmers may currently receive massive amounts of funding from different sectors of the government, it is inevitable that if ethanol becomes the main source of alternative transportation fuel, demand may become higher than supply and ethanol will have to be imported from other countries. In fact, the United States Energy Secretary Samuel Bodman admitted that "he did not see subsidies to U.S. farmers remaining in place beyond 2010 or import tariffs on ethanol beyond 2008." Government aid is necessary since, according to the National Center for Policy Analysis, ethanol production would come to a halt without government funding.

16. *Land Debate*

a. ***Enough Land***

450 million acres of U.S. land are used for growing crops, 580 million acres of grassland are used as pastures, and 640 million acres of the U.S. are made up of forests, according to Bruce Dale. He said these figures amount to “1,700 million acres of land potentially available to produce feedstocks for ethanol production. Approximately 40 million of these acres are in the Conservation Reserve Program.” With around 15 tons of biomass produced per acre every year, he believes that 150 billion gallons of ethanol can be produced every year with only 100 million acres of land used for energy crop production.

It is estimated by one CEO, Don Endres of VeraSun Energy, that ethanol production can reach as high as 15 billion gallons per year *very soon*. It is expected to double soon after the beginning of next year. “We think there is also another 20 to 30 million acres that could be put into production that would provide enough corn for another 15 billion gallons,” he said.

b. ***Not Enough Land***

According to the Huffington Post, there is not enough land in the United States to grow more corn. The president of the National Environmental Trust, Philip E. Clapp, showed a similar view when he said, “Producing 35 billion gallons [the target amount by the Bush Administration by 2017] of ethanol a year would require putting an additional 129,000 square miles of farmland – an area the size of Kansas and Iowa – into corn production.”

Although the necessary 129,000 necessary square miles suggested by Clapp is equivalent to 82,560,000 acres, less than what Bruce Dale suggests is needed, Bruce Dale have a discrepancy in his report. Dale concluded that 15 tons of biomass per acre every year would be produced from 100 million acres of land used for energy crops, ultimately leading to 150 billion gallons of ethanol per year (impressive compared to the roughly 15 billion gallons of ethanol per year produced currently). This is equivalent to 1.5 billion tons/year (found by multiplying 15 tons/acre-year by 100 million acres). However, according to the U.S. Department of Energy and the Department of Agriculture, there is a *sustainable* amount of biomass of around 1.3 billion tons per year. This is less than what Dale proposed in his research. Therefore, the United States should *never* supersede the amount of acreage that supplies 1.3 billion tons per year.

17. ***Energy Debate***

The reason why ethanol (corn and cellulosic) has not caught on in the past with many scientists is because of its net energy. While some calculate a net positive energy to ethanol production (which includes, growing the crop, transporting it, and fermenting it), some opponents have proposed a net *negative* energy to ethanol production.

a. ***Positive Net Energy***

Hosein Shapouri is an important economist at the USDA. He and other colleagues wrote a report in 2004 dismissing the idea of negative net energy as outdated and promoting ethanol as an environmentally beneficial fuel. He declared that ethanol *used* to be inefficient when its production was still in its infancy. However, now, there is improved technology to production so that greenhouse gas emissions are reduced, not gained. In fact, according to the study, ethanol yields 26% more energy than it needs to produce it, because of the way corn is grown; the sunlight does not cost anything and current farming methods have increased in efficiency.

Below are some statistics that he and his colleagues determined for the calculation of net energy (from Shapouri et al., 2004)

- Average of 49,733 Btu/gallon net energy for distillation
- Distribution cost of 1487 Btu/gallon
- Corn production: 18,713 Btu/gallon
- Cost of nitrogen fertilizer: 7,344 Btu/gallon
- Closings of old US plants; cheaper ammonia/nitrogen imported from other countries (Trinidad and Tobago, for example)

Byproducts are given off during ethanol production, such as Distillers Dried Grains (DDG) and small amounts of Corn Gluten Feed (CGF) and Corn Gluten Meal (CGM). Shapouri gave these byproducts energy credit of 18.167 BTU/gallon. This equates to 26.6% of the total energy cycle. Shapouri's report believes these coproducts should be assigned a positive energy value, since they can substitute similar products (such as corn and soybean meal in animal feed).

Ethanol production can be shown to be beneficial by comparing its net energy (concerning corn) with gasoline. In a report by Bruce Dale, "Thinking Clearly about Biofuels: Ending the Irrelevant 'Net Energy' Debate and Developing Better Performance

Metrics for Alternative Fuels," 1 MJ of gasoline needs 1.1 MJ of petroleum, .03 MJ of natural gas, and .05 MJ of coal to produce ethanol. This equates to a 1.18 MJ of input to 1 MJ of output. Therefore, net energy is concluded to be Output- Input, which equals 1.0 MJ-1.18 MJ, which equals -18% net energy. For ethanol, 1.0 MJ of ethanol needs 0.05 MJ petroleum, 0.3MJ of natural gas, and 0.4 MJ of coal, which totals a net input of .75 MJ for every 1 MJ of output. The net energy is therefore Output – Input, which equals 1 MJ-.75 MJ which equals .25 MJ.

Finally, there are reasons why Shapouri and other proponents of ethanol say that opponents' views are not reputable. First, Pimental and Patzek used old data and inefficient methods during their calculations. Shapouri and colleagues also argue that the two dissenters do not compare the different types of biofuel with other alternative fuels.

b. *Negative Net Energy*

While some say this view is outdated, opponents of ethanol still believe ethanol contains a negative net energy, or it requires *more* energy during production than the energy in the final ethanol product. Leading supporters of this view are Dr. David Pimental, an entomologist at Cornell University, and Tad Patzek, a geoengineering Professor at University of California, Berkeley. Pimental and Patzek experimented with different types of ethanol, as did their opponents, Shapouri et al. Here is a summary of their findings (Pimental and Patzek "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower").

:

- Ethanol production using corn grain required 29% more fossil energy than the ethanol fuel produced.
- Ethanol production using switchgrass required 50% more fossil energy than the ethanol fuel produced.
- Ethanol production using wood biomass required 57% more fossil energy than the ethanol fuel produced.
- Biodiesel production using soybean required 27% more fossil energy than the biodiesel fuel produced
- The ethanol yield from a large production plant is about 1 L of ethanol from 2.69 kg of corn grain
- The production costs are about $917/ha [ha is equivalent to hectare, a unit that is about 2.47 acres] for the 8,655 kg or approximately 11c/ /kg of corn produced. To produce a liter of ethanol requires 29% more fossil energy than is produced as ethanol and costs 42c/ per l ($1.59 per gallon) (Table 2). The corn feedstock alone requires nearly 50% of the energy input.

Pimental and Patzek criticized Shapouri and his colleagues, because they did not account for energy used to manufacture farm machinery or distillation equipment. They also stated that Shapouri's data was limited: he only included data from 9 states, while

Pimental included data from every state. Pimental and Patzek also claimed their information was up-to-date.

The ethanol opponents also say that since ethanol does not carry as much energy as gasoline, an output of 775 gallons of ethanol per hectare (the output calculated by Shapouri et al.) is equivalent to as much energy as 512 gallons of gasoline. Finally, the opponents state, “To replace only a third of this gasoline with ethanol, 0.6 ha of corn must be grown. Currently, 0.5 ha of cropland is required to feed each American.”

Conclusions and Recommendations

This report presented conflicting views among energy activists. Most agree that corn ethanol and hybrid vehicles should be used currently, while hydrogen, fuel cells, and cellulosic ethanol will be used in the future. However, there are dissents on how to move away from a gasoline economy. What unites these dissenters is the fact that most advocate their own favored fuel, rather than multiple ones.

With all of the options available for alternative energy, it is difficult for the government and the public to decide which fuel should replace gasoline. However, after this research, it has been concluded that not *one* dominating fuel should replace gasoline. The alternative fuels industry is catching on too quickly with top businessmen eager to make money. Instead of the current monopoly of gasoline in the transportation energy sector, there should be competition among alternative fuels. This would not be as economically straining as it sounds, since many companies have already created vehicles that can be powered by multiple sources: regular hybrids utilize electricity and gasoline, Flex Fuel Vehicles (FFVs) can utilize ethanol and/or gasoline, and Ford and GM have created hybrids that can use both electricity and a fuel cell.

Although the solution *proposed* for the short-run is the use of biofuels, particularly corn-based ethanol, judging from the advantages and disadvantages of ethanol, it appears that the disadvantages outweigh the advantages (Note: although this report portrays opinions from opponents and proponents of ethanol, this report has not concluded which opinion is correct.). Yes, ethanol reduces greenhouse gas emissions. Yes, there is a larger consensus that ethanol has a positive net energy as opposed to a negative net energy. However, will big business keep expanding ethanol production plants until they practically encroach upon each other's territory and use up every last bit of land America has left? Will consumers continuously have to pay for ethanol subsidies *and* increasing food prices? Will ethanol plants even be willing to convert to cellulosic ethanol plants in the future? Will the government every *heavily* promote an alternative with a higher efficiency than ethanol? Will energy production take precedence over food production, not even considering that 3.7 billion people are malnourished? Judging from these factors, ethanol only seems to take away competition, precious land, and food necessary for survival. It is also not clear whether it provides a net gain or a net loss of energy, but even with a net gain, this gain is only about 20%, while gains for other fuels, like gaseous hydrogen, is about 40%. Also, ethanol

A better plan is one that incorporates more than one fuel. Hydrogen is currently not economically viable, due to the high price of natural gas. Once economically viable, hydrogen fuel cells should be combined with a plug-in hybrid vehicle for the long-term option, emitting only water and using gaseous hydrogen so a great amount of energy will not be expended to liquefy the gas. Also, the government should (it slowly is) remove tax breaks from the oil companies and give them to the alternative energy research facilities not receiving as much attention as ethanol (such as electric vehicles, fuel cells, hydrogen, and other types of ethanol besides corn ethanol). If the government continues to fund more ethanol production plants as it is currently doing, will our country again begin another century as a slave to only one fuel?

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