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A CENTURY LONG PURSUIT OF ALTERNATIVE FUELS AND FEEDSTOCKS: A CONTENT ANALYSIS

THESIS

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AFIT/GFA/ENV/11-M01

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

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THESIS

Presented to the Faculty

Department of Systems and Engineering Management

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Financial Analysis

Elias J. Halvorson, BS

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A CONTENT ANALYSIS

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Abstract

The United States has dramatically increased its production of alternative fuels over the past seven years. With the passing of the Energy Independence and Security Act of 2007 (EISA), alternative fuel production will increase in the United States over 700% from 2005 levels. However, the pursuit of petroleum alternatives is not a recent trend. Over the last 100 years, various nations have pursued petroleum alternatives with varying levels of success. This research focuses on the historical development of 10 leading alternative fuels and feedstocks. Through a thorough literature review we will identify commonalities among these fuels and feedstocks which have hindered their adoption. Further, the research evaluates the 10 alternative fuels and feedstocks with text mining software to support findings from the literature review. This research finds that alternative fuels face significant challenges with regards to environmental impacts, technological maturity, and societal costs. Further, these petroleum alternatives have rarely been economical solutions. The research findings suggest that while there are National Security reasons for pursuing petroleum alternatives, rarely are there economic ones.

I dedicate this to my beautiful, patient girlfriend and our daughter. Without either of you this never would have happened.

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I would like to start off by thanking my thesis advisor, Dr. Charles Bleckmann, who provided me with such an interesting topic! I felt lucky to have been able to do a thesis I was so interested in. It made the endless hours of reading go by much faster. I would also like to thank my other committee members, Dr. Tim Edwards and Lt Col Eric Unger for their support (and proofreading).

I would like also express my gratitude for such wonderful classmates. I joined the Air Force because I liked the people in it. You all have not disappointed and I feel very privileged to have been a part of this class. I would not have made it without your help and support. Thank you.

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Elias Halvorson

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I: Introduction

Background

Energy independence has been a common goal discussed by United States politicians for decades. When energy prices spike, inevitably discussions lead to finding foreign oil alternatives and the need for energy independence. The past eight U.S. presidents have declared the need for the United States to become less dependent on foreign oil sources. Developing our own alternative fuels and feedstocks is often mentioned as one of the key factors in the United States achieving energy independence.

Although energy independence has been noted to score points with voters across all demographics, it is not realistic (Bryce, 2008). Besides a brief period in the 1930s, when a combination of larger discoveries of oil in Texas and export demands fueled by World War II, the United States has never been energy independent. The United States has only been a net exporter of oil in seven of the past 100 (Bryce, 2008). Figure 1.1 shows total net imports of oil since 1910.

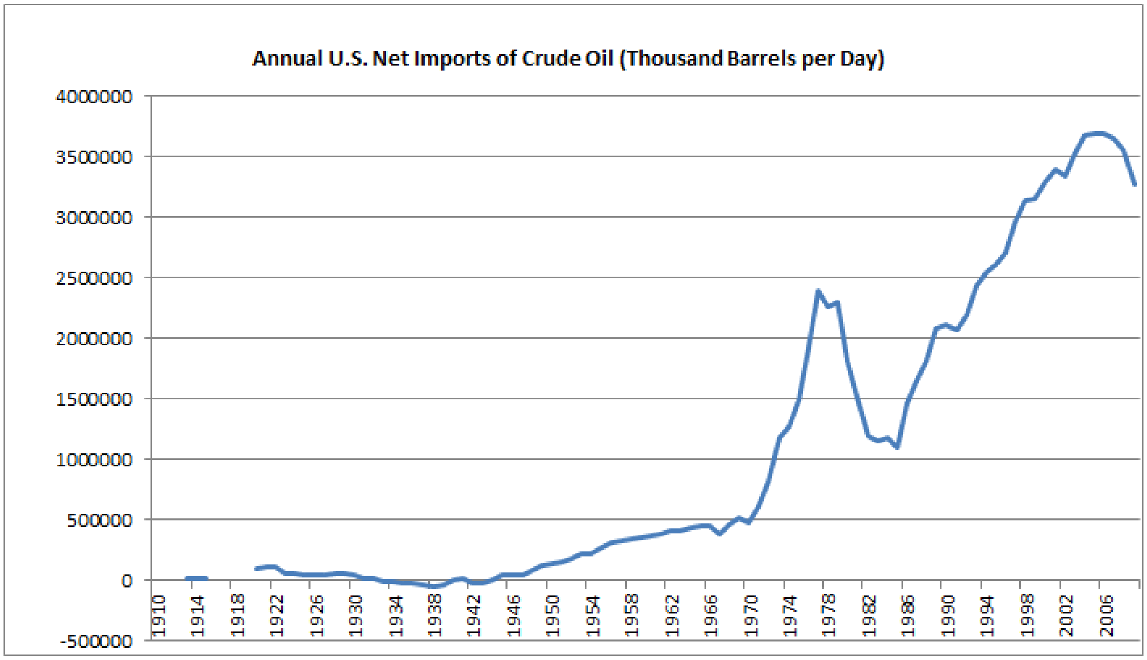

Figure 1.1 Annual U.S. Net Imports of Crude (Thousand Barrels per Day)

One of the key provisions in the 2007 Energy Independence and Security Act (EISA) mandated a dramatic increase in the use and production of renewable fuels (CRS, 2007). The ambitious plan called for a 700% increase in biofuel production by 2022, with nearly all of the production increases after 2014 coming from advanced biofuels (DOE, 2009). EISA is not unlike other goals the United States has set in the past. During the 1980s and 1990s, "the United States set goals to derive a substantial portion of its fuel for transportation from alternative sources, 10% by 2000, and 30% by 2010" (Melendez, 2006). Although EISA has resulted in production capability has rising dramatically, the production targets have not been met. In 2009, the United States only met 8% of its domestic fuel demand while using 35% of its corn crop in ethanol production (Economic Research Service, 2010). Further, many producers are not profitable.

There is a growing body of literature focused on the cost and benefits of biofuels (Tao, et al, 2009; Zhang & Wetzstein, 2008) and the near-term outlook for biofuels (Ghobadian & Rahimi, 2004; National Research Council, 2010). However, less research has been done reviewing why biofuels have failed to help the United States achieve energy independence and what traits these alternative fuels and feedstocks share. Although many associate alternative fuel development with the oil embargos of the 1970s, the history of alternative fuels goes back much further.

Purpose of This Study

In this study, we examine literature written on 10 of the many proposed alternative fuels and feedstocks. This study focuses on the historical development as well as sections pertaining to the environment, technology, economics, and viability of each. This study includes a fairly even mix of both alternative fuels and feedstocks presently in use, and feedstocks which may enjoy increased use in the future. We hope to identify commonalities among present alternative fuels and prospective feedstocks which have hindered or helped diffusion. In addition, we will review the documents from the literature review with text mining software as another method of identifying common traits these alternative fuels and feedstocks share. Countries throughout the world have been trying to make alternative fuels work for more than 100 years. This study hopes to further research into why alternative fuels have failed.

Research Questions

1. Are increased use of alternative fuels and feedstocks the appropriate path for the United States to become energy independent?

2. Are there commonalities among alternative fuels and feedstocks which have prevented their widespread adoption?
3. What qualities do alternative fuels and feedstocks need to ensure widespread adoption in the future?

Chapter Summary

The rest of this paper is arranged as follows: Chapter II provides an extensive review of past research involving the selected alternative fuels and feedstock. In Chapter III, we will detail the procedures we used in creating the database which the text-mining software will analyze. In Chapter IV, we will articulate the results and themes identified by the text mining software. Finally, in Chapter V we will summarize the results and offer conclusions based on the research.

II: Literature Review

In this chapter we will discuss the development of 10 alternative fuels and feedstocks being heavily promoted today as potential replacements for petroleum use. We will review their historical development and examine each from an environmental, technological, economic, and viability perspective. Through a thorough literature review, we hope to find common themes and traits that are shared which have helped or hindered the development of alternative fuels. There have been many biofuels touted as petroleum alternatives, but we will first examine ethanol.

Corn Ethanol

History

Although most people think ethanol fuel story began in the 1970s, the use of ethanol for industrial applications has been around for almost 200 years. In 1826, Samuel Morey developed an engine that ran on ethanol and turpentine while the developer of the modern internal combustion engine used ethanol as the fuel in one of his engines in 1860 as well (EIA, 2008). Automobile inventors had many choices of potential fuels such as whale oil, lard oil, and camphine,"a mixture of ethyl alcohol, turpentine, and camphor" (Bernton, Kovarik, & Sklar, 1982). According to Morris, "alcohol was already one of the nation's premier illuminants and industrial chemicals with 90 million gallons were produced in the late 1850s" (Morris D. , 1993) and was half the price of lard oil and whale oil (Bernton, et al, 1982). Unfortunately, taxes levied on alcohols during the outbreak of the Civil War prevented ethanol's continued rise.

The tax on distilled spirits was repealed in the early 1800s until the Civil War, when taxes were initially levied at 20 cents a gallon but rose to $2.08 a gallon by 1864 (Herrick, 1907). This made it virtually impossible to compete with other potential sources of illumination. Lard oil and recently discovered kerosene were only taxed at the rate of 10 cents a gallon (Bernton, et al, 1982). Congress wished to eliminate industry from the taxation, leaving the tax burden solely on alcohol purchased for beverage consumption. However, as Herrick states, “no way could be devised, as at that time denaturing was not an established fact, as it is now” (Herrick, 1907). Europe, on the other hand, embraced alcohol fuels. Germany did not have plentiful oil reserves and passed legislation enacting tariffs on imported petroleum to increase domestic industrial alcohol production (Bernton, et al, 1982). From 1887 to 1902 Germany increased its production of alcohol from 10 million gallons to more than 29 million gallons (Herrick, 1907). With the beginning of the 20th century, industrial alcohol finally got a reprieve from the Civil War imposed tax.

The success in Europe was noticed in the United States, and farmers suffering from large grain surpluses were looking for other markets to reduce their surpluses and increase crop prices (Bernton, et al, 1982). In 1906, farmers’ pressure and Roosevelt’s concern over monopolistic activities by Big Oil led to legislation eliminating the tax (Carolan, 2009). However, ethanol had fallen far behind in the race to supply America with fuels. While the tax-induced price of ethanol had prevented more widespread use over the previous 40 years, Standard Oil had been busy laying pipelines and investing in infrastructure (Tarbel, 1904). While alcohol was economically competitive with whale and lard oil, it could not compete with the new petroleum products. Petroleum was naturally cheaper, and the infrastructure spending added to petroleum's advantage. As Benton, et al state, "Even without the tax, the Agriculture Department noted, alcohol sold for a minimum of 30 cents per gallon, while gasoline sold for a minimum of 10 cents per gallon, and kerosene for 8 cents per gallon" (Bernton, et al, 1982). However, the outbreak of World War I would temporarily change alcohol producers' fortunes, and this time for the better.

World War I led to a huge increase in demand for all industrial products, including alcohol. Demand increased from 10 million gallons in 1914 (Bernton, et al, 1982) to more than 52 million gallons by the end of the war (Scientific Station For Pure Products, 1920). Alcohol aided in the manufacture of explosives (Scientific Station For Pure Products, 1920), and in the production of mustard gas (Bernton, et al, 1982). The rapid increase in production led to much enthusiasm about the future potential of industrial alcohol. Shortly after the war, The Scientific Station for Pure Products proclaimed, "The future of industrial alcohol is limited only by the restrictions which may surround its use. Now that the United States has gotten a start in the chemical and allied industries in which alcohol is an absolute necessity, developments should be rapid and extensive" (Scientific Station For Pure Products, 1920). Unfortunately, with the Prohibition movement gaining strength, industrial alcohol would soon be dealt another blow.

The Anti-Saloon League had gradually been gaining strength in the early 1900s and Prohibition was passed in 1919, taking effect in 1920 (Bernton, et al, 1982). It is of note that The Rockefeller family contributed more than $1 million dollars to the anti-alcohol movement (Bernton, et al, 1982) and Prohibition had the indirect effect of reducing or eliminating potential competitors of Standard Oil, Rockefeller's company. The alcohol movement floundered when Prohibition took effect, but there were still vocal supporters. Chemical engineers and distillers fought to distinguish industrial alcohols (Giebelhaus, 1980) but to no avail. Other scientists warned of its necessity in developing other sources of fuel. In 1921, a research scientist from General Motors warned that oil reserves were decreasing rapidly and proposed alcohol as a substitute (Bernton, et al, 1982). However, the most vocal and influential pro-alcohol group was compromised of members of the farm chemurgic movement.

The term "chemurgy" combining the Egyptian root for chemistry, and the Greek root for work, was coined by the Dow Chemical Company's Director of Organic Chemical Research in 1926 (Carolan, 2009). Chemurgists had lofty goals to transform the country, including opening new markets to farmers, creating greater income for farmers, helping create full employment, and helping the United States achieve self-sufficiency in industrial materials (Beeman, 1994). In 1926 the economy was still booming, so creating full employment was not as important as it soon would become.

The onset of the Great Depression helped the chemurgic movement grow. From 1929 to 1932 prices received by farmers collapsed and the economics of corn to alcohol made more sense, leading to intense lobbying efforts in the Midwest (Bernton, et al, 1982). In 1933, the constitutional amendment establishing prohibition was overturned and the ethanol movement would again flourish. Midwestern states soon began to mandate 10% alcohol blends (Morris D. , 1993). The potential of mandates spreading instigated an oil industry backlash, leading the National Petroleum Association publically campaign against blending. Widespread pamphlets questioned the use of tax dollars and stated, “to force the use of alcohol in motor fuel would be to make every filling station and gasoline pump a potential speakeasy” (Morris D. , 1993). It wasn’t just Big Oil that questioned increased research and government support for industrial alcohol, detractors came from within the government as well.

In 1933 the Assistant USDA Secretary questioned the economics of industrial alcohol in his letter to Ohio Senator Bulkley stating,

> “in this Department we have come to expect the rediscovery of the possibilities of alcohol and the agitation for its wider use about every ten years…One of the great troubles with the situation is that there are so many people chasing an imaginary rainbow in hope of discovering at each end of it a pot of gold which they may kindly distribute to the farmer…It’s [making power alcohol economically feasible] like trying to extract gold from sea water and attracts the same sort of people” (Wright D. E., 1993).

Nevertheless, many research projects were initiated in the Midwest by the chemurgic movement and Iowa State University in collaboration with the USDA (Wright D. E., 1993). The Secretary of the USDA was not as pessimistic as his assistant but did acknowledge in an editorial that getting the industry moving further would entail high capital costs for plants of $4 million, as well as government assurances with regards to purchases, and price floors (Wright D. E., 1993). However, the question on what to do with the crop surpluses ceased to exist after a period of droughts commonly known as the Dust Bowl. In 1935 and 1936, Henry Ford sponsored two chemurgic conferences where members of the chemurgic movement and Big Oil debated the merits of alcohol’s use as a fuel (Giebelhaus, 1980). Each side did little to aid their cause, but at the end of the second conference private loans were announced to convert a brewery in an experimental distiller (Giebelhaus, 1980).

Within two years of starting their distillery for fuel alcohol, creative marketing and the support of many Midwestern farmers who disdained Big Oil enabled the Atchinson group to sell their Agrol blend in more than 2,000 stations in eight states (Giebelhaus, 1980). The distillery's product was popular but never competed economically with oil. Big Oil waged a nasty PR campaign against the blend and with demand dipping and the novelty of purchasing the blended product wearing off, in 1938 the company closed the distillery (Bernton, et al, 1982). The production costs were 500% greater than refining gasoline and the distillery's remarkable failure led the USDA to issue a report recommending against any incentives to help stabilize the alcohol fuels industry (Bernton, et al, 1982). Although the distillery had successfully removed excess grain from the market, it became known as, "the greatest fiasco of the chemurgic movement" (Time, 1943). Once again, when things looked bleak for the farm-based alcohol movement, war would save the industry.

World War II changed the United States farm problem, "from surplus to shortage" (Time, 1943). These shortages even brought the Atchison plant back online with expanded operations (Giebelhaus, 1980). During World War II the production of alcohol rose to 500 million gallons a year (Time, 1942) and with the conflict in Asia cutting off traditional supplies of rubber (Morris D. , 1993), the alcohol industry filled a vital need. Most of the production of alcohol was used to produce synthetic rubber and explosives, not fuel (Time, 1943). Even in wartime, the alcohol and oil industry were bitter competitors.

According to Morris, "The federal government initially gave two large contracts to the agriculture and the petroleum industry for synthetic rubber production" (Morris D.

, 1993). Although the agriculture community started producing in larger quantities first, the petroleum industry's product was always more economical. At the end of the war rubber production from alcohol cost $.21 lb., while their petroleum competitors averaged $.11 lb (Bernton, et al, 1982). After the war, the market for farm-based alcohol collapsed. Access to rubber imports was restored pushing prices down further, while gasoline remained a much cheaper transportation fuel. Additionally, food shipments to Europe caused grain prices to rise rapidly, making farm-based alcohol products even less economically competitive (Bernton, et al, 1982). The government withdrew its support for grain alcohol (Morris D. , 1993), and the industry died.

Large projects were discontinued (Finlay, 2003) and low oil prices continued to subdue interest in alcohol fuel in the 1950s. Grain surpluses in the 1950s did, however result in sporadic government interest. However, presidential commission in 1958 found that technology and economics were unfavorable and the use of alcohol for fuel could not be justified (Bernton, et al, 1982). Despite these setbacks, the turbulent 1970s would see the farm-based fuels industry rise from the ashes.

The Clean Air Act of 1970 reintroduced the possibility of ethanol blending by mandating the inclusion of oxygenates, or chemicals containing oxygen which help gasoline burn cleaner (Mousdale, 2008). Shortly thereafter, the oil embargo of 1973 caused oil prices to more than double overnight. Originally, grain prices spiked, enabling farmers to cover some of the increased fuel costs, but farmers' overproduction caused grain prices to collapse the following year (Bernton, et al, 1982). Farmers, faced with lower revenue and increased costs began to look for solutions. Soon many farmers were distilling their own alcohol to use as fuel on the farm (Bernton, et al, 1982).

By 1978, the pro-alcohol movement had become increasingly mainstream. South Dakota State University received funding to produce the first operating dry mill in the United States (Songstand, Lakshmanan, Chen, Gibbons, Hughes, & Nelson, 2009), while the Carter Administration and Congress passed the Energy Tax Act of 1978 defining gasohol as coming from plant-based sources, and providing a subsidy of $.40 cents per gallon of ethanol blending into gasoline (Soetaert & Vandamme, 2009). In 1978 the first gasohol pump opened in Nebraska, and by 1981 over 10,000 stations in all 50 states had gasohol pumps while more than 6,000 permits for fuel production had been granted (Bernton, et al, 1982). However, even with the subsidies gasohol was only competitive in states that removed state highway taxes (Bernton, et al, 1982).

Throughout the early 1980s, subsidies were increased for United States producers of gasohol. Support for ethanol production did not waiver with the Regan Administration taking office. Loan guarantees, tariffs enacted on cheaper Brazilian ethanol, and gradually increasing their subsidies to $.60 cents a gallon were measures taken to support the industry (Bryce, 2008). By the mid-1980s, ethanol production had exploded to 163 ethanol plants (EIA, 2008). However, oil prices collapsed in 1986 and by the end of the year less than half remained in business (EIA, 2008). To ensure survival, ethanol plants would have cut production costs while finding new ways of generating revenue if they wanted to stay afloat.

In 1990 ethanol plants began adopting cost-reducing technologies and expanded production of wet mill plants which produced marketable by-products (EIA, 2008). Although the blending credit was reduced, the government increased support in other areas. The Energy Policy Act of 1992 required flex-fuel vehicle purchases and for the vehicles to use alternative fuels (Mousdale, 2008), while amendments to the Clean Air Act of 1990 helped ethanol spur more demand for use of ethanol as an oxygenator (EIA, 2008). However, even increase in demand would not make up for the poor economics of the industry.

In the mid-1990s, poor yields and increased crop prices caused many Midwestern states to increase subsidies to ethanol plants to sustain the industry (Bryce, 2008). In 1997, United States automakers began mass producing Flex Fuel Vehicles (FFV) (EIA, 2008). Although the vehicles would not change demand for ethanol, they would help provide a customer base for when the industry recovered. For the third time in its history, war and geo-political events would save the industry shortly after the new millennium.

With the events of September 11th and the Iraq War, oil became associated with supporting enemies of the United States. In the eyes of many, increasing ethanol production would increase our energy independence and lessen purchases of oil thus preventing more money going to support terrorists and unfriendly nations. In addition, states were beginning to ban the oxygenate MTBE due to environmental concerns which helped lead to the passing of the Energy Policy Act of 2005 (Carolan, 2010). The Act contained billions in support for ethanol programs, R&D incentives for cellulosic ethanol, while also instituting a renewable fuels standard (RFS) requiring a doubling of biofuel output to 7.5 billion gallons by 2012 (Soetaert & Vandamme, 2009). Creating market demand and ensuring that demand will grow in the future have been instrumental in ethanol flourishing in the new millennium (Carolan, 2010).

With massive subsidies and high oil prices, production capability nearly doubled two years after the passing of the Energy Policy Act of 2005 (Renewable Fuels

Association, 2010). President Bush continued to encourage greater ethanol production with his passing of the 2007 Energy Independence and Security Act. The Act ensured producers of a massive increase in demand. Bush's 20 in 10 required the domestic production of alternative fuels to increase by more than 700% to 35 billion gallons while also increasing funding for biofuels research and infrastructure (CRS, 2007). This act has helped ethanol production to increase to almost 11 billion gallons by the end of 2009 (Renewable Fuels Association, 2010). Although ethanol production is up, many producers are still not profitable.

Russian drought and other extreme weather throughout the world have caused many agricultural commodities to skyrocket with the price of corn going up nearly 40% in 2010 (CME Group, 2010). This has led to a gallon of ethanol becoming even more expensive than a gallon of gas (Caylor, 2010). Further, some states are beginning to propose new rules which take into account land use change, potentially classifying ethanol a less green fuel (Burns, 2009). Although proponents tout corn ethanol as a "green fuel", there are many environmental concerns.

Environmental Perspective

Ethanol proponents like to point to direct CO_2 emission reductions by up to 59% when compared with gasoline (RFA, 2010). There is no argument that ethanol burns cleaner, but what many proponents fail to account for is the total life cycle assessment of ethanol. Land use change from grassland to crops is a big concern (Pimentel, Patzek, & Cecil, 2007; Kim, Kim, & Dale, 2009; Heath, Hsu, Inman, Aden, & Mann, 2009), and many argue this land use change creates a carbon debt which takes decades to pay back

(Pimentel & Pimentel, Food, Energy, and Society, 2008). Carbon debts can occur when land is converted from woodland or prairie to agriculture. This conversion can result in large quantities of greenhouse gases being released into the atmosphere, thus creating a 'carbon debt'. Further, corn is an energy intensive crop requiring large amounts of nitrogen fertilizer with runoff potentially polluting groundwater and aquifers (Pimentel, et al, 2007). In addition, the large amounts of water required during the production process could contribute to water scarcity in certain areas of North America by 2030 (Van Lienden, Gerbens-Leens, Hoekstra, & Van Der Meer, 2010).

Technological Perspective

Today, investments in crop science have enabled the doubling of corn yields since 1980 and refineries are always looking for technologies to improve processes and decrease inputs (RFA, 2010). However, although there may be room for improvement, it appears the technology is nearing the height of its maturity. The Energy Independence and Security Act specified after 2016 the biofuel production increase must come from advanced biofuels (CRS, 2007). Most of today's research is now focusing on cellulosic ethanol (RFA, 2010).

Economic Perspective

The economics of ethanol are challenging and without government aid it is questionable if the industry would survive. Ethanol proponents tout ethanol as, "the highest performance fuel on the market and it keeps engines running smoothly" (RFA, 2010). However, they often neglect to mention the lower energy content in ethanol compared to gasoline. The energy content of one gallon of gasoline is 125,000 BTU while ethanol supplies only 84,000 BTU per gallon, or 33% less energy (ORNL, 2010). In 2006, Consumer Reports ran a test, finding that the vehicles fuel economy dropped by 27% when running on 85% ethanol (E85) (Bryce, 2008). Thus, although gas and ethanol might be the same price at the pump, the lower energy content of ethanol makes it much more expensive. Consumers pay more at the pumps, and also support the industry through numerous subsidies.

Tarrifs, purchase mandates, blending credits, reduced state sales taxes, and small producer tax credits are a few of the ways the government supports the industry (Koplow, 2006). Former Presidential Candidate John McCain stated that subsidies cost $3 per gallon in 2003 (Pimentel & Pimentel, 2008). Further, Pimentel found that if one were to account for ethanol's lower energy content, it would take $7.12 to produce the energy equivelant of 1 gallon of gasoline (Pimentel & Pimentel, Food, Energy, and Society, 2008). Ethanol has many indirect costs. Consumers pay for the increased demand of corn through higher food prices.

Increased ethanol production has increased the prices of many different types of food. A 2009 Congressional Budget Office Report stated, " The increase in amount of corn used to produce ethanol has exerted upward pressure on corn prices, boosted the demand for cropland, and raised the price of animal feed. Those effects, in turn, have lifted the price of soybeans, meat, poultry, and dairy, and consequently the retail price of food" (CBO, 2009). The amount of the increase is debated, but the Congressional Budget Office's conservative estimate found that increased ethanol production was responsible for 10-15% percent of the increase in food prices from 2007 to 2008 (CBO, 2009).

Viability

Corn ethanol production will never be able to to be produced on a scale enabling the United States to achieve energy independence. In 2005, a study found if the United States devoted its entire corn crop to ethanol production, it would have only met 12% of the gasoline demand (Hill, Nelson, Tilman, Polasky, & Tiffany, 2006). While it has been shown to have a modest effect on lowering gasoline prices and increasing farmers incomes (CBO, 2009), there are many environmental and societal costs associated with increased ethanol production. Most importantly, ethanol has never been economical. Its success is dependent on both the price of gasoline and the price of corn. According to the CBO, "It is unlikely that, on average, ethanol producers the past several decades would have turned a profit if they had not received production subsidies" (CBO, 2009). Corn ethanol will only remain a viable alternative energy solution so long as politicians and the American taxpayer allow.

Sugar Ethanol

History

Sugar has played an integral part in Brazil's economic development since shortly after it was discovered in 1500. Initially, the Portuguese developed trade in brazilwood but as the large tracks of forest were cleared near this land became used for sugarcane plantations (Bernton, et al, 1982). Sugarcane plantations spread rapidly and by the 17th century, Brazil was among the world leaders in sugar production (Nass, Pereira, & Ellis, 2007). According to Martines-Filho, et al,

> "For many nations, the size and stability of domestic consumption has been critical in the development of export markets. The rise of the ethanol industry in

> Brazil may be due to the reverse. Its long history as a leading sugar producer and exporter has led to the development of a dynamic domestic cane-based ethanol industry" (Martines-Filho, Burnquist, & Vian, 2006).

The advent of the automobile created many new uses for sugar.

As automobile technology diffused a vigorous pro alcohol fuels movement in Brazil in which, "local officials and plantation owners promoted alcohol fuel use and cross-country tours of pure alcohol fueled cars were staged" (Bernton, et al, 1982). In 1903, Brazil promoted increased ethanol use and production by staging the International Exhibition of Ethanol Equipment in Rio de Janeiro (Gordinho, 2010). Later, some local governments in Northeastern Brazil began ordering official vehicles to operate on alcohol and by 1931, "the federal government had ordered gasoline importers to mix a minimum 5% alcohol into their fuel" (Bernton, et al, 1982). Shortly thereafter, sugar production became even more closely aligned with the government with the creation of the Institute of Sugar and Alcohol (Nass, et al, 2007). A mere eight years later, the Brazilian Government declared a monopoly of the export and external marketing of sugar (Cordonnier, 2008). In 1941 a quota system was established and in 1945 subsidies were established for smaller sugar mills as well as an established floor price for sugar (Cordonnier, 2008).

Increased government involvement starting in the 1930s led to a great expansion in distilleries and fuel alcohol production. From 1933 to 1945 the number of distilleries increased from a single unit to over 54 while the fuel alcohol production increased from 100,000 liters to 77,000,000 liters (Bernton, et al, 1982). German attacks on oil tankers led mandatory fuel blending levels to reach heights of nearly 50%, but the end of the war ushered in a period of cheap oil and a massive decrease in alcohol blend use (Bernton, et al, 1982).

The 1970s ushered in a new boom to sugar ethanol production. A combination of the first oil price spike and plummeting sugar prices led Brazil to make huge increases in its ethanol programs (Schuring, 2008). In 1975 Brazil created the Programa Nacional do Alcool or PROALCOOL (Soetaert & Vandamme, 2009). The decision to move ahead on PROALCOOL was made for strategic reasons, not economic ones. The Brazilian Government sought to safeguard its sugar industry and secure more domestic fuel production (Cordonnier, 2008) even though the cost of ethanol from sugarcane was more than twice the cost of gas from imported oil (Bernton, et al, 1982). PROALCOOL was a broad sweeping program which helped potential producers in numerous areas.

The decree which created PROALCOOL offered a panacea for the sugar industry's efforts to reduce its surpluses. PROALCOOL offered; assistance with transportation costs (Cordonnier, 2008), massive increase in credit and low interest loans for infrastructure investment (Xavier, 2007), mandatory blending (Schuring, 2008), and the government invested heavily in research to reduce costs and increase production (Nass, et al, 2007). The aid and incentives led to a rapid increase in Brazilian production capability. Within five years of the program initiation, Brazil's production increased from 600 million liters to 3.4 billion liters (Schuring, 2008). Increased aid did not have an entirely positive effect on Brazilian society. This great increase in production capability had adverse effects on the food supply. From 1976 to 1981, most new cropland was devoted to sugarcane while food production remained stagnant (Pimentel & Pimentel, 2008). This led to reduced availability of food, higher prices, and in certain instances, riots (Pimentel & Pimentel, 2008). The second oil price spike in 1979 led to even more favorable government actions for the sugar and ethanol industry.

The second oil spike led to the creation of more government agencies to move PROALCOOL forward (Schuring, 2008). The Brazilian government pursued agreements with car companies to modify production lines to produce cars running on 100% ethanol, mandated these cars use in government fleets, and gave taxi drivers tax breaks to convert engines (Xavier, 2007). In addition, to spur demand for 100% ethanol cars the government decreased taxes on ethanol car purchases and decreased the yearly license fees (Nass, et al, 2007). By the mid-eighties, ethanol fueled cars accounted for over 94% of new car sales (Xavier, 2007) and ethanol production quadrupled to 12.3 billion liters (Schuring, 2008). However, in the mid-eighties, wild swings in oil and sugar prices would deal a strong blow to Brazil's ethanol industry.

According to Schuring, "Beginning in 1986, the price per barrel of crude oil fell from a level of $30-$40 to between $12-$20….coinciding with a time of scarce public funds for subsidizing programs to encourage energy alternatives, hampering ethanol production growth" (Schuring, 2008). In addition, the inflation rate was in the triple-digits and leadership changing from military rule to democracy led to cuts in ethanol subsidies (Nass, et al, 2007). The industry was hurt by the price floor of ethanol being lowered to below production costs in 1986 (Nass, et al, 2007). In 1988, sugar prices skyrocketed making the economics even more unfavorable (Xavier, 2007). This led to sugar crops being diverted to exports which created ethanol shortages (Xavier, 2007) and purchases of ethanol fueled cars to plummet (Nass, et al, 2007). The end of the 1980s signified the end of heavy government subsidies and a continued stagnation of the ethanol industry.

Both the Sugar and Alcohol Institute and PROALCOOL were abolished in the early 1990s which were characterized as a period of great deregulation (Shikida, 2010). This deregulation was not without challenges as sugar was overproduced causing sugar prices and ethanol production to collapse (Nass, et al, 2007) as the price floor had been removed. By the late 1990s ethanol production had fallen to below 1985 levels (Goldemberg, 2006). However, a rebound in oil prices in 2001, coupled with the introduction of flexible fuel cars capable of running on any percentage of gasoline and ethanol mixture helped the industry recover (Schuring, 2008). Today, Brazil's ethanol industry is growing rapidly. Almost four decades of heavy R&D spending has enabled the Brazilian ethanol industry to compete with gasoline without subsidies (Soetaert & Vandamme, 2009). High oil prices, along with large increases in acreage and mills coming online (Zuurbier & Vooren, 2008)will enable Brazil to continue being a world leader sustainable ethanol production.

Environmental Perspective

Environmental concerns are often voiced by detractors as the main reason against producing more sugarcane ethanol. Central to the issue are concerns over land-use changes and deforestation in the Amazon (Zuurbier & Vooren, 2008). Some argue that certain trends could lead to over half closed-canopy forests in the Amazon Basin being damaged or replaced by 2030 (Nepstad, Stickler, Soares-Filho, & Merry, 2008). However, this argument does not hold considering more than 95% of growth occurred in the south-central region of Brazil, not the Amazon Basin (Zuurbier & Vooren, 2008). Furthermore, sugarcane ethanol is significantly better when comparing net energy yields and GHG reductions (Zuurbier & Vooren, 2008). Other concerns are; soil degradation, water use, water pollution, and air pollution from sugarcane burning (Schuring, 2008). However, even with these drawbacks sugarcane ethanol has less of an environmental impact than other biofuels currently in use (Zuurbier & Vooren, 2008)and much of this is due to the great improvements in technology.

Technological Perspective

The advantages of Brazilian ethanol production,"are mostly due to the technological developments that have been conducted for many years in private companies, research centers, and universities" (Soetaert & Vandamme, 2009). Early in the PROALCOOL program, ethanol costs were near $100 per barrel (Goldemberg, 2006), but through many years of research the costs have decreased significantly. Improvements in juice extraction, fermentation, distillation, cane washing, and automation have resulted in higher yields, lower costs, and positive environmental benefits (Soetaert & Vandamme, 2009). According to Xavier, " Between 1975 and 2000, modernization of the sugarcane yield per hectare increased by 33% and ethanol yield from sugar rose by 14%" (Xavier, 2007). Heavy investment in R&D continues with researchers continuously working to breed better varieties increasing yields further while reducing inputs (Preto, 2008). The continuous improvement in technology via R&D has led to the economics of Brazilian sugarcane ethanol to be more favorable than any biofuel to date.

Economic Perspective

Initially, the economics of Brazil's ethanol program were not favorable, but they have improved greatly. According to Goldemberg, "Estimates of the total investments in the agricultural and industrial sectors for automobile ethanol fuel between 1975 to 1989 reached a total of 4.92 billion (in 2001 dollars), but oil imports avoided meant savings of 52.1 billion (in 2003 dollars) from 1975-2002" (Goldemberg, 2006). Production costs are naturally lower than corn-ethanol because of fewer steps in the conversion process (Jacobs, 2006) and lower labor costs (Xavier, 2007). Brazil has averaged a decrease of 2-3% in production costs per year since 1975 (Soetaert & Vandamme, 2009). A shorter production process is not the only reason why sugarcane ethanol holds an economic advantage over corn ethanol.

A by-product of sugarcane ethanol production process is bagasse. Bagasse is used to power the sugar mills and allows the mills to be net power generators while helping sugarcane ethanol achieve energy balances two to eight times greater than ethanol produced from other crop sources (Mandil & Shihab-Eldin, 2010). The economics of sugarcane ethanol today are favorable and continued infrastructure spending will only increase its economic competitiveness. Ethanol pipeline construction from mainland cities to the coast, as well as port improvements scheduled for completion by 2013 will ensure Brazil remains the world leader in biofuels exportation.

Viability

Sugarcane ethanol is viewed as the only biofuel considered achieving a measure of success when examining environmental impact and remaining economically competitive (Mandil & Shihab-Eldin, 2010). It is exceeds corn and other starch based ethanol in almost all facets. Environmentally, GHG reductions are a minimum twice that with corn ethanol (Mandil & Shihab-Eldin, 2010). Continued improvements in genetics leading to increased yields and decreased inputs will reduce GHG emissions even further. It has proven to be the only biofuel economically competitive with oil without the help of subsidies. Socially, increased sugarcane production does not directly raise the price of other food staples. This enables it to sidestep many food or fuel debates. However, the problems for the United States lie in economics, geography, and scale.

Most ethanol plants are located in the Midwest, while sugar production would be located in the southern states. This would necessitate new ethanol plant construction in the South (Jacobs, 2006). In addition, sugarcane crop growers believe that it is more profitable to produce sugar for consumption rather than for ethanol (Jacobs, 2006). Geography and scalability must also play an important part in examining sugarcane ethanol's potential in the United States. With the difference in fuel use between the two nations, as well as only small portions of the United States being able to grow sugarcane, it would be difficult to replicate Brazil's results. Brazil has demonstrated sugarcane as a biofuel feedstock can be a success, but their situation is unique.

Biomass/Cellulosic Crops as Feedstocks

History

There is often some ambiguity as to what the term biomass actually means. According to a recent biomass feasibility study conducted jointly by the DOE and USDA, biomass is defined as, "all plant and plant-derived materials including animal manure, not just starch, sugar, oil crops already used for food and energy" (USDA & DOE, 2005). For the purpose of this section, we will focus on wood, crop residues, and waste-to-energy. Humans have been using biomass since man discovered how to make fire.

Where available, wood is generally the biofuel of choice in developing countries (Yevich & Logan, 2003). Humans used biomass to fuel one of our earliest forms of transportation, the horse. However, widespread use of horses for transportation was not without its drawbacks. Horse pollution was a hot issue in the 19th century. In 1894, the London Times predicted, “by 1950 every street in the city would be buried in nine feet deep of horse manure” (Morris E. , 2007). Fortunately, as automobile use became widespread, the issue of horse pollution gradually faded away. The first vehicles were built to run on ethanol, but even early on some academics realized the drawbacks to producing fuel from food crops.

Fueling a significant portion of the country’s fuel needs would require a significant portion of the country’s crop production. Two pilot plants were built in the early 1900s to convert forest and wood-processing waste to ethanol but failed to become commercially successful (Kamm, et al, 2006). Nevertheless, Yale Chemistry Professor Harold Hibbert believed that cellulose was the answer (Kovarik, 2007). In 1920, Hibbert was quoted as asking, “Does the average citizen understand what this means? In from 10 to 20 years this country will be entirely dependent upon outside sources for a supply of liquid fuels…paying out vast sums yearly in order to obtain crude from Mexico, Russia, and Persia. Alcohol from cellulose will solve this problem” (Kovarik, 2007). Throughout the late 1930s Russia and Germany built many plants to create ethanol from wood waste, however the water intensive process produced a rather diluted product making it very expensive to process (Kamm, et al, 2006).

During World War II, the United States researched various methods to produce Rubber and Ethanol via cellulose, as well as enzymatic processes using the fungus which was the culprit of jungle rot (Kamm, et al, 2006). Research slowed in the 1950s, but biomass continued to play an important role in the daily life of Americans. The majority of North Americans still relied on wood to heat their homes until the 1950s, after which electricity and natural gas displaced biomass (Centre for Energy, 2010). Sporadic research continued into various pathways of cellulosic ethanol production until the late 1960s (Kamm, et al, 2006), but low energy prices tempered enthusiasm for alternative forms of energy.

The turbulent 1970s led to renewed interest in all forms of alternative fuels, including biomass. The United States was introduced to the European method of creating energy from waste in the mid-seventies with the newly created Energy Research and Development Administration actively supporting research (Hickman Jr, 2001). Waste-to-Energy (WTE) was a synergistic solution helping alleviate bulging landfills while also providing an alternative form of electricity. The National Energy Act of 1978 created a regulatory mandate encouraging plants to look to renewable energy sources for power creation (Duffield & Collins, 2006). Meanwhile, the Oak Ridge National Laboratory took charge of the DOE's Bioenergy Feedstock Development Program to develop energy crops out of short-rotation tree crops and other potential herbaceous energy crops (Kszos, et al., 2000).

The 1980s and early 1990s brought about continued research in ethanol via cellulose but pilot plants mediocre results and low oil prices did little to increase enthusiasm. However, biomass as a means to produce electricity did spread among North

America and Europe. States such as California rapidly developed their biomass power capacity (Centre for Energy, 2010). In Europe, in addition to wood fueled biomass power plants, increased attention was given to WTE plants utilizing manure. The Dutch invested large amounts of resources promoting WTE plants utilizing manure, but the projects were plagued with cost overruns and technical difficulties (Negro, Hekkert, & Smits, 2007).

Increased energy prices have once again led to increased interest in biomass. Government spurred innovation with the passage of the Agricultural Risk Protection Act of 2000, which contained the Biomass Research and Development Act (Duffield & Collins, 2006). This Act promoted cooperation and coordination of policies to promote R&D with regards to bio-products, and provided financial assistance to those entities engaged in Biomass research (Duffield & Collins, 2006). The Farm Bill 2002 and Healthy Forests Restoration Act of 2003 increased Federal procurement of bio-based products and helped promote biomass production through use of grants (DOE, 2009). However, the Energy Policy Act of 2005 did much more to spur commercial biomass development.

The Energy Policy Act of 2005 established a Renewable Fuel Standard (RFS) which mandated 250 million gallons of fuel derived from cellulosic biomass by 2013 and called for a program to guarantee loans for energy projects that employ new or improved technologies (DOE, 2009). Around the same time the Energy Policy Act of 2005 was being debated, the USDA and DOE sponsored a study to examine the feasibility of harvesting a billion tons of biomass annually. A billion tons of biomass was needed to fulfill potentially replace 30% of petroleum consumption by 2030 (USDA & DOE, 2005). A mere two years later, the Energy Independence and Security Act of 2007(EISA) cemented the billion ton study's vision.

EISA drastically increased the Renewable Fuel Standards from 4.7 billion gallons in 2007 to 36 billion gallons by 2022 (DOE, 2009). Further, almost 90% of the expansion after 2011 will come from cellulosic ethanol or other advanced biofuels (DOE, 2009). EISA also greatly expanded grants available for various cellulosic and advanced biofuel development as well as plant construction. With government mandates the future of ethanol appeared bright. However, even with government mandates, cellulosic ethanol has faced significant headwinds recently. The technological uncertainty, credit crises, and problems with the DOE's Loan Guarantee program have all slowed cellulosic ethanol's advance (Lane, 2010). Biomass and cellulosic ethanol have to overcome many barriers to become viable in the future.

Environmental Perspective

Biomass harvested for energy requires very few agricultural inputs when compared to crops such as corn-based ethanol. Perennial crops such as switchgrass and *Miscanthus* require less fertilizer and water inputs, as well as less tilling (Jones & Walsh, 2001; Heaton, Voigt, & Long, 2004). Biomass and cellulosic ethanol dramatically reduces GHG emissions. Cellulosic ethanol has the potential to cut GHG emissions by 86% (Kumar, Barrett, Delwiche, & Stroeve, 2009). When compared with corn-based ethanol, cellulosic ethanol use results in over three and a half times the GHG emission reductions (DiPardo, 1999). Establishing biomass energy crops on marginal and deforested land can also improve the soil quality (Field, Campbell, & Lobell, 2007). WTE also provides many environmental benefits.

In 2003, the EPA noted that, "WTE as a power source had less environmental impact than any other source of electricity" (Glover & Mattingly, 2009). Each ton of MSW combusted results in one ton of carbon equivalent removed from the atmosphere (Glover & Mattingly, 2009). This reduction is achieved by eliminating potential landfill methane emissions, recovering metals, and by the offset of fossil fueled sources of electricity (Glover & Mattingly, 2009). Increased biomass use has a myriad of environmental effects, but not all are positive.

The removal of forests and agricultural waste can have many negative consequences as well. Removing forest residues could lead to nutrient depletion and habitat damage for small animals (Land Use Consultants, 2007). Removing agricultural residues may lead to increased soil erosion, increased water demand, and reduced beneficial organisms in the soil (Andrews, 2006). Finally, although biomass energy crops reduce emissions when compared with many other traditional renewable energy crops, increased harvesting of biomass can lead to deforestation and other potentially harmful land-use changes resulting in a carbon debt (Field, Campbell, & Lobell, 2007). WTE also has its share of environmental drawbacks.

Although the EPA has reported WTE's smaller environmental impact than other sources of electricity, it has faced resistance due to a history of toxic emissions. No new waste combustion plants have been constructed since 1996 due to resistance over potential emissions (Glover & Mattingly, 2009). EPA regulations have significantly reduced toxic emissions from combustion plants, but landfill gas capture systems have faced significantly less resistance due to lower levels of toxic emissions released (Glover & Mattingly, 2009). Although gas capture releases less dioxins and mercury than combustion, it has been found to release somewhat higher levels of SO_x and NO_x.

Technological Perspective

Technical issues are the primary bottleneck affecting cellulosic ethanol. Although production has been demonstrated at a pilot level, the technology has not been demonstrated on a commercial scale (Office of Science, 2010). Biomass feedstock is more difficult to break down than corn ethanol. A key obstacle lies in breaking down the complicated structure of cell walls (Yuan, Tiller, Al-Ahmad, Stewart, & Stewart Jr, 2008). Biomass feedstock need pretreatment to correct this problem. Not all forms of pretreatment work efficiently on all biomass feedstock (Kumar, et al, 2009) and there are often problems with recalcitrance occurring (Himmel, Vinzant, Bower, & Jechura, 2005). Biotechnology may offer the answer to the recalcitrance problem, but further research is needed.

Modifying a plant's cell wall could result in greater susceptibility to pathogens and insects (Li, Weng, & Chapple, 2008). After biomass completes pretreatment, enzymes are used to break down the cellulose into glucose. This is challenging because, "cell walls have evolved for strength not only but for resistance to biochemical attack by living organisms" (Gomez, Steele-King, & McQueen-Mason, 2008). Greater research is needed in the development of enzymes. According to Wyman, "enzymes with greater specific activity are needed to increase reaction rates and achieve high conversions with much less enzymes" (Wyman, 2007). Discovering new enzymes with properties enabling higher conversion and reaction rates are high priority research goals (DOE, 2006). According to Yuan, et al, "Improvement or replacement of processes are crucial for increasing efficiently and decreasing costs….Technology breakthroughs are badly needed" (Yuan, et al, 2008). Without breakthroughs in technology, cellulosic ethanol will never be economically viable.

Economic Perspective

Biomass and cellulosic ethanol face significant economic challenges. Although the Billion Ton study suggests that a large annual supply of biomass is technically feasible, it may not be economically feasible. Recently harvested biomass is bulky, often wet, and only contains a fraction of the energy on a volume basis that coal does (Boyles, 1986; Timmons, et al, 2007). Transporting wet, bulky biomass weighs on costs. Additionally, factors such as steep terrian, unroaded areas, and low-impact removal signficantly affect the economic viability of biomass (USDA & DOE, 2005). According to Fales, et al, "feedstock production and logistics currently constitute an estimated 35 to 65% of total production costs of cellulosic ethanol, while logistics associated with moving the biomass to a refinery can comprise 50-75% of those costs" (Fales, Hess, & Wilhelm, 2007).

Many different methods are being tested to reduce logistical costs. Fast pyrolysis is a method that has great potential to reduce these costs. Fast pyrolysis systems may be built on portable units and be situated near the biomass source (Huber, 2008). Although being situated next to the biomass sourcereduces logistic costs, its smaller scale may suffer from economies of scale. Studies have shown production costs to decrease as the plant size increases (Dwivedi, Alavalapati, & Lal, 2009; Lange, 2007). Processing costs further hinder the diffusion of biomass and cellulosic ethanol.

Although biomass feedstock is traditionally cheaper than corn, processing costs result in much higher conversion costs than corn-ethanol (DiPardo, 1999). As with many advanced biofuels, technological challenges and cost are highly correlated. New technology is expensive to develop but until new, efficient technology is developed the total production cost will not be competitive. The process of pretreatment and hydrolysis add significant costs (Binder & Raines, 2010). Enzymes to break down biomass are up to 10 times more expensive than enzymes required to breakdown corn grain starch (DOE, 2006). Recently, some research has focused on process integration. Integrating the pretreatment and hydrolysis phases (DOE, 2006) could result in reduced capital and energy costs (Demirbas, 2009). Capital costs are prohibitive for cellulosic refineries.

Lowering the debt financing cost could help alleviate high initial outlays for capital costs (Solomon, Barnes, & Halvorsen, 2007). However, this remains a goal and is not a reality. Financial institutions require high rates of return to mitigate the percieved risk for investing in a technology yet to be proven commerically viable (Wyman, 2007). Although many facets of biomass energy and cellulosic ethanol are expensive, biomass energy and cellulosic ethanol does have postive economic benefits.

Biomass can be an economical source of heat and electricity. According to Lucia, et al, “Biomass based Combined Heat and Power (CHP) provide the primary energy for large segements of the population in Scandinavian and Norther European countries” (Lucia, Argyropoulos, Adamopoulos, & Gaspar, 2007). This process is more energy efficient with the combustion used to produce electricity while lower pressure steam is used for heating (Lucia, Argyropoulos, Adamopoulos, & Gaspar, 2007). Further, these powerstations are not dependent on any one biomass crop helping ensure they have a steady stream of feedstock throughout the year (Venedaal, Jorgensen, & Foster, 1997).

Viability

Although many studies have indicated biomass fulfilling up to one third of global energy by 2100 (Hamelinck & Faaij, 2006), many potential hurdles remain before biomass can achieve more widespread use. A continuous and economic supply regardless of weather and region remain a key constraint for biomass (Wang, Li, Wang, Zhu, & Wang, 2010). To date, Europe has been much more active in electricity plants using biomass as a feedstock. Northern Europe has used its tremendous forest resources (Lucia, 2007), while other areas of Europe depend on a variety of feedstocks such as manure (Negro, et al, 2007; Antoni, et al, 2007). Biomass can replace 10% of coal usage in coal power plants while compacted biomass pellets used for heat may be the most efficient method for biomass (Field, Campbell, & Lobell, 2007). Biomass for heat and electricity is presently the most economical use. To date, there has been no cost effective production of cellulosic ethanol on a commercial scale.

The challenges cellulosic ethanol faces are similar to other advanced biofuels with uncertainty being a primary obstacle. Although high yields have led researchers to estimate energy crops like switchgrass may be more profitable than corn, processing technologies need to progress for cellulosic ethanol production to be profitable (Yuan,et al, 2008). Further, government support is also needed to spur creation of cellulosic ethanol refineries (Buckley & Wall, 2006). Recently, companies have experienced problems receiving low cost government loans and grants (Lane, 2010). Problems securing loans resulted in a slowdown in production of biorefineries forcing the EPA to lower the cellulosic biofuel mandate for 2011 over 90%, from 250 gallons to a 6-25 million range (Lane, 2010) .

Until uncertainties over technology, RFS implementation, and government aid are settled, large scale production cellulosic ethanol will remain challenging. Without technology improvements and government mandates, the economics are prohibitive. A plant capable of producing only 100 million gallons annually has capital costs of at least $400 million (2008$) and would only be competitive with oil priced at $140 a barrel or higher (Taheripour & Tyner, 2008). A recent GAO report found the government subsidizes cellulosic ethanol $3 per gallon (Chicago Tribune, 2010). Cellulosic ethanol will not be a viable option until there are technology breakthroughs or the price of oil skyrockets.

Switchgrass as a Feedstock

History

Perennial grasses have been used as feedstock for centuries. They have contributed greatly as an energy source for farm animals since this country was settled. Switchgrass is a perennial grass native to North America and, “Since the 1940s, switchgrass has been used for pasture purposes in the Great Plains and Midwest states.” (Keshwani & Cheng, 2009). The focus on switchgrass as a potential energy crop came much later.

Deeper investigation into the energy potential of biomass was stimulated by the crises of the 1970s (Boyles, 1986). When the United States began looking at crops for biomass potential in the early 1980s switchgrass was one of thirty-four plants involved in screening trials by the Department of Energy (DOE) and seven institutions (Wright, et al., 2009). The goal of herbaceous energy crop research was, “to develop crops that can be economically produced on a wide variety of sites and readily and practically incorporated into conventional farming operations” (Ferrell, Wright, & Tuskan, 1995). It was also important that the production of biomass did not lead to a large reduction of food production so research focused on finding species that could be grown on marginal land or in winter (Wright L. , 2007). Many potential benefits of switchgrass were noted (Keshwani & Cheng, 2009) by the institutions and six of the seven recommended it for further study (Wright, et al., 2009). Other potential crops were documented but switchgrass’ geographical range throughout much of North America and location in many diverse habitats set it apart (Ferrell, Wright, & Tuskan, 1995).

Funding limitations limited the DOE’s crop development funding to one species (Wright, et al., 2009) and switchgrass was chosen in 1990 (Wright L. , 2007). By focusing on one herbaceous crop, “it was believed there would be a greater chance for proving the value of genetics and biotechnology in increasing yields and improving economics” (Wright L. , 2007). Emphasis was placed on switchgrass because it had high productivity, could be grown on lands of marginal quality, low water and nutrient requirements, high soil carbon sequestration potential, and the flexibility for multipurpose uses (Keshwani & Cheng, 2009; Wright, et al., 2009). Throughout the 1990s research was focused on enhancing yields and agronomic best practices (Wright, et al., 2009). Switchgrass production provides many environmental benefits when compared to traditional crops.

Environmental Perspective

Switchgrass is described as having the potential for high output but requiring low inputs (Sanderson & Adler, 2008) . Inputs into the agricultural process degrade the net energy value of the biofuel produced. Among the biggest inputs into the process are fuel and fertilizer use. According to Soetaert and Vandamme, "No-till cropping tends to reduce fuel and fertilizer use…for dedicated energy crops such as switchgrass, tilling is not required (Soetaert & Vandamme, 2009)". Further, switchgrass improves soil quality (Mann & Tolbert, 2000), improve surface water quality (Keshwani & Cheng, 2009), and sequesters carbon from the atmosphere (Rinehart, 2006; Bransby, Mclaughlin, & Parrish, 1998). Finally, switchgrass is native to North America and, "more environmentally acceptable than the introduction of an exotic species for the same purpose" (Heaton,et al, 2004).

Switchgrass has been demonstrated to have broad benefits in regards to the environment, but there are some concerns. Switchgrass has low water requirements to survive, but to thrive it requires much more water. When exposed to drought conditions switchgrass suffered, "severe reductions (75-80%) in biomass yield" (Barney, Mann, Kyser, Blumwald, Deynze, & DiTomaso, 2009). This could lead to an irrigation requirement if greater yields are desired. Nitrogen fertilizer may also be required to maximize yields (Heaton, et al, 2004). Perennial grasses like switchgrass do offer high output but to achieve the highest outputs inputs from water and nitrogen are needed.

Technological Perspective

Technological barriers in the conversion of switchgrass to ethanol were discussed in the cellulosic ethanol as a feedstock section on.

Economic Perspective

The economic problems with converting cellulosic crops into biofuels were documented in the cellulosic section. However, there are also many economic challenges associated with switchgrass as an energy crop. Establishment of switchgrass as a crop is a persistent issue with most switchgrass crops not reaching maturity until after their second year (Wright L. , 2007). According to Hipple and Duffy, "The economic uncertainty around the costs and benefits of producing switchgrass, as well as the potential loss of Conservation Reserve Program benefits were identified as key factors in Iowa farmers' slowness to embrace switchgrass (Hipple & Duffy, 2002). Had costs and expected return on investment (ROI) been identified, farmers would have been more open to adopting switchgrass (Hipple & Duffy, 2002).

Viability

The United States has invested heavily into switchgrass research over the past 30 years. Being regarded as a biofuel with great potential has demonstrated that, "rapid and significant progress can be made in developing an energy crop with a focused, broad-based and intensive research effort" (Sanderson, et al., 1996). Switchgrass' many environmental and social benefits are key factors which have resulted in continue funding for research. However, a key factor in switchgrass' future development will be further technological progress into making cellulosic ethanol conversion more cost effective. The economics of switchgrass, "can be improved by developing value-added by-products"

(Keshwani & Cheng, 2009), but until the economics of cellulosic ethanol conversion are improved, switchgrass will not be a viable option.

Miscanthus as a Feedstock

History

Miscanthus is a genus that encompasses 14 to 20 species (Jones, 2001; Heaton et al, 2010) which originated from Southeast Asia (Jones, 2001). *Miscanthus* species have played an important role in throughout many countries in Asia. “From ancient times, human life in Japan depended closely on the use of *Miscanthus* for fodder and roofing.” (Jorgensen & Schwarz, 2000). Heaton notes that, “*Miscanthus* species have long been used for grazing and structural materials in China and Japan” (Heaton et al, 2010). While long used in Asia, its first mention in western literature was in 1885 (Jones, 2001).

Miscanthus was first introduced to Europe in the 1930s (Lewandowski, 2000), although its cultivation was primarily for ornamental use (Jones, 2001). In the 1960s, “a sawmill entrepreneur who foresaw a future lack of wood for paper pulp performed minor cultivation trials in Denmark” (Jorgensen & Schwarz, 2000). However, the potential for energy began to outshine its pulp potential. It was evaluated as a potential bioenergy crop due to concerns over fossil fuel dependence in the 1970s (Heaton, et al 2010) and Finch notes that, “In the 1970s and 1980s, the expected end use was for direct combustion, either for heat or electricity production from steam turbines” (Finch, 2009). Interest grew in *Miscanthus* potential from the EU agricultural policy reformation in 1992. Jorgensen notes, “ Extended areas of new crops to produce not only food, but also energy and materials, was one of the visions when the EU agricultural policy was reformed in 1992” (Jorgensen & Schwarz, 2000).

Unfortunately, high establishment costs and losses during the first winter hindered more expansive trials of *Miscanthus* (Venedaal, et al, 1997). Total losses of *Miscanthus* crops in Germany during the early 1990s were a major contributor in *Miscanthus* research in Germany nearly grinding to a halt (Jorgensen & Schwarz, 2000). In the late 1990s, the European *Miscanthus* Improvement program worked to identify *Miscanthus* breeding and genotype performance under different weather conditions to help prevent crop losses (Heaton et al, 2010). In 2000, European researchers developed a model to predict *Miscanthus* potential performamce in the United States (Heaton et al, 2010). Following this model, researchers went on to show that *Miscanthus* would, "likely produce more biomass per unit of input of water, nitrogen or heat, than would switchgrass" (Heaton et al, 2004). Research on *Miscanthus* has exploded in the United States the past 10 years going from, "virtually non-existent to work being underway in nearly every state" (Heaton et al, 2010). Over the past 40 years extensive research on the viability of *Miscanthus* as an energy crop has been performed(Lewandowski, 2000; Styles, 2008; Finch, 2009; Heaton, et al 2010). It has many potential benefits, but there also factors that have prevented a more widespread adoption.

Environmental Perspective

The environmental benefits of *Miscanthus* are very similar to those listed for switchgrass. *Miscanthus* can also be described as requiring low inputs but producing high yields (ADAS Consulting Ltd, 2001). Large CO_2 reductions when compared with other crops such as corn (Mousdale, 40), reduced nitrate leaching (Finch, 2009), and reduced soil erosion (Heaton, et al, 2010) are common environmental benefits associated with *Miscanthu*. *Miscanthus* crops require much less nitrogen fertilizer inputs than switchgrass (Heaton, et al, 2004). However, there are some environmental drawbacks.

Water use (Heaton, et all 2010) and soil impact (Lewandowski, 2000) are major concerns when discussing widespread planting of *Miscanthus*. *Miscanthus* has great water use efficiency, but *Miscanthus* uses great amounts of water (Jones, 2001). When compared to regular crops such as potatoes and winter wheat, the water evaporation rate is nearly double with a rooting depth of 2.5 meters compared to 1 meter of the conventional crops(Finch et al, 2009). Earthworms, which are believed to bring many benefits to the whole soil ecosystem decreased by 50% in *Miscanthus* fields, relative to a meadow (Finch et al, 2009). *Miscanthus* use does have some drawbacks, but overall *Miscanthus* use is more environmentally friendly than many biofuel feedstocks. The biggest challenges *Miscanthus* faces is in the technical and economic arenas.

Technological Perspective

The technological barriers in the conversion *Miscanthus* to biofuels were highlighted in the Biomass/cellulosic feedstocks to biofuels in the preceding pages.

Economic Perspective

While the economics of *Miscanthus* appear to be better than switchgrass due to higher crop yield (Heaton, 2010;Finch, 2009), *Miscanthus* has many hurdles to clear. Perhaps most important, all biomass crops like *Miscanthus* face near-term economic challenges. Cheaper fossil fuel alternatives and the investment required to start producing biomass crops (Fischer, Prieler, & Velthuizen, 2005) are obstacles that cellulosic ethanol crops have yet to overcome. Some economic findings suggest that policies are needed to provide incentives for producing and using these crops based not only on energy content, but also environmental benefits (Khanna, Dhungana, & Clifton-Brown, 2008). Like other biomass crops, Lewandowski notes, “the economics of *Miscanthus* depend upon a number of assumptions: the yield, the chosen production chain, propagation method, number of years of assumed production, whether costs are annualized, transport and land-use costs, and the farmer’s own profit margin” (Lewandowski, 2000).

The scale of propagation is also economically challenging. According to Heaton et al, “ because *Miscanthus* is sterile micropropagation must be used to multiply *Miscanthus* into commercial quantities…Micropropagated *Miscanthus* plants are available in the US, but very expensive” (Heaton, et al 2010). It is hard to induce farmers to produce a perennial grass crop when there is so much uncertainty regarding cost, price, and profit (Hipple & Duffy, 2002). Another concern is water use. According to Jones, “Since the potential economic return from energy crops is currently low relative to other arable enterprises, farmers are more likely to consider growing energy crops on their less productive land….in many cases the low productivity is the result of poor water availability” (Jones, 2001). The irrigation required for commercial scale production of *Miscanthus* detracts from the economic viability even further.

Viability

Miscanthus is a crop with potential to fill the low input, high output role that is desired for biofuels today(Finch, et al 2009). The life cycle assessment of *Miscanthus* has been demonstrated be positive when compared with current ethanol crops and other perennial grasses. However, for *Miscanthus* to satisfy the low input, high output mantra cellulosic ethanol technology must become economically viable. In addition, establishment costs are high and the governments may need to provide greater economic incentives such as price floors and guaranteed purchases for farmers to adopt *Miscanthus* crop production. Widespread adoption of *Miscanthus* will remain a challenge until farmers' uncertainty over costs and profit are reduced.

Biodiesel from Soybean, Canola, and Waste Cooking Oil

History

When discussing biodiesel, the historical feedstock for the United States has been soybean oil, while canola oil has primarily been used in Europe (Knothe, Gerpe, & Krahl, 2005). For the purpose of this section, we will focus chiefly on the development soybean oil use, with references to canola oil, and waste cooking oil as well. The use of vegetable oil in diesel engines dates back to the diesel engine's creation. Although not specifically designed for vegetable oil, a diesel engine exhibition in the 1900 World Fair in Paris had one engine which ran on peanut oil (Knothe, et al, 2005). According to Knoth, et al, "The engine ran on peanut oil at the request of the French Government. The peanut grew in considerable quantities in France's African colonies. It was viewed as a way of for African colonies to be supplied with power and industry from their own resources, without being compelled to buy and import coal or liquid fuel" (Knothe, et al, 2005).

The use of vegetable oils continued sporadically until the 1920s (Lim & Teong, 2010). The spread of the automobile indirectly hurt the burgeoning biodiesel industry. As oil companies refined more gasoline, the surplus distillate they were left with proved to be a quality fuel for diesel engines and a much cheaper alternative to vegetable oils

(Radich, 1998). The availability of cheaper petroleum led to manufactures altering the diesel engine to more efficiently use the lower viscosity petroleum effectively killing the use of vegetable oils (Lim & Teong, 2010).

Throughout the 1930s and 1940s biodiesel was used sporadically, but often only in emergencies (Ma & Hanna, 1999). Some research continued after the war (Knothe, et al, 2005), but biodiesel remained an afterthought until the turbulent 1970s sparked renewed interest (Radich, 1998). By the 1980s, countries were creating policies for future biodiesel growth. Initiatives supportive of biodiesel were passed in South Africa, Germany, France, and New Zealand in the early 1980s (Knothe, et al, 2005). The United States hosted the first international conference on plant and vegetable oils in 1982 focusing on the cost and effect of biodiesel on engine performance (Singh & Singh, 2010). By 1992, soybean growers organized into the National Biodiesel Board which focused on promoting biodiesel use throughout the United States (Singh & Singh, 2010).

The end of the 20th century ushered in a period of growth of biodiesel production in Europe and the United States. In Europe, large plants were built and warranties were expanded by Volkswagen and Audi to include biodiesel use in their engines (Korbitz, 1999). While in the United States, amendments to the Energy Policy Act of 1998 provided credits for biodiesel use and blending (Knothe, et al, 2005). These policies have enabled biodiesel’s exponential growth. Production of biodiesel in the United States has increased from 500 thousand gallons in 1999, to more than 700 million gallons in 2008 (National Biodiesel Board, 2010).

Environmental Perspective

Biodiesel's biggest benefits in comparison to gasoline or petroleum diesel are in the environmental arena (Demirbas A. , Importance of biodiesel as transportation fuel, 2007). Soybean production does not require energy intensive nitrogen fertilizer (Pimentel & Pimentel, 2008) which helps reduce some of the harmful run-off experienced with increased corn production. Biodiesel use significantly reduces many different types of harmful emissions (Sharma & Singh, Development of biodiesel: Current scenario, 2009; Haas, Scott, Alleman, & McCormick, 2001). Further, the polluting emissions are have less toxicicity than petroleum diesel emissions (Haas, et al, 2001). It can be particularly beneficial in mining and marine operations where emission reductions are more important (Ma & Hanna, 1999). Biodiesel is considered biodegradable with plants being able to grow in a spill-contaminated area within four weeks (Knothe, et al, 2005). Finally, when the feedstock is waste oil, valuable resources are conserved and emissions are reduced.

The environmental challenges are similar, to the challenges facing corn ethanol. Increased fertilizer use (although not nitrogen), and potential soil erosion (Pimentel & Pimentel, 2008) are always issues when dealing with terrestrial crop production. Additionally, although biodiesel use reduces most harmful emissions, studies have found a slite increase in nitrogen oxide emissions, a potent GHG (Vertes, Qureshi, Blaschek, & Yukawa, 2010). Its lower energy content results in more fuel being consumed for the same distance travelled (Singh & Singh, 2010). However, even with these drawbacks, the net energy gain is much higher with biodiesel than with corn-ethanol (Hill, et al, 2006).

Technological Perspective

There are few technical barriers converting vegetable oils to biodiesel. However, to make vegetable oils compatible with diesel engines and lower the viscosity vegetable oils need to go through a process called transesterification (Atadashi, Aroua, & Aziz, 2010). Without processes such as transesterification, a myriad of engine problems could occur (Meher, Sagar, & Naik, 2006). The transesterification process also produces valuable by-products, such as glycerol, which can contribute to making biodiesel more economical (Atadashi, et al, 2010).

Economic Perspective

Biodiesel faces the same economic challenges as other terrestrial crops used for alternative fuels: it is not economical. The energy content is also lower when compared with fossil based diesel. Studies have shown biodiesel to be more than 10% lower than fossil based diesel (Radich, 1998; Wassell Jr & Dittmer, 2006) resulting in a 5-10% reduction in fuel economy (Demirbas A. , Importance of biodiesel as transportation fuel, 2007). Like ethanol, biodiesel customers are paying the same price for fuel with less energy than their fossil based counterparts.

The need for marketing of by-products in biodiesel production is crucial to its economic viability. Glycerol can be sold to a variety of commercial manufacturing industries and its marketing is a key factor in making biodiesel more economical (Atadashi, Aroua, & Aziz, 2010; Hasheminejad, Tabatabaei, Mansourpanah, Far, & Javani, 2010). However, by-products are not always marketable, and increased biodiesel production could saturate the market. Recently, some biodiesel producers have been incinerating glycerol to avoid such a glut (Santana, Martins, da Silva, Batistella, Filho, & Maciel, 2010).

Most importantly, the major cost of producing biodiesel lies in the feedstock. Feedstock compromises roughly 80% percent of the operating costs which results in biodiesel costing up to three times more than fossil-based diesel (Demirbas A. , Importance of biodiesel as transportation fuel, 2007). Some suggest using multiple feedstocks to reduce costs (Moser, 2008), while others list waste oil as a potentially cheaper, more economical solution (Groschen, 2002). Although waste cooking oil is cheaper, processing it into usable biodiesel not. In certain trials, the expensive processing costs completely neutralized the savings from cheaper feedstock (Zhang, Dube, McLean, & Kates, 2003).

Viability

The prospects of biodiesel via terrestrial crops replacing a significant amount of our demand is unrealistic for numerous reasons. Singh and Singh state, “Constraints on the availability of agricultural feedstock impose limits on the possible contribution of biodiesel to transport” (Singh & Singh, 2010). Converting our entire soybean crop to biodiesel production would supply less than 10% of our domestic diesel demand while we would have to plant soybeans over an area 160% larger than the entire U. S. cropland for biodiesel to meet domestic demand (Bryce, 2008). Waste oil, often discussed as a replacement feedstock, has the potential to produce 350 million gallons of diesel per year in the United States (Groschen, 2002). 350 million gallons wouldn’t even replace 1 percent of 2007 domestic U.S. demand (Bryce, 2008).

The lower energy content, prohibitive production costs, and scalability issues make it difficult for terrestrial crops to replace a significant percentage of our diesel demand. Even with present subsidies, biodiesel is far from being economically competitive. With feedstock comprising 80% of the production cost and agricultural commodities recently rising near 2008's all-time high (CME Group, 2010), it is not economically feasible to expand production of biodiesel. Biodiesel may remain a niche, such as in mining or marine operations, but widespread use will remain challenging as long as the primary feedstock is terrestrial crops.

***Jatropha* as a Feedstock**

History

Jatropha is a small tree that grows up to 7m tall and can live up to 50 years (Achten, et al., 2008). Trees and shrubs in arid regions serve many purposes for populations of developing countries, and today, there is discussion about commercial cultivation of *Jatropha* (Heller, 1996). *Jatropha* is native to Mexico and parts of South America and is believed to have been distributed by Portuguese seamen in the 16th century throughout the Caribbean and parts of Africa (Heller, 1996).

For a time, *Jatropha* oil was used for lamp lighting (Brittaine & Lutaladio, 2010). In the first half of the 20th century parts of Africa exported *Jatropha* seeds to Europe where the oil was extracted for production of soap (Brittaine & Lutaladio, 2010). During World War II, *Jatropha* was used for production of diesel in parts of Africa (Gubitz, Mittelbach, & Trabi, 1999; Kumar & Sharma, 2008). Today, it is still used for medicinal purposes and soap production in rural communites, while there is renewed interest in its potential for biodiesel production (Brittaine & Lutaladio, 2010).

Environmental Perspective

Jatropha has many of the same positive environmental effects as other biodiesel feedstocks, but it also offers many additional benefits. It has the lowest emissions when compared with engines running on other vegetable oils (Gubitz, Mittelbach, & Trabi, 1999). It can also be grown in low rainfall areas, marginal soils, and all the while helping prevent soil erosion (Openshaw, 2000; Achten, et al., 2008). Today, it is being viewed as having the potential to combat climate change and provide a source of renewable energy (Parawira, 2010).

However, few long-term feasibility studies have been attempted. Not all environmental effects are positive. Yearly harvesting may lead to resource depletion (Prueksakorn & Gheewala, 2006). Little is published about the fertilizer requirements of *Jatropha*, creating uncertainty with regards to the energy balance (Openshaw, 2000). Although *Jatropha* does grow on marginal land, fertilization and irrigation will be required to produce optimal yields (Achten, et al., 2008). Finally, many countries worry about *Jatropha*'s invasive potential (Parawira, 2010).

Technological Perspective

Production of biodiesel has few technological barriers, but more research is needed into *Jatropha* genetics. Kumar and Sharma state, "Before exploiting any plant for industrial application, it is imperative to have complete information about its biology, chemistry, and all other applications so that the potential of the plant can be utilized maximally" (Kumar & Sharma, 2008). Little is known about the different genotypes

(Parawira, 2010) and more research is needed to find which types produce more oil (Achten, et al., 2008).

Economic Perspective

Jatropha is easy to establish and has a rapid growth rate (Openshaw, 2000). This growth rate gives it higher yields than other biodiesel crops such as sunflower, soy, or peanuts (Foidl, Foidl, Sanchez, Mittelbach, & Hackel, 1996). Further, because it can be grown on marginal land, it could turn formally worthless land into potential revenue for land owners and while creating jobs (Prueksakorn & Gheewala, 2006). The key for *Jatropha* to become commercially viable is using the whole product, not just crushing the seeds for oil (Kumar & Sharma, 2008; Openshaw, 2000). However, many argue that producing *Jatropha* for biodiesel is an inefficent use of recources.

If the whole product of *Jatropha* is not used, *Jatropha* biodiesel production is not energy efficient (Openshaw, 2000). Additionally, producing *Jatropha* for biodiesel production is potentially forgoing more profitable markets such as soap production (Openshaw, 2000). The cultivation of *Jatropha* is very labor intensive and often times the predicted costs are underestimated. According to Parawira, "predictions of productivity seem to ignore the results of [*Jatropha*] plantations from the 1990s, most of which are abandoned now for reasons of lower productivity and or higher labor costs than expected" (Parawira, 2010). Although it is possible to grow *Jatropha* without fertilizer and irrigation, many doubt the potential of a commercial yield without those inputs (Gressel, 2008). Production costs have been estimated at up to 10 times the selling price of fossil-based diesel in developed countries (Openshaw, 2000).

Viability

Presently, *Jatropha* is garnering more attention than other oil seed crops (Parawira, 2010). *Jatropha* does not compete with food and the ability to grow on marginal land has helped it become the leader of potential terrestrial biodiesel feedstocks. However, in order to become truly viable the economics of *Jatropha* must change. Producers must develop a commercial market for the co-products of *Jatropha*. Finally, more research is needed in identifying potential yield, optimal growing conditions, and best practices in order to remove producers' uncertainty. Until more knowledge is acquired, many commercial companies may be hesitant to invest heavily in cultivation of *Jatropha* oil.

Palm Oil as a Feedstock

History

Humans have been using palm oil for thousands of years. It is estimated that palm oil may have been part the food supply in ancient Egypt (Kiple & Ornelas, 2000). During the 18th and 19th centuries, it was used for a variety of purposes from producing soap (Gathmann, 1893) to medicinal (Willich & Mease, 1803), and also as a lubricant for machinery during the British Industrial Revolution (Kiple & Ornelas, 2000). Palm oil plantations spread from Africa into Southeast Asia early in the 20th century (Kiple & Ornelas, 2000). The tree was first introduced to Malaysia as an ornamental plant in 1875 and the sector began to grow during the war in 1917 (Abdullah, Salamatinia, Mootabadi, & Bhatia, 2009). Both England and Germany were importers of palm oil during World War I (United States Tariff Commission , 1921).

The first biodiesel patent given in Belgium in 1937 was made from palm oil (Knothe, et al, 2005). Belgium tested palm oil based biodiesel in a commercial bus in 1938 and reported no operational problems (Knothe, et al, 2005). Although war made all feedstocks more valuable, palm oil development greatly expanded in Malaysia after 1960 when government policies led to increased production (Basiron, 2007). According to Kiple and Ornelas, “The oil palm was seen as a useful means of diversification to avoid a dangerous dependence on rubber” (Kiple & Ornelas, 2000). In the early 1980’s palm oil prices collapsed and the country announced plans to convert palm oil into biodiesel (Cross, 1985). The Malaysian Palm Oil Board was created in 1982 and two years later construction began on the first plant to convert palm oil to biodiesel (Lim & Teong, 2010).

Creation of biodiesel was encouraged through continued and new Malaysian Government incentives in the late 1980s helping enable the drastic increase in palm oil production in the 1990s (Abdullah, et al, 2009). From 1960 to 2005 the palm oil industry experienced 10-11% compound annual growth (Basiron, 2007). The National Biofuels Policy of 2005 further encouraged production and set mandatory biodiesel blending limits of 5% (Abdullah, et al, 2009). The postive economics of palm oil, as well as favorable government policies have helped Malaysia become a world leader in palm oil production.

Environmental Perspective

Biodiesel burns cleaner than fossil diesel with emission tests showing positive reductions (Lim & Teong, 2010; Crabbe, Nolasco-Hipolito, Kobayashi, Sonomoto, &

Ishizaki, 2001). Additionally, recent IEA and United Nation reports showed a greater reduction of GHG emissions when using palm oil than other any biodiesel feedstock excluding effects of land use change (Jayed, Masjuki, Saidur, Kalam, & Jahirul, 2009). However, the effects of land use change are key factors in growing backlash against the increased production and use of palm oil based biodiesel. When considering land use change, it is a stretch to call palm oil based biodiesel environmentally friendly.

Over the past 50 years, crops dedicated to palm oil production have expanded rapidly with land dedicated to oil palm cultivation increasing nearly 400% (Koh & Wilcove, 2008). Government policies have indirectly encouraged conversion of former forests to be cleared for agriculture (Koh & Wilcove, 2008) while large amounts of GHG were released as burning was the method of choice for clearing land (Reijnders & Huijbregts, 2008). Widespread clearing has resulted in a 30% loss of forest land in Indonesia and a 20% loss in Malaysia while up to 85% of new palm oil plantations in some provinces being created on former forest land (Wicke, Sikkema, Dornburg, & Faaij, 2011). These forests are rich in biodiversity and home to many endangered species (Abdullah, et al, 2009). Malaysia has created the Roundtable on Sustainable Palm Oil (RSPO) to find solutions in growing a more environmentally sustainable practice (Lim & Teong, 2010), but little has changed thus far.

Technological Perspective

There are few technical challenges in palm oil biodiesel production but extensive research has been done to increase yields (Lim & Teong, 2010). According to Basiron, “Since the 1960s, experiments have been carried out to produce hybrid strains of oil palm that give higher yields of oil" (Basiron, 2007). This has led some strains to produce over 100% more than their original counterparts (Basiron, 2007). Recently, the DNA for the oil-palm tree was decoded, which should lead to even more breakthroughs in yield potential (Lim & Teong, 2010). Further research leading to increased yields will enable palm oil based biodiesel to continue its march toward economic viability.

Economic Perspective

The economics of palm oil based biodiesel are more positive than other feedstock. Its high yield and cheap labor sources in the region have allowed palm oil to remain low (Jayed, et al, 2009). It has been estimated that the industry provides direct or indirect employment to almost 900 thousand workers in Malaysia alone (Abdullah, et al, 2009). Unlike corn-based ethanol, it has a positive net energy balance (Ester da Costa & Lora, 2007) and significant amounts of capital are invested in research annually to improve operations (Basiron, 2007).

Palm oil based biodiesel consumes less energy than other biodiesel feedstocks because electricity is produced during the production process (Pleanjai & Gheewala, 2009). This energy balance is the best among current oil seed crops (Pleanjai & Gheewala, 2009; Thoenes, 2006; Abdullah, et al, 2009). High yields enable palm oil to achieve signficantly lower production costs when compared with competitors soy, sunflower, coconut, and rapeseed (Thoenes, 2006; Crabbe, et al, 2001). Palm oil biodiesel presently has the cheapest production costs, but other feedstocks are becoming more competitive.

Labor costs are a large portion of production costs and these have not improved significantly over the past 20 years (Thoenes, 2006). While labor costs and productivity have remained steady for palm oil, competitor crops such as soy and sunflower have experienced significant improvements (Thoenes, 2006). In addition, headwinds are coming from the European Union. Subsidies and failure to obtain International Sustainability and Carbon Cetification (ISCC) may prevent increased exportation to the EU (Lim & Teong, 2010). Obtaining these certifications will increase company costs and potentially make palm oil less competitive.

Viability

The palm oil based biodiesel industry has rapidly expanded over the past few decades. This expansion has been aided by the general consensus that, "in the absence of subsidies, palm oil is by far the most competitive vegetable oil for the production of biodiesel" (Thoenes, 2006). While the most economically competitive, it suffers the same drawbacks as many other biofuels. The competitiveness of biodiesel from palm oil is directly related to feedstock prices and the price of crude. Recently, price spikes in palm oil have forced many companies to stop producing or shut down completely due to higher feedstock prices (Jayed, et al, 2009; Yusup & Khan, 2010).

Biodiesel from palm oil has been blamed on pressuring food prices as well (Lim & Teong, 2010). Further, with regulations in the EU emphasizing environmental sustainability, palm oil production costs should rise. Although palm oil has found a good niche, it still has a problem of scalability. In some areas expansion is beginning to slow due to land scarcity (Thoenes, 2006). Finally, geographic and climate differences limit the United States ability to ever produce palm oil biodiesel on a commercial scale. Palm oil is a valuable supplement to certain tropical countries, but it will never be the answer to United States quest for energy independence.

Algae as a Feedstock

History

Algae are one of the oldest life-forms (Brennan & Owende, 2010) and could be part of the answer to our energy independence goals. Over the past decade, algae have increasingly been mentioned for their potential fuel production (Christi, 2007; Dismukes, Carrieri, Bennette, Ananyev, & Posewitz, 2008; Amin, 2009). Algae are often listed as the best, or among the best of potential feedstocks for future biofuel production because they do not have the limitations of terrestrial feedstocks (Brennan & Owende, 2010; Beer, Boyd, Peters, & Posewitz, 2009). Although much attention has been placed on algae recently, proposals for using algae to create fuel date back to the 1950s (DOE, 2009).

The potential for microalgae to produce lipids under certain conditions was discovered in the 1940s (DOE, 2009). In the 1950s, scientists continued their examination of algal uses and by the end of the decade there were propsals to use algae both as fuel (DOE, 2009) and food (Stimson Jr, 1956). During these early years, focus was placed on what growing conditions were most conducive to algal lipid production (DOE, 2009). However, research into algae energy production only gained serious traction during the oil spikes of the 1970s (DOE, 2009; Sheehan, Dunahay, Benemann, & Roessler, 1998).

The high energy prices of the 1970s were the driving factor behind the creation of the Department of Energy's (DOE's) Aquatic Species Program (ASP) in 1978 (DOE, 2009). Initially, researchers envisioned a process where wastewater could be used as feed for algae which would produce methane but the focus gradually shifted into algae's fuel production potential (Sheehan, et al, 1998). The ASP studied more than 3,000 different microalgae (Radakovits, Jinkerson, Darzins, & Posewitz, 2010), looking not only at the amount of oil algae could produce, but also finding algae who could grow in extreme conditions with regards to temperature, pH, and salinity (Sheehan, et al, 1998). These strains were collected and identified from 1980 to 1987 (Sheehan, et al, 1998). The ASP gradually narrowed potential algae down to 300 strains and began further examination of the best strains (DOE, 2009).

Unfortunately, funding gradually decreased after the mid-1980s and the program was finally killed in 1996 due to budget reductions, which forced the DOE to focus on bioethanol production (Sheehan, et al, 1998). The ASP significantly progressed algae research and provided a good base for future algal endeavors but the economics never worked. ASP concluded that even with optimistic cost assessments, algae would still cost between $59-186 per barrel while oil cost $20 in 1995 (DOE, 2009).

Japan also took interest in Algae research. In 1990, the 10-year RITE program was established with 2 dozen private companies, various academic institutions, and some national laboratories supporting research efforts (Sheehan, et al, 1998). While the ASP used the more economical open pond cultivation of algae, Japan's research focused on closed photobioreactors because they required less land area and could potentially be more productive (Sheehan, et al, 1998). However, Japan's program was an epic failure and was cancelled after costing more than $250 million (Benemann, 2008).

Since the end of the ASP program in 1996, the DOE, DOD, USDA, Defense Advanced Research Projects Agency , Air Force, and many other agencies in the government has provided funding for additional algae research (DOE, 2009). Despite the past failures, interest in algae for fuel is on the upswing. Recent oil price spikes and progression of science has led interest in algae to bloom. However, key obstacles must still be overcome.

Environmental Perspective

Part of the draw to algal production is the relative few environmental barriers. Although algae do use water and may require high inputs of energy (Groom, Gray, & Townsend, 2008), this is negated by algae's ability to grow in wastewater or brackish conditions unsuitable for other feedstocks(Pittman, Dean, & Osundeko, 2011; Subhadra B. G., 2010; Subhadra & Edwards, 2010). The effect is two-fold, saving freshwater, and an environmentally friendly way to treate wastewater (Park, Craggs, & Shilton, 2011). In addition, they do not require environmentally harmful pesticides that many other terrestrial feedstocks use (Brennan & Owende, 2010). Finally, algae is very efficient in CO_2 conversion, and could be 'fed' with emissions from power plants (DOE, 2009). Algae is still early in its development as a biofuel and has many technological barriers to widespread adoption.

Technological Perspective

Significant technical barriers remain in algal cultivation, harvesting, and conversion. Although research is progressing rapidly in genetic maniplation (Beer, et al, 2009), we are, “far from” understanding molecular biology and regulation of lipid body metabolism in algae” (Scott, et al., 2010). Additionally, there is potential for a negative energy balance during the process (Brennan & Owende, 2010). Further research identifying best practices in minimizing energy use during the harvesting, extraction, and conversion phases as well as increasing yields is needed (DOE, 2009). Finally, at the present time it is difficult to extract by-products (Brennan & Owende, 2010). Algae productivity is higher than land plants (Scott, et al., 2010), the key to success is being able to utilize this higher productivity. Much further research and progress are needed in these areas to improve the economics of biofuels from algae.

Economic Perspective

Algae will never be a viable alternative fuel without the economics changing. Thus far, high capital and operating costs have tempered enthusiasm. Both the ASP and Japan’s RITE program were shut down being deemed not economically viable. Algae production does have the potential of producing valuable by-products (Dismukes, et al, 2008), but the technological barriers associated with utilizing these by-products have yet to be overcome. Many believe the key to successful commercialization depends on being able to produce high value by-products (Singh & Gu, 2010).

One idea being discussed to increase algae’s economic competitiveness is creating integrated renewable energy parks (IREP) (Subhadra B. G., 2010). These parks could potentially utilize heat via the IREP’s solar panels to create conditions favorable for algae growth (Subhadra B. G., 2010). IREPs theoretically would lower energy usage and bring down total production costs associated with algae. Unfortunately, to date, algae have not proven economical (Pittman, et al, 2011). The ASP cost estimate of algal oil production being competitive with crude priced at $56-189 per barrel. However, there is much uncertainty in production costs and today, 15 years after the ASP program ended, some estimate the production cost to be between $9-40 per gallon of oil or $378-1,680 per barrel of oil (Singh & Gu, 2010) .

Viability

Today, over 150 companies worldwide are working toward making a cost-competitive biofuel from algae (Singh & Gu, 2010). It is often listed as the best future feedstock candidate (Subhadra B. G., 2010). It is capable of producing year round and doesn't compromise food production (Brennan & Owende, 2010; Mutantda, Ramesh, Karthikeyan, Kumari, Anadraj, & Bux, 2011; Singh & Gu, 2010; Scott, et al., 2010). To date, it is the only biofuel crop with the potential to completely displace fossil diesel (Singh, Nigam, & Murphy, 2011; Christi, 2007). However, there is much uncertainty in regards to costs and production potential. Experts agree that further R&D is needed in many facets of algae biofuel production (DOE, 2009). Past research efforts in the U.S. and Japan were deemed failures. Until technology improves and costs fall dramatically algae will never be a practical solution to our alternative fuel needs.

Coal-to-Liquid Processes

History

In searching for alternative fuels and feed stocks to replace United States dependence on petroleum, renewed emphasis is being placed on synthetic fuels from coal, natural gas, and biomass. Many people regard coal conversion technology as being a new development but its use almost predates the United States. Although not used for transportation purposes, use of gas produced via coal distillation for lighting has been used for centuries. As early as the 1790s, use of coal gas for lighting purposes was documented and leading the technology to rapidly diffuse throughout much of the world shortly thereafter in the 1800s (Probstein & Hicks, 1982). Coal to liquid (CTL) technology was developed in Germany during the early 1900s.

Similar to the United States today, one of the key factors in Germany's pursuit of alternatives to petroleum was strategic reasons. Germany had a large supply of coal resources but lacked any meaningful petroleum reserves. This posed a serious problem during the turn of the century when coal was being replaced by gasoline and diesel (Stranges, 1984). Friedrich Bergius' work with high-pressure coal hydrogenation or coal liquefaction process from the early 1900s until the mid-1920s kick-started Germany's CTL progress (Probstein & Hicks, 1982)and later earned Bergius the Nobel Prize for his work (The Nobel Foundation, 1966). In 1926, the first commercial plants producing synthetic fuels via coal hydrogenation were being developed (Probstein & Hicks, 1982). Franz Fischer and Hans Tropsch published their own research on gaseous synthesis (Schulz, 1999). Although coal hydrogenation and the Fischer-Tropsch (FT) process both sought to end Germany's need for foreign petroleum imports, they were not competitors.

"Coal hydrogenation and the Fischer-Tropsch process were complementary because coal hydrogenation produced high quality gasoline and aviation fuel while the

FT process produced high quality diesel and lubricating oil" (Stranges, 2003). Their growth was encouraged by the government and various subsidies helped the industry expand. Imported fuel tariffs, minimum government purchases of the product, and government funding of capital expenditures all led to a more rapid build-up of Germany's CTL industry (Stranges, 2003).

CTL development was the centerpiece in Hitler's call for petroleum independence (Stranges, 2003). The industry grew from three small-scale CTL plants in 1933 to satisfying over 60%of Germany's petroleum use near the end of the war (Stranges, 2003). Germany succeeded in developing CTL technology and proved it could be viable on a commercial scale. However, it was viable because it had the financial and political support of the German government. CTL technology never succeeded in being a cost effective way of replacing petroleum. Production of CTL fuel cost the German government over double the price of imported products (Stranges, 2003). After the war, a combination of the forced dismantling of German CTL plants (Stranges, 2003) and an era of cheap petroleum led to commercial scale CTL production being phased out (Probstein & Hicks, 1982).

However, the United States did continue CTL research after the war. The Bureau of Mines annual report in 1949 expressed interest in CTL technology because of the United States' vast coal resources and limited oil and natural gas deposits as well as "stabilizing the coal market whose prospects appear bleak" (U.S. Bureau of Mines, 1950). However, further economic analysis led the Bureau to find that a commercial CTL plant would not be economically attractive due to high startup costs and cost of production (U.S. Bureau of Mines, 1950). The Bureau's findings led United States research to gradually taper off by the mid-1950s. However, South Africa continued their research into CTL technologies.

Much like Germany, South Africa had a large resource base of coal and little petroleum reserves. And, much like Germany, South Africa had strategic reasons for developing alternatives to petroleum. Loss of petroleum imports due to their apartheid policies, investment in CTL technology gave South Africa a path to petroleum independence (Speight, 2008)South Africa’s first plant became operational in 1955 and during some periods it was commercially profitable (Anastai, 1980). With the tumultuous 1970s, South Africa’s investments in FT plants were needed because Iran stopped exporting crude to South Africa in 1979 (Anastai, 1980). The uncertainty of the 1970s led to increased investment from South Africa (Anastai, 1980) and renewed R & D in the United States (Bartis, et al, 2007). South Africa’s plant expansion would satisfy almost 50% of their annual petroleum demand when finished (Anastai, 1980). The United States annual budget in direct coal liquefaction R&D grew from $100 million in 1975 to more than $500 million in 1981 (Bartis, Camm, & Ortiz, 2007). However, within two years falling oil prices and cost escalation of programs led to their cancellation (Bartis, et al, 2007)

Recent years’ spikes in oil prices have brought renewed interest into oil from “unconventional” sources such as CTL (Bartis, et al, 2007). The United States is often called the “Saudi Arabia of Coal” (Thomas, 2006), and producing liquid fuels from a plentiful feedstock as coal could help achieve greater energy independence. Many benefits are discussed by proponents of developing a robust CTL industry. Developing a robust CTL industry could potentially increase employment (Bartis, et al, 2007) increase our energy security (Gray, 2005), decrease world oil prices (Bartis, et al, 2007)and CTL fuels burn cleaner than regular petroleum products (Marano & Ciferno, 2001). Although there are many potential benefits, there are also many reasons why only Germany (Stranges, 2003)and South Africa (Anastai, 1980) have successfully run commercial size CTL plants.

Environmental Perspective

Besides our push to achieve energy independence, mitigating GHG emissions and using 'cleaner' fuels are factors in our push away from traditional petroleum sources (Takeshita & Yamaji, 2008). However, many argue that one of the biggest obstacles in regards to CTL is that it is not a clean fuel (Packham, 2003). Without carbon sequestration, a large scale CTL industry in the United States capable of producing three million barrels of liquid fuels would dramatically increase the amount of carbon dioxide emissions (Bartis, et al 2007). In addition, methane emissions, air toxins, and damaged and contaminated aquifers are all issues associated with increased coal mining (Bartis, et al, 2007)

Technological Perspective

The technological barrier exists primarily in the development of a large scale carbon sequestration program. Although in 2007 the DOE planned to have, "fossil fuel conversion systems that achieve 90% CO_2 capture with 99% storage permanence at less than a 10% increase in the cost of energy services" (NETL, 2007)by 2012, there remains a lack of confidence in carbon capture and the ability address technical issues (Williams, et al, 2009). Until carbon capture technology improves, CTL will continue to face strong opposition to its development

Economic Perspective

CTL technology's failure to produce liquid fuels at price economically competitive with conventional petroleum is the primary reason CTL technology has not enjoyed widespread use throughout the world. If CTL technology was more economical, it would have greater success. If CTL is to enjoy widespread use among western nations carbon sequestration will be required. Unfortunately, technology has not yet proven to be viable on a commercial scale. Additionally, carbon sequestration will raise the price of CTL significantly (NETL, 2007). Although Sasol has operated a sporadically profitable plant in South Africa, their success is not easy to replicate. CTL production in South Africa works because, "their availability of low cost coal, scarcity of domestic petroleum resources, and abundance of cheap labor" (Anastai, 1980).

Scale is an issue that is often neglected. When South Africa was expanding plants and production it spent, " $6-7 billion to increase its production to 112K bpd….to get the similar results the United States would need to spend $300 billion (1980$s)" (Anastai, 1980). Previous pilot scale CTL projects in the United States were closed down because of massive cost overruns. "Initial cost estimates in 1979 for the plants were $700 million but within two years they had grown to $1.4 and $1.9 billion respectively. (Bartis, et al, 2007). Some have stated that a high estimate in cost of a plant capable of producing 80,000 bpd of synthetic fuels would only be $8-10 billion but acknowledge, "there is a lack of recent experience in designing and constructing FT CTL plants" (Bartis, et al, 2007). The uncertainty of oil prices has played a role in investment apprehension. A conservative estimate by Rand estimated that CTL production could be between $55-65 [2007 dollars] a barrel but admitted that, “costs remain highly uncertain and could fall out of the $55-65 per barrel crude oil equivalent range” (Bartis, et al, 2007). Many factors affecting operating costs are very prohibitive.

The type of coal can have an effect on operational costs. Certain coals have a propensity to cake more. Caking is defined as, “when heated, coal softens and fuse together, swelling and re-solidifying into a porous char or cake which is greater than the original volume” (Probstein & Hicks, 1982). Most American coals have a high caking propensity (Probstein & Hicks, 1982)which can require blending and/or performance modifications (Dyk, Keyser, & Coertzen, 2006). Further, “The caking coals tend to form a plastic mass in the bottom of a gasifier and subsequently plug up the system thereby markedly reducing process efficiency” (Speight, 2008).

With climate change often dominating the headlines, carbon sequestration is also something that must be accounted for. There is uncertainty about the costs associated with carbon sequestration. In coal powered electricity plants, the cost of carbon sequestration has been estimated to increase the price of electricity by “60-100% in older plants and 25-50% in more advanced plants” (NETL, 2007). Costs for CTL plant carbon sequestration are thought to be less expensive (Bartis, et al, 2007). However, these estimates are based on assumptions and no carbon sequestration technology has been demonstrated on a “megascale” which a commercial size CTL plant would operate (Williams, Darson, Liu, & Kreutz, 2009).

Viability

Increasing the use of CTL technology does offer the United States a path towards energy independence. However, there are many barriers to CTL adoption. Uncertainties surrounding environmental consequences and carbon sequestration technology, as well as the high initial capital costs, and cost associated with carbon sequestration are significant barriers in CTL adoption. More widespread use of CTL technology will likely depend on oil prices, successful demonstration of carbon capture technology, and government incentives. It should be noted that CTL technology has yet to be proven more economical than petroleum. The only two countries that used CTL technology to meet a majority of their fuel needs did so for strategic purposes, not economic. Subsidies initially provided by Germany and South Africa were instrumental in supporting the growth of domestic CTL production. Further, government sponsored research was key to making processes more profitable and reducing risk for companies venturing into CTL production.

Chapter III: Data Collection and Methodology

Introduction

The extensive literature review provided the foundation of this report. However, we used content analysis and text mining to corroborate the findings of the literature review. Content analysis and text mining focus on extracting pieces of information out of collections of textual information. In our case, we used the literature review articles as our sources of documents. In this section, the research will examine the process we used for the content analysis and text mining. There are many pre-processing steps before starting content or text analysis.

Data Preparation

Description of Data

The documents analyzed consist mostly of journal articles, government reports, and other scholarly information relating to the alternative fuels and feedstocks reviewed in our research. The breakdown of fuel/feedstock type and number of documents is listed below in Table 3.1. Most of the journal articles and reports were from the period of 2000 to 2010.

Table 3.1 Number of Documents by Fuel/Feedstock

Fuel/Feedstock Type	Number of Documents
Corn Ethanol	60
Sugar Ethanol	33
Biomass/Cellulosic	86
Switchgrass	46

Miscanthus	26
Biodiesel	52
Jatropha	15
Palm Oil	17
Coal-to-Liquid	28
Algae	39
Total	**402**

Collection

The initial documents collected were comprised of the most accessible documents via a Google Scholar search on the selected fuel and feedstock type. Google Scholar searches were performed not only on fuel and feedstock type, but also on journal articles pertaining to the LCA, economics, technology, and viability of each. Further documents that were applicable to the research were found through the works cited section of the original documents. According to Peladeau and Stovall,

" …When one wants to perform comparison among several groups, it is essential the number of examples from each group be large enough to ensure the information obtained for this subgroup is reliable and representative….Otherwise the descriptive or inferential statistics computed may be unreliable" (Peladeau & Stovall, 2005).

A large enough number of documents were collected for each fuel and feedstock type in order to be reliable and representative of each group's population. Appendix A lists additional articles used in the text mining process but not quoted in the literature review. Unfortunately, most of the journal articles and reports collected were written after 2000. Due to the recent nature of the articles, the ability to measure the evolution of themes over time was limited.

Importation

Most journal articles were imported into QDA Miner content analysis software (from Provalis Research) without problems. However, some article formats proved difficult to transfer. To ensure correct coding and that QDA Miner read the documents properly ABBYY FineReader 10 Professional Edition was used. This software allowed the conversion of difficult to read PDF files into MS Word. The newly created MS Word documents were uploaded into QDA Miner. The process minimized the loss of documents due to conversion problems.

Database Cleansing

It was necessary for any database cleansing. The database consisted of peer reviewed journal articles and government reports from scholarly sources. Misspelled words can create problems when analyzing text, but because the articles and reports were taken from scholarly sources, a check of spelling was deemed unnecessary.

Database Structure

Constructing the database was a critical part of the process. Poor structure could affect the results significantly. Data was classified into three main categories and various subcategories. Table 3.2 shows the data breakdown by group and subgroup information for fuel type and topic. Data was classified by fuel type, topic, and report date. The topics were very similar to themes identified. Themes identified consisted of environmental considerations, energy efficiency, world region, technology, societal costs and benefits, financial considerations, agricultural consequences, and national security.

Table 3.2 Breakdown of Groups and Subgroups

Fuel/Feedstock Type	Topic
Corn Ethanol	LCA/Environmental
Sugar Ethanol	Economics

Biomass/Cellulosic	Ag/Food Prices
Switchgrass	Policy
Miscanthus	Technology
Biodiesel	
Jatropha	
Palm Oil	
Coal-to-Liquid	
Algae	

Dictionary Development

Dictionary development is an important prerequisite to the analyses. We decided to proceed with a categorization process in creating our dictionary instead of stemming or lemmatization approaches. Stemming and lemmatization both had significant drawbacks which led us to believe categorization would be the most appropriate path. Stemming seemed too aggressive and could have potentially created more problems.

Peladeau and Stovall describe stemming as, "a well-known technique of form reduction by which common suffix and sometimes prefix are stripped from the original word form" (Peladeau & Stovall, 2005). Stemming often reduces words to word roots (Peladeau & Stovall, 2005) , which could make it nearly impossible to interpret our results. Using a stemming approach, common terms in this analysis could be reduced to words with completely different meaning. Words such as biogas, biomass, and bioenergy could potentially be reduced to gas, mass, and energy giving researchers completely different meanings while making inferences unreliable. While not as aggressive as stemming, lemmatization had drawbacks as well.

The most significant problem that stemmed from lemmatization was the potential ambiguousness of words reduced to their root form. Although lemmatization can significantly reduce word count, it can potentially create more work if researchers cannot determine the meaning of the word. It was not necessary to reduce word count for this research. It is believed that the 402 articles analyzed were a representative and reliable sample from the population. The collection of articles was not large enough to require stemming or lemmatization.

With the categorization process, ambiguousness was not a problem. The process of dictionary creation requires subject knowledge because the user will be creating categories and categorizing the words/phrases (Davi, Haughton, Nasr, Shah, Skaletsky, & Spack, 2005). Given the extensive literature review, developing the dictionary for alternative fuels and feedstocks was not challenging.. The extensive literature review enabled the identification of many core and related words within the journal articles and reports.

Exclusion List

Lists of exclusion words are common in content analysis or text mining projects. The exclusion list removes, “words that have little semantic value such as pronouns and conjunctions” (Provalis Research, 2010) from content analysis. Exclusion lists both reduce processing time and allow retention of the most relevant words (Peladeau & Stovall, 2005). The standard exclusion list in QDA Miner containing about 550 words was used for this analysis.

Categorization Process

1) Research identified technical terms commonly used in journal articles reviewing alternative fuels and feedstocks.

2) A random sample of 5% of the documents and WordStat (phrase finding software by Provalis Research) was used to look for the frequency of phrase occurrence in text. This allowed the identification of how many times the phrase occurred in the text. Phrases were chosen because the same word in different contexts can have completely different meanings. Phrases offer more specific insight which is hard to gather from individual words. Further, the specific insight that phrases give allowed proper categorization of important phrases.
3) For further support, key phrases in context were examined using the Key Word In Context(KWIC) tool in Wordstat. Viewing the key phrases in context, allowed proper classification of data into appropriate themes.

Chapter IV: Analysis and Results

Co-Occurrences of Keywords

Often in text mining words there are incidences of co-occurrence. When words or phrases appear in the same sentence or paragraph they may offer the opportunity for further understanding of relationships. We used cluster analysis. Cluster analysis gives us a path in which to group themes. Categories that tend to appear together are combined at an early stage and may show evolution of themes. Additionally, relationships that we may not anticipate finding may appear, which provide a new way of looking at the relationship between categories.

Keywords by Numerical or Categorical Variables

A technique we used to explore the themes was keywords by numerical or categorical variables. Specifically, we used correspondence plots, histograms, and pie charts, to analyze themes by frequency of occurrence. Further, "correspondence analysis is a descriptive and exploratory technique designed to analyze relationships among entries[fuel types]" (Provalis Research, 2010). These plots enabled us to view the basic statistics and themes by documents.

Figure 4.1 Correspondence Plot

Figure 4.2 is a correspondence plot showing the relationships between themes and groups. Each group [biofuel/feedstock in white box] contains a distribution of each of the themes listed. The closer a group is to the origin (center), the more similar the distribution of themes within the group is when compared with the document collection as a whole. In figure 4.2 we see that Coal-to-liquid has a similar distribution of themes when compared to the document as a whole. For *Miscanthus*, we see the distribution of themes different from the document collection as a whole. From the extensive literature review we believe this may be due to many articles focusing on technology breakthroughs needed for *Miscanthus* to become a viable replacement for corn ethanol. Technology is not as prevalent of a theme for other feedstock reviewed in this study.

For themes, location closer to the origin means most documents in the collection as a whole contain a similar number of the particular theme. Figure 4.1 shows financial considerations location close to the origin. Financial considerations location closer to the origin shows this theme is consistent throughout the document collection as a whole.

For relationships between the groups and themes, proximity is not as important as angle (Provalis Research, 2010). An acute angle means the words and themes are correlated (Provalis Research, 2010). On the right side we see a correlation between the themes technology and energy efficiency to Biomass/cellulosic, switchgrass, *Miscanthus*, and algae. This supports data gathered in the literature review showing technology is an overriding theme within biomass, cellulosic ethanol crops, and algae. Specifically, technological barriers to efficient production of ethanol from any of the aforementioned feedstocks have been impediments to successful development of the advanced biofuels. Further, the feedstocks mentioned gravitate towards the energy efficiency theme. This supports the literature review where many articles often mentioned potential for biomass to be used in electrical power generation. Many articles believe this is the most efficient current use of biomass energy crops.

Further, we see corn and sugar ethanol correlated with the theme Food/Ag consequences. This supports earlier research. Corn is an ingredient in most animal feed and people depend on it as a staple throughout the world. With biofuel production causing an unnatural rise in demand, it is only natural that prices begin to rise.

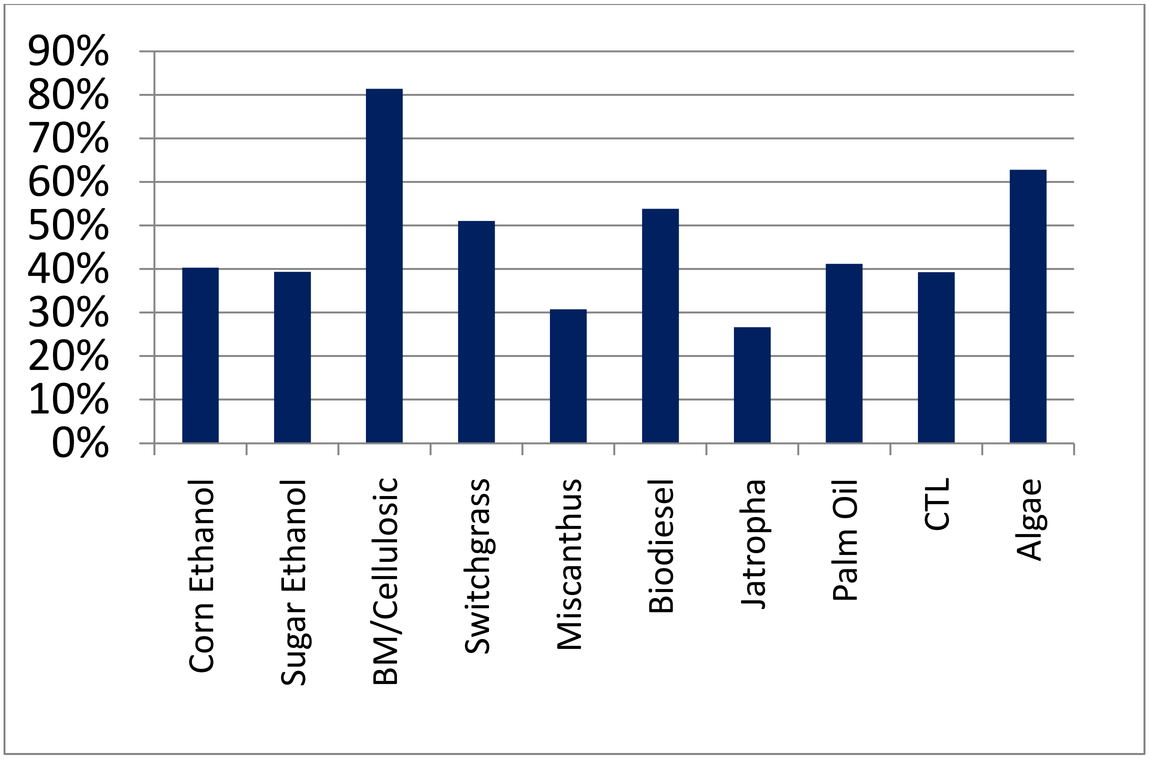

Figure 4.2 Percentage Occurrence of Theme Technology by Group

Figure 4.2 illustrates the percentage occurrence of the theme technology by fuel/feedstock. This figure is another illustration of the technology theme being prevalent in many of the advanced fuels and feedstocks. The occurrence of technology in the biomass/cellulosic group and algae is over 80% and 60% respectively. This supports much of the literature review showing that technology is the key barrier for many of the advanced alternative fuels.

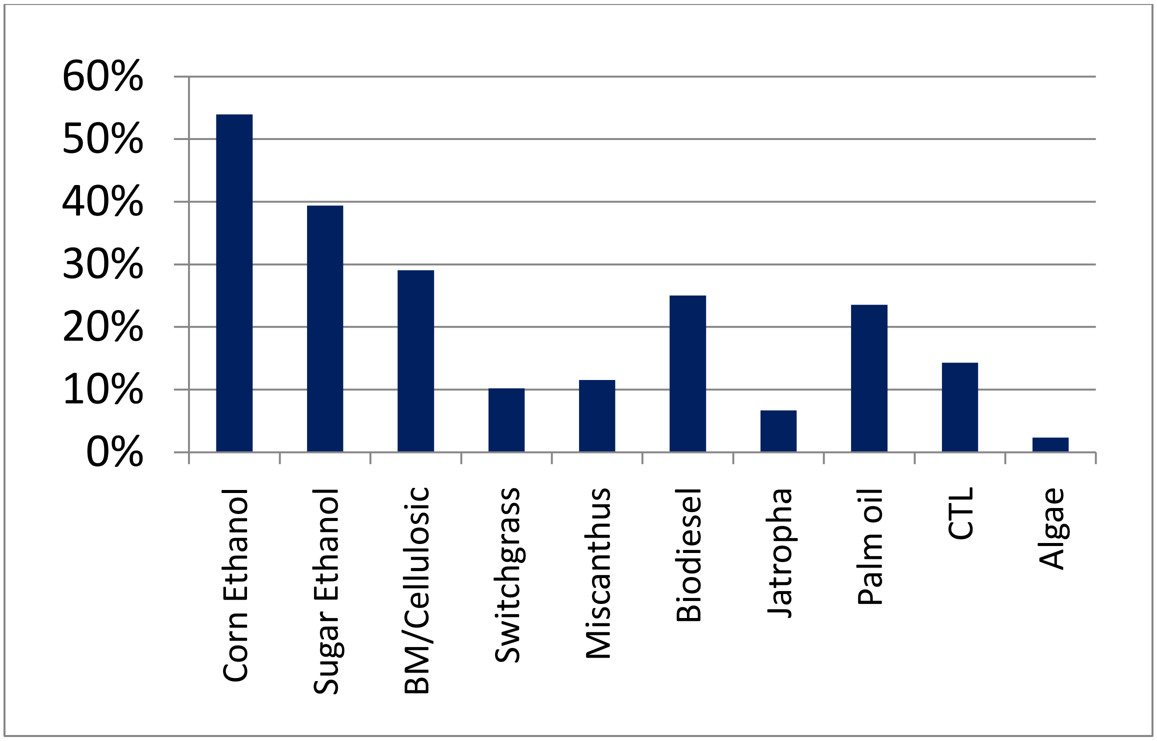

Figure 4.3 Percentage Occurrence of Theme Subsidies by Group

Figure 4.3 shows the percentage occurrence in the document collection by fuel/feedstock type of the theme subsidies. Figure 4.3 supports the literature review showing the prevalence of the theme subsidies in corn ethanol articles. With over 50% of the articles categorized in the corn ethanol fuel type containing the theme subsidies, the text mining provided support for our belief that subsidies are a key theme in corn ethanol. Although we reviewed roughly the same number of sugar ethanol articles, subsidies play a much smaller theme in this fuel type. This further supports information gathered during the literature review. Although subsidies were important early in sugar ethanol's development, it is produced more efficiently now and subsidies play a diminishing role in its success.

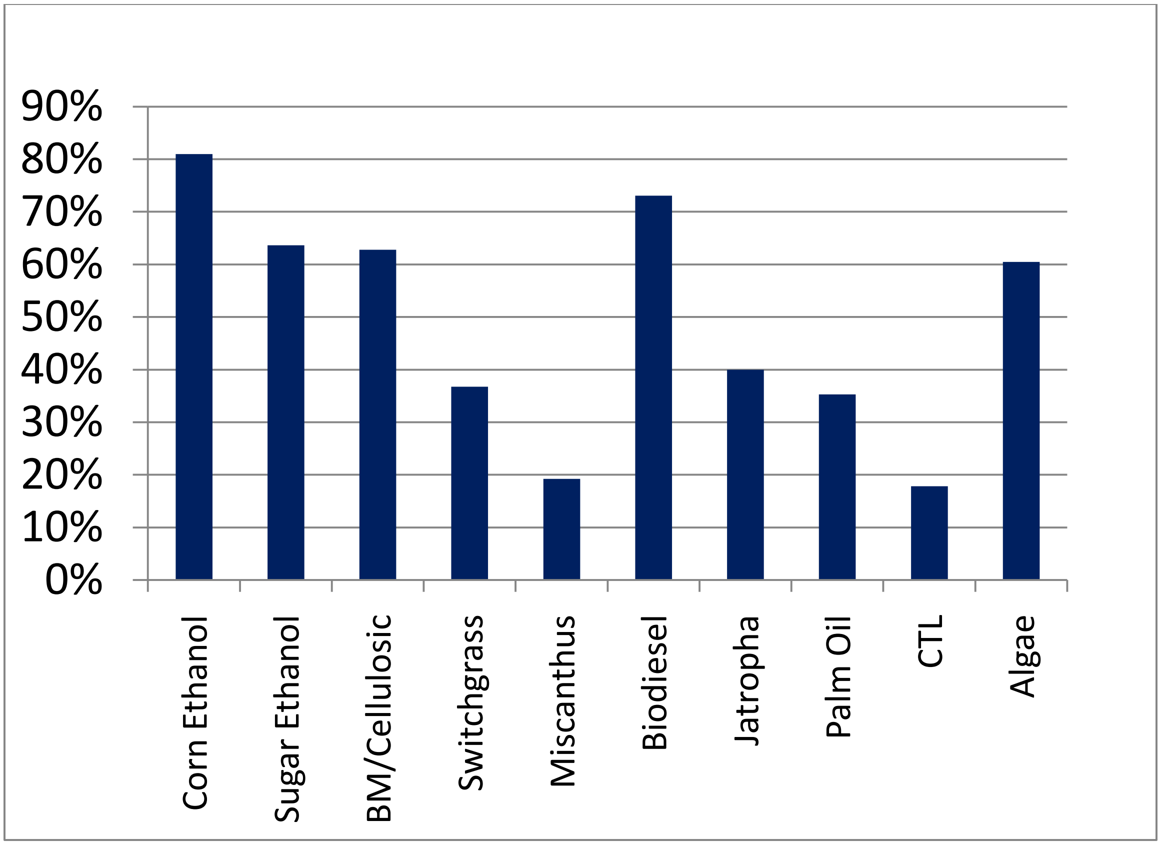

Figure 4.4 Percentage Occurrence of Theme Food/Ag Effects by Group

Figure 4.4 shows the prevalence of Food/Ag Effects throughout many of the fuel types. Food/Ag Effects is a prevalent theme in corn & sugar ethanol, as well as biodiesel. Biomass/cellulosic and algae likely have a high percentage of articles with the Food/Ag Effects theme occurring as well. This is most likely because of the potential positive effects associated with increased production of these feedstocks which were frequently mentioned in articles. Figure 4.5 discusses the prevalent Food/Ag Effects trend in further depth.

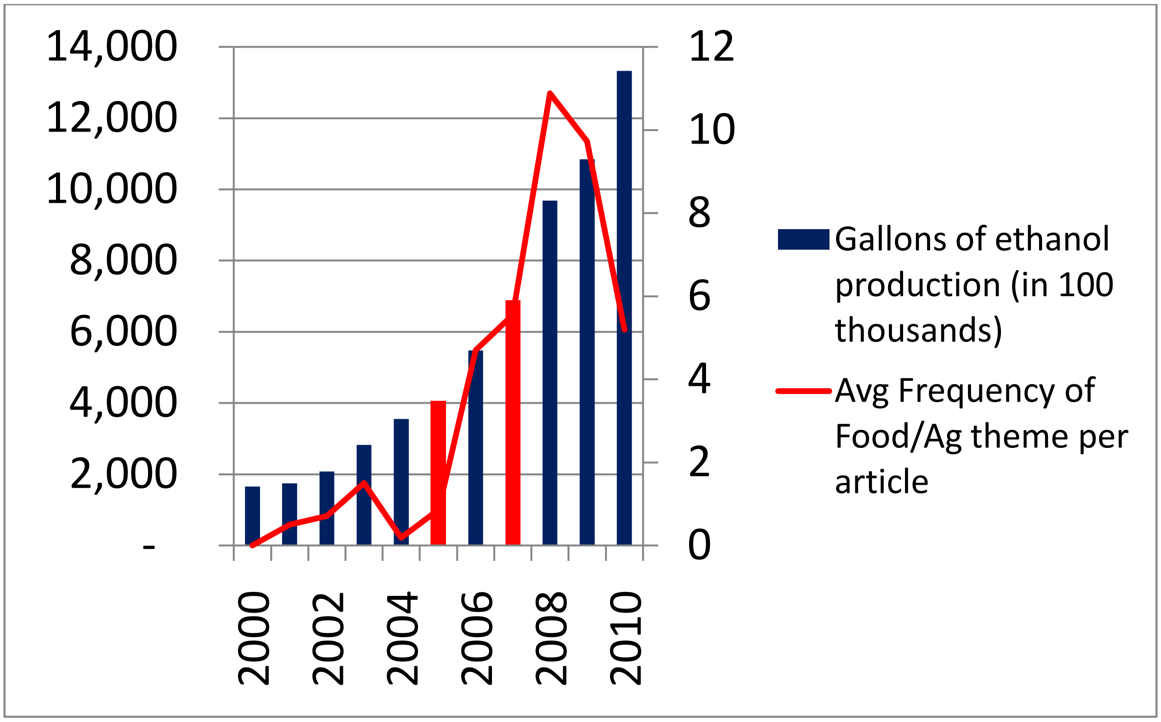

Figure 4.5 Average Frequency of Food/Ag Theme per Article

Figure 4.5 lists the average frequency of Food/Ag Effects theme per article reviewed. The bars show the amount of ethanol produced each year. From 2000 to 2005, the frequency of the Food/Ag Effects theme occurs on average less than one time per article while the increase in ethanol production averages around 400M gallons per year. However, after 2005 the Food/Ag Effects theme is mentioned much more often. 2005 and 2007 are highlighted red because during these years major U.S. political initiatives were passed to encourage and expand biofuel production. After 2005 both production and the average frequency of Food/Ag themes per article increase much more rapidly. As biofuel production has increased, the frequency of occurrence for the theme of Food/Ag effects has increased as well. There is a decrease in frequency from 2008-2010 which is believed to have resulted from a collapse in agricultural prices over this period. Although originally many alternative fuels and feedstocks were developed as a way of supporting agricultural prices and increasing market demand, we now see demand may be increasing too much. Since June of 2010, most agricultural prices are up 50-100%. It is expected that there will be an uptick in frequency of this theme for articles written in late 2010 and 2011. With food and agricultural prices becoming a much more prevalent theme, we may see increased resistance to expanding alternative fuel and feedstock production.

Chapter V: Conclusion

Although humanity has pursued petroleum alternatives since petroleum's discovery, alternative fuels have yet to successfully supplant petroleum. Throughout both the literature review and the text mining results, there were many shared traits and themes among alternative fuels. These commonalities have limited alternative fuels acceptance, and will likely continue to limit their use as a substitute for petroleum. Alternative fuels have been found to be much less environmentally sound than proponents claim, require great advancements in technology, have scalability issues, result in many societal costs, and are not economical.

Although proponents of alternative fuels tout how the alternative fuel [end product] burns cleaner, recently much discussion has focused on the life cycle assessments of these alternative fuels. Many petroleum alternatives are often dirtier than the fuel they are trying to replace. When considering alternative fuels produced in the tropics, land use change must be considered. When forests or grassland are cleared for energy crop production, it creates carbon debts which may require up to decades to pay back. CO_2 emissions released from the land use change are something now being measured when countries consider a petroleum alternative's cleanliness. Further, one must factor in the tremendous resources energy crops require.

Most terrestrial crops require large amounts of fertilizer and water to harvest. Corn has some of the highest water and nitrogen fertilizer demands. Although cellulosic crops such as *Miscanthus* and switchgrass have lower water demands, to be produced commercially it is thought they would have a significant water requirement. Fertilizer, which is energy intensive to produce, would also be required for commercial scale production of the cellulosic crops. CTL fuels are even worse environmental offenders.

Production of CTL fuels release tremendous emissions. CTL production is an inherently dirty process, both during coal mining and processing. CTL proponents count on breakthroughs in carbon sequestration technology to alleviate many of the environmental concerns, but carbon sequestration, as with many technologies in the alternative fuel industry, has yet to be demonstrated on a commercial level.

Technology is truly one of the biggest limiting factors in advanced alternative fuels. Through our research, it seemed that technological breakthroughs are often mentioned as only being a few years away. This appears to be an exaggeration. Carbon sequestration has been discussed since the 1970s, but a successful, commercial scale operation has yet to be demonstrated. Cellulosic ethanol’s potential was discussed over 80 years ago and it has yet to be demonstrated on a commercial level. Algal based alternative fuels have the greatest potential to be produced on a large scale with minimal impact, yet the technology to produce it economically remains an elusive target. Technology enabling wide spread, economical, commercial production being 5 to 10 years away was a theme prevalent throughout the documents reviewed. Further, alternative fuels and feedstocks have tremendous limitations with scalability.

Another common theme in the research was the lack of scalability for most alternative fuels. With current production yields, devoting entire food crops to energy production would only solve a fraction of our current needs. Other countries such as South Africa and Brazil, which rely on alternative fuels to meet a large percentage of their transportation needs, do on smaller scales. Cellulosic ethanol, algal fuels, and CTL are viewed as having the potential to be produced on a much wider scale without disrupting food supplies, but until technology breakthroughs happen, producing large amounts of these fuels would be cost prohibitive. Currently, increased production of terrestrial crops for alternative energy has resulted in a massive spike in food prices.

With the United States and other nations devoting larger portions of their food crops to alternative fuel production, food prices have spiked dramatically. United States citizens consume a larger percentage of processed foods, thus blunting the effects of rising food prices. However, most of the world's population does not. Although proponents debate the effect, the United Nations has listed increased biofuel production as one of the biggest factors in the commodity spike since June of 2010 (NY Times, 2011). These rising prices have been one of the factors exacerbating unrest of people throughout the developing world and played a significant role in protests sweeping throughout the Middle East (Russia Today, 2011). Finally, and most importantly, alternative fuel production is not economical.

The overwhelming theme throughout the research was the lack of economic viability in regards to most alternative fuels. Throughout the history of alternative fuels, their production has rarely been economical. All nations support their alternative fuel industries with subsidies to encourage production. Excluding Brazil, no nation has consistently achieved economical production of alternative fuels. Further, even the Brazilian industry lost money during periods of sugar price spikes.

An underlying problem with terrestrial crops profitability is the assumption they will be profitable at a certain price level of oil. Unfortunately, increased oil prices result in higher production costs for these petroleum alternatives. Additionally, because a large percentage of the cost is feedstock, increasing alternative fuel production increases demand for these feedstocks, thus raising prices. Rarely have nations been able to satisfy their transportation fuel needs from alternative fuels.

Over the past century, only Germany, South Africa, and Brazil have successfully produced alternative fuels to satisfy a large portion of their domestic needs. The common threads these countries share are identifying alternative fuel production as a matter of national security and massive government subsidies to get their nascent industries off the ground. These countries all placed national security motivations above the economics of alternative fuel production. There are certainly reasons for the United States to pursue alternatives to petroleum, but economics is not one of them.

Appendix A: Additional documents used in text mining

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14. ABSTRACT
The United States has dramatically increased its production of alternative fuels over the past seven years. With the passing of the Energy Independence and Security Act of 2007 (EISA), alternative fuel production will increase in the United States over 700% from 2005 levels. However, the pursuit of petroleum alternatives is not a recent trend. Over the last 100 years, various nations have pursued petroleum alternatives with varying levels of success. This research focuses on the historical development of 10 leading alternative fuels and feedstocks. Through a thorough literature review we will identify commonalities among these fuels and feedstocks which have hindered their adoption. Further, the research evaluates the 10 alternative fuels and feedstocks with text mining software to support findings from the literature review. This research finds that alternative fuels face significant challenges with regards to environmental impacts, technological maturity, and societal costs. Further, these petroleum alternatives have rarely been economical solutions. The research findings suggest that while there are National Security reasons for pursuing petroleum alternatives, rarely are there economic ones.

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