The Sustainability of the BioFuels Revolution

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Executive Summary

There has been an increasing interest in the pursuit of BioFuels and alternative energy in the United States. As energy demand and fuel prices continue to rise, Americans are seeking more renewable fuels. Current research is limited and focused upon a few fuels, limiting the availability of BioFuels to the public. In his 2007 State of the Union speech, President George W. Bush challenged the United States to replace 35 billion gallons of gasoline with BioFuels by 2017.

We, the sophomore Honors class of Clarkson University, were tasked with evaluating the feasibility of achieving President Bush's goal. Because most BioFuels are not developed, we studied the fuels that held the most potential to help achieve President Bush's goal. We examined three of the most developed BioFuels in America, namely: ethanol, biodiesel, and butanol. To analyze this problem, we studied technological limitations, current infrastructure compatibility, as well as socio-political and environmental implications.

Though ethanol is currently one of the most prevalent BioFuels in the United States, our research indicates that, of the three selected BioFuels, it holds the least potential for growth. Ethanol can be made from corn or cellulosic feedstocks. Corn ethanol, widely promoted as an easy way to solve our nation's oil squeeze, is energy inefficient and impractical to distribute on a national scale. In addition, the fertilizers necessary to grow corn have harsh environmental implications. Due to the limitations of corn ethanol, new research is focused upon the use of alternative feedstocks. Cellulosic ethanol, primarily produced from woody plants and waste materials, shows great potential for future growth. Cellulosic ethanol has promise as a local fuel, but transportation issues and low energy content limit its success on a national scale.

Biodiesel has the most potential out of the three fuels that we researched. Biodiesel has a higher energy density than traditional diesel fuel and also lower emissions. It is fully compatible with the nation's current fuel infrastructure, and can be used pure or in blended concentrations in modern diesel engines. Traditional biodiesel production has focused on soybeans as a feedstock, though they are energy intensive, have low yields, and require large amounts of machinery. Waste feedstocks such as used vegetable oil are better for the environment, but are in limited supply. Biodiesel can also be produced from non-traditional sources, such as canola seeds and algae. These sources are more environmentally friendly than soy, and have higher yields. Biodiesel shows the largest amount of promise as a fuel for 2017.

Butanol is another BioFuel that can be used in the place of gasoline. Though it is produced from the same feedstocks as ethanol, butanol has a higher energy content and is water-repellant. It is also much less corrosive than ethanol, and can be used in current engines and transportation systems without modification. Historically, butanol has been used as an industrial solvent, produced from petroleum. Butanol, much like ethanol, is usually produced with a corn fermentation process, and its low yields have meant that it receives little funding. However, research is being done on new processes that can produce butanol from waste feedstocks such as whey, or cellulosic feedstocks such as switchgrass. The development of this new technology and a large upswing in public interest make butanol a viable fuel for the future, but it is unlikely that it will be ready by 2017.

Currently, corn ethanol is produced in approximately 425 industrial plants at an annual production rate of 8.6 billion gasoline-gallons, or about 33% of President Bush's goal, of corn ethanol per year. We predict 11.7 billion gasoline-gallons of ethanol per year will be produced in 2017 in 525 different production facilities. Cellulosic ethanol, still in the development stage, is projected to be produced in 175 plants with an annual production capacity of 7.3 billion gasoline-gallons, or 21% of the goal.

Biodiesel, another first generation BioFuel, has an annual production capacity of 1.8 billion gallons of biodiesel. According to market research and the historical progression, we predict approximately 5.4 billion diesel gasoline-gallons will be produced from vegetation in 2017. In addition, the United States produces about 11 billion gallons of used vegetable oil annually. If only 75% of this oil is used to create biodiesel, the amount of biodiesel created would be equivalent to an additional 4 billion diesel gasoline-gallons. In total, we predict biodiesel production will offset 9.4 billion gasoline-gallons by 2017.

It is difficult to predict how many gallons of butanol can be produced by 2017, because of the non-linear progression of the increase in butanol research. A significant increase in funding, research, and public awareness has occurred in recent years. In accordance with current growth trends, we predict that one billion gasoline-gallons of butanol will be manufactured in 2017.

In short, none of these fuels can support the BioFuels revolution as defined by President Bush. Even together, these three fuels will not produce enough to meet the required goal by 2017.

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Introduction

Historical Background

American society is heavily dependant upon gasoline as an energy source. Whether for use in making plastic, heating for homes, or powering automobiles, hundreds of millions of gallons of gasoline are consumed daily. A large majority of this fuel is imported from other nations. The large population boom and technological advancements have combined to strain Earth's resources. Human environmental impact is more apparent than ever before. Harmful effects from chlorofluorocarbons created a hole in the ozone layer over Antarctica and threaten the environmental stability of the globe, and a rapidly growing global population now poses new threats and risks. Greenhouse gas emissions and global climate change, including altered temperature and rainfall patterns, have become new areas of research for scientists.

In the United States, a desire for less dependence on foreign oil imports and a cleaner environment led the country to develop alternative methods of energy production. Economic incentives, including significant government subsidies, were introduced to motivate businesses to invest in alternative energy. Academic institutions soon developed alternatives for gasoline in automobiles. The source of these fuels was the nation's fields. These new BioFuels were generated from corn, soy, and waste feedstocks using advanced technology developed in laboratories across the country.

The first recorded automotive use of BioFuels in America was with the Model T Ford in 1908. Henry Ford called ethanol "the fuel of the future" (Whipnet Technologies, 2007). Ethanol was used into the depression era before the movement lost momentum. Years later, America was crippled during the oil embargo in 1973 and the nation's dependence upon foreign oil was made obvious. Resulting legislation in 1978 and 1980 offered tax breaks to ethanol consumers (Whipnet Technologies, 2007).

As petroleum prices continue to rise, Americans are turning away from conventional petroleum in search of more efficient, economically viable, and environmentally friendly alternatives. The significant development of the US ethanol industry resulted from this movement. With a capacity of close to seven billion gallons of ethanol per year, ethanol is the most commonly used BioFuel in America. As ethanol development was occurring at an astonishing rate, the development of alternative BioFuels kept pace. Biodiesel, an alternative to conventional diesel, is the second most prevalent BioFuel in America. Methods of vehicle alteration and fuel distribution were developed to satisfy the growing desire for so-called ‘green fuels.’ As the United States’ dependence on foreign oil increased, political disagreements between the United States and OPEC escalated, and more studies were published about the effects of global climate change, the necessity for new vehicle fuels became apparent. The American BioFuels revolution had begun.

Problem Statement

In January 2007, politics once again became a large factor in the BioFuels revolution. The President of the United States of America, George W. Bush, challenged the nation to create thirty-five billion gallons of gasoline-equivalent fuel by 2017. He stated:

> Tonight, I ask Congress to join me in pursuing a great goal. Let us build on the work we've done and reduce gasoline usage in the United States by 20 percent in the next 10 years. When we do that we will have cut our total imports by the equivalent of three-quarters of all the oil we now import from the Middle East. To reach this goal, we must increase the supply of alternative fuels, by setting a mandatory fuels standard to require 35 billion gallons of renewable and alternative fuels in 2017 -- and that is nearly five times the current target. (United States White House, 2007)

President Bush’s goal of 35 billion gallons of gasoline-equivalent BioFuels represents approximately 15% of the nation’s fuel consumption. As millions of dollars pour into the BioFuel industry, the feasibility of this statement was questioned. The sophomore honors class of Clarkson University was challenged to analyze the implications of the recent statements by the US Government regarding the decision to support the expanded use of BioFuels in the US. We have aimed to answer these questions and give an unbiased account of the sustainability of the BioFuels revolution.

Course Structure

Because the BioFuels industry is extremely complex, we chose to subdivide our class. In order to efficiently analyze the problem, we divided into four different groups: technology, infrastructure, environmental, and socio-political. The four different groups were created to allow specialization in different areas of BioFuels research. We also elected group leaders, who guided the scope and direction of the course. The technology group focused on the technological aspects of the creation of the BioFuels, while the infrastructure group analyzed the manufacturing and distribution processes to use the fuel. The environmental group studied the various environmental impacts of the different fuels and feedstocks, and the socio-political group investigated the social and political ramifications that the BioFuels revolution will have on the world. Each group also elected two of their members to represent their group in the editorial board. The editorial board, consisting of eight students, was created to help facilitate the flow of information between groups and to clearly define each group's divisions and responsibilities.

After initial research concerning the state of the industry, we concluded that only three BioFuels would largely contribute toward achieving President Bush's goal. Ethanol and biodiesel, both first generation fuels, were examined in greater detail. In addition, butanol, a well-developed second generation BioFuel, was studied. Our ultimate findings are set forth in this paper and were also discussed in a public forum on December 7, 2007.

Definition of Sustainability and Feasibility

A sustainable BioFuels revolution is defined as the development and implementation of an industry that contributes to energy independence in an economical manner that does not temporarily or permanently cause significant damage to the environment. Feedstocks shall cause little damage to the environment, including loss of nutrients, erosion, and non-point-source pollution from pesticides, fertilizers, and herbicides. The demand for feedstocks for the BioFuels industry should not damage other sectors of the economy, especially food supply.

For the purpose of effectively analyzing President Bush's statement, we have defined feasibility as evaluating the practicality of reaching the goal of 35 billion gallons of BioFuels by 2017. The feedstocks studied should be able to produce large volumes of fuel reasonably, without having to devote huge amounts of land or other resources, such as fresh water, to the process. National success of a single feedstock or fuel is not necessary; a combination of different feedstocks, varying by region, may be more feasible. The fuel types studied must have a positive risk analysis, including toxicity, volatility, solubility, biodegradability and partitioning.

In order for this goal to be feasible by 2017, the processes in question must be in use in a pilot plant at this time with a positive energy balance and a carbon footprint that is lower than petrol. To successfully introduce BioFuels into the American society in 10 years, the fuels must be easy to use in today's vehicles and general infrastructure without massive modifications. The cost of implementation must be within the government's national budget and the transition can not significantly reduce American job availability. While BioFuels cannot cause the average cost of fuels to rise considerably, subsidies are an acceptable way to reduce the cost of the fuels while they are in the developmental stage. Most importantly, the American people must be willing to accept BioFuels as an alternative fuel and the American government must be willing and able to facilitate the transition.

Ethanol

Introduction

Ethanol was first used as fuel for vehicles as early as 1908. Henry Ford's Model T could be modified to run on gasoline or pure ethanol, and ethanol was used as a fuel in other vehicles through the 1920s and 1930s. In the 1920s, Standard Oil attempted to sustain an ethanol program in the Baltimore area using 25% ethanol by volume gasoline (E25). By 1938, an ethanol plant in Kansas was generating 18 million gallons of ethanol annually to supply over 2,000 service stations in the Midwest with fuel. Soon afterwards, however, as cheap fuels derived from petroleum became more common, the ethanol fuel program was scrapped. Many ethanol production facilities were converted into beverage plants or dismantled entirely (DiPardo, 1999). Ethanol fuel went largely ignored until the fuel crisis of the 1970s, which sparked renewed interest in domestically produced, renewable fuels. Today, with gas prices soaring and foreign oil sources in high conflict areas, interest in renewable fuels has skyrocketed. Currently, ethanol fuel is one of the most prevalent and publicized alternative fuel sources in America.

Corn Ethanol

In the United States, most of the ethanol produced for fuel is derived from the fermentation of corn starch. In 2006, seven billion gallons of ethanol were produced in the United States, roughly equivalent to 4.7 billion gasoline-gallons (National Corn Growers Association, 2007). The abundance of arable land and water in the United States has facilitated corn as a fuel feedstock as well as a food for human and animal consumption. However, corn has intense fertilizer requirements, as well as a lower yield per acre than other ethanol feedstocks. These limitations keep it from being an economically and environmentally viable source of ethanol in the U.S.

Environmental Impact

Emissions due to the combustion of ethanol are significantly less than those of gasoline. Ethanol contains 35% oxygen, allowing for a more complete combustion reaction and a reduction in tailpipe emissions. It has been shown to reduce carbon monoxide emissions by as much as 30%, Volatile Organic Compound (VOC) emissions by up to 12% and particulate matter emissions by more than 25% when compared to gasoline (Mississippi Department of Agriculture and Commerce, 2006). Ethanol also emits lower amounts of the carcinogens benzene and butadiene, though it does have increased emissions of formaldehyde and acetaldehyde. Unfortunately, the combustion of ethanol produces more ozone than combustion of gasoline. Ozone is a main component in the formation of smog. The National Resources Defense Council (NRDC) issued a report and cited numerous other studies concluding that ethanol reduces smog forming ozone emissions (National Resources Defense Council, 2007). It is worth noting that ethanol, depending upon the process used to produce it, has the potential to greatly reduce net greenhouse gas (GHG) emissions during its seed to pump life cycle.

Burning E85 instead of gasoline drastically reduces the emissions of VOCs, carbon monoxide, particulate matter, NO_x, and SO_x. Blending ethanol at lower quantities such as E10 also reduces emissions. In 2004, greenhouse gas emissions were reduced by approximately 7 million tons in the US due to ethanol use. This is equivalent to the annual emissions of more than 1 millions cars (American Coalition, 2007).

Energy Balance

When considering ethanol as a replacement for gasoline, it is very important to consider the energy content per gallon, or energy density, of each respective fuel. The energy density of ethanol is 84,600 Btu/gal, which is significantly less than to the energy density of gasoline, which is 125,000 Btu/Gal (Oak Ridge National Laboratory, 2007). From these values, we can calculate that the energy density of ethanol is approximately 68% that of gasoline, meaning that 1 gallon of ethanol is equivalent to 0.68 gallons of gasoline, or one gallon of gasoline is equivalent to 1.47 gallons of ethanol. Therefore, assuming all other parameters remain constant within an engine, running ethanol as opposed to gasoline will result in a theoretical miles per gallon reduction of about 31%.

One of the most important statistics of any bio-based fuel is something that is referred to as Net Energy Value (NEV), energy balance, or Energy Return on Energy Invested (EROEI). In essence, this value reflects the energy contained in the final product (ethanol fuel) compared to the total energy that is used to produce it (harvesting, transporting, etc.). Many research studies have been devoted to quantifying this number with respect to corn ethanol in the United States, and they have been in notorious disagreement due to the number of assumptions used in the calculation of the EROEI value.

A study released in 2002 by the U.S. Department of Agriculture (USDA), "The Energy Balance of Corn Ethanol: An Update", discusses the assumptions associated with obtaining a realistic volume for energy balance. This study reflects upon previous research to analyze how a large range of values have been obtained for the energy balance of corn ethanol. The report states that the variation in energy balance values can be attributed to assumptions pertaining to "corn yields, ethanol conversion technologies, fertilizer manufacturing efficiency, fertilizer application rates, coproduce evaluation, and the number of energy inputs included in the calculations." By analyzing these various assumptions, the USDA study came up with a final value of the energy balance of corn ethanol of 1.34, meaning that ethanol fuel contains 34% more energy than the energy required to produce the same volume of fuel (Shapouri, Duffield and Wang, 2002).

As of October 24, 2007, there are 135 ethanol production facilities in the United States producing approximately seven billion gallons of ethanol per year. An additional 75 production facilities are under construction with an estimated output of an additional 5.4 billion gallons per year (American Coalition for Ethanol, 2007). Thus, in the near future, the entire production capacity of ethanol is predicted to be about 12.5 billion gallons of ethanol per year. This figure is equivalent to 8.5 billion gallons of gasoline per year, or about 24% of President Bush's projected goal.

Vehicle Modifications

It costs a considerable amount of money to convert a standard gasoline vehicle to run on ethanol blends higher than 10%. Some car dealerships will install factory-recognized conversion kits. However, these kits usually void the warranty of the vehicle. The modifications can be made by an individual if he/she has the proper knowledge and tools to perform the alterations.

Because of ethanol's low energy balance, the engine computer, which regulates the amount of fuel sent to each cylinder, must send more fuel if the engine is to run on ethanol. Since standard computers are programmed to assume that the fuel injectors are sending gasoline to the cylinder, the engine computer must be replaced with one that is programmed to work on ethanol. Replacement computers (and associated sensors and wiring harnesses) can range in cost from \$90 to \$500. The cheaper models usually require two fuel tanks (one E85 and one for gasoline) while the more expensive models can sense the ethanol concentration in the gas tank and adjust accordingly, essentially making the vehicle 'Flex fuel' compatible. The increase in injected fuel can sometimes be achieved with traditional fuel injectors, by keeping them open for a longer period of time. However, the flow rate of the standard injectors may not be high enough to provide enough fuel even with an extended time period. High flow fuel injectors can add \$100 to \$500 to the cost of vehicle modification.

Due to ethanol's corrosive nature, all fuel line components need to be replaced with lines made from corrosion-resistant materials like stainless steel. Fuel rails can cost from \$100 to \$200 and lines and gaskets approximately \$100. A corrosion-resistant fuel tank must also be installed for the same reasons and costs approximately \$500. Because of increased fuel requirements the fuel pump usually needs to be upgraded, which can cost between \$100 and \$200.

A full conversion can be expected to cost anywhere from \$1000 to \$2000, or possibly more, depending on the quality of products used as well as the type of vehicle converted. It should be noted that there are currently no aftermarket ethanol conversion kits that are endorsed by the EPA; these conversion kits do not meet emissions regulations.

Distribution Methods

It is most efficient to produce ethanol when production facilities are placed near the fields where the feedstock is grown. This is due to the fact that ethanol has a higher energy density than corn. It is more economical to transport the final product than to transport the feedstock. Due to its low energy density and thus low shipment efficiency, ethanol cannot be a practical national fuel. This is why this model is not only based on the refineries being located close to the locations the feedstocks are being grown, but also upon an infrastructure of many relatively small refineries scattered about a region producing fuel primarily for the surrounding towns and cities. The movement of ethanol from any of the refineries to destinations beyond its economically viable range will be greatly limited.

Transportation of feedstocks and associated infrastructure from the fields to the refinery is similar across the nation. Although corn is the most abundant feedstock used in ethanol production at the present time, other feedstocks are used for ethanol production. Regardless of the feedstock, the primary mode of feedstock transportation will be by truck unless the distance the raw materials must travel exceeds the economic limitations of the trucking industry. Any feedstocks needing to be transported long distances will be moved using trains, and barges whenever possible. However, these methods of transportation are inefficient when moving the feedstock to an ethanol production facility.

Trains and barges are recommended for use because one standard jumbo hopper railroad car can be loaded with up to 3.5 times more corn than a standard tractor-trailer. An average train pulling 100 hopper cars could transport up to 100,000 tons of corn. Barges, while they can be much more efficient than both trucks and trains, are limited to use transporting feedstocks north and south along the Mississippi and Ohio River systems. These are the only major river systems that pass through the heart of the nation where the majority of corn is grown. A single barge can ship 52,500 bushels of corn, an equivalent of 1500 tons. Two barges are needed to move the same amount of corn as a hopper car. Assuming a standard barge train consists of fifteen barges, one of these arrays could ship as much as 22,500 tons of corn in one shipment. There are numerous complications when considering the shipment of ethanol by pipe. Pipelines are the most efficient manner to transport a liquid product great distances (Whims, 2002). Due to the hydrophilic nature of ethanol, it cannot be distributed in the same pipeline system in which petroleum is distributed. Thus, either new pipes must be constructed or trains, trucks, and barges must be utilized. These are not extremely efficient methods of moving liquid fuel when compared with pipelines. It would be impossible to modify the existing pipe system because special pipes with a nickel coating required for ethanol are very expensive. In addition, ethanol is predicted to be gradually replaced by a different alternative fuel in the future due to its low energy content. It would be impractical to build an entirely new pipe system for ethanol. In addition, the current pipeline distribution system in the U.S. is centralized along the Gulf Coast and runs from the south to the eastern and western coasts. See Figure 1 below. Thus, existing pipelines could not be modified to distribute ethanol, as they are located in the wrong part of the country. Because pipelines cost approximately one million dollars per mile to build, the costs of entirely new infrastructure for ethanol would be astronomical and impractical (Whims, 2002).

Figure 1: Pipeline Infrastructure for United States

Source: http://www.futuresindustry.org/images/FIMag/01-05PIpelineMap.jpg

Trucks, trains, and barges are recommended as the primary mode of transportation of both raw materials and the ethanol product in the regional model. It is unlikely that ethanol will ever be used on a national scale and its growth is expected to significantly slow due to its many inefficiencies. With a low energy return and many potential negative consequences, it is likely that ethanol will only be produced long enough to develop, optimize, and establish a more stable alternative to fuel our economy.

Synthesis of Ethanol

The most common method of producing fuel ethanol uses feedstocks that contain a large amount of sugar. In the United States this sugar is often in the form of starch. Glucose, a simple sugar, is a more common feedstock in warmer climates such as Brazil. The production process itself is relatively simple. The production process includes the separation of the sugary material from the rest of the plant through milling, fermentation of the sugar into ethanol and carbon dioxide, and distillation of the resulting solution into 99.9% pure ethanol, which is suitable for use as fuel.

The first step in the ethanol production process is to obtain the sugary material from within the plant, which will later be converted into ethanol. This can be carried out in two main ways: the first is dry milling. In this process, the entire grain of the plant being used is mechanically ground into fine flour referred to as meal. This meal is then mixed with water to form a thick slurry called mash. Enzymes such as amylase are added to the mash to convert the starches to simpler sugars, and then the mixture is cooked to kill any unwanted bacteria (Renewable Fuels Association, 2005).

The second process used to obtain sugary material is called wet milling. The feedstock is soaked in a dilute sulfuric acid solution for 24 to 48 hours, which helps to separate the starches from other materials contained within the grain, such as protein, fiber, and germ. After this soaking process is completed, the resulting slurry is passed through a series of grinders, screens, and centrifuges in order to further separate the component materials. The byproducts of this process can then be sold for various uses, while the starch is saved for ethanol production (Renewable Fuels Association, 2005).

As of January 2007, dry milling plants accounted for 82% of domestic corn ethanol production while wet milling only contributed 18%. The main reason for this is that wet milling is more complicated and expensive to employ. However, the wet milling process does allow for the waste materials, such as the fiber and protein, to be sold for use as livestock feed (Renewable Fuels Association, 2005).

After the mash has been prepared and the starch converted to simpler sugars such as dextrose and glucose, the mash is ready to enter the fermentation step of ethanol production. The mash is placed in large fermentation tanks with strains of yeast bacteria, usually *Saccharomyces cerevisiae*. The bacteria metabolize the sugars in the mash into carbon dioxide and ethanol; this process usually takes 40 to 50 hours. Because ethanol is toxic to yeast at high concentrations, this brewing process can only produce a solution that is about 15% ethanol (Morais et. al, 1996).

Ethanol must 99% pure to be used as a fuel; the solution resulting from fermentation must be purified before it can be used. Conventional evaporative distillation can increase the concentration to about 95%. The solution must then be further concentrated using a molecular sieve system, which can reach the required 99% purity (Renewable Fuels Association, 2005). Once the ethanol has reached the proper concentration, it is denatured (usually with gasoline) in order to make it non potable, and therefore not subject to taxing as an alcoholic beverage.

Feedstock: Corn

There exist some differing opinions regarding the actual yield of corn for the purpose of ethanol production. The USDA estimates that per bushel of corn, 2.5 gallons of ethanol can be produced (Hardin, 1996). Considering, that for the 2007 growing season, the average yield for corn was about 150 bushels per acre, it appears that our current average production of corn ethanol is approximately 375 gallons per acre per year. As previously stated, corn ethanol contains about two-thirds of the energy of gasoline. Accordingly, to produce 35 billion gallons of gasoline equivalent fuel the United States would need to produce more than 50 billion gallons of corn ethanol. To accomplish this feat, about 30% of the nation's arable land must be used for only the growth of corn for ethanol (CIA Facebook, 2007). Though it is not realistic to suggest that corn ethanol can meet the goals set in the State of the Union address on its own, it is important to note how much land would be required to accomplish these goals.

Corn has the highest pesticide and fertilizer requirements of any current BioFuel feedstock. On average, an acre of cropland planted with corn will use 58 pounds of phosphate, 84 pounds of potash, and 138 pounds of nitrogen (USDA: U.S. Fertilizer Use and Price, 2007). Generally, crops do not use all of the fertilizer that is applied. The remainder of this fertilizer leaches into groundwater or is volatized into the atmosphere. The percentage of fertilizer that leaches out of a given field is highly dependent on local farming practices and rain patterns. The use of nitrogen fertilizers used for corn farming is a major contributor to the nitrogen loading of the Mississippi river, as well as other major waterways. Nitrogen loading is of concern due to its contribution to so called "dead zones" such as the one in the Gulf of Mexico. Experts recommend that we reduce the nitrogen loading of the Mississippi by 30% (Powers). The hope is that reduction of nitrogen content will promote recovery of the ecological damage in the hypoxic zones that have been created by nitrogen runoff. Though ethanol has environmentally beneficial characteristics, the high fertilizer demands of corn and their implications for non-point source pollution indicate that corn is not a feasible feedstock for ethanol.

In addition to requiring large amounts of fertilizer, corn is highly dependent on the use of pesticides and herbicides such as Atrazine, Acetochlor, and Metolachlor (Water Implications, 2007). The EPA's *National Survey of Pesticides in Drinking Water Wells* found Atrazine to be the most commonly detected pesticide in drinking water. The presence of Atrazine in drinking water is of concern, because it is a carcinogen known to cause muscular and cardiovascular conditions (Fact sheet on Atrazine, 2007). Increasing corn production for use as an ethanol feedstock would lead to higher applications of Atrazine as more land became dedicated to corn farming. Acetochlor, a common herbicide, is also a know carcinogen (Regulating Pesticides, 2007). Metolachlor has been shown to be moderately toxic to fish (Pesticide Information Profiles, 1996). Another herbicide with environmentally deleterious consequences is Glyphosate. Glyphosate is highly toxic to invertebrates and a large variety of fish (Relyea, 2005). Additionally, Glyphosate has been shown to damage beneficial insects (Springett & Gray, 1992). Corn's dependency on numerous hazardous pesticides and herbicides, particularly known carcinogens like Atrazine and Acetochlor, is a cause for concern. Though pesticide and herbicide usage is often necessary for large-scale farming, the quantities necessary to maintain corn suggest that there would be substantial negative environmental impacts from expanding corn production.

During the 2007 growing season, 93.6 million acres of corn were planted in the United States. Of this amount, 86.1 million acres of corn were harvested (Corn Acreage, 2007). This means that approximately 20% of America’s arable land was solely devoted to the production of corn.

To cultivate enough corn to produce one gallon of ethanol, 785 gallons of water are required. 96% of the corn used to produce ethanol does not require irrigation (Aden, 2007) However, the production of large amounts of corn places a great stress on the local water table. Sugar beets and sugar cane, the most popular ethanol feedstocks in Brazil, have proven to be more efficient than corn. A Brazilian study released in 2006 by Andreoli and De Souza claims an energy balance of 3.24 for sugarcane-derived ethanol, but the authors do not go into detail regarding any assumptions made in the calculation process (Andreoli and De Souza). A great deal of sugarcane's efficiency can be attributed to the use of the waste part of the plant as an energy supply for the distillation process. Most American facilities use natural gas as an energy source.

Future Projections

By 2017, our model predicts 525 corn ethanol production facilities will be operational in the United States. These plants will have an annual capacity of approximately of 11.7 billion gasoline-gallons of corn ethanol per year. This is equivalent to 33% of President Bush's goal. The cost of these new plants will be minimal when compared with the other fuels which currently have few or no operating facilities. We predict government funding and public support will continue into the future for ethanol and begin to wane in approximately 10 years.

Corn ethanol, a first generation feedstock and BioFuel, will not a practical long-term fuel. Though corn ethanol has the most developed infrastructure of any BioFuel at the present time, the effect upon the environment from grown the corn outweighs the benefit of the current infrastructure. Thus, it seems apparent that corn ethanol will not and should not become an integral part of the BioFuels industry. While it is a good place to start to research alternatives, corn ethanol should be slowly phased out and replaced by cellulosic ethanol.

Cellulosic Ethanol

The differences between cellulosic ethanol and corn ethanol are found strictly in the production processes. The end product for both processes is chemically identical. These chemicals have the exact same chemical makeup, energy content, and properties. While corn ethanol is made by fermenting the simple sugars contained within corn kernels, cellulosic ethanol is made from the tougher, more complex sugars cellulose and hemicellulose. These sugars are found in the cells of woody plants such as switchgrass and reed canary grass. Because cellulose is a complex sugar, it contains more energy within its chemical bonds than the simple sugar in corn does. The result of this is that ethanol produced from cellulosic feedstocks has a more positive energy balance than ethanol produced from corn. Unfortunately, because cellulose serves to protect plant cells, it is inherently strong and resistant to outside forces. To produce ethanol from this tough material, a few extra steps must be carried out to transform cellulose into simpler sugars before the fermentation process can begin. Either a biochemical or a thermochemical process can be used to liberate these simpler sugars from cellulose.

Processes

During pretreatment, cellulose is freed from its protective lignin casing. This can be accomplished with of a variety of methods: acid hydrolysis, steam explosion, ammonia fiber expansion (AFEX) among others. The next step is to break the cellulose down into smaller chains of simpler sugars. Cellulose itself is a very long hydrocarbon chain made of various simple sugars. Two main methods exist for performing this task: the biochemical process and enzymatic hydrolysis, each of which will result in five and six carbon sugars (mostly xylose, arabinose, and glucose).

Biochemical Processes

The biochemical process begins with what is called "pretreatment," a step that separates the extremely tough lignin casing from the cellulose. Once the cellulose has been freed from the lignin, it still needs to be converted into simpler sugars before the fermentation process can begin. The process of splitting the long hydrocarbon chain of cellulose into smaller five or six carbon sugars (usually xylose, arabinose, and glucose) is called hydrolysis, and it can be carried out by chemical or enzymatic hydrolysis.

Chemical hydrolysis uses acids to break down the cellulose molecules. However, this is not typically the best option due to high temperature and pressure conditions necessary for the reaction to occur. Enzymatic hydrolysis is the more desirable of the two methods. This process uses enzymes to break cellulose down into simple sugars and can occur at fairly standard conditions of 50°C and a pH of 5. In the past, the cost of these enzymes has inhibited the use of this process. However, DOE research funding has resulted in new methods enzyme production that have cut the cost down to between $0.10 and $0.30 per gallon of final ethanol produced. This is a 30-fold reduction in cost (Greer, 2005). Recent research into methods of producing these enzymes from fungi have shown promise to reduce the price even further.

The simple sugars are converted into ethanol by a microbial fermentation process. Standard yeast (saccharomyces cerevisiae) is not the best microbe due to the presence of sugars other than glucose. *Zymomonas mobilis* and *E. Coli* strains are better alternatives. Additional microbes are being developed that would be able to perform this fermentation even more effectively. An interesting development is the engineering of microbes that could skip the hydrolysis step and convert cellulose directly to ethanol. *Clostridium thermocellum* is a good example of these microbes; however this microbe also produces materials such as lactate and acetate, reducing its effectiveness as an ethanol producer.

The final step is to distill the resulting ethanol solution into 99% pure ethanol that can be used as fuel. Much like the bagasse in sugar cane, the lignin that was removed from the feedstock can be burned in order to provide the heat necessary for this distillation. The use of lignin as opposed to natural gas, which is often used in the production of corn-based ethanol, greatly reduces the net greenhouse gas emissions of cellulosic ethanol. This is the main reason that cellulosic ethanol can claim an 85% greenhouse gas reduction over gasoline.

Chemical hydrolysis is much more efficient than ethanol production from corn. Depending upon the feedstock used, anywhere from 300 to 1000 gallons of ethanol can be produced from one acre of land. Approximately one hundred gallons of ethanol can be produced per dry ton of cellulosic biomass used. The production cost falls between $1.15 and $1.45 per gallon, $0.05 to $0.35 greater than that of corn ethanol. Depending upon the source, the net energy balance of this process is said to be anywhere between two and eight (National Geographic).

Thermochemical Processes

The thermochemical process is a more experimental method of ethanol production, and relies upon a process called biomass gasification. This process turns biomass into SynGas, a combination of carbon monoxide, carbon dioxide, and hydrogen gases, which is then converted into ethanol. It is worth noting that this Syngas can also be converted into other fuels such as butanol or biodiesel.

Instead of using pretreatment and enzymes to liberate the carbon from the feedstock, the gasification process uses combustion in a low oxygen environment to break the bonds within the biomass until only very simple hydrocarbons remain, in the form of Syngas. Once the simple carbons are freed, they are fermented into ethanol through Microbial Fermentation. Since the inputs of this fermentation process aren't sugars, a different microbe, *Clostridium ljungdahlii*, must be used. Research is currently underway to find more efficient versions of this microbe. Once the ethanol is produced, it must be distilled until it is pure enough to be used as a fuel.

The thermochemical process is more efficient than ethanol production from corn, although definitive numbers are hard to come by as this process is still in its early stages of development and research. Up to seventy five gallons of ethanol can be produced per dry ton of biomass using this process, with an energy balance greater than positive four and a production cost of less than $0.80 per gallon.

Production Facilities

As is the case with corn ethanol, plants for cellulosic ethanol should be located where the crops are being grown and in the areas that ethanol will be sold. Keeping the transportation of crops and ethanol to a regional level will lower costs, reduce emissions, and increase efficiency. Transportation of raw materials is more expensive than transportation of fuel due to its greater volume of product transported; however with ethanol, the fuel transport is not much more convenient or cheaper than transporting the raw good.

Whey and perennial grasses can be used to create ethanol and can be shipped in the same manner as corn. These alternative feedstocks also have a higher yield per acre than corn, which would mean that less would have to be grown and transported to the refineries to create an equal amount of fuel. This is the primary reason that ethanol supporters are looking for advances in the processing of cellulose to make ethanol; these feedstocks, unlike corn, require a pretreatment to break down the cellulose into simple sugars.

Feedstock Growth and Distribution

The limiting factor in cellulosic ethanol production from feedstocks such as perennial grasses is not how many production plants can be built, but rather the amount of cropland available for feedstock production. While it is possible to build many more ethanol plants, all of the currently existing plants can be converted to cellulosic technology. However, due to the importance of food crops, feedstocks will need to be grown on land not already being used to produce food for humans or livestock. There are various feedstocks, such as perennial grasses and switchgrass, which are not suitable for human consumption. These grasses and plants can grow in many different environmental locations. Observing Figure 2 below, the large amount of grassland and pasture range in the United States where feedstocks such as perennial grasses can grow.

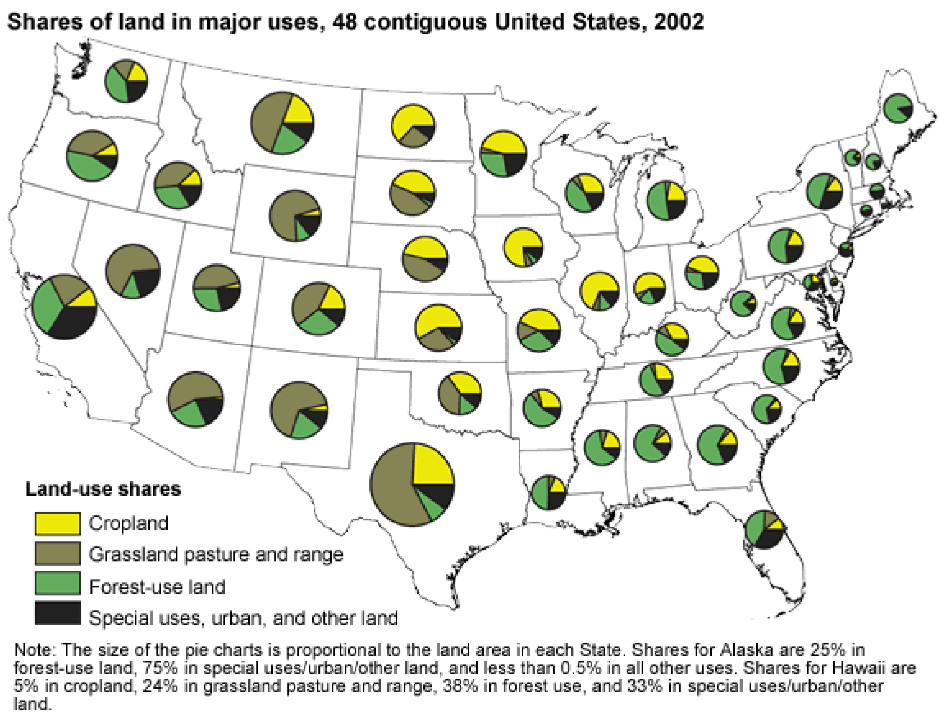

Figure 2: Land Use in United States

Source: http://www.ers.usda.gov/Data/MajorLandUses/map.htm

Accordingly, the best national distribution system for cellulosic ethanol is to grow the feedstocks all over the country, and then process them regionally using smaller plants. Then the ethanol produced in a region can be used by the people of that region, eliminating long-range transportation of feedstocks and fuels. Within each region trucks and trains will still be used to move the feedstocks from the fields to the plants and then from the plants to the fueling stations. Though trains are more efficient than trucks, rail lines do not always exist where the products need to be transported.

Feedstock: Switchgrass

Producing ethanol from cellulose reduces emissions by 90% when compared to gasoline. Feedstocks such as corn only reduce emissions by 30% (Wu, 2007). Switchgrass is a perennial grass that is native to North America and can be grown on marginal lands, areas that cannot sustain food crops. It requires little maintenance and has been known to sustain itself with little or no inputs for up to 100 years (Wu, 2007). However the addition of nutrients will increase yields and pesticide use will encourage growth during early stages, when the plant is most susceptible to weed competition. Fertilizers used on switchgrass include nitrogen, potassium, and phosphorous. The amount applied depends on the composition of the soil; however the maximum application is less that that of corn. Once switchgrass has reached maturity, which takes about three years, it can be cut using standard harvesting techniques.

Switchgrass has other benefits besides its low maintenance. It provides a habitat for grassland birds that are facing extinction. Even though the grass would be harvested up to twice a year, it grows back relatively quickly and would still provide a sustainable habitat (Bransbury, 2007). Switchgrass also prevents erosion and runoff because it is a perennial and does not require seeding every year. With today’s technology and methods, switchgrass can produce about 300 gallons of ethanol per acre (Babcock, 2007).

Alternate Feedstocks

In addition to switchgrass, other perennial grasses such as reed canary grass would make suitable feedstocks for the production of cellulosic ethanol. Canary reed grass is similar to switchgrass in terms of yields and energy balances, but it has a different growth pattern from switchgrass, with its most productive periods occurring in the spring and the fall. In addition, canary reed grass is better suited to colder climates and wet soil than switchgrass is; canary reed grass can be grown in areas that switchgrass can not. This difference in growth patterns and climate needs could allow canary reed grass to serve as a good complement to switchgrass in a multi-feedstock ethanol program. Canary reed grass is also very good at minimizing soil erosion due to its rhizomatic root structure (Brummer, Burras and Duffy). Reed canary grass has not been heavily pursued in the United States. Because of its cold-weather tolerance, however, it has become one of the most popular bioenergy crops in Nordic Europe. There the grass is used directly as fuel in a dry pelletized form, or as a feedstock to produce ethanol fuel. In terms of yield, reed canary grass has been found to produce an average of about 3.4 dry tons of biomass per acre (Pahkala, Kontturi and Kallioinen). This yield produces approximately 300 gallons of ethanol per acre, which is similar to switchgrass. Since reed canary grass has not been widely researched in the U.S. its seed to wheel energy balance is still unknown. However, it can be expected that the energy balance of reed canary grass is similar to that of switchgrass.

Other feedstocks than plant matter are also suitable for use in ethanol production, especially when biomass gasification is employed as the production method. Feedstocks that can be used to feed this process include various types of wastes such as wood, agricultural waste (e.g. corn stover), citrus peel waste, municipal waste, and garbage. These types of feedstocks already exist in large quantities, so converting them into ethanol requires only that the waste be transported to the conversion plant. Although there are currently very few plants producing ethanol from these materials, Range Fuels, Inc. announced in February 2007 that it was planning to open a cellulosic ethanol plant in Georgia that would produce ethanol from waste biomass (mainly wood waste obtained from the region's indigenous Georgia Pine) through a proprietary biomass gasification process called K2. The potential output of this plant is over 1 Billion gallons of ethanol per year (Range Fuels, Inc.). Due to the wide variety of waste feedstocks, definitive energy balances for the ethanol produced from them have not yet been determined.

Future Projections

By studying the historical progression of corn ethanol and the current movement towards cellulosic ethanol by the federal government, it is estimated that 175 cellulosic plants will be operational by 2017. This estimate is based on the historical progression of corn ethanol, as well as the current push for cellulosic ethanol. Assuming that each plant produces an average of sixty million gallons of cellulosic ethanol per year (the average capacity for plants currently under construction), the annual capacity of the cellulosic industry will be about 10.7 billion gallons of cellulosic ethanol per year. These 10.7 billion gallons of cellulosic ethanol are equivalent to approximately 7.3 billion gasoline-gallons (National Geographic) which accounts for approximately 21% of our targeted 35 billion gallons of gasoline-equivalent gallons by 2017.

Because cellulosic ethanol plants are not tailored to any particular feedstock, each plant can use a different variety of feedstock, depending upon what is in locally available. In areas where there is a large amount waste, plants could be constructed to run solely on waste feedstocks. Waste is produced in large amounts in the United States, so it would be hard to limit where or how much cellulosic ethanol can be produced. The limiting factor for waste ethanol plants will be the number of plants constructed. Plants currently under construction are will use a combination of waste and crop feedstocks. Because cropland is limited, plants should be located where feedstocks are grown. Waste feedstocks can be used as a supplement to traditional feedstocks. Of the six cellulosic ethanol pilot plants, most use waste as well as traditional feedstocks. The plant that is planned in LaBelle, Florida, for instance, will use sugarcane as its main feedstock as well as citrus peel waste, which is in great excess in this part of the nation (Ethanol Producer Magazine).

While it may look promising, cellulosic ethanol is not the save-all for the American society. It has promise, but is not yet available on an industrial scale. There are currently no cellulosic ethanol plants operating commercially in the United States. The federal government has selected 6 cellulosic pilot plant projects around the country to receive federal funding to begin cellulosic research on an industrial scale (Ethanol Producer Magazine). The success of these pilot plants will have a huge impact on the future of the American BioFuel revolution.

Biodiesel

The US consumes 56 billion gallons of diesel a year, and 95% of the fuel used in industry and construction is diesel fuel. On average, diesel engines are 60% more efficient than gasoline engines, and they withstand wear much better (Blue Sun Biodiesel). The average cost of petroleum diesel in the US is $3.44 a gallon, with a price increase of almost a dollar a year (Energy Information Administration). This increasing cost in addition to the current depletion of the world's oil supply has led many to search for an alternative to traditional diesel.

Biodiesel is a long chain of fatty acids with an alcohol added. Its chemical properties compare favorably to petroleum diesel; it actually burns more rapidly and much cleaner than regular diesel. It also acts as a lubricant and reduces engine wear. Biodiesel is available both pure and blended with petroleum diesel. New vehicles can run 100% biodiesel without any modifications; older engines may require some minor modification to run pure biodiesel. Any diesel engine can run easily on lower blends of biodiesel.

Biodiesel has much better emissions than regular diesel for all pollutants, with the exception of NO_X. See Table 1 below. It also has a slightly lower energy density than petroleum diesel; one gallon of diesel has the same amount of energy as 1.1 gallons of biodiesel (Gable).

Table 1: Biodiesel Emission Statistics

Emissions of Biodiesel Compared to Regular Diesel

Emission Type	B100	B20
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
NO_x	+10%	0%

Source: http://www.biodiesel.org/pdf_files/fuelfactsheets/emissions.pdf

Biodiesel is usually produced by a process called transesterification, using vegetable or waste oils as a feedstock. An alternate two-step method called Biomass-to-Liquid begins with a process known as biomass gasification. This process produces Syngas, which can then be used to produce biodiesel. This process can use a variety of feedstocks, including wood waste and switchgrass.

Energy Balance

Petroleum diesel has an energy density approximately 10% higher than that of biodiesel (UNH Biodiesel Group). While in theory it should take 11% more biodiesel than diesel to travel the same distance, it actually takes 4-5% less (Blue Sun Biodiesel). This is due to biodiesel's increased performance in a diesel engine. Though biodiesel contains less energy per unit volume, its higher cetane ratings, better engine lubrication and other properties improve engine performance, partially making up for the decreased energy density.

According to the U.S. Department of Energy and the Department of Agriculture, biodiesel's overall energy balance is 3.2; for every unit of fossil fuel energy used in the production of biodiesel, 3.2 units of energy come out in the form of biodiesel. Of all the alternative fuels in use today, biodiesel has the best energy balance and energy density. Diesel engines are much more efficient than gasoline engines; a diesel engine running on biodiesel seems to be the most energy efficient and environmentally friendly option for transportation.

Vehicle Modifications

Perhaps biodiesel's greatest benefit is that it can be used in diesel vehicles without any modifications. Cars that currently use diesel fuel can be easily modified to be able to run on biodiesel (Tat, 1999). In some older vehicles, rubber seals used in the fuel lines may need to be replaced with non-rubber products such as Viton™. These modifications are relatively inexpensive, and newer cars require fewer modifications than older cars. If a low blend of biodiesel, such as a five percent blend, is used, the concentration of biodiesel is not high enough to cause damage to rubber linings. Most new cars can run biodiesel blends without any modifications. The only downfall of biodiesel is its high NO_x emissions, but these can be decreased with the use of advanced injection timing and increased injection pressure (Tickell, 2005). It is worth noting that catalytic converters are just as effective on biodiesel emissions as on fossil diesel.

A diesel engine's performance is dependant on the cetane rating of the fuel that it is run on. Higher blends of biodiesel are produced with a maximum cetane number of 55, whereas petroleum diesel has a maximum cetane number of 52. The higher the cetane number, the faster a fuel ignites. Pure biodiesel burns cleaner than petroleum diesel and acts as a lubricant, eliminating deposits that build up in regular diesel engines and reducing engine wear. This can cause problems in older engines that have been run on petroleum diesel; biodiesel cleans out the fuel system. The petroleum deposits released by biodiesel can clog filters and cause blockage in the fuel lines. This problem can be avoided by beginning with a low blend of biodiesel and gradually increasing the percentage of biodiesel over a few weeks (Radich, 2004).

Starting a vehicle at lower temperatures can be problematic while using higher concentrations of biodiesel. This is due to highly viscous nature of biodiesel. Pure biodiesel has a viscosity of approximately 13.5 cSt at zero degrees Centigrade, while number 2 petroleum diesel has a viscosity of about 5.25 at the same temperature. Currently, biodiesel viscosity is beyond the permitted range of viscosity for D975 as defined by the ASTM, the standard set of regulations regarding various grades of diesel fuel (Tat, 1999). To compensate for this high viscosity, lower blends of biodiesel should be used during colder weather. Alternatives include having a fuel heating system for the vehicle engine block or using biodegradable additives which reduce the viscosity. With lower blends of biodiesel, this is less of a problem.

In general, engines running on biodiesel tend to require more frequent oil changes than similar engines using conventional diesel petroleum. This effect is amplified by higher blends of biodiesel, generally above 20% biodiesel. During an experimental project, one Mercedes Benz bus was operated using a blend of biodiesel while a second bus used diesel fuel. It was found that the bus running on biodiesel fuel required an oil change after an average of 12,000 Km compared to 21,000 Km for the bus operating with fossil diesel. While the bus required more oil changes, the engine was not affected in any adverse manner.

Production and Distribution Facilities

Currently, the biodiesel infrastructure is not as well developed as that of corn ethanol. However, over the last decade, the infrastructure for biodiesel has grown at an astonishing rate. As of September 7, 2007, there are 165 industrial plants manufacturing biodiesel in the United States (National Biodiesel Board). Combined, these 165 plants have a capacity equivalent to approximately 2.0 billion diesel gallons, a number significantly higher than the current annual production of biodiesel. Due to rotating crop seasons, biodiesel plants do not operate at full capacity all year long.

As biodiesel infrastructure develops, it will continue to be modeled after the incredibly successful diesel distribution system. Diesel fuel is currently distributed by barge, rail, and train, and its distribution is very similar to the conventional petroleum distribution previously discussed. Large barges and ships take the diesel to regional hubs such as New Orleans, Philadelphia, Los Angeles, and New York City. From large port cities such as these, the fuel is then distributed by pipe and rail.

Currently, biodiesel plants are not uniformly distributed throughout the United States. As is seen in Figure 3 and Figure 4, there is a localized concentration in the Midwest and southeastern portions of the nation. Some of the largest plants in the nation are found in the Midwest (National Biodiesel Board). It is important to note that thus far the biodiesel industry has experienced the most growth in areas where feedstocks are readily available and easily accessible.

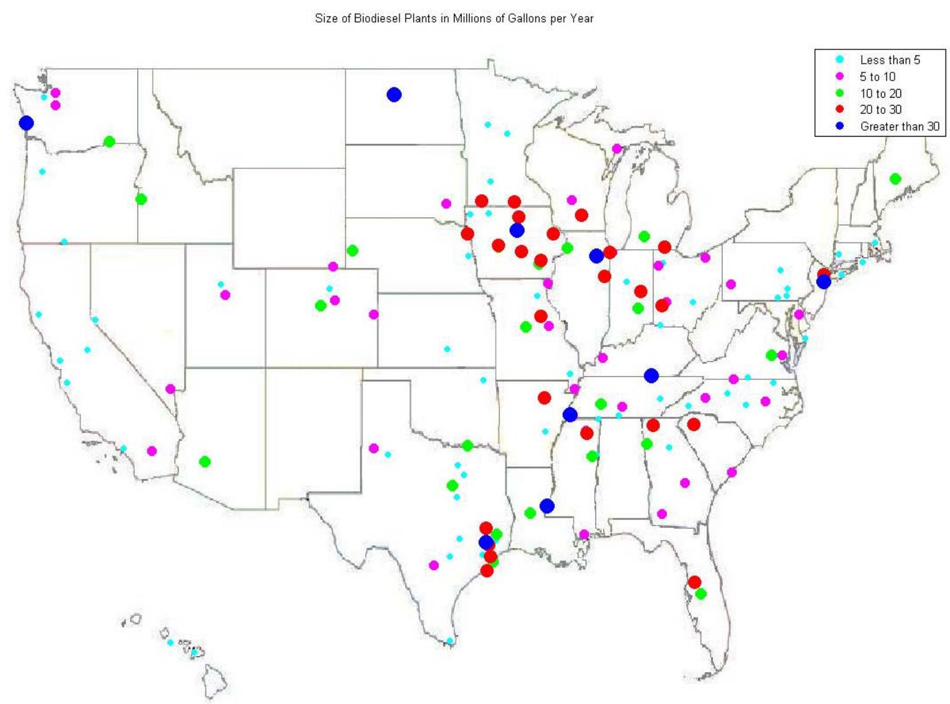

Figure 3: Biodiesel Production Facilities by Relative Size in United States

Data Source: National Biodiesel Board

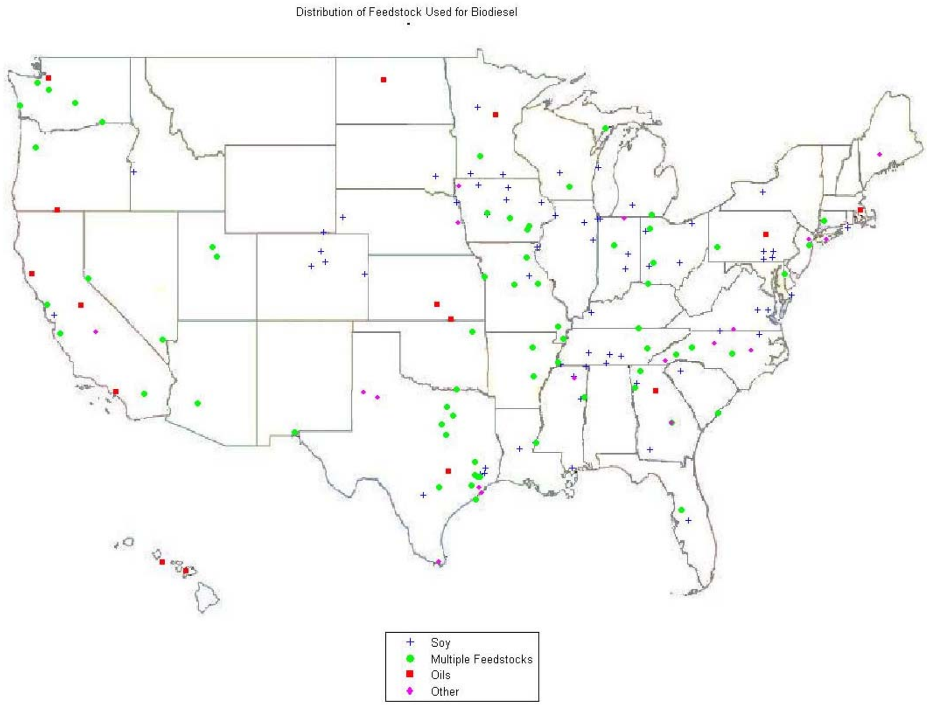

Figure 4: Biodiesel Production Facilities by Primary Feedstock

Data Source: National Biodiesel Board

When a truck delivers grain to the biodiesel plant, there is not a return good going back to the farm where the grain originated like there is in pipelines. This creates a negative trade balance with respect to the farms in the nation, making it less profitable and feasible to transport the raw grain long distances. In the future, feedstocks such as switchgrass, canola, and algae may allow for a wider national distribution of processing facilities. Due to the abundant land and water resources, the Midwest may become an ideal center of growth for the biodiesel industry.

The *Biodiesel Magazine* cites a trial test of the transportation of biodiesel through a pipeline. The quality of the sample at the end of the shipment was the same as the beginning of the shipment. However, the blend that was shipped was only a five percent blend, and the high diesel content may have contributed to the stability of the fuel. While this is a superb first step to the distribution of biodiesel, more research is needed.

There is currently very little regulation of the transportation and storage of biodiesel. Organizations such as the ASTM, an international group that standardizes such regulations, and the BQ9000 should monitor these rules. Currently, biodiesel producers and suppliers can choose whether or not to be accredited by BQ9000 (Rob Elam, Propel BioFuels). Regulating the transportation of biodiesel would have the advantage of ensuring the quality of the biodiesel that is sold to customers. This would help to decrease sludge accumulation and fleet failure in vehicles utilizing biodiesel as a fuel. Due to the highly viscous nature of biodiesel, these regulations must also include a recommendation to blend biodiesel and petroleum at cold temperatures.

As was defined earlier, for biodiesel to be considered feasible, the United States “should be able to produce large volumes of fuel reasonably.” In addition, this massive amount of fuel must be easily distributed. Currently, there are approximately 1000 gas stations in the United States that offer biodiesel as a fuel choice. See, as is shown Figure 5 below. The process of adding a biodiesel pump is very similar to that of adding an E85 pump at a gas station, as discussed earlier. For biodiesel to be at least regionally feasible in the Midwest, many more gas stations must be either converted or constructed.

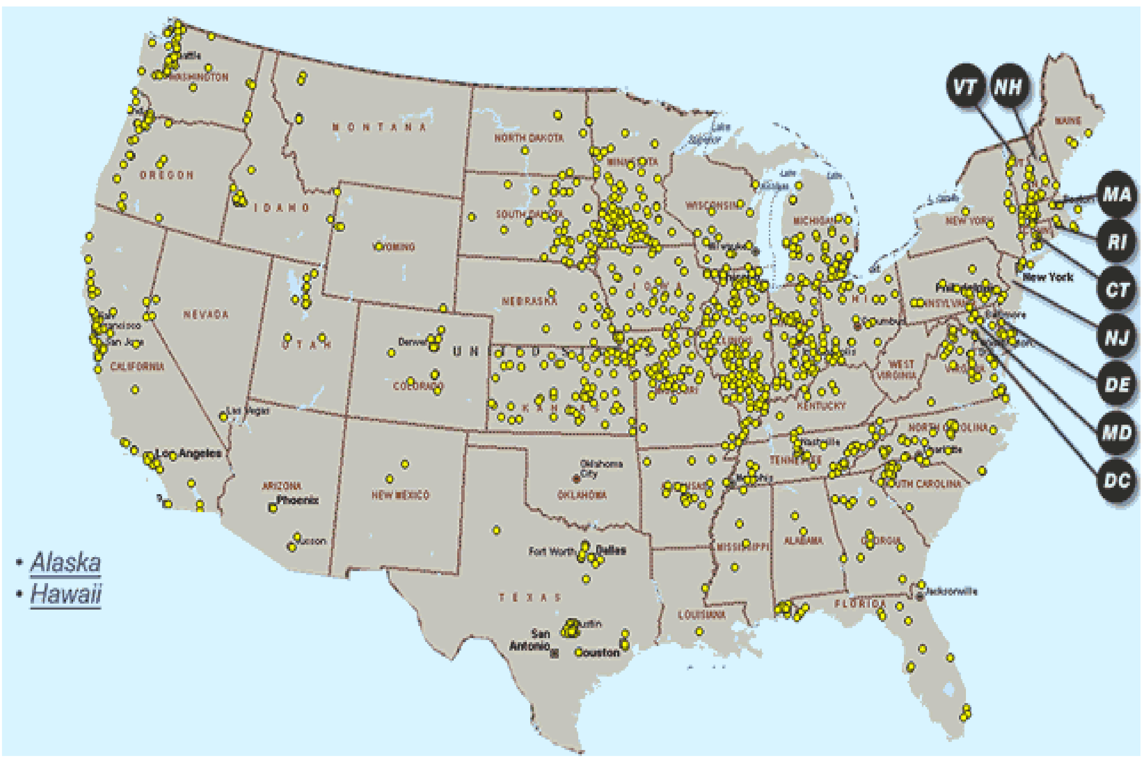

Figure 5: Biodiesel Retail Centers

Source: http://www.biodiesel.org/buyingbiodiesel/retailfuelingsites/

Although biodiesel may look more promising from a technological perspective, it is extremely difficult to transport, especially when compared to conventional diesel. Pipeline installation costs approximately one million dollars per mile, and the limited connectivity of the nation’s rail system limits transportation by train. The infrastructure currently in place for grain distribution in the Midwest should remain intact to help support the development of biodiesel in this part of the country. Future biodiesel plants should be centered near transportation hubs such as interstates and rail lines. In the future, grain transportation from the farm to the plant will remain very similar to the current model.

Risk Analysis

Risk analysis of biodiesel shows a low oral, dermal, and aqueous toxicity. Slight skin irritation is possible. In a University of Idaho study on aqueous toxicity, it was found that canola methyl esters are 16 times less toxic than diesel, while ethyl esters are 69 times less toxic (University of Idaho, 2004). Studies on trout have shown the lethal concentration (LC50) for diesel fuel is 1.43ppm while that of biodiesel is 23ppm. Much of the toxicity from biodiesel occurs when it is vigorously blended in water; the methyl esters form a temporary emulsion of little droplets that can harm fish by coating their gills (von Wedel, 1999). Biodiesel is insoluble in water, with a saturation concentration of 7ppm in seawater and 14ppm in freshwater (EPA, 2007). Biodiesel has been shown to degrade more rapidly than dextrose and will degrade 98% in 28 days. Regular diesel fuel will degrade about 40% in the same amount of time (Biodiesel, Green Trust). The flashpoint of biodiesel is >270˚F, making its vapors less flammable than petrol vapors, which have a flashpoint of 125˚F (EPA, 2007).

Environmental Implications

Because of its high oxygen content, biodiesel combusts more efficiently than petroleum diesel and results in lower emissions. Though biodiesel emits more carbon dioxide than traditional diesel, it releases less carbon monoxide. Biodiesel also emits 90% fewer hydrocarbons, 100% less sulfate, 40% less particulate matter than gasoline, which burns cleaner than regular diesel. Though biodiesel has higher NO_x emissions than gasoline or petroleum diesel, any attempt to decrease the NO_x emissions would lead to slightly higher particulate matter, hydrocarbon, and carbon monoxide release. See Figure 6.

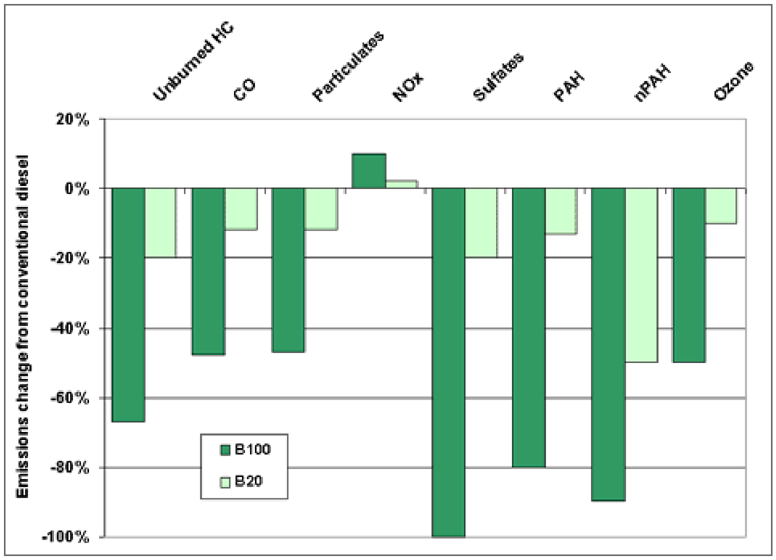

Figure 6: Emissions of Biodiesel versus Same-Volume Gasoline

Creation of Biodiesel - Transesterification

Biodiesel is usually made from vegetable oils through a chemical reaction known as transesterification. During transesterification, a vegetable oil molecule is reduced to about 1/3 its original size, and the chemical composition is altered. This reaction produces three molecules of ester fuel from every molecule of vegetable oil.

When vegetable oil is added to the reactor vessel, it reacts with one of two alcohols and a catalyst, usually Sodium Hydroxide. The alcohol must be either a methyl or an ethyl alcohol. If the reaction uses a methyl alcohol, the resulting biodiesel is known as a methyl ester. Similarly, the biodiesel is an ethyl ester if an ethyl alcohol is utilized in the reaction. Generally, the methyl process is cheaper than the ethyl alcohol reaction. (See Figure 7, Figure 8 and Figure 9 below.) The reaction generates biodiesel and glycerol. The biodiesel must then be refined, to remove excess fatty acids. If left in the biodiesel, these free fatty acids cause some problems with the shipment of biodiesel.

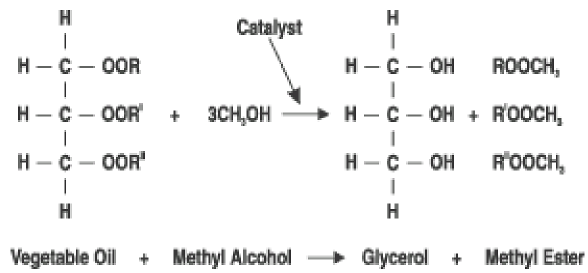

Figure 7: Basic Biodiesel Synthesis

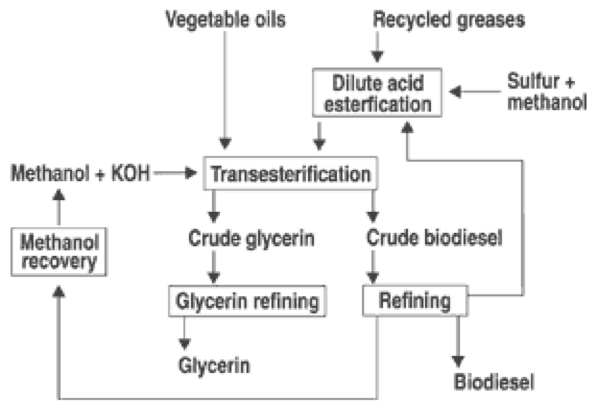

Figure 8: Biodiesel Production Process

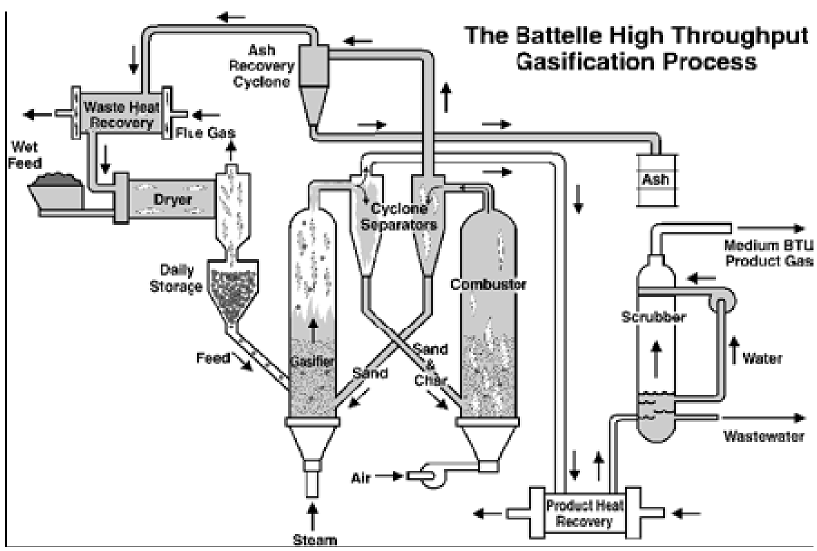

Figure 9: Biodiesel Synthesis Schematic

Source: http://www.fercoenterprises.com/downloads/seville.pdf

Feedstock: Soy

Soy is considered a first generation BioFuel feedstock because it is already being grown and used for biodiesel production. It has begun to be implemented on a regional scale in the

Midwest, though distribution methods are still under development. As the BioFuel industry expands, soy will play an integral role in the growth of the biodiesel sector. Soy is a better feedstock than corn. For each unit of energy used to produce biodiesel from soybeans, 3.2 units of energy in the form of biodiesel are returned.

In general, a bushel of soybeans produces 1.33 gallons of soy oil; a field that produces 30 bushels per acre would yield about 40 gallons of soybean oil. This figure is dependent upon the method of oil extraction. Studies show that if all of the soybean oil produced in the United States were used for biodiesel, it would meet approximately 12 percent of the U.S. trucking industry's fuel needs. Clearly, soy alone is not the answer. However, if the total U.S. soybean crop of about 3 billion bushels per year could be converted to biodiesel, it would produce roughly 4.2 billion gallons of biodiesel, or 3.7 billion diesel gasoline-gallons. This would account for approximately eleven percent of President Bush's goal for 2017, which is a significant contribution.

One of the disadvantages of soy is its relatively low yield as a feedstock. Since soy has a yield of 56 gallons of biodiesel per acre per year, 625 million acres would be required to produce 35 billion gallons of soy biodiesel (Roberts, 2006). Unfortunately, the United States only contains 407 million acres of arable land (CIA Factbook, 2007). During 2006, 90 million gallons of soy biodiesel were produced (Water Implications, 2007). It does not seem practical to use soy as a large component of the theoretical 35 billion gallons, simply because soy does not yield enough biodiesel per acre to justify significant land use. An ideal feedstock would possess characteristics similar to soy's low fertilizer and pesticide requirements as well as high BioFuel yields.

Although soy will not be a major national source of biodiesel in 2017, it is a feasible regional feedstock. The current production infrastructure in the Midwest can continue to produce biodiesel from soy into the future. Production plants in this area are close to the fields where feedstocks are grown, making transportation and distribution cheap and practical. Although soy will not be feasible on a national scale, it is still extremely practical on a local or regional scale.

Though soy and corn are both first generation feedstocks, they have radically different pesticide requirements. When adjusted for net energy balance, soy biodiesel requires 2% of the nitrogen and 8% of the phosphorus needed to produce corn ethanol (Water Implications, 2007).

Additionally, soy uses only 13% of the pesticides that corn requires (Hill et al., 2006). It is important to recognize that, in addition to using lower quantities of pesticides, soy does not use Atrazine, Acetochlor, or any other known carcinogenic pesticides (Water Implications, 2007). As with other crops, the amount of sediment runoff depends on local farming practices. Because soy uses dramatically smaller amounts of fertilizers and pesticides, it does not contribute to non-point source pollution as much as corn farming does.

Water requirements for soy are largely dependent upon the region in which the crop is grown. Irrigation water requirements range from 130,000 to 360,000 gallons per year per acre of soy. At a yield of 56 gallons of soy biodiesel per acre and year, on average, between 2,400 and 6,300 gallons of irrigated water are required to cultivate enough soy to produce one gallon of biodiesel (Water Implications, 2007).

Multi-Grained-Feedstock and Other Feedstocks

Another common type of feedstock in the biodiesel industry is what is known as a multi-feedstock. Multi-grained-feedstock plants use various types of feedstocks to fuel the hydrolysis reaction, depending on the geographic location of the plant and the time of year. Because of the prevalence of various types of biomass in the Midwest portion of the nation, there is a high concentration of multi-grained feedstock plants in this part of the country. Therefore, as the biodiesel industry grows over the next ten years, the Midwest will remain a forerunner in the production of biodiesel.

Alternate Feedstocks

Various types of oils can also be used as biodiesel feedstocks. Feedstock oils may include used vegetable oil from restaurants, animal oils and fats, and certain types of grease. Oil-processing biodiesel plants are scattered randomly throughout the nation and produce a relatively small portion of the biodiesel for the nation as a whole. However, this production method has a large potential for future development. The United States produces approximately 11 billion gallons of waste vegetable oil annually. Currently, most companies must pay to have their used vegetable oil taken off site. Any market that develops for these businesses to sell their waste, will provide environmentally-friendly financial relief for the restaurant and entertainment industry. If only three-fourths of this used vegetable oil is converted to biodiesel, approximately 4.5 billion gallons of pure biodiesel can be created each year (MIT). These gallons of biodiesel would replace about 4 billion gallons of diesel gasoline.

Fischer-Tropsch and Biomass Gasification

An alternative method used to produce biodiesel is a combination of biomass gasification and the Fischer-Tropsch process. During biomass gasification, the biomass is converted into a synthetic gas. This synthetic gas, or Syngas, consists mainly of carbon monoxide and hydrogen. The Syngas can then be reacted using the Fischer-Tropsch method to create biodiesel. Though the efficiency varies by feedstock, the process has a positive energy balance for the feedstocks we considered, and is about 45% efficient (Unnasch).

The most practical feedstocks for this production method are waste products, including wood waste and waste from agricultural and industrial sources. These feedstocks may be shipped in a wet, dry, or pelleted form. Generally, pelleting is the most energy efficient packing method, as pellets have almost twice the energy density of a dry product. However, the process of pelleting also requires energy to produce the pellets from the raw materials. Because wet stock can contain up to three-fifths moisture by mass, an enormous gassifier is required to achieve a positive energy return and much more time is required to burn the feedstock. Because of these complexities, most biomass gassifiers being used today are designed to handle either dry or pelleted feedstock.

Fisher-Tropsch and Biomass Gasification Feedstocks

The same feedstocks cannot be used for the transesterfication and Fischer-Tropsch processes; Fischer-Tropsch feedstocks are predominantly waste products. One of the most prevalent feedstocks for the Fischer-Tropsch method is wood waste. A study done by the US Department of Agriculture has projected that by 2020 the US could sustainably produce 163 million dry tons of wood waste per year. This number includes forest wastes, logging, siteclearing waste, and debris from construction. Most of this waste would be concentrated in rural areas, though the construction waste would be more evenly distributed.

The same USDA study also examined agricultural waste. Agricultural waste consists of crop residue, perennial grasses, and dry grains, among others. The study concluded that approximately 870 million dry tons of biomass per year could be sustainably produced in the year 2020. The same study projected that 145 million dry tons of biomass per year will be produced at the current rate.

Biomass gassifiers can also be run on alternative feedstocks, such as switchgrass (already mentioned in the ethanol portion of the report), canary reed grass, and poplar. These perennial plants are an excellent option for future development because they are not energy intensive to grow, and thrive on marginal land that cannot be used for other crops. In addition, these alternative feedstocks have relatively high yields.

Biodiesel: The Next Generation

Although the current outlook for biodiesel is fairly grim on a national scale, the industry has a bright future. Feedstocks that are more environmentally friendly and have higher energy contents are being researched at universities across the nation. While first generation feedstocks such as soy and multi-grained feedstocks will not play a large role in the production of biodiesel in 2017, second generation feedstocks such as canola and algae will.

Canola has a higher oil content than first generation feedstocks, and is being researched as a potential biodiesel feedstock. Although it has energy balance of approximately 20, it requires a large quantity of nitrogen fertilizer to grow. Nitrate released from fertilizer reacts in the atmosphere to create N_20, which increases the rate of global warming up to 1.7 times more than CO_2. Nitrate can also cause hypoxia if large quantities are introduced into streams or rivers. More research must be completed to fully understand the feasibility and possible implications of canola as a feedstock. Despite its high energy balance, canola only produces 100 gallons of biodiesel per acre of field.

Biodiesel production from waste oils should be expanded in the future. These oils are already extracted, eliminating the crushing and separation stages required to remove oil from other feedstocks. This vastly improves the energy balance and efficiency of the process. Waste oils are made up primarily of used cooking oil from restaurants and animal fats from meat processing plants. Since these oils are waste products, they can currently be obtained at low cost. However, there is a finite amount of waste oil available in the US, and increasing demand promises to turn these oils from a waste product into a saleable commodity, potentially driving up prices.

Another feedstock for biodiesel, specifically for the transesterfication process, is algae. Although few studies have been published, the results thus far have indicated that algae has an unparalleled energy balance and yields that are hundreds of times higher than any other feedstock. Specific strains of algae contain 50% oil by weight, which is much more than soy or even canola. They require only sunlight, water and a carbon dioxide source to grow and can be harvested daily, securing a steady feedstock supply. Many algae cultivation methods have been proposed, including standing ponds, raceway ponds and towers or bags. Still ponds are the least energy intensive, but since they are open to the environment, they are vulnerable, and harder to maintain at optimal production levels.

A raceway pond is a cement "track" filled with constantly flowing, nutrient rich water. These ponds require a higher energy investment than still ponds; however, they make it easier to monitor algal growing conditions. Waste streams can be used to provide nutrients to algae in raceway ponds, feeding the algae and purifying the waste stream at the same time.

Towers or bags made of clear glass or plastic offer a very controlled setting in which to grow algae, and enable maximum optimization of the environment. One particularly intriguing design that is currently in development involves connecting algae bags or towers to the smokestacks of power plants, which produce large quantities of steam and carbon dioxide (National Geographic, 2007). The algae are fed by the exhaust, removing air pollutants in the process. The only obvious question is whether the amount of water the algae require would overstress the water table.

Though algae production is still under development, it has the benefit of being much more compact than first-generation feedstocks. Recent research funded by the NREL claims that 7.5 billion gallons of biodiesel produced from algae could be produced from as little as 500 thousand acres of land. The current experimental yield of algal biodiesel is approximately 819 gallons of biodiesel per acre, much higher than first generation feedstocks which rarely have yields above 100 gallons of biodiesel per acre. As the cultivation of algae is further refined, it will become more practical as a feedstock. At its current rate of advancement, algae will not be a large contributor to biodiesel production by 2017. While biodiesel production from algae is still in the pilot stage, it has much more promise than any other feedstock.

Future Projections

Across the nation, the biodiesel industry is not as well developed as that of corn ethanol. The annual capacity for an average biodiesel plant is twelve million gallons per plant per year: there are 165 plants in the United States. See Figure 3 above on page 28 and Figure 10 below. Assuming the average plant capacity will increase by about 20% in the next ten years while the current rate of plant construction and expansion remains constant, we estimate that a biodiesel equivalent to 5.4 billion gallons of diesel, or approximately 15.4% of President Bush's goal, will be manufactured in 2017.

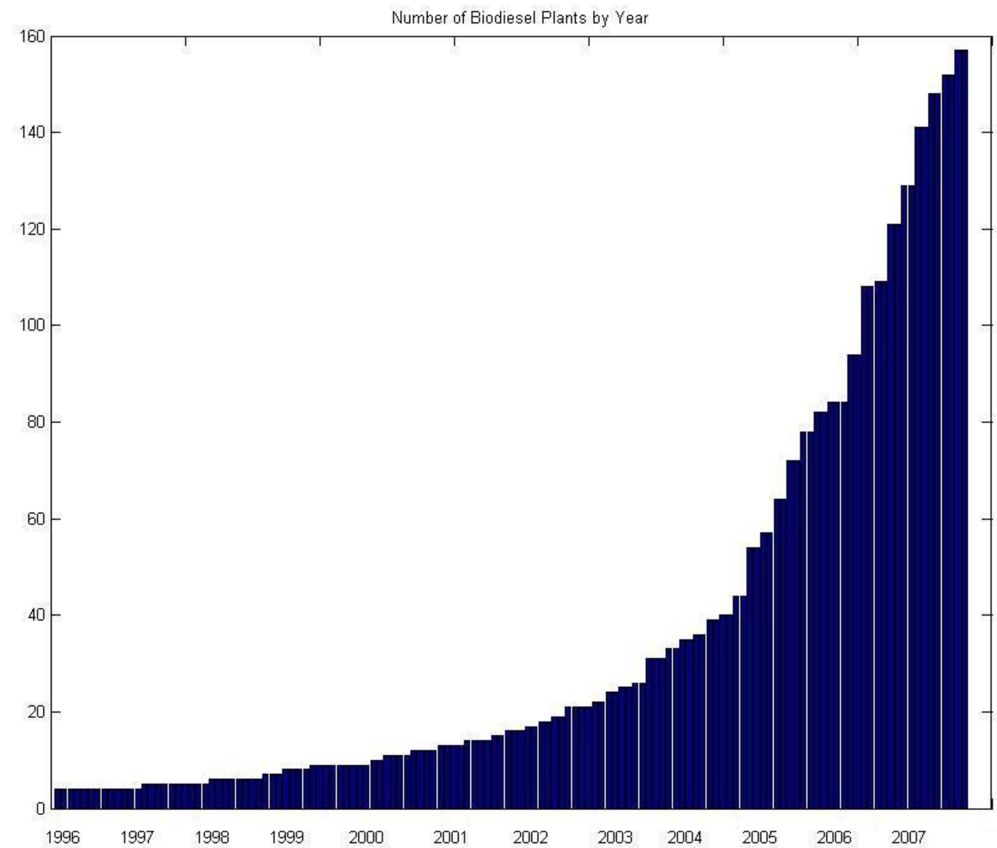

Figure 10: Biodiesel Production Capacity by Year

Data Source: National Biodiesel Board

In addition to conventional feedstocks, used vegetable oil will also be used for biodiesel production. If only 75% of the United States' 11 billon gallons of used vegetable oil is used to create biodiesel, the amount of biodiesel created would be equivalent to an additional 4 billion gasoline-gallons. In total, we predict biodiesel production will offset 9.4 billion gasoline-gallons by 2017.

Butanol

Much like ethanol Butanol is an alcohol, which means that it is produced with similar processes. However, butanol ($C_4 H_{10} O$) includes two more carbons than ethanol, and therefore has a much higher energy content. A gallon of butanol contains approximately 95% of the energy of a gallon of gasoline, while a gallon of ethanol contains only 68%. Butanol has a very high viscosity, which means that it is more chemically stable than gasoline, and is much safer to use. It can also be used in vehicles with little or no engine conversion, though adjustments can be made to fuel injectors and car central computers to optimize performance. Because butanol is hydrophobic (does not absorb water), and less corrosive than ethanol, it can be transported though existing gasoline infrastructure. Butanol is used widely as a paint thinner, gasoline additive, and industrial solvent, but currently is not mass produced in quantities large enough for mass fuel dispersion.

Risk Analysis

The risk analysis of butanol shows a low oral, dermal, and inhalation toxicity. It is a moderate skin irritant and severe eye irritant. Butanol is not genotoxic or developmentally toxic and is not likely to be reproductively toxic. Its carcinogenic potential is very low (BP, 2007). Butanol is more hydrophobic than ethanol and is more likely to repel water (Brekke, 2007). It is expected to partition mainly through air and readily moves through the soil to ground water. Butanol is biodegradable and will not persist in the environment for long periods of time (EPA). Butanol will volatize from water surfaces with a half life of 2.4 hours for streams, 3.9 hours for rivers, and 125.9 days for lakes (Butanol, 2007).

Vehicle Modifications

Unlike many BioFuels, butanol can safely be used in up to 100% concentrations without engine modification. Because of butanol's higher viscosity and different energy-to-octane ratio, adjustments to fuel injectors and vehicle computers can help butanol-powered vehicles to run at optimum performance. However, new computer-controlled cars are not the only vehicles that can be run on butanol; older models can also make the switch from gasoline without much trouble. In July 2005, David Ramey, a researcher affiliated with Environmental Energy Inc., drove from Blacklick, Ohio to San Diego, California in a 1992 Buick that ran on 100% butanol. This trip marked the first real experiment with butanol as a gasoline replacement, as Ramey had previously only produced enough butanol to run a lawnmower. This trip proved to be a success, and Ramey states that, “We had no problems. With gas, my Buick gets about 18 miles per gallon. With butanol, we’re getting 25 or 26.” Ramey continues to run his Buick on a 25 to 50 percent butanol-gasoline blend; blending butanol with gasoline increases both performance and gas mileage. Unfortunately, butanol cannot be used in diesel engines. Currently, butanol costs around $3.70 per gallon when bought by the barge load, or $6.80 per gallon when bought in 55 gallon drums.

Energy Density

On gallon of butanol has approximately 95% of the energy content of gasoline while ethanol, a similar alcohol, contains 68% of the energy of gasoline. This means that the energy density of butanol is almost 40% greater than that of ethanol. Because butanol is created from similar feedstocks as ethanol, the butanol production process is much more efficient than that of ethanol.

Octane is a measure of how easily a fuel can be combusted. Despite its lower energy content, butanol has a higher octane level than gasoline: the octane rating for butanol is 94, compared to a level of 87 for gasoline. As octane level increases, so does the compression ratio for the fuel. This ignition ability is measured with the engine compression ratio, and is used to predict how well an engine functions; engines with larger compression ratios produce more power. Therefore, because butanol has a higher octane rating than gasoline, it actually produces more power. Thus, an engine run on butanol can actually have better gas mileage than the same engine would when run on gasoline. A gallon of butanol is equivalent to 0.9 gallons of gasoline.

Safety Factor

Gasoline is extremely volatile and can both evaporate and combust easily, which means that even a minor gasoline leak can be very dangerous. Butanol is much more viscous than gasoline and ethanol and has a lower vapor pressure than either fuel: 0.33 psi compared to 2 psi for ethanol and 4.5 psi for gasoline at 100 degrees F (butanol.com). Since the vapor pressure of a liquid measures its volatility, butanol's low vapor pressure means that it is much less evaporative than ethanol, and more than 13 times less evaporative than gasoline, which makes it much safer to pump and transport.

Environmental Implications

Butanol is considered to be environmentally friendly because it is carbon neutral. The feedstocks that are used to produce butanol, such as sugar beets, sugar cane, wheat, and cassava, absorb CO2 as they grow (Alternative 2007). Additionally butanol releases less carbon from tailpipe emissions than gasoline. Butanol production also releases hydrogen, which can be recycled in a variety of ways, further increasing its total energy yield. Using butanol as a BioFuel has been shown to reduce hydrocarbon emissions by 95%, NO_x emissions by 37% and carbon monoxide emissions by nearly 100% (Holan 2006).

Feedstock-to-refinery distribution

Currently, corn is the most abundant feed stock for butanol, though it should be replaced by other feed stocks as soon as they are economically viable. This is beneficial because corn is a large food source for this country, as well as a sizeable export. Corn is primarily transported by truck from field to refinery. Trains and barges are an option for transportation in areas close to rails or waterways, when the quantity of feedstock to be shipped exceeds the economic limitations of trucks. Trains are more economic for long-distance shipping, since the capacity of a truck is much lower than that of a hopper car.

Whey and perennial grasses are two other butanol feed stocks, which can be shipped in the same manner as corn. Both whey and perennial grasses have a higher yield than corn, which means that smaller amounts of these second-generation feedstocks can be processed to produce a comparable amount of butanol.

Trucks are generally the best method of transportation for methane waste feed stocks or bio-wastes such as wood pulp or wood shavings. Depending on the particular form of bio-waste, it might be more advantageous to use train as a first source of transportation. Most specifics of transportation logistics can be addressed in terms of feedstocks and quantity being transported, although reliance on trucks, and in some cases barges and trains, is an effective general model.

Distribution Methods

Butanol has a distinct advantage over ethanol and biodiesel in regard to transportation of the final product. Ethanol's problem is that it is hydrophilic; meaning that it readily absorbs or dissolves in water. In addition, ethanol is also highly corrosive. This corrosive nature means that ethanol cannot be transported through the United States' extensive pipeline system, which is integral to making fuel transportation economically feasible in the US.

Butanol is hydrophobic and less corrosive than ethanol, so it can be transported through pipelines without the risk of water contamination. Because of this, the economics of butanol transportation are comparable to those of petroleum. Butanol plants should be placed near pipelines when they are built to help facilitate this cost-reducing form of transportation. A further advantage of butanol's hydrophobic nature is that existing fueling stations are compatible with butanol; no retrofitting is required for butanol to be sold to the public (DuPont and BP). Therefore, from an infrastructural perspective, the only major change needed for the United States to sustainably support the production of butanol is the construction and operation of refineries.

ABE Synthesis

Bio butanol is produced through two main processes. The first process is called the Acetone-Butanol-Ethanol (ABE) Fermentation process. ABE fermentation processes can be classified into two main categories: a cellulosic process and a basic fermentation process.

The ABE cellulosic process is used to break down fibrous or woody feedstocks such as perennial grasses, wood waste, or paper pulp: materials that have sugar structures too complex to be broken down into alcohol with traditional fermentation. Much like ethanol's cellulosic reduction process, the butanol ABE process can utilize two different pretreatments (acid or enzymatic reduction) to break the cellulose down into simpler sugars. After the woody feedstock has been simplified with one of these pretreatments, the resulting relatively simple sugars can be converted into alcohol with a standard fermentation process.

During the acid reduction pretreatment, an acidic environment is used to break down the cellulose and hemicellulose in the feedstock - these are complex sugars that cannot be fermented - to create xylose and glucose, simple sugars. Once the simple sugars are obtained, they can be fermented with yeast to produce alcohol. After fermentation, the resulting solution is filtered, and the liquid from the filter is distilled, to condense the butanol.

The enzymatic pretreatment is similar to that of the acid reduction pretreatment. The fibrous feed stock is heated and mixed with enzymes, which react with the complex sugars in the feedstock to release simple sugars. Once released, these simple sugars are fermented with yeast, as with the acid reduction pretreatment. The fermented solution is filtered and the filtered liquid can then be distilled to condense out butanol. Feedstocks for this cellulosic process include perennial grasses and fibrous waste products.

An alternate ABE process, the basic fermentation process, is similar to the post treatment described for the cellulosic processes. Simple sugars are fermented, the resulting solution is filtered, and the liquid from the filter is distilled to condense out butanol. For this process, feedstocks must be high in sugar, and include corn and sugar-rich waste products.

CFBB Synthesis

The other main process used to make butanol has recently been developed by ChemLac Corporation. The Chem-Lac process is a two-stage fermentation method that uses sugar-rich feedstocks such as sugar beets, sugar cane, corn mash, or whey to produce carboxylic acids, which are then converted into butanol in a second stage. The feedstock that used is not important as long as it contains a large amount of simple sugar. In general, one gallon of butanol can be produced from 14 pounds of simple sugar (Ramey).

David Ramey, one of the main researchers behind ChemLac's new technology, is focusing on whey permeate as a possible feedstock for butanol. Whey is the liquid left over after cheese production; whey permeate is produced when the butterfat and whey protein have been removed for commercial purposes. Whey permeate makes an excellent feedstock because it consists primarily of simple sugars, which makes it very easy to ferment. ChemLac, Inc is currently building two plants that will each process 5 million pounds of whey per day. These two butanol plants are projected to produce about 4.5 million gallons of butanol per year, which is the equivalent of 5 million gallons of gasoline.

According to David Ramey of ChemLac, Inc., the first plant that employs this process will begin operation in 2007, operating at about 25% of its full capacity. The second plant is planned to open in 2010, also operating at 25% of full capacity. Full capacity is expected to be achieved in 2011, where the total production of butanol is projected to be at approximately 9 million gallons a year.

The Future of Butanol

Because of its historically low yield from ABE fermentation, butanol has not received as much attention as more popular BioFuels such as ethanol. However, in the last three years, interest in butanol as an alternative fuel has increased exponentially. Before 2004 there was very little public interest in butanol. Since David Ramey's butanol-powered trip across America, however, there has been an enormous increase in public interest, as evinced by blogspots, journal articles, and new research into butanol. Because of butanol's high energy content, the recent development of new, more efficient production methods has made it an attractive alternative to gasoline.

Though butanol produced from petroleum has been marketed for many years as an industrial solvent, butanol has not received the federal attention that other BioFuels have. This means that butanol research is supported by far fewer federal grants than ethanol, and therefore most butanol research has been privately funded. This privatization makes it very hard to asses the progress that butanol has made toward becoming a large-scale fuel. However, though plans to develop butanol facilities are not always available to the public, some companies have published their plans to promote butanol as a BioFuel. In addition to ChemLac's two planned plants, the oil companies British Petroleum and DuPont have teamed up to produce butanol. Their hope is to have introduced a pilot plant in Europe within the next two years, which will use sugar beets as a feedstock (Forbes, 2006).

Much like ethanol plants, butanol plants can be run on local feedstocks such as corn, sugarcane, or sugar beets, though at present we have not heard of a CFBB process can be directly used with cellulosic feedstocks. Non-woody waste products can be used as feedstocks in butanol bioreactors, and any current ethanol plant can be converted into a butanol plant with some adjustments to the reactor.

Butanol seems to be a viable alternative to gasoline, but further technological developments are required before it can be competitive with ethanol and biodiesel. Current butanol research is in its preliminary stages, and is susceptible to widespread skepticism from the scientific community. The lack of sound scientific data is a barrier to butanol's commercial production; because of the lack of current production facilities in the nation, few plants will be operational by 2017. Thus, we predict only one billion gasoline-gallons of butanol will be produced in 2017.

Socio-Political Aspects of BioFuels

History of BioFuel Legislation

In his State of the Union Address, President Bush called for legislation that would reduce gasoline consumption by 20 percent over the following 10 years. To achieve that goal, he estimated that 35 billion gallons of renewable and alternative fuel should be available by 2017. The United States government will help fund BioFuels expansion, providing $1.6 billion in funding for energy research and development, and $2 billion in loans for alternative fuel plant construction, specifically for cellulosic ethanol. A large number of bills and legislation have already been introduced to Congress to reach these goals, in addition to the large amount of BioFuels legislation that has already been passed in the past few decades.

The United States began its campaign to reduce oil use in the 1970s with the Energy Policy and Conservation Act of 1975, shortly after the Arab oil embargo and petroleum shortages. The 1975 Conservation Act enacted the Corporate Average Fuel Economy regulations, also called CAFE, which mandated fuel economy standards, measured in miles per gallon, for passenger cars and light trucks. Civil penalties were then imposed upon manufacturers that did not meet the standards, although “credits” were awarded to offset poor future performance if the standards were exceeded (National Highway).

Alternative fuels began their development in 1980, when President Carter approved the Wood Residue Utilization Act. The bill established a program to develop alternative energies, including fuel, from the 190 million annual dry tons of wood and wood residues left in areas dedicated to timber harvesting. The motivation behind this bill was not a need for alternative energy, but rather a desire to find an efficient and environmentally friendly use for waste wood, which was commonly burned for disposal (American Presidency).

The year 1980 also produced the Biomass Energy and Alcohol Fuels Act, which promoted the use of biomass energy resources and alcohol fuels and established development plans and loans. This bill was established to reduce the dependence of the United States on imported petroleum and natural gas. Thus, Congress determined that a national program for alternative fuel production should be established, with a goal similar to that expressed in President George H. Bush’s State of the Union Address: to prepare “a comprehensive plan for maximizing… biomass energy production and use… to achieve a level of alcohol production within the United States equal to at least 10 percent of the level of gasoline consumption within the United States … [by] 1990." The Biomass Energy and Alcohol Fuels Act also realized the possible effect of BioFuels on markets outside of the fuel industry, and required that they not "impair the Nation's ability to produce food and fiber on a sustainable basis for domestic and export use" (Office of the Law).

The Alternative Motor Fuels Act of 1988 encouraged the production of motor vehicles capable of operating on alternative fuels. The act provided CAFE credit incentives, up to 1.2 mpg for the entire manufacturer's fleet, for vehicles that used natural gas or alcohol fuels to encourage alternative fuel use and production. In particular, this act encouraged the production of "flexible-fuel" vehicles, which can be run on any combination of ethanol and gasoline. However, the Alternative Motor Fuels Act did not cover vehicles powered by electricity, biodiesel, or liquid petroleum gasoline.

The first BioFuel legislation to impact the fuel industry was the Biomass Research and Development Act of 2000, which developed programs for crops and systems that would improve alternative fuel production and processing, along with the conversion of biomass into biobased fuels. Its primary purpose was to develop production methods for a range of BioFuels, then maximize the efficiency of each fuel and analyze each fuel's sustainability, environmental quality, and impact on economic security and rural economic development (Biomass Research).

Soon after, the 2002 Farm Bill became the first farm bill since 1985 to address BioFuels. Title IX acknowledged that development of BioFuels would stimulate the agricultural economy and create jobs in rural areas. It also established new programs and grants for BioFuel education, development, testing, and purchase. The bill also requested that the Secretaries of Agriculture and Energy look into hydrogen and fuel cell technology (Department of Agriculture).

The most recent major development in BioFuel legislation is the Energy Policy Act (EPA) of 2005, mentioned in the 2007 State of the Union Address. It set forth an energy research and development program to investigate energy efficiency, renewable energy, oil and gas, and alternative vehicle and motor fuels, including ethanol, hydrogen, and electricity. This legislation created a research and development program for bioenergy and offered production incentives for cellulosic BioFuels in addition to tax credits for alternative fuel vehicles and fueling stations. The EPA also amended the Clean Air Act to include a Renewable Fuel

Standard (RFS) program, which required all gasoline sold or dispensed in 2006 to contain at least 2.78 percent renewable fuel, primarily ethanol and biodiesel; this percentage increased to 4.02 percent in 2007. The establishment of the RFS was an especially effective portion of the Clean Air Act, and the production of ethanol and other renewable fuels have significantly increased since it came into effect (Environment News Service).

The Advanced Energy Initiative of 2006 continued the work of the 2005 EPA, providing the funding for additional research, development, demonstration, and commercial application of advanced energy technologies.

Subsidies and incentives

Each country must approach BioFuels in a way that is tailored to their own individual needs and issues. The United States must approach BioFuels on two main fronts. First, due to the abundance crop land, a large portion (if not all) American BioFuels will be produced locally. Therefore, the government must support farming and agriculture specific to BioFuels. Secondly, the government must also provide incentives and benefits that encourage everyday people to change their habits despite minor inconveniences.

In the United States many of the most notable incentives have been made on the state level; BioFuel laws and incentives are present in every state, and only Puerto Rico and the Virgin Islands have no alternative fuel laws. However, state regulation is probably a more effective means of incentive due to the vast differences among states and the natures of their individual economies. The involvement of each state in BioFuel promotion is also variable. While there is an average of 42 laws and incentives per state, there is a standard deviation of 29, indicating that while the majority of states have a good deal of support, several also have a startlingly low number of alternative fuel laws and incentives (State and Federal Incentives and Laws). California has the most laws and incentives, with 180; Lower Emission School Bus Grants are given to purchase alternative fuel or diesel school buses, and some cities have alternative fuel vehicle parking incentives, such as better spaces or free parking for those with alternative fuel vehicles. The state is also establishing a biodiesel blend use requirement for San Francisco's public agencies, which they hope to reach 20% by the end of 2007 (State and Federal Incentives and Laws).

Texas offers grants for the conversion to ethanol and biodiesel vehicles. Forty-one counties provide non-profit grants to exchange old school buses with new clean fuel efficient school buses through the Adopt-A-Bus foundation. In Ohio, public schools and various businesses can apply for a $900,000 from the Alternative Fuel Transportation grant for alternative fuel facilities (Methanol Institute).

Reimbursements for the consumption of biodiesel are offered in New Jersey. Colleges and universities are local governments are eligible for the reimbursement if they use at least 5% blend of biodiesel. Since May 1, 2004, Zero Emissions Vehicles sold, leased or rented are exempt from state sales and use tax. The taxi services also receive monetary reimbursements in Wisconsin for a minimum of one hundred gallons of alternative fuels. Wisconsin also supports school districts' biodiesel purchases for their buses (Methanol Institute). Businesses in Vermont that participate in the production of vehicles that do not use fossil fuels can receive extensive tax credits. In addition, alternative fuel vehicles can also utilize the HOV lanes with numerous passengers with a FasTrak account in California. HOV lanes are accessible to alternative fuel vehicles promoting clean air with the "Clean Special Fuels" license plate in Virginia. Methanol and ethanol-run vehicles can use the New Jersey Turnpike Authority's HOV lanes (Methanol Institute).

Overall, there are 395 federal and state laws in effect that support biodiesel, 385 for ethanol, and 144 for blends of fuels. In addition to benefits and subsidies on the fuels themselves, there are also extensive federal and state subsidies for agriculture (primarily for corn). In 2005, for example, the U.S. spent almost $9.5 million on corn subsidies (an increase of $6.7 million per year since 1995) (Environmental Working Group). This is primarily money given by the government to farms where corn is grown.

When corn subsidies are taken into account, corn ethanol is undoubtedly the most subsidized BioFuel in the United States. Given that corn ethanol is inefficient and impractical as a way to meet the President's goal in the State of the Union, these subsidies are obviously a misdirection of our resources.

Employment

One of the appealing effects of the growing BioFuels industry is the prospect of new job creation. However, there is also the concern of producing or maintaining enough jobs during change or transition periods. The BioFuel industry can provide a solution to this concern by creating jobs in more than just one type of area.

Currently, corn ethanol production is the largest source of BioFuel- related jobs in America. These jobs are both blue- and white-collar, and the increasing demand for ethanol broadens ethanol-related job opportunities every year. Rural areas receive the greatest boost from ethanol production. Because of the incentives and subsidies that support corn ethanol, farmers who have the means to grow corn benefit immensely. They are able to buy more land, hire more farmhands, and purchase new equipment, which opens up more jobs related to agriculture and corn production. The Future Energy Coalition, an organization that focuses on the promotion of alternative energy sources, has conducted studies showing for every 10 billion gallons of ethanol produced nearly 200,000 jobs are created (FAQs). Based on the indications from ethanol alone, BioFuels make a strong case for employment sustainability.

In general, BioFuel researchers agree that a large number of jobs will be created during the transition to BioFuels. In a time of outsourcing and a staggering trade deficit, attributed mostly to our $250 billion in oil imports, a switch to BioFuels points towards self-sufficiency and economic revitalization (Kammen). The nations ahead of the United States in BioFuels production and implementation, such as Brazil and Japan, have witnessed tremendous job growth patterns and increased export opportunities (Kammen). Maintaining domestic employment is a major issue in the United States. The BioFuels industry provides increased job stability and opportunity, unlike the oil industry.

Consumer Attitudes

For the transition to BioFuels to be feasible, American citizens must be willing to make the transition from petroleum fuels to BioFuels. They must also recognize the need for alternative energy sources in order to support new advances in research, development, and production. A large number of people are familiar with BioFuels; 91% of those in a poll had some knowledge of natural gas, ethanol, methanol, or biodiesel. Still, only 2% have actually driven a vehicle that runs on these alternative fuels (Biotechnology Industry Organization). This is the primary issue that laws and incentives must address; the public supports the idea of BioFuels in theory, but most citizens have not supported BioFuels by purchasing a flex-fuel or alternative fuel vehicle.

Among those who view alternative energy websites there is increased knowledge of popular BioFuels such as ethanol, but also more interest in lesser-known fuels. CleanTech, an alternative energy website, found that 56% of pollers had enough knowledge of algal BioFuel to vote on which company is closest to commercial production (CleanTech).

When it comes to the support of BioFuels in general, 82% of Americans favor government research and development, 69% think that the government does not do enough to support BioFuel production, and 29% are willing to pay slightly more for American-made BioFuel (Biotechnology Industry Organization). That then begs the question of whether Americans are willing to pay more due to political, economic or environmental reasons.

About four out of five Americans would like BioFuel to make America less dependent on foreign oil, 73% would use it to reduce gasoline prices, and 68% would use it to create jobs in rural areas. Though all of these goals are beneficial, independence from foreign oil clearly carries the most weight with the public. According to *Biodiesel Magazine*, the top reasons that fleet operators use biodiesel are its environmental benefits, energy security, economic benefits, and federal or state mandates (An Industry Rising). Three out of four of these concerns depend on monetary motivation, indicating that for large-scale operations, finances are more important than the environmental protection.

Another poll with similar results showed that while American and Canadian consumers have similar BioFuel awareness levels and adoption behaviors, Americans primarily want to reduce dependence on foreign energy, while Canadians, along with most respondents across the globe, want cleaner emissions. In the Unites States, the primary deterrents to BioFuel use are high vehicle costs and the perception that alternative fuel vehicles have a limited driving range (The Auto Channel).

Polls also show that Americans see conservation as a better solution to our energy problem than alternative energy production, and readily favor proposals for more stringent emissions standards (Gallup).

International Implementations

The United States is just beginning to express serious interest in BioFuels; however, there are several countries that have already implemented their own BioFuels program, with varying degrees of success. These countries have used such techniques as tax incentives for biodiesel users or government-mandated BioFuel requirements to support their transition away from petroleum fuels.

Many governments promoted their transition by providing tax incentives. Tax incentives encourage more people to switch to BioFuels due to decreased cost, which in turn increases production demand, making BioFuels attractive for industries. In Argentina, for example, producers of BioFuel receive a 15 year exemption from the country's diesel tax. In the Netherlands, there is a tax exemption for BioFuel blends proportional to the percentage of BioFuel contained in the blend. Currently, only a few select countries have chosen to provide tax cuts as a reward for BioFuel use and production (A Biodiesel Primer). However, as importing fossil fuels becomes more costly other countries may choose to follow suit.

Some countries have also chosen a more direct form of encouragement in moving away from fossil fuel dependence. Argentina, for example, has passed legislation that will require a 5% biodiesel or ethanol blend for all fuels by 2009. Currently BioFuel use in Brazil is voluntary, yet by 2008 Brazil's B2 program, which encourages distributors to sell a 2% biodiesel blend, will become mandatory. This will be increased to B5 (a 5% biodiesel blend) by 2013. In order to make these requirements more palatable, Brazil will reduce its diesel imports and subsidize its agricultural program. Similarly, Canada has passed legislation which will mandate that 2% of its diesel and heating oil must be made from biomass within one year. It is likely that the earliest this would possibly happen would be 2010. Like Brazil and Canada, other countries are setting mandatory fossil fuel limits, but they are encountering difficulties in the process. Italy's program to mandate BioFuels blends was planned for 2006, but was recently pushed back to January 2007. By 2010, Italy claims it will have 5% blends by volume (U.S. Department of Energy). By mandating use of renewable fuels, these countries have taken a direct approach to the fossil fuel problem.

The United States' transition to BioFuels is happening slowly and deliberately. America is not alone in its approach to BioFuels; many other countries are taking their time to eliminate their dependence on fossil fuels. It will be helpful for American policymakers to observe which countries succeed or fail in their goals. The feasibility of different techniques will vary by country, possibly even by region. Ultimately, the speed of transition will depend on whether the change to BioFuels is mandatory or voluntary. The entire transition over to BioFuels will hinge on how seriously each individual nation approaches the issue, and also largely on the incentives and motivation provided.

American Influence Abroad

Demand for ethanol in the American market is currently at an all-time high, and it is still rising. This increase in demand comes from legislation like the 2005 Energy Bill (described earlier in this report), and also largely by state government-mandated phasing out of MTBE (Methyl tertiary-butyl ether) as an anti-knocking additive for gasoline, for which ethanol is an effective replacement (Amaldo, et al, p 11). In one estimate, the United States will require between 4.8 and 5.3 billion gallons of ethanol per year by 2010, (p 12) barring any new BioFuels legislation.

Currently, we cannot meet our huge BioFuel demand. In 2004, the national demand for ethanol was somewhere around 3.6 billion gallons, but we only produced 3.4 billion (p 11). The remainder of this fuel was imported from other countries. As the nation strives to meet Bush's 2007 State of the Union goal of 35 billion gallons by 2017, our national BioFuel supply must be able to match nation demand.

Brazil and Canada are already exporting ethanol to the United States on a large scale. Given the economic opportunity BioFuel production provides, countries such as Malaysia (Clean Air Initiative), Thailand, Colombia, Uruguay and Ghana have also been attracting BioFuel investment, and will soon seek to enter the US BioFuels market (Physorg.com and Johnston, et al).

President Bush's 2007 State of the Union “Twenty in Ten” policy initiative centered around reducing America's dependence on foreign sources of oil. This dependency, in part, has been responsible for leaving us “more vulnerable to hostile regimes, and to terrorists – who could cause huge disruptions of oil shipments, raise the price of oil, and do great harm to our economy” (United States White House). Large-scale importation of BioFuel from other nations would do little to reduce our dependency on foreign sources of fuel. Unchecked importation may also result in environmental damage, as we open markets to countries that destroy their forests and other natural resources in order to make room for biomass generation (Junginger, 2006).

On the other hand, President Bush's policy initiative continues:

> Global production of alternative fuels helps us reach our goal and increases our energy security. The President expects most of the expanded fuel standard to be met with domestically-produced alternative fuels. However, importing alternative fuels also increases the diversity of fuel sources, which further increases our energy security. (United States White House, 2007)

As long as the majority of American-consumed BioFuels are grown and processed in the United States, we will have met the president's goal. In order to ensure that most of America's BioFuels are nationally produced, we must make sure that American producers have the ability to remain economically competitive in the global market. Assuming this cannot be accomplished merely with a free, open market, the government can help reach this goal by imposing restrictions on trade. The government can help the American BioFuels industry compete in the global marketplace (Walter, et.al. p.11) by increasing tariffs and levies on imported BioFuels and biomass, by subsidizing American biomass growers, or by legislating that a certain percentage of American-consumed BioFuels must be locally produced. .

Sustaining healthy relationships with third-world countries is beneficial for America's security and its economic well-being. American actions that cause or sustain poverty in third-world countries give those countries reason to view us as enemies, increasing dangers from terrorism as well as barriers to trade, treaties, and healthy international diplomacy. America is already one of the largest grain-exporting nations on the planet. One study notes that American subsidies on the production of grains is devastating for third-world countries in Africa, because we can export grains so cheaply and effectively, rendering them unable to sell biomass competitively in the world market (Biopact).

Given the consequences, then, we must be sure not to resort too heavily on tariffs and levies to sustain America's control over its own BioFuels market. Instead, we must take care to use technologies and systems that make nationally-grown and produced BioFuels feasible to consume at market prices.

Societal Restraints

President Bush's problem statement's feasibility relies heavily on the technology and infrastructure that must be put in place to produce alternate fuel sources. However, without public support, the necessary technologies will never develop. If the public does not recognize a need for alternate energy sources, public funding will not support the research. There are three major steps to implementing BioFuels that rely on the public: development, producer adoption, and consumer acceptance (Klein, 2004). The technology and infrastructure needed to develop BioFuels is important, but will come to a halt without consumer approval. The government also plays a huge role in how quickly the fuels are developed, but can do nothing without public support.

Motivation and Relativity

Consumption in the United States is based on a variety of motivations. People today are generally concerned about how and where they are going to survive and thrive, and their primary concern is economics. According to *Biodiesel Magazine*, fleet operators claim their top reasons for using biodiesel are environmental benefits, energy security, economic benefits, and federal/state mandates (Bryan, 2006). Three out of four of these concerns closely tie in with the money motivation factor. See Figure 11 and Figure 12 below. However, people will claim that they want to protect the environment until it comes down to a few more dollars subtracted from their bank account.

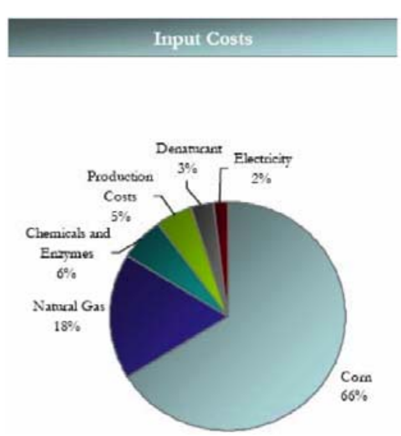

Figure 11: Input Costs of BioFuel Production

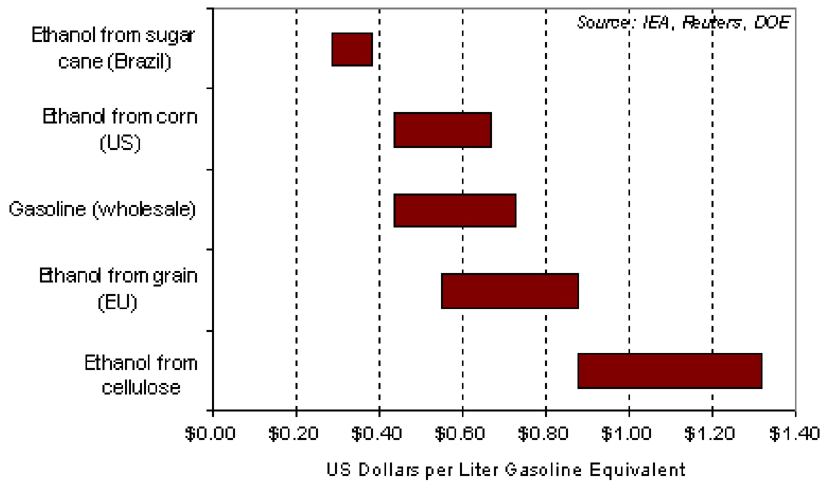

Figure 12: Relative Retail Prices of Assorted BioFuels

In order for BioFuel production to gain public support, it must be comparable to petroleum. The above chart, for example, relates the prices of gasoline with other fuel sources. This comparison is the kind of information the public will be looking for when deciding to buy BioFuels.

Feedstock Pricing and Distribution

In order for BioFuels to develop, the public must support the production process and feedstocks. The costs of individual feedstocks are nearly impossible to predict until the BioFuels are implemented into our government and societal structure. Their cost will largely depend on government taxes and subsidies, infrastructure, supply, and demand. For example, only 75% of the cost of biodiesel comes from the actual feedstock. The other 25% comes from the energy and labor necessary to produce it. Figure 11 displays the input costs to producing ethanol; the feedstock used, corn, takes up only 66% of the total cost of producing it (Montara). Unless the public supports the use of certain feedstocks, BioFuels cannot be produced and integrated into society. The key is to find a balance that society will accept and pursue.

Environmental Implications

One of society's main motivations for switching to BioFuels will be their effects on the environment. Many people are concerned about global warming and current fuel emissions' effect on the environment. The environmentally conscious are also aware of the farming practices used to produce BioFuels, including irrigation, and the use of pesticides and fertilizers. Fuels affect our environment during their growth, production, and use. Although BioFuels themselves reduce emissions, the processes used to produce them can be hazardous to the environment and human health.

The final issue that must be addressed is the nation's "shrinking" land area. The country's population is increasing everyday, and needs more land area to survive. Our farmland cannot just be used for producing BioFuels. It also produces the food we need to survive. With an increasing population, we will need more food. When it comes down to it, most Americans would rather have a source of food rather than a cheaper fuel. For this reason, feedstocks that can be grown on marginal land would receive more public support.

If the society does decide to make the switch to BioFuels, new legislation will have to be put into action. Experts have recommended reducing the nitrogen loading of the Mississippi by 40%. To protect our health, the use of toxic pesticides will have to be regulated. New ways of attaining food might also have to be found, if we are going to use much of our farmland to produce BioFuel feedstocks.

Conclusion

Through our research concerning ethanol, biodiesel, and butanol, we have concluded that President Bush's goal of 35 billion gasoline-gallons is not attainable. Our projections indicate that 29.4 billion gasoline-gallons of BioFuels will be manufactured in 2017. The BioFuels revolution is simply not sustainable. Growth of the BioFuels industry is too slow to achieve this goal because of the current lack of funding, facilities, technological advancements, and public support. Furthermore, negative environmental implications and infrastructural incompatibility hinder the expansion of the use of BioFuels. The findings set forth in the paper are based upon information found in 2007, and the state of the BioFuels industry at the time.

Ethanol

Ethanol, the foremost BioFuel at the present time, is a good starting point for the industry and a suitable development model for upon which future development should be based. The production of the feedstocks used to create the ethanol is frequently harsh on the environment. The major hindrances to the success of ethanol lie within the production of the fuel on an industrial and agricultural level.

Currently ethanol can be created from traditional corn feedstock or from cellulosic biomass. Corn consumes an incredibly large volume of water and fertilizer. To shift such a large portion of our farmland to BioFuel feedstock production would certainly have negative effects on the price and availability of food. Fertilizer runoff would have adverse effects upon the nation's watersheds and contribute to dead zones. Corn is also highly dependent upon carcinogenic pesticides and dangerous herbicides; these pesticides are becoming more prevalent in public drinking water. Based on current farming techniques, an increase in the amount of corn produced would result in an increase of the prevalence of dangerous substances in the ecosystems. The high fertilizer and pesticide demands of corn and their negative environmental impacts indicate that corn, as it is grown now, is not a sustainable feedstock for ethanol. Though as a fuel, ethanol is more environmentally friendly than gasoline, ethanol from corn is not a sustainable fuel.

Corn ethanol is produced in approximately 425 industrial plants at an annual production rate of 8.6 billion gasoline-gallons of corn ethanol per year. According to our model, 525 industrial corn ethanol plants will be operational in 2017 with an annual production capacity of 11.7 billion gasoline-gallons of ethanol per year. This is equivalent to 33% of President Bush's goal. The cost of these new plants will be minimal when compared with the other fuels which currently have few or no operating facilities.

While corn ethanol has the most developed infrastructure of any BioFuel as of 2007, its negative environmental implications outweigh the benefit of developing a national ethanol infrastructure. Thus, we conclude that corn ethanol should not become a staple of the American BioFuels industry and should be slowly phased out and replaced by a more environmentally friendly alternative.

Cellulosic ethanol is more promising than corn ethanol. Feedstocks such as perennial grasses and switchgrass are less resource intensive and are not as harsh on the environment as corn. While fertilizer and pesticides are still needed to ensure a healthy feedstock, less of these are consumed. Cellulosic feedstocks grow in different conditions than corn and other common crops. Many of these grasses can be grown on marginal land. This eliminates competition with highly productive arable land which makes cellulosic ethanol a more viable option than corn ethanol. Nevertheless, these crops demand a high amount of water and thus should not be grown in a region where the water table is already stressed.

From an infrastructural standpoint, cellulosic ethanol can be easily integrated into the current model of corn ethanol with minimal cost and alterations. The final fuels created through corn and cellulosic techniques are the same. Various types of feedstocks growing in different climates make cellulosic ethanol feasible on a regional scale. Thus, the transportation of ethanol remains the same regardless of the method of production. The cost of the plants is approximately the same as that of corn ethanol. We predict that by 2017, there will be 175 plants manufacturing cellulosic ethanol at an annual production capacity of 7.3 billion gasoline-gallons, or 21% of the goal.

Biodiesel

Biodiesel, currently being produced from first generation feedstocks, is less prevalent than ethanol. When analyzing large-scale biodiesel production, the feedstocks currently being utilized are not practical. Feedstocks such as algae have shown the potential to be more viable national solutions in the future. Nevertheless, these methods of biodiesel production are still in development and have not yet been tested on an industrial scale.

Biodiesel is currently being created on an industrial scale throughout the U.S. from as many as four different feedstocks, such as soy, various oils and terrestrial-oil crops are used in the production of biodiesel. Soy, which accounts for about two-fifths of the national biodiesel production, competes with corn for arable land. While soy does not demand as many resources as corn, some farmers are growing only corn instead of using a soy-corn bi-annual crop rotation. This is because the current ethanol market and driving political incentives have increased the demand for corn and, thus, decreased the attractiveness of soy. Soy has a low projected yield of only about 50 gallons of biodiesel per acre of crop.

Feedstocks such as canola and algae are being researched. Canola has a yield of approximately 125 gallons of biodiesel per acre but requires large amount of nitrogen and other raw materials. For some of the same reasons as corn, canola should be analyzed and carefully considered before further industrial developments take place. Algae could produce as much as thirty times as much biodiesel per acre of land when compared with terrestrial oil crops. Industrial scale methods of biodiesel production from algae are being developed and improved so that algae may become a national contributor in the biodiesel industry. Until research proves these feedstocks are regionally implementable and achievable on an industrial level, they will not be a major contributor to the BioFuels industry.

Due to the diversity of feedstocks, various climates can be used to grow feedstocks, allowing for a wider distribution of biodiesel manufacturing facilities. As of September 2007, there are 165 operations that manufacture biodiesel on an industrial level. Currently, the industry has an annual capacity of approximately 1.8 billion gallons of biodiesel per year. According to market research and the historical progression, approximately 5.4 billion diesel gasoline-gallons will be produced from vegetation in 2017.

In addition to these feedstocks, another common feedstock is used vegetable oil. The United States produces about 11 billion gallons of used vegetable oil annually. Most of this oil is currently disposed at a cost to the restaurant and not reused. If only 75% of this oil is used to create biodiesel, the amount of biodiesel created would be equivalent to an additional 4 billion gasoline-gallons. In total, we predict biodiesel production will offset 9.4 billion gasoline-gallons by 2017.

Biodiesel is currently the only BioFuel that can be used in diesel engines. Because the vast majority of the trucking, construction, and train industries depend on diesel, it is necessary to develop a practical BioFuel alternative to diesel. Compared to diesel, biodiesel has up to a 50% emission reduction. In addition, biodiesel has a power output of approximately 5% more than that of diesel. The overall energy balance of biodiesel is positive, and the methods of production are relatively simple. While there are some issues with the transportation of biodiesel, these concerns can be alleviated when practical alternatives are developed in the future. We predict that biodiesel will be a contributor, but not an independent solution, to the advancement of the American BioFuels industry.

Butanol

Still in the early stages of development, butanol is a less common fuel than either ethanol or biodiesel due lack of existing infrastructure. Though it can be produced from the same feedstocks as ethanol, at the moment the main source of butanol is corn. The largest barrier to the success of butanol can be found in the current lack of public awareness about it.

On an industrial scale, butanol is commonly used as a solvent, and is usually produced from petroleum. Corn, the most common feedstock for butanol, is water, chemical, and energy-intensive to grow. Because of corn's poor energy balance, more research should be focused on the production of butanol from alternative feedstocks. Perennial feedstocks such as switchgrass are easily grown in the western US, and do not require the fertilization or tilling of other, food-based feedstocks. Other options include waste products such as paper pulp, sawdust, wheat straw, or whey. These waste feedstocks have an added benefit in that they make use of products that would otherwise be troublesome to dispose. Whey, for instance, cannot be used as a fertilizer due to its high sugar content souring fields over time. Therefore, cheese manufacturers must dispose of their waste in less environmentally-friendly ways while paying enormous fines to dump their waste into local sewage systems. As the average cheese factory produces 2 million pounds of whey permeate per day, this waste stream can place a large burden on local disposal systems.

In 2007, Environmental Energy Inc. is focusing on upgrading its current 50 gallon per week plant to a larger facility, with a production capacity of around 9 million gallons per year, which will begin at a production level of 2.25 million gallons per year. This is just one small example of the number of plants that are expanding. BP and DuPont have also teamed up to research butanol in Europe; they hope to establish a pilot plant there within the next few years.

It is difficult to predict how many gallons can be produced by 2017, because of the non-linear progression of the increase in butanol research. Before David Ramey's trip across the US in 2004, there was very little public interest in butanol. Since then, interest, and therefore research, in butanol has increased exponentially, which increases the difficulty of predicting its future trends. In accordance with current growth trends, we predict that one billion gasoline-gallons of butanol will be manufactured in 2017.

Unlike other BioFuels, butanol can be used in gasoline engines without modification. It has a relatively high energy density, and a higher octane rating than gasoline. This means that cars can actually get better mileage with butanol than with gasoline. It is compatible with our current petroleum infrastructure. While butanol needs a significant amount of development before it will be ready for the industrial fuel market, it shows a great amount of promise. In the long term, butanol may fill a niche within the revolution.

2017 Verdict:

Based upon the findings set forth within this document, we conclude that the United States will not be able to achieve the goal proposed by President Bush. We formed our predictions by studying investments trends, industry growth models, and historical background. Ultimately, we predict the industry to be able to produce a total of 30.2 billion gallons of gasoline-equivalent BioFuels. The major contributors to this total will be corn ethanol, cellulosic ethanol, and biodiesel. Butanol will not play a significant role in the BioFuels industry in 2017. Other alternatives such as hydrogen fuel and new feedstocks like algae will continue to develop as more research is conducted.

In terms of the long term sustainability of the BioFuel revolution, the future is clear. The revolution is simply not sustainable based upon current development and growth of the BioFuels industry. For the revolution to become self-sustaining, new feedstocks must be researched. Though new fuels, such as butanol, are developed, the infrastructure must be updated, delaying the fuel's release to the public. Environmental implications must be weighed and studied, and public support is a major factor in the success of the revolution. We conclude that BioFuels are not sustainable and will not replace oil.

According to President Bush's 2006 State of the Union address, the United States is "addicted to oil." With an oil crisis quickly approaching and reserves in the Middle East rapidly waning, it is obvious that the U.S. must find a viable alternative to oil. BioFuels and alternative energy will only be one aspect of this cultural shift. Energy conservation methods must develop and consumption habits need to change. The future of the BioFuels revolution, and a practical model solving the U.S. energy crisis, must be focused and further defined. The development of the BioFuels industry is an exciting aspect of the U.S. society and many developments will take place within the next decade.

A: Glossary of Commonly Used Terms

Biodegradability: the extent to which the fuel can be broken down by living organisms in the environment

Biodiesel: A BioFuel used in diesel vehicles. Can be used in diesel vehicles made after 1992. Second most prevalent BioFuel in the United States

BioFuel: An alternative method of fueling vehicles as opposed to conventional petroleum or gasoline. Examples include ethanol, biodiesel, and butanol.

British Thermal Unit (BTU): Unit of energy equivalent to the energy required to raise one pound of water by one degree Fahrenheit at atmospheric pressure.

Butanol: A BioFuel that is in development. It is not yet available on a national scale. Much research is being invested in it.

Carbon Dioxide (CO_2): greenhouse gas that is produced or consumed by all animals, plants, fungi, and microorganisms. Carbon dioxide is also one of the main components of combustion. It remains in the atmosphere for long periods of time and absorb infrared radiation.

Carbon monoxide (CO): colorless, odorless gas that is produced from incomplete combustion of fuel containing carbon. It is a greenhouse gas that is highly toxic but short lived, as it oxidizes into carbon dioxide (CO_2).

Cellulosic Ethanol: An alternate method of ethanol production. Uses second generation feedstocks such as canola, switchgrass, and willow.

Cetane: A measure of the combustibility of conventional diesel. Biodiesel has a higher cetane number than number two diesel.

Energy Density: A measure of the amount of energy in one gallon of fuel divided by the amount of energy invested to create the fuel (which incorporates energy for the growth of the feedstock and in the reaction).

Energy Return on Energy Invested: A measure of energy density. The common method used in this report.

E85: A fuel containing 85% ethanol and 15% conventional gasoline. One of two first generation BioFuels. Cars must be E85 modified to use the fuel.

Ethanol: A BioFuel that is most widely available at the current time. Currently it is made primarily from corn but more research is being conducted into cellulosic feedstocks

Feasibility: Defined by our class as the ability of a fuel to contribute largely to the American BioFuels revolution.

Feedstock: A type of biomass that is used to extract alcohols or plant oils used in the reaction to create a BioFuel. Examples include waste vegetable oil, soy, corn, and wood pulp.

Flashpoint: The lowest temperature at which a substance will combust

Gasoline-Gallons: Unit equal to the energy of one gallon of petrol, or about 140,000 BTU.

Genotoxic: A characteristic describing a material with carcinogenic properties. Has potential for genetic mutations in humans.

Greenhouse Gases (GHGs): Components in the atmosphere that contribute to global warming and global climate change. GHGs are necessary to regulate the climate of the Earth. The majority of GHGs are released by nature; a small percentage are released by humans. GHGs include water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Hydrophobic: A material that cannot absorb water.

Hydrophilic: A characteristic of a material that has the potential to absorb water. When shipping materials in pipelines, hydrophobic cannot be in the same pipe as hydrophobic chemicals.

NO_x: Nitrogen oxides are greenhouse gases and include nitric oxide (NO) and nitrogen dioxide (NO_2). They are produced during combustion due to the high temperatures involved. NO_2 eventually forms nitric acid (HNO_3) a contributor to acid rain.

Octane: A measure of the ease of combustibility of a fuel. Common gasoline octane ratings include: 87, 89, 93.

Particulate matter: Is made up of tiny particles suspended in a gas. Inhalation of particulate matter can cause asthma, lung cancer, and cardiovascular problems.

Partitioning: The physical distribution a substance in various phases, typically solid, liquid, and gaseous

Pilot Plant: An example of a trial production facility currently manufacturing a BioFuel on an industrial scale

Solubility: The extent of which a solute can dissolve or dissociate into a solvent which is typically water

SO_x: Sulfur oxides include sulfur monoxide (SO), sulfur dioxide (SO2), which is the most common form, sulfur dioxide (SO2) which is a major contributor to acid rain, and others.

Sulfur oxides are toxic, causing eye irritation and breathing difficulties from minor exposures.

Toxicity: the ability of a substance to damage or create illness upon exposure

Volatile Organic Compound (VOC): a harmful organic chemical with a high volatility and enters the atmosphere. Research shows it has harmful effects on humans including carcinogenic properties.

Volatility: the tendency of the fuel to evaporate into gaseous form

B: Appendix of Supplemental Tables

Ultimate Prediction Model

Table 2: Final Prediction of BioFuel Production in 2017

	2007 Plants	2017 Plants	2007 Production (Billion Gasoline Gallons)	2017 Production (Billion Gasoline Gallons)	Percent of Goal
Corn Ethanol	425	525	4.7	11.7	33%
Cellulosic Ethanol	0	175	0	7.3	21%
Biodiesel	151	380	2	9.4	27%
Butanol	0	50	0	1	3%
Totals	**576**	**1130**	**6.7**	**29.4**	**84%**

Table 3: Regional Average Retail Prices of Biodiesel

Table 11. Biodiesel (B99-B100) Average Prices by Region from Clean Cities Sources

	Biodiesel (B99 B100) Information Reported by Clean Cities ($ per gal)		*Diesel Information Reported by Clean Cities ($ per gal)*	
	Average Price / Standard Deviation of Price	*Number of Data Points*	*Average Price / Standard Deviation of Price*	*Number of Data Points*
New England	-	-	$3.03 / 0.11	27
Central Atlantic	$3.26 / 0.45	3	$2.96 / 0.10	33
Lower Atlantic	$3.41 / 0.70	2	$2.87 / 0.10	60
	$2.85 / 0.00	2	$2.92 / 0.10	116
Gulf Coast	$3.09 / -.--	1	$2.85 / 0.07	34
Rocky Mountain	$3.52 / 0.27	4	$3.03 / 0.11	41
West Coast	$3.24 / 0.15	13	$3.10 / 0.21	66
NATIONAL AVERAGE	$3.27 / 0.29	25	$2.96 / 0.15	377

C: Relative Rankings of BioFuels

The relative rankings of ethanol, biodiesel and butanol have been compiled into this appendix. These tables relate the BioFuels to each other and also to gasoline. All aspects were ranked from on a scale from -10 to 10. A zero on the scale represents the current state of petroleum in the United States for each category. Each individual category was ranked relative to petroleum and other feedstocks.

Table 4: Weighted Objective Table for Ethanol

Ethanol Classification	Sugar			Cellulose					
Process Used	Microbial Fermentation			Microbial Fermentation			Biomass Gasification		
Feedstock	Corn	Sugar Cane	Sugar Beets	Switchgrass	Reed Canary Grass	Waste	Switchgrass	Reed Canary Grass	Waste
Cost of Production	5	6	5	3	3	4	6	6	4
Energy Balance	-5	-1	-6	-2	-2	-1	-3	-3	-1
Carbon Balance	2	7	5	8	8	8	8	8	8
Land Use	-7	-4	-7	-4	-5	N/A	-4	-5	N/A
Current Production Volumes	-3	-10	-10	-10	-10	-8	-10	-10	-10
Source to Refinery Transportation	-3	-9	-8	-8	-8	-2	-8	-8	-2
Compatibility with Current Infrastructure	-7	-7	-7	-7	-7	-7	-7	-7	-7
Existing Infrastructure	-5	-5	-5	-5	-5	-5	-5	-5	-5
Usage	-3	-3	-3	-3	-3	-3	-3	-3	-3
Awareness	-1	-1	-1	-1	-1	-1	-1	-1	-1
Job Creation	3	3	3	3	3	3	3	3	3
Subsidies	-1	-1	-1	-1	-1	-1	-1	-1	-1
Incentives	3	3	3	3	3	3	3	3	3
Cost	1	1	1	1	1	1	1	1	1
Imports	0	0	0	0	0	0	0	0	0

Table 5: Weighted Objective Table for Biodiesel

Biodiesel									
Process Used	Transesterification					BTL Method			
Feedstock	Soy	Corn	Canola	Waste Oil	Algae	Perennials	Agri. Waste	Wood Waste	Ind. Waste
Cost of Production	-5	-9	-3	-2	3	-5	1	3	2
Energy Balance	1	-6	3	5	8	-4	-2	-1	1
Carbon Balance	2	-2	4	7	10	3	2	4	2
Land Use	2	-4	4	10	8	3	8	8	10
Current Production Volumes	-5	-9	-4	-6	0	-4	-3	-6	-7
Source to Refinery Transportation	-4	-3	-9	-7	-10	-8	-2	-2	-2
Compatibility with Current Infrastructure	-4	-4	-4	-4	-4	-4	-4	-4	-4
Existing Infrastructure	-4	-4	-4	-4	-4	-4	-4	-4	-4
Usage	-5	-5	-5	-5	-5	-5	-5	-5	-5
Awareness	-3	-3	-3	-3	-3	-3	-3	-3	-3
Job Creation	2	2	2	2	2	2	2	2	2
Subsidies	-1	-1	-1	-1	-1	-1	-1	-1	-1
Incentives	4	4	4	4	4	4	4	4	4
Cost	3	3	3	3	3	3	3	3	3
Imports	0	0	0	0	0	0	0	0	0

Table 6: Weighted Objective Table for Butanol

Butanol	Sugar					Cellulose	
Process Used	ABE					Continuous Fibrous Bed Bioreactor	
Feedstock	Corn	Sugar Cane	Sugar Beets	Switchgrass	Waste	Corn	Whey
Cost of Production	5	6	5	3	4	6	5
Energy Balance	-3	-2	-4	-1	-3	-1	0
Carbon Balance	2	7	5	8	8	2	1
Land Use	-7	-4	-7	-4	N/A	-7	N/A
Current Production Volumes	-9	-10	-10	-10	-10	-10	-10
Source to Refinery Transportation	-3	-9	-8	-8	-2	-3	-2
Compatibility with Current Infrastructure	0	0	0	0	0	0	0
Existing Infrastructure	0	0	0	0	0	0	0
Usage	-10	-10	-10	-10	-10	-10	-10
Awareness	-9	-9	-9	-9	-9	-8	-9.5
Job Creation	3	3	3	3	3	3	3
Subsidies	-10	-10	-10	-10	-10	-10	-10
Incentives	-7	-7	-7	-7	-7	-10	-10
Cost	-2	-2	-2	-2	-2	-2	-3
Imports	-1	-1	-1	-1	-1	-10	-10

D: Appendix Containing Original Problem Statement

The Sustainability of the BioFuels Revolution
Fall 2007

Problem Statement:

On January 23, 2007, President Bush issued this statement in his State of the Union address:

> *Tonight, I ask Congress to join me in pursuing a great goal. Let us build on the work we've done and reduce gasoline usage in the United States by 20 percent in the next 10 years. When we do that we will have cut our total imports by the equivalent of three-quarters of all the oil we now import from the Middle East.*
>
> *To reach this goal, we must increase the supply of alternative fuels, by setting a mandatory fuels standard to require 35 billion gallons of renewable and alternative fuels in 2017 -- and that is nearly five times the current target.*

Bush's goal of replacing 35 billion gallons of gasoline with renewable and alternative fuels by 2017 represents about 15% of our total gasoline usage. (For more details regarding this announcement, see http://www.whitehouse.gov/stateoftheunion/2007/initiatives/energy.html)

This positional statement by our government forms the core of the problem to be addressed in HP200 this year, namely:

> "What are the implications of the recent statements by the US Government regarding the decision to support the expanded use of BioFuels in the US and around the world?"

The challenge will be to critically analyze this positional statement, including the issues surrounding this question, from various perspectives and present the findings in the form of a feasibility study. The final deliverable will be a public forum open to the public community.

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