Ethanol and Biodiesel: the Good, the Bad and the Unlikely

Prepared by Kirk R. Berge

Updated December 5, 2008

1.0 Introduction

The US consumed approximately 7.5 billion barrels of oil in 2007. Approximately 2.5 billion barrels were produced in the US and another 5 billion barrels of oil were imported. See reference 1. The ability of the US to import oil will decrease sharply and the cost per barrel will increase significantly in the next few years after oil has peaked and world oil production starts declining. A major goal of the Energy Independence and Security Act of 2007 is to reduce US dependence on imported oil. See reference 2.

In 2007 ninety-six percent of US transportation fuels were derived from oil and sixty-nine percent of US oil was used to make transportation fuels. See reference 1. US gasoline consumption increased steadily at a rate of about 2 billion gallons per year during the period from 1986 through 2006, reaching almost 143 billion gallons in 2007. See reference 4. This is the equivalent of about 3.12 billion barrels of oil. US distillate fuel oil (diesel) consumption was about 65 billion gallons in 2007. See reference 1. This is the equivalent of 1.6 about billion barrels of oil.

Two popular biofuels are ethanol and biodiesel. In 2007 the US produced approximately 6.5 billion gallons of ethanol and 500 million gallons of biodiesel. See reference 1. Increased production of these fuels to 36 billion gallons per year by 2022 is a key aspect of the US Biofuels program defined in the 2007 Energy Act. See reference 2.

The good aspects of the biofuels program include:

> Ethanol and biodiesel do indeed reduce the amount of oil needed to be imported for transportation fuel. The 6.5 billion gallons of ethanol and 500 million gallons of biodiesel produced in 2007 offset approximately 24 million barrels of oil, which is slightly over 0.3 percent of total US oil consumption.
>
> Congress recognizes that exploitation of cellulosic feedstocks is essential to the biofuel program. The 2008 Farm Bill increases the subsidy for cellulosic ethanol production to $1.01 per gallon while reducing the subsidy for corn kernel ethanol production from $0.51 per gallon to $0.45 per gallon.
>
> The 2007 Energy Act calls for increased biofuel production each year until 2022 at which time the production goal is 36 billion gallons of biofuels, most of which is ethanol. It is more likely that ethanol production will top out at about 16 billion gallons per year and will reduce the need to import the energy equivalent of about 197 million barrels of oil per year by 2012. Biodiesel production will be about 13.2 billion gallons per year by 2022 which will reduce the need to import the energy equivalent of 257 million barrels of oil per year.

The bad aspects of the biofuel program include:

In 2007 six percent of all natural gas imported into the US was used to produce ethanol from corn kernels.

Taxpayers are paying a large subsidy in the form of tax incentives for the production of ethanol and biodiesel.

The use of corn kernels, soybeans and canola for the production of ethanol is causing the cost of these food sources to increase.

The increased production of corn and other food crops used for biofuels on poorer croplands in the US is resulting in substantially increased fertilizer related pollution of the Mississippi river watershed which is contributing to an increase of the so called "Dead Zone" in the Gulf of Mexico off the coasts of Louisiana and Texas.

The conversion of forests to croplands for increased food production in other countries, to make up for reduced food imports from the US, is causing greenhouse gas emissions to increase.

The 2007 Energy Act mandate that US government agencies purchase Flexible Fuel Vehicles (FFVs) to replace old worn-out government vehicles when such vehicles are available has had the net effect of causing FFVs with more cylinders than the original vehicles to be purchased in places where E85 fuel (85% ethanol and 15% gasoline) is unavailable. This has caused gasoline consumption to increase relative to not having this mandate.

The unlikely aspects of the biofuel program include:

It is unlikely that more than 38 percent of the corn crop will be diverted from food consumption to ethanol production to meet the mandate of the 2007 Energy Act.

It is unlikely that FFVs and E85 will become popular enough to meet the production and consumption mandates of the 2007 Energy Act.

It is unlikely that more than 16 billion gallons of ethanol will be produced or consumed per year in the foreseeable future.

The biofuel program can be improved significantly with a few changes that are described in the last section of this report.

2.0 Energy Independence and Security Act of 2007 and the 2008 Farm Bill

The Energy Independence and Security Act of 2007, passed by Congress and signed by President Bush in December 2007, mandates US production of 36 billion gallons of biofuels by 2022. See reference 1.

The 2007 Energy Act mandated biofuel production quantities per year are defined in Table 1. Renewable biofuel includes biofuels made from corn kernels and other biomass. Requirements for advanced biofuels exclude biofuels made from corn kernels. Cellulosic biofuels are limited to those made from any cellulose, hemicellulose or lignin that is derived from renewable biomass. Biomass-based diesel excludes biodiesel made from corn starch. Advanced and cellulosic biofuel production will slowly phase in starting in 2009 and 2010, respectively. The requirement for corn kernel ethanol production increases from 9 billion gallons per year in 2008 to 15 billion gallons per year by 2015.

Table 1 - Billion of Gallons of Biofuel Production per Year

Year	Renewable Biofuel	Advanced Biofuel	Cellulosic Biofuel	Biomass-based diesel
2006	4.00	0	0	0
2007	4.70	0	0	0
2008	9.00	0	0	0
2009	11.10	0.60	0	0.50
2010	12.95	0.95	0.10	0.65
2011	13.95	1.35	0.25	0.80
2012	15.20	2.00	0.50	1.00
2013	16.55	2.75	1.00	to be defined
2014	18.15	3.75	1.75	to be defined
2015	20.50	5.50	3.00	to be defined
2016	22.25	7.25	4.25	to be defined
2017	24.00	9.00	5.50	to be defined
2018	26.00	11.00	7.00	to be defined
2019	28.00	13.00	8.50	to be defined
2020	30.00	15.00	10.50	to be defined
2021	33.00	18.00	13.50	to be defined
2022	36.00	21.00	16.00	to be defined

The 2007 Energy Act does not define oil displacement goals or even require that the equivalent amount of oil displaced per year by the biofuels program be reported.

The 2007 Energy Act requires the combined fuel economy average for model year 2020 to be at least 35 miles per gallon for the total fleet of automobiles and small trucks manufactured for sale in the United States for that model year. Increasing mileage standards leading to this level are imposed for the years between now and 2020. The 2007 energy act does not spell out specific relationships for mileage requirements for pure gasoline, E10 or E85.

The 2007 Energy Act requires US government agencies to replace old worn-out vehicles with Flexible Fuel Vehicles (FFVs) if such vehicles are available. This has led to some agencies purchasing replacement FFVs with more cylinders than the vehicles that they are replacing and purchasing FFVs in places where E85 fuel is unavailable. One example is that the government is purchasing FFVs in Hawaii where there is no ethanol production. The net result of this is that the replacement vehicles use substantially more gasoline than the vehicles that they replaced. See reference 3.

Prior to 2008 federal taxpayers provided ethanol producers with a $0.51 per gallon tax credit (subsidy). The 2008 Farm Bill reduced this to $0.45 per gallon for corn kernel ethanol. This subsidy is called the “Volumetric Ethanol Excise Tax Credit” (VEETC) and remains in effect through December 31, 2010. The tax package includes a new production tax credit for up to $1.01 per gallon of cellulosic ethanol available through the end of 2012. Total ethanol subsidies are actually higher. A 2006 report by the International Institute for Sustainable Development estimated that if one took into account state renewable fuel tax breaks and direct agricultural subsidies, the total ethanol subsidy is actually $1.05 to $1.38 per gallon of ethanol. Ethanol and corn producers were given over $6.825 billion in subsidies for ethanol produced in 2007. The US has a tariff of 54 cents per gallon on imported ethanol. This tariff was lowered to $0.45 per gallon in the 2008 Farm Bill. See references 4 and 5.

US biodiesel producers receive a tax credit (subsidy) of $1.00 per gallon of biodiesel produced from virgin oil. This is in addition to other subsidies provided to farmers for growing the crops used to produce the biodiesel. The virgin oil can be obtained from animal fats or oilseeds. Producers of biodiesel from recycled cooking oil are granted a tax credit of $0.50 per gallon. These subsidies expire at the end of 2008.

3.0 Ethanol

Ethanol, also known as ethyl alcohol or grain alcohol, can be used either as an alternative fuel or as an additive to gasoline. Pure, 100% ethanol is not generally used as a motor fuel; instead, a percentage of ethanol is combined with unleaded gasoline. Any amount of ethanol can be combined with gasoline, but the most common blends are E10 and E85.

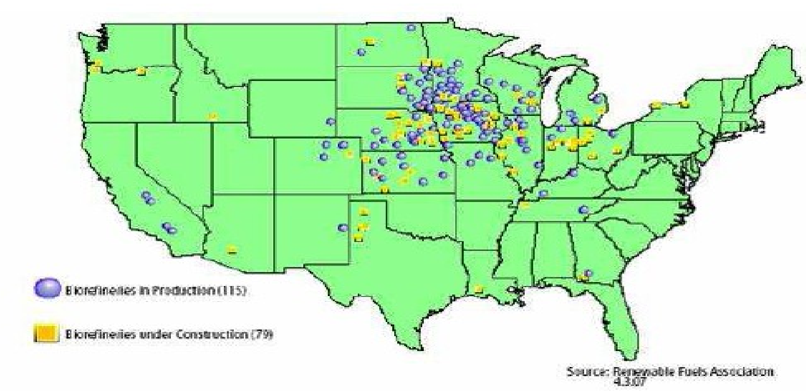
> E10 is 10% ethanol and 90% unleaded gasoline. E10 is approved for use in any make or model of vehicle sold in the US Many automakers recommend its use because of its clean-burning characteristics. Today about 46% of America's gasoline contains some ethanol, most as the E10 blend. Gas stations that sell E10 typically do not also sell pure regular gasoline. As of mid-April 2006, E10 was sold at approximately 40% of all gas stations in the US All states except the following require pumps selling ethanol be labeled as such: Indiana, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, Nevada, New Jersey, North Carolina, Ohio, and Oklahoma
>
> E85 is 85% ethanol and 15% unleaded gasoline. E85 is an alternative fuel for use in flexible fuel vehicles (FFVs). In late-2008 there were fewer than 1,800 E85 pumps among the nation's 170,000 gas stations. See reference 3. When E85 is not available, FFVs can operate on pure gasoline or any ethanol blend up to 85%. An FFV costs about $100 more than the same vehicle without this capability. There are currently more than 6 million FFVs in the US. America's automotive

companies (Chrysler, Ford and GM) plan to increase annual production of FFVs to two million cars and trucks per year by 2010. In conjunction with more flexible fuel vehicles, more E85 pumps are being installed across the country. See reference 6.

"E10 presents no problem for contemporary automobiles but can damage the engines of some boats, general aviation aircraft, ATVs, gasoline powered tools and classic cars. Since ethanol is a solvent, E10 fuel can dissolve gummy residues in non-metal fuel tanks. This can then clog filters, carburetor jets, and fuel injectors which can then cause the engine to stall. The problem can be particularly acute in vessels with fiberglass fuel tanks, since ethanol can actually dissolve the tank walls. Ethanol absorbs water, which can lead to "phase separation," a problem for engines that are not run frequently. When that happens, the ethanol-water mix can settle at the bottom of the tank, near the fuel intake, and this presents a safety problem". See reference 7. Starting January 1, 2009, gasoline sold for use in boats, aircraft, ATVs, gasoline powered tools and classic cars in Oregon will be exempt from a 2007 Oregon law requiring that all fuel contain 10% ethanol in recognition of the above.

Ethanol production is centered in the Corn Belt, i.e., those states in the Mid-West producing most of the corn in the US. See Figure 1 from reference 8. In 2006 there were 131 production facilities having the capacity to produce 6.9 billion gallons of ethanol per year. Over the next 2-3 years an additional 6.5 billion gallons of capacity is being added by current facilities expanding their capacity and the addition of 73 new facilities. By 2009, the corn grain ethanol industry in the United States will be able to produce over 13 billion gallons per year.

Figure 1 – Ethanol Production Facility Locations in 2006



The energy content of gasoline is about 115,000 British Thermal Units (BTUs) per gallon. The energy content of ethanol is about 76,000 BTUs per gallon. See reference 8. If gasoline costs $3.00 per gallon, then E10 should cost $2.90 per gallon and E85 should cost $2.14 per gallon to break even in terms of energy content per gallon. If a vehicle gets 30 miles per gallon using gasoline, it should also get about 29.0 miles per gallon using E10 and about 21.4 miles per gallon using E85. See Tables 2 and 3 for other values.

Table 2		
Fair Price per Gallon of E10 and E85 Based on Energy Content ($)		
Gasoline Price	Fair Price of E10	Fair Price of E85
2.00	1.93	1.42
2.10	2.03	1.49
2.20	2.13	1.57
2.30	2.22	1.64
2.40	2.32	1.71
2.50	2.42	1.78
2.60	2.51	1.85
2.70	2.61	1.92
2.80	2.71	1.99
2.90	2.80	2.06
3.00	2.90	2.14
3.10	2.99	2.21
3.20	3.09	2.28
3.30	3.19	2.35
3.40	3.28	2.42
3.50	3.38	2.49
3.60	3.48	2.56
3.70	3.57	2.63
3.80	3.67	2.70
3.90	3.77	2.78
4.00	3.86	2.85

Gasoline BTUs per Gal = 115,000
Ethanol BTUs per Gal = 76,000

Table 3		
Expected Miles per Gallon of E10 and E85 Based on Energy Content		
Gasoline MPG	Expected E10 MPG	Expected E85 MPG
10	9.7	7.1
12	11.6	8.5
14	13.5	10.0
16	15.5	11.4
18	17.4	12.8
20	19.3	14.2
22	21.3	15.7
24	23.2	17.1
26	25.1	18.5
28	27.1	19.9
30	29.0	21.4
32	30.9	22.8
34	32.8	24.2
36	34.8	25.6
38	36.7	27.0
40	38.6	28.5
42	40.6	29.9
44	42.5	31.3
46	44.4	32.7
48	46.4	34.2
50	48.3	35.6

Gasoline BTUs per Gal = 115,000
Ethanol BTUs per Gal = 76,000

Almost all US ethanol is currently produced using corn kernels. Corn and other starches and sugars are only a small fraction of the biomass that can be used to make ethanol. Advanced Bioethanol Technology allows fuel ethanol to be made from cellulosic (plant fiber) biomass such as agricultural forestry residues, industrial waste, material in municipal solid waste facilities, trees, and grasses. Cellulose and hemicellulose, the two main components of plants - and the ones that give plants their structure - are also made of sugars, but those sugars are tied together in long chains. Advanced bioethanol technology can break those chains down into their component sugars and then ferment them to make ethanol. This technology turns ordinary low-value plant materials such as corn stalks, sawdust, or waste paper into fuel ethanol.

Ethanol Production from Corn Kernels

The following corn kernel ethanol production process description is a summary of information provided in “Biomass to Ethanol: Potential Production and Environmental Impacts,” by Tiffany Groode, MIT Laboratory for Energy and the Environment Report No. LFEE 2008-02 RP, February 2008, Reference 8, which is one of the most useful reports on the internet for understanding ethanol related issues.

Initially, the corn kernels are mechanically broken down in a hammer mill. High temperature water is then added in a slurry tank and jet cooker to additionally help in the break down of the material. After special enzymes are added, the substance is called "mash." Once the mash is converted to sugar it needs to be cooled to the fermentation temperature. There are two types of fermentation; continual or batch. During a continual fermentation process the mash is pumped from one container to another. For a batch fermentation process the mash stays in the same container for 2 days with continuous mixing. At the end of the fermentation process the mixture that exits the container, called "beer", is approximately 10% by volume ethanol and contains all the solids from the original feedstock. The beer is then distilled resulting in 190 proof or a 95% ethanol mixture. This mixture goes through a dehydration step where the remaining water is removed by passing the mixture through a molecular sieve, resulting in 200 proof ethanol. The ethanol is then denatured by adding 5% gasoline to prevent human consumption.

Corn grain ethanol's conversion efficiency is approximately 2.5-2.8 gallons/bushel depending on the age of the production facility and the processes used. A typical value is 2.7 gallons/bushel.

The residue remaining at the end of distillation is referred to as "stillage" and is pumped from the distillation columns to the coproduct processing sector. The stillage is sent through a centrifuge to remove excess liquid, which can be reused in the liquefaction step. The remaining solids are referred to as wet distillers grain (WDG) and can be sold as animal feed. Depending on the shipping distance WDG may need to be dried further due to its short storage life and high shipping cost from the excess water weight. If additional drying is required, the WDG is put through a dryer to remove additional water until the final product has 10% moisture content. This product is now called dried distillers grain with solubles (DDGS). During the production of ethanol, 17-18 lbs of DDGS are produced per bushel of corn.

In the United States the majority of DDGS is fed to beef and dairy cattle with some also being fed to pork and poultry. While selling DDGS provides additional income, it can also be used as a fuel source by the facility to displace fossil fuel and electricity consumption in times of high fuel prices. As an example, Corn Plus of Winnebago Minnesota is utilizing the energy content of DDGS to displace the facility's natural gas consumption. This alternative use of DDGS can also be applied in geographic regions where an animal feed market is not available or transport is to costly. The consumption of DDGS as a fuel source rather than a feed source provides corn grain ethanol facilities with an additional economic alternative. It also substantially reduces the amount of natural gas needed to produce ethanol, which in turn substantially reduces the amount of greenhouse gas produced.

Ethanol is controversial in that some experts claim that it takes more energy to produce ethanol from corn than the resultant energy content of the ethanol produced. Other experts claim just the opposite. The US Department of Agriculture reported that the energy ratio for ethanol production is 1.67. See Reference 9. The ethanol lobby claims that there is a 30 percent net gain in BTUs from ethanol made from corn kernels. This infers that it requires 58,462 BTUs to produce each gallon of ethanol. Reference 10 and many other articles on the internet cite a 2002 report by David Pimentel and Tad Patzek. These scientists calculated all the fuel inputs for ethanol production—from the diesel fuel for the tractor planting the corn, to the fertilizer put in the field, to the energy needed at the processing plant—and found that ethanol is a net energy-loser. According to their calculations corn ethanol requires 29% more fossil energy to produce than the ethanol contains. In comparison, a gallon of gasoline contains about 115,000 BTUs per gallon. But making that gallon of gas—from drilling the well, to transportation, through refining—requires around 22,000 BTUs or 19 percent of the energy of the gasoline. Reference 11 is a study by Argonne National Laboratory that concludes that corn ethanol requires 26% less fossil energy to produce than the energy content of the ethanol. Cellulosic ethanol requires 90% less fossil energy and soybean-based biodiesel requires 69% less fossil energy than the energy that the biodiesel contains. "A review of Pimentel/Patzek reveals that they made pessimistic assumptions and had double-counted certain energy costs without detailed elaboration." Many other researchers have published reports that provide a wide range of estimates of the amount of energy needed to produce ethanol. See reference 11.

A very informative report on the amount of energy needed to produce ethanol is the reference 8 MIT Laboratory for Energy and the Environment report "Biomass to Ethanol: Potential Production and Environmental Impacts." This report recognizes that the energy inputs to produce ethanol from corn include:

> Agricultural energy use including corn seed production; nitrogen, phosphate, and potash fertilizer production and application; lime production and application; herbicide and insecticide production and application; farm machinery fossil fuel consumption; and farm electricity consumption.
>
> Corn transport diesel fuel consumption assuming a roundtrip from the farm and corn storage station to the ethanol processing plant; semi-trailer truck capacity; semi-trailer truck loaded and unloaded engine efficiency.
>
> Natural gas or other fuel and electricity energy consumption is utilized by the ethanol processing plants to convert corn to ethanol.

The report states that there is much variability found within the agricultural sector, where seasonal effects, soil characteristics, and geographic locations significantly influence required energy related inputs such as fertilizer application and yield as well as technological variability. The energy required to produce a gallon of ethanol will vary from state-to-state and from farm-to-farm within each state. It probably varies from field-to-field on the same farm and the same field will vary from year-to-year based on the weather. This is the reason why different researchers arrive at different estimates of the energy needed to produce a gallon of ethanol. The MIT report analysis is based on a Monte Carlo analysis methodology and presents results in terms of distributions instead of single values.

The MIT report notes that "the Iowa corn (kernel) ethanol scenario represents the current best practice case for corn kernel ethanol production, since Iowa has the highest crop yields for the lowest agricultural inputs. The mean (average) Net Energy Value (NEV) required to produce ethanol from corn kernels in Iowa is 3.7 MJ/liter." [NEV = Energy in one unit of fuel - Energy needed to produce one unit of fuel.] This is equivalent to an energy-out to energy-in ratio of 1.21. The highest efficiency one-half percent of the farms in Iowa have a corn kernel ethanol NEV of approximately 11.0 or more (Energy out/Energy in = 1.89) and the lowest efficiency one-half percent of the farms in Iowa have an ethanol NEV of approximately -2.0 or less (Energy out/Energy in = 0.91).

The MIT report shows that corn grown in Georgia, a traditionally non-corn producing state, results in an average NEV of negative 7.6 MJ/L (Energy-out / Energy-in = 0.74) and resulted in a 47% increase in Green House Gas (GHG) emissions. This is due to increased fertilizer inputs, the need for irrigation, lower bushels per acre of corn yields and longer transportation distances. The very best Georgia farms have an Energy-out / Energy-in = 1.74 or more and the very poorest farms have an Energy-out / Energy-in = 0.48 or less. Any time that Energy-out / Energy-in is less than 1.0 it means that more energy is needed to produce the ethanol than is contained in the ethanol produced.

If the overall US average NEV corn kernel ethanol is 1.21, as in Iowa, then the net energy gained is 13,190 BTU per gallon of ethanol. Since one barrel of oil has an energy equivalent of 5.8 million BTU, then the production of 6.5 billion gallons of ethanol in 2007 resulted in the equivalent energy offset of 15,360 million barrels of oil. Since the Iowa scenario represents the current best practice, the overall US average NEV was lower and the total US 2007 ethanol production of 6.5 barrels resulted in the equivalent energy offset of fewer than 15,360 million barrels of oil.

Not all of the energy used to produce ethanol is from oil. Table 4 presents a break down of average Iowa corn kernel ethanol production energy use by production phase and energy source. This data was obtained from reference 8.

Table 4 - Energy Used (BTUs) per gallon to Produce Iowa Corn Kernel Ethanol

	Electricity	Natural Gas	Oil Derived	Total
Agriculture	2,340	7,800	4,413	14,553
Transportation	0	0	951	951
Processing	11,965	35,340	0	47,305
Total BTUs	14,306	43,140	5,364	62,810
Percent BTUs	23	69	9	100

The high use of energy in the agriculture phase of ethanol production is due to the high amount of energy used to produce fertilizers, insecticides, and herbicides. See Table 5 which has data from reference 8.

Table 5 - Energy (BTUs) used to produce one pound each of fertilizers, herbicides and insecticides

	Electricity	Natural Gas	Oil Derived	Total
Nitrogen Fertilizer Production	2652	17434	0	20086
Phosphate Fertilizer Production	936	5654	0	6590
Potash Fertilizer Production	778	1128	0	1906
Lime Production	581	0	0	581
Herbicide Production	31388	50224	37247	118858
Insecticide Production	40404	55252	31596	127252

Average fertilizer applications for growing corn are: nitrogen fertilizer: 140 pounds per acre; phosphate fertilizer: 87 pounds per acre; potash fertilizer: 60 pounds per acre; and lime: 250 pounds per acre. Only small amounts of insecticide and herbicides are used, but the energy needed to produce even small amounts of these is substantial.

Since an average of 5,364 BTUs of the energy used to produce ethanol in Iowa is specifically derived from oil the actual displacement of oil from the production of 6.5 billion gallons of ethanol is 79.2 million barrels of oil, assuming Iowa ethanol production statistics.

On the other hand, 41,340 BTUs of natural gas are required to produce each gallon of ethanol. This indicates that at least 274.6 billion cubic feet of natural gas was used to produce 6.5 billion gallons of ethanol. This is over 6 percent of the 4 trillion cubic feet of natural gas imported by the US in 2007. See reference 12.

The reference 8 MIT report goes on to note that approximately 70% of the DDGS can be gasified to produce all of the facility's process steam, or 77% of the DDGS could be consumed to provide all the facility's steam and electricity needs using combined heat and power. If the ethanol producers used the DDGS coproduct as a fuel, instead of natural gas, then only 7,800 BTUs of natural gas is needed to produce each gallon of ethanol. This would reduce the total amount of natural gas for the production of ethanol to 49.7 billion cubic feet, which is approximately 1.0 percent of the total natural gas imported into the US in 2007. Doing this would raise the Iowa corn average NEV to 15.4 MJ/liter (Energy-out / Energy-in = 3.66). This approach uses only 77 percent of the DDGS coproduct, allowing the remaining 23 percent to be sold by the producer for additional income.

Almost all US ethanol is now made from corn kernels and the best farm land in the country is now being used to grow corn for ethanol. As additional farm land is used to produce corn for ethanol, the amount of energy and pollution per gallon of ethanol produced will increase due to the decreased fertility of the land.

Figure 2 shows historical and projected future US corn production per year. It also shows the historical and projected future use of corn for ethanol production. The projected future total corn crop forecast is from reference 13. The projected future use of corn for ethanol production is computed as the 2007 Energy Act mandatory corn ethanol production divided by 2.7 gallons of ethanol / bushel of corn.

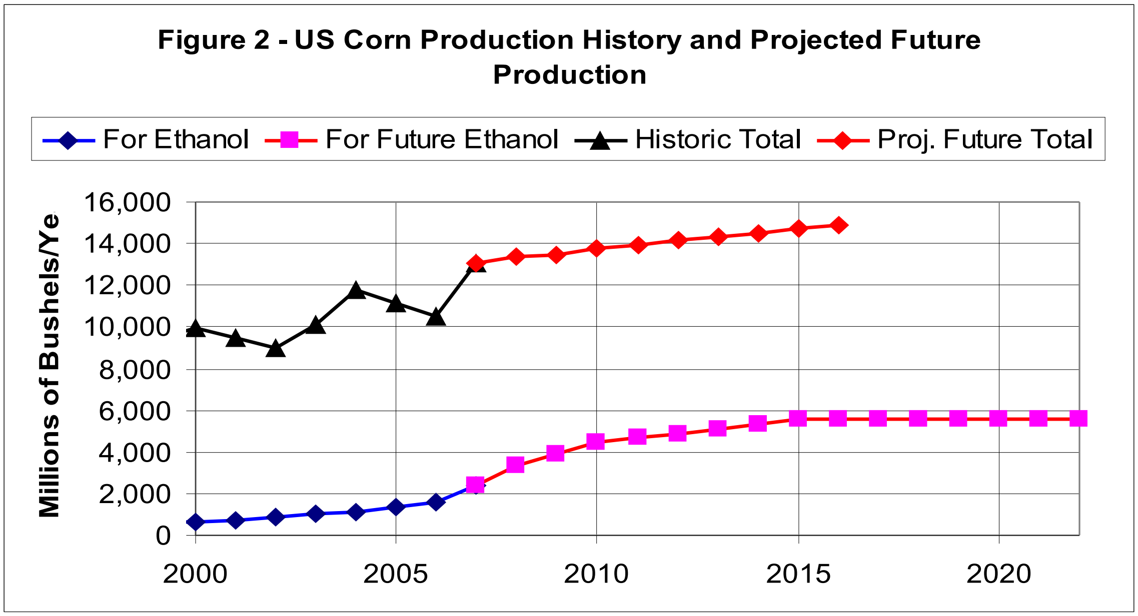
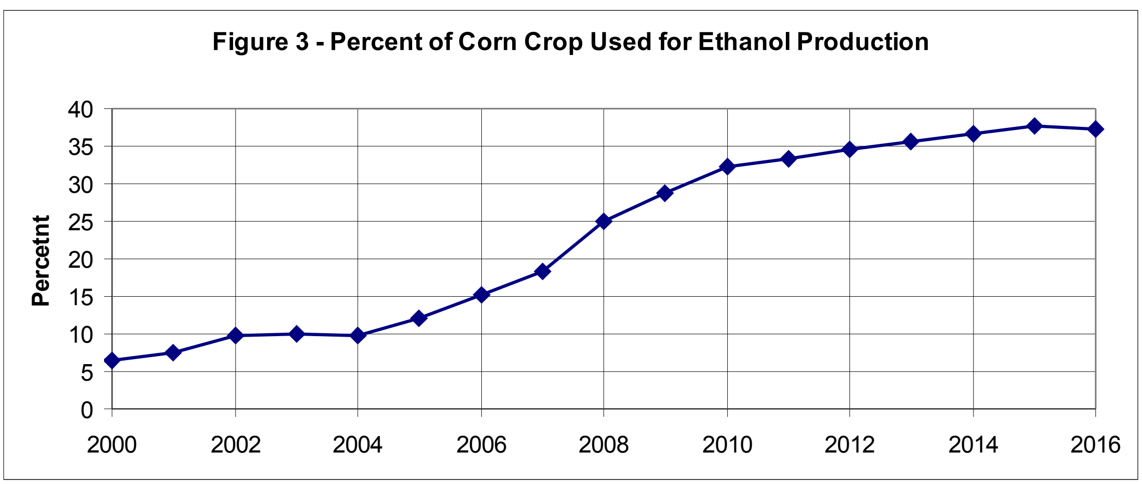


Figure 3 shows the historic and future percent of the US corn crop used for ethanol production per year based on the data in Figure 2. Eighteen percent of all US corn was used for ethanol production in 2007. This is projected to more than double by 2015, at which time only 62 percent of the corn crop will be used for food.



Ethanol Production from Corn Stover

Reference 14 states that "The use of next-generation cellulosic biomass feedstock has the potential to dramatically expand the resource base for producing biofuels in the future. So far, however, the costs of producing liquid fuels from cellulosic biomass are not competitive with petroleum-derived fuels, even with the recent rise in petroleum costs. Various government and industry-sponsored efforts are under way to lower the costs of making liquid fuel from cellulosic biomass by improving the conversion technologies.

The economic competitiveness of biofuels and the development of the conversion pathways will depend on the future price of petroleum. Since these conversion technologies are close to being viable, their deployment is important so that operators can streamline new facilities. Government incentives such as loan guarantees and guaranteed markets for new cellulosic biofuel production facilities can play an important role in the early stages of the second generation of biofuels."

The reference 8 MIT report states that "Agricultural residues, such as corn stover, are seen as the initial feedstock for a cellulosic ethanol industry as they are readily available and located within an existing ethanol production and distribution network. The biomass ratio of corn kernels to corn stover is typically 1:1 on a dry basis. Therefore from this ratio, in 2006 approximately 332 million metric tons of corn stover was produced. In the future as corn production increases due to increased ethanol demand, the production of corn stover will also increase as they are dependent. Currently, as a corn picker passes over the field, it uptakes the entire corn plant harvesting the corn kernels and returning the corn stover to the field. Corn stover, left on the ground, provides protection to the soil from wind and water erosion. Additionally, during the decomposition process, stover returns nutrients back into the soil decreasing the amount of fertilizer required for the subsequent year. It also adds organic matter back into the soil increasing biological activity which serves as a vital link in the dynamics of soil nutrient storage, release and use by plants. These positive environmental impacts reduce soil quality degradation over time and minimize fertilizer application rates. Therefore, when considering stover as a feedstock, long term research is needed to determine the maximum quantity that can be removed without having negative environmental impacts on the soil. Initial studies have indicated an allowable removal rate of 30%-50%."

The only agricultural fossil energy associated with corn stover is due to its collection, removal, and packaging. Corn can be harvested and corn stover can be baled in one step with the use of advanced farm machinery thus eliminating the need to pass through the field more than once for harvesting. Bales are then collected and transported to a storage area for later transport to the ethanol processing facility.

The reference 8 MIT report states the process for converting corn stover or switchgrass to ethanol is more complex than the process used for converting corn kernels to ethanol. A pretreatment process is needed to increase the accessibility of cellulose to enzymes that will later be converted to sugar. Pretreatment happens with heat, enzymes, and/or acids that destroy the matrix of polymers so that the cellulose is accessible during hydrolysis. Pretreatment is an additional step from the starch to ethanol conversion process and is one of the most expensive processing steps due to large equipment cost and the high costs of enzymes. Two companies that are advancing research to decrease the cost of enzymes are Genencor and Novozymes Biotech. Currently enzymes costs are between \$0.3-\$1.0/gallon and are needed to decrease to \$0.1/gallon to be cost competitive with corn grain ethanol. Genencor and Novozymes have both achieved significant progress in reducing cellulose costs. Each company now projects costs below \$0.20/gallon ethanol for their advanced cellulose products developed specifically for biomass conversion applications. See reference 15. The efficiency of the pretreatment process impacts the ethanol yield of lignocellulosic materials. Improving this process has been a major obstacle to making lignocellulosic ethanol high yielding and cost competitive.

Once cellulose and hemicellulose are broken down to simpler sugars, the next step of fermentation can begin. Fermentation is the biological process in which yeast converts sugars to ethanol and carbon dioxide under anaerobic conditions. While there currently is no commercial scale lignocellulosic ethanol facility, research tests have shown a current ethanol yield rate of 62.9 gallons/dry ton which is 67.5% conversion efficiency. As research continues to improve the efficiencies of these processes the ethanol yield from cellulosic sources will increase. At 90% conversion efficiency 86.7 gallons/dry ton of ethanol would be produced from corn stover or switchgrass.

The corn stover analysis scenario in the MIT report looks at ethanol produced from corn stover in today's timeframe. The location of the stover is assumed to be within a 50 mile radius of an ethanol conversion facility. The agricultural inputs to produce the corn are traditionally allocated to the grains and not the stover, as stover is a residue of corn production. A laboratory demonstrated cellulosic ethanol conversion rate of 62.9 gallons/dry ton is assumed. In practice initially this value would be lower. It is also assumed that lignin, a part of the plant not converted to ethanol, will be used to provide the facility's energy requirements. Analysis results indicate an NEV = 17.1 MJ/liter which is an energy-out to energy in ratio of 5.7. This would result in 7 to 11 billion gallons of ethanol if 30 to 50 percent of all corn stover were used for ethanol production. This is not feasible due to transportation costs. Using half this amount would result in 3.5 to 5.5 billion gallons of ethanol from corn stover.

The 2025 corn stover analysis scenario in the MIT report projects corn stover ethanol production 20 years into the future. The main assumption that changes in this scenario is the cellulosic feedstock to ethanol conversion efficiency rate, which improves to 86.7 gallons/dry ton. It is also assumed that lignin, a part of the plant not converted to ethanol, will be used to provide the facility's energy requirements. Analysis results indicated an NEV = 17.6 MJ/liter which is an energy-out to energy in ratio of 5.89. This would result in 10 to 16 billion gallons of ethanol if 30 to 50 percent of all corn stover were used for ethanol production. This is not feasible due to transportation costs. Exploitation of corn stover for ethanol production will require cooperation and close coordination between corn farmers and ethanol producers in local regions. Farmers will need to invest in new harvesting equipment to simultaneously harvest corn and bale the stover. Producers need to be assured that their investment in a cellulosic processing facility will be supported with an appropriate supply of corn stover. Using 25 percent of all corn stover would result in 8 billion gallons of ethanol.

If, in 2025, 8 billion gallons of ethanol is produced from processing corn stover and the Energy-in/Energy-out ratio is 5.89:1 then this would provide a net gain of 6.64 billion gallons of ethanol. This is equivalent to a net gain of 4.39 billion gallons of gasoline or 104 million barrels of oil.

Ethanol Production from Switchgrass

Switchgrass is a perennial drought-tolerant prairie grass with an extensive natural range in North America. See Figure 4. Switchgrass is currently used to prevent erosion on poor agricultural land. Switchgrass grows well in many parts of the country that are not conducive to corn production.

Unlike the single planting and cultivation season for corn, switchgrass is planted once and cultivated multiple times over a ten-year period. See reference 8. Switchgrass has an extensive rooting system which helps decrease soil erosion rates. A range of varieties of switchgrass are used extensively on acreage set aside by the federal Conservation Reserve Program (CRP) to minimize erosion. Switchgrass is also often planted as streamside buffers, or vegetative filter strips, due to its stiff stems that act like barriers to slow runoff, promote infiltration, and encourage infield sedimentation.

Figure 4 - Switchgrass

The entire above ground portion of the plant is assumed to be harvested. Switchgrass, being very similar to alfalfa and hay, is harvested and baled using similar practices and equipment. Once baled, switchgrass will need to be stored either on the farm, at a storage facility, or at the ethanol facility site. If left on the field, the bales may need to be covered to prevent them from getting wet and rotting. In a storage facility, issues related to the potential of spontaneous combustion of the biomass need to be addressed. The costs of loading and unloading at an additional facility also need to be considered. Typically ethanol facilities have storage space to accommodate one months worth of feedstock. Therefore, more space would be needed to have switchgrass stored at a facility.

Once switchgrass is baled it must be transported to a storage facility and/or a cellulosic ethanol facility. The transport of switchgrass is similar to the transport of other forage crops such as alfalfa and hay which can be transported by trailer. The costs associated with switchgrass handling and transport can be large. Being a low density material switchgrass is more costly to transport than corn grains for the same mass. Transport and handling costs, without preprocessing, have been estimated from $5 to $10 per dry ton-mile, within a 50 mile radius. Transport costs directly affect the economically viable biomass transport distance and thus the potential geographic regions that can supply a large scale cellulosic facility.

Processing switchgrass to ethanol is similar to processing corn stover to ethanol. This process is described above. It is also assumed that lignin, a part of the plant not converted to ethanol, will be used to provide the facility's energy requirements.

The Reference 8 MIT report switchgrass analysis scenarios show that Alabama switchgrass has an NEV = 20.1 MJ/liter (Energy-out / Energy-in = 19.3), Iowa switchgrass has an NEV = 19.1 MJ/liter (Energy-out / Energy-in = 10.1) and the 2025 switchgrass scenario has an NEV = 20.6 MJ/liter (Energy-out / Energy-in = 35.3). The current technology ethanol yield rate is 62.9 gallons/dry ton and the future technology ethanol yield rate is expected to be 86.7 gallons/dry ton of switchgrass. The current expected switchgrass yield is approximately 3 tons per acre. This is expected to increase to 6 tons per acre by 2025 with appropriate fertilizaton. Using the entire Conservation Reserve Program (CRP) 32.4 million acres for switchgrass production would yield 6.1 billion gallons of ethanol with current technology and as much as 16.8 billion gallons of ethanol using future technology.

Exploitation of switchgrass for ethanol production will require cooperation, long-term planning and close coordination between farmers and ethanol producers in local regions. Farmers will need to convert CRP lands to switchgrass production and be assured that there is a viable market for it. Producers need to be assured that their investment in a cellulosic processing facility will be supported with an appropriate supply of switchgrass. Even if only half of the CRP lands are used to grow switchgrass for ethanol production, this would result in the production of over 8 billion gallons of ethanol by 2025.

If, in 2025, 8 billion gallons of ethanol is produced from processing switchgrass and the Energy-in/Energy-out ratio for this production is 10:1 then this would provide a net gain of 7 billion gallons of ethanol. This is equivalent to a net gain of 4.67 billion gallons of gasoline or 110 million barrels of oil.

<u>Ethanol Production from Sugar Cane</u>

"About a third of the fuel Brazilians use in their vehicles is ethanol. All gasoline sold in Brazil contains at least 26 percent ethanol, but motorists driving Brazilian flexible-fuel cars have the option of filling up with pure ethanol, or E100, which currently is selling for about half the price of the 26 percent blend. Use of pure ethanol will rise sharply as carmakers in Brazil such as General Motors and Volkswagen make more flexible-fuel cars. Half the new vehicles sold this year will be able to use either pure ethanol or the 26 percent blend, according to the Sao Paulo Sugar Cane Industry Union." See reference 16.

"The use of ethanol in Brazil was greatly accelerated in the last three years with the introduction of "flex fuel" engines, designed to run on ethanol, gasoline or any mixture of the two. Ethanol can be made through the fermentation of many natural substances, but sugar cane offers advantages over others, such as corn. For each unit of energy expended to turn cane into ethanol 8.3 times as much energy is created, according to scientists at the Brazil Center for Sugarcane Technology and other Brazilian research institutes. In the past, the residue left when cane stalks are compressed to squeeze out juice was discarded. Today, Brazilian sugar mills use the residue to generate the electricity to process cane into ethanol, and use other byproducts to fertilize the fields where cane is planted. Some mills are now producing so much electricity that they sell their excess electricity to the national grid." See reference 17. Ethanol yield (gallons/acre) for sugar cane under good tropical conditions, as in Brazil, is double that of corn in the US

Ethanol Production Greenhouse Gas Generation and Pollution

The reference 8 MIT report concludes that greenhouse gas (GHG) resulting from ethanol production is highly dependent on seasonal effects, soil characteristics, and geographic locations and the technology used to produce the ethanol. The report concludes that average GHG emissions (gCO2equivalent) for the following ethanol production scenarios, relative to the production and consumption of gasoline, are:

Iowa Corn (Kernel) Ethanol	100 %
Georgia Corn (Kernel) Ethanol	156 %
Iowa Corn (Kernel) Ethanol plus DDGS	42 %
Iowa Corn Stover Ethanol	31 %
2025 Corn Stover Ethanol	29 %
Alabama Switchgrass Ethanol	6 %
Iowa Switchgrass Ethanol	7 %
2025 Switchgrass Ethanol	6 %

Rising ethanol production has added to a fertilizer-saturated "Dead Zone" in the Gulf of Mexico. The zone of oxygen-depleted water was discovered in 1985 and has been growing steadily since then. Nitrogen-based fertilizer, running off fields in Corn Belt states into the Mississippi River watershed, is considered the prime culprit. The zone this year (2007) is the third-largest on record, after 2002 and 2001. Researchers expect the 7,900-square-mile dead zone to keep increasing. According to US EPA estimates, up to 210 million pounds of nitrogen fertilizer enter the Gulf of Mexico each year. Scientists said they expected the tonnage to increase with corn acreage, especially since corn absorbs less nitrogen per acre than other crops like soybean and alfalfa. Environmentalists are warning the gulf could reach a tipping point where it is unable to maintain stability. "The ecosystem might change or collapse as opposed to being just impacted," said Matt Rota of the New Orleans-based Gulf Restoration Network. See reference 18.

Reference 19 is a Los Angeles Times article about two studies published February 7, 2008 in the journal Science. "One analysis found that clearing forests and grasslands to grow the crops releases vast amounts of carbon into the air -- far more than the carbon spared from the atmosphere by burning biofuels instead of gasoline." The second study found that converting existing farmland in the US from food to biofuel crops increases greenhouse gas emissions as food production is shifted to other parts of the world which is resulting in the destruction of more forests and grasslands to make way for farmland. "The study found that clearing an Indonesian peatland rain forest to make way for a biofuel plantation -- a conversion that is occurring rapidly to satisfy Europe's rising demand for biodiesel -- releases so much carbon that a net reduction in emissions would not begin for 423 years. Cutting down a tropical rain forest in Brazil to grow soybeans for biodiesel increases carbon emissions for 319 years."

EPA Mileage Ratings

Reference 20 is the Environmental Protection Agency's (EPA's) "Model year 2008 Fuel Economy Guide," which describes its procedures for making mileage ratings and lists the ratings for 2008 model year vehicles. This document states that "There is no noticeable difference in vehicle performance (relative to pure gasoline) when low-level ethanol blends are used. However, FFVs operating on E85 usually experience a 20–30% drop in miles per gallon due to ethanol's lower energy content. Based on the relative energy content of ethanol and pure gasoline, the expected mileage using E10 would be 96.6 percent that of pure gasoline. The expected mileage of E85 would be 71.6 percent that of pure gasoline which is a 28.4 percent reduction, thus agreeing with the EPA statement of a 20-30% drop. That infers that E10 users would experience a 3.4 percent reduction in gas mileage, which may or may not be "noticeable." It would be curious to know if any EPA officials would "notice" an unannounced 3.4 percent reduction in their pay.

4.0 Biodiesel

Biodiesel is a commercially available diesel replacement fuel manufactured from vegetable oils or animal fats. It produces fewer greenhouse gases than petroleum diesel. Biodiesel can be blended at any ratio with petroleum diesel. It is most commonly sold at ratios of 20% or 100%, denoted as B20 and B100. Any standard diesel engine will operate well on biodiesel. See reference 21.

Biodiesel is rapidly becoming more popular with consumption increasing from only 2 million gallons per year in 2000 to 250 million gallons in 2006 and 450 million gallons in 2007. This is at least partially due to country singer Willie Nelson who has popularized biodiesel by selling it at a truck stop that he co-owns and producing and distributing it to other truck stops as "BioWillie." See reference 22.

Most major engine companies have stated formally that the use of blends up to B20 will not void their parts and workmanship warranties. Some engine companies have already specified that the biodiesel must meet ASTM D-6751 as a condition, while others are still in the process of adopting D-6751 within their company or have their own set of guidelines for biodiesel use that were developed prior to the approval of D-6751. It is anticipated that the entire industry will incorporate the ASTM biodiesel standard into their owner's manuals over time. With biodiesel that meets the D-6751 specification, there have been over 45 million miles of successful, problem-free, real-world operation with B20 blends in a wide variety of engines, climates, and applications. The steps taken by the biodiesel industry to work with the engine companies and to ensure that fuel meets the newly accepted ASTM standards provides confidence to users and engine manufacturers that their biodiesel experiences will be positive and trouble-free. See reference 23.

"Tests run by Exxon showed that, compared to reference diesel fuel in 1993, a 20% blend of Biodiesel had significant, quantifiable improvements in reducing wear (193 micron scar for B-20 vs. 492 micron scar for petrodiesel) and friction (0.13 micron scar for B-20 vs. 0.24 micron for petrodiesel) while improving film coating ability of the blend (93% film with the B-20 vs. 32% film with the petrodiesel). The B-20 blend compared favorably for lubricity results against Exxon's own lubricity additive." See reference 24.

The energy content of diesel is about 129,500 BTUs per gallon. See reference 20. *(A gallon of diesel has 12.6 percent more energy content than a gallon of gasoline.)* The energy content of biodiesel is about 118,296 BTUs per gallon. If diesel costs $3.00 per gallon, then B20 should cost $2.95 per gallon and B100 should cost $2.74 per gallon to break even in terms of energy content per gallon. If a vehicle gets 30 miles per gallon using diesel it should expect to get about 29.5 miles per gallon using B20 and about 27.4 miles per gallon using B100. See Tables 6 and 7 for other values.

Biodiesel is made by transforming animal fat or vegetable oil using an alcohol like methanol and a chemical process that separates glycerin and methyl esters (biodiesel) from fats or vegetable oils. See reference 25. Glycerin is used in many common products including soap and is highly marketable. In Europe, the largest producer and user of biodiesel, the fuel is usually made from rapeseed (canola) oil. In the United States, the second largest producer and user of biodiesel, the fuel is usually made from soybean oil or recycled restaurant grease.

As described in reference 26 the production processes for biodiesel are well known. "There are three basic routes to biodiesel production from oils and fats: Base catalyzed transesterification of the oil; direct acid catalyzed transesterification of the oil; or conversion of the oil to its fatty acids and then to biodiesel. Most of the biodiesel produced today is done with the base catalyzed reaction. The base catalyzed production of biodiesel generally occurs using the following steps:

> Mixing of alcohol and catalyst. The catalyst is typically sodium hydroxide (caustic soda) or potassium hydroxide (potash). It is dissolved in the alcohol using a standard agitator or mixer.

Table 6		
Fair Price / Gallon of B20 and B100 Based on Energy Content ($)		
Gasoline Price	Fair Price of B20	Fair Price of B100
2.50	2.46	2.28
2.60	2.56	2.38
2.70	2.65	2.47
2.80	2.75	2.56
2.90	2.85	2.65
3.00	2.95	2.74
3.10	3.05	2.83
3.20	3.14	2.92
3.30	3.24	3.01
3.40	3.34	3.11
3.50	3.44	3.20
3.60	3.54	3.29
3.70	3.64	3.38
3.80	3.73	3.47
3.90	3.83	3.56
4.00	3.93	3.65
4.10	4.03	3.75
4.20	4.13	3.84
4.30	4.23	3.93
4.40	4.32	4.02
4.50	4.42	4.11
4.60	4.52	4.20
4.70	4.62	4.29
4.80	4.72	4.38
4.90	4.82	4.48
5.00	4.91	4.57

Diesel BTUs per Gal = 129,500
Biodiesel BTUs per Gal = 118,296

Table 7		
Expected Miles per Gallon of B20 and B100 Based on Energy Content		
Gasoline MPG	Expected B20 MPG	Expected B100 MPG
10	9.8	9.1
12	11.8	11.0
14	13.8	12.8
16	15.7	14.6
18	17.7	16.4
20	19.7	18.3
22	21.6	20.1
24	23.6	21.9
26	25.6	23.8
28	27.5	25.6
30	29.5	27.4
32	31.4	29.2
34	33.4	31.1
36	35.4	32.9
38	37.3	34.7
40	39.3	36.5
42	41.3	38.4
44	43.2	40.2
46	45.2	42.0
48	47.2	43.8
50	49.1	45.7
52	51.1	47.5
54	53.1	49.3
56	55.0	51.2
58	57.0	53.0
60	59.0	54.8

Diesel BTUs per Gal = 129,500
Biodiesel BTUs per Gal = 118,296

Reaction. The alcohol/catalyst mix is then charged into a closed reaction vessel and the oil or fat is added. Ten pounds of fat or oil (such as soybean oil) are reacted with each one pound of a short chain alcohol in the presence of a catalyst to produce one pound of glycerin and 10 pounds of biodiesel. The system from here on is totally closed to the atmosphere to prevent the loss of alcohol. The reaction mix is kept just above the boiling point of the alcohol (around 160 °F) to speed up the reaction. Recommended reaction time varies from 1 to 8 hours, and some systems recommend the reaction take place at room temperature. Excess alcohol is normally used to ensure total conversion of the fat or oil to its esters.

Separation. Once the reaction is complete, two major products exist: glycerin and biodiesel. Each has a substantial amount of the excess methanol that was used in the reaction. The reacted mixture is sometimes neutralized at this step if needed. The glycerin phase is much denser than the biodiesel phase and the two can be gravity separated with glycerin simply drawn off the bottom of the settling vessel. In some cases, a centrifuge is used to separate the two materials faster.

Alcohol Removal. Once the glycerin and biodiesel phases have been separated, the excess alcohol in each phase is removed with a flash evaporation process or by distillation. In others systems, the alcohol is removed and the mixture neutralized before the glycerin and esters have been separated. In either case, the alcohol is recovered using distillation equipment and is re-used.

Glycerin Neutralization. The glycerin by-product contains unused catalyst and soaps that are neutralized with an acid and sent to storage as crude glycerin. In some cases the salt formed during this phase is recovered for use as fertilizer. In most cases the salt is left in the glycerin. Water and alcohol are removed to produce 80-88% pure glycerin that is ready to be sold as crude glycerin. In more sophisticated operations, the glycerin is distilled to 99% or higher purity and sold to the cosmetic and pharmaceutical markets.

Methyl Ester Wash. Once separated from the glycerin, the biodiesel is sometimes purified by washing gently with warm water to remove residual catalyst or soaps, dried, and sent to storage. In some processes this step is unnecessary. This is normally the end of the production process resulting in a clear amber-yellow liquid with a viscosity similar to petrodiesel.

Product Quality and Registration. Prior to use as a commercial fuel, the finished biodiesel must be analyzed using sophisticated analytical equipment to ensure it meets ASTM specifications. Additionally, all biodiesel produced must be registered with the Unites States Environmental Protection Agency under 40 CFR Part 79."

The US Departments of Energy (DOE) and Agriculture (USDA) have major research and development programs under way to reduce the cost of biodiesel production. These agencies have jointly funded research to identify high oil content crops with diesel market potential. DOE programs include long-term research for production of algal strains with high lipid content and development of biodiesel conversion technologies using algal lipids and higher plant oils. Use of algae as a biodiesel feedstock may have the potential to significantly reduce the cost of production. See reference 27. There are many companies pursuing algae for use as a feedstock of biodiesel production. Reference 27 lists 15 different companies and describes their approaches for producing biodiesel from algae.

Biodiesel significantly lowers polluting engine emissions, particularly hydro carbons, carbon monoxide, and nitrous oxides. The environmental benefits of biodiesel include reducing greenhouse gases and improving air quality. B20 helps reduce total hydrocarbons by 20%, carbon monoxide up to 12%, and particulate matter around 12%. Recent scientific studies of nitrous oxide or NOx impact, including the National Renewable Energy Laboratory's September 2006 findings, indicate "no significant increase in NOx for B20 blends." The 20% biodiesel in B20 contains no sulfur and helps reduce sulfur emissions. Utilizing B20 decreases these pollutants and thus reduces formation of smog and ozone. The exhaust of biodiesel is free of sulfur and doesn't contribute to the acid rain that sulfur in diesel otherwise causes. Carbon monoxide is 48% lower for biodiesel than diesel fuel. The combinations of nitrogen and oxygen are a contributor to smog and ozone. Recent studies indicate that biodiesel is neutral for these emissions. See reference 26.

"A new analysis shows that the energy balance (energy-out /energy-in) of biodiesel is a positive ratio of 3.5:1. For every unit of fossil energy needed to produce the fuel over its life cycle, the return is 3.5 units of energy, according to new research conducted at the University of Idaho in cooperation with the US Department of Agriculture (USDA). The researchers found soybean yield has increased at the rate of 0.6 bushels per acre per year from 1975 to 2006. Yet, the fertilizer application rate has essentially remained the same and the herbicide application rate has declined to one-fifth of its rate in 2000. Reduced herbicide applications have the added benefit of requiring less diesel for field spraying. At the processing level, technology improvements at soybean crushing facilities led to 55 percent less energy needed than was reported in the NREL study. Although transesterification to convert soybean oil into biodiesel has also become more energy efficient, this process only contributes a small fraction of overall energy in the lifecycle analysis." See reference 28.

65 billion gallons of petroleum distillate (diesel) were consumed in the US in 2007. This is the energy equivalent of 66.15 billion gallons of B20. If all of the diesel consumption was B20 it would require 13.23 billion gallons of biodiesel and 52.92 billion gallons of diesel to make this amount of B20. This would reduce the consumption of diesel by 12.1 billion gallons which is the equivalent of 270 million barrels of oil.

Assuming a 10 percent increase in demand, as forecast by EIA, there will be a need for 71.5 billion gallons of petroleum distillate by 2030. This is the energy equivalent of 72.8 billion gallons of B20. If all of the petroleum distillate consumption was B20 it would require 14.6 billion gallons of biodiesel and 58.2 gallons of diesel to make this amount of B20. This would reduce the consumption of diesel by 13.3 billion gallons which is the equivalent of 327 million barrels of oil.

It may be possible to produce 14.6 billion gallons of biodiesel by 2022.

5.0 Unlikely to Occur Aspects of the 2007 Energy Act

Table 8 shows the projected breakdown of total equivalent gasoline, E10, E85 and pure gasoline produced and consumed by year through 2022 using the following assumptions. The total BTU equivalent gasoline consumed is the 2006 consumption with an increase of 2 billion gallons per year, which is consistent with recent US gasoline consumption growth. The ethanol production per year is the amount mandated by the 2007 Energy Act, except for 2007 which is the actual production for that year. All gasoline will be used to produce E10 or E85. Other amounts are computed using simple algebra and assuming that all gas will be used to produce ethanol and all ethanol is used to produce

E10 until at least some of the ethanol must be used to produce E85 because there is not enough pure gasoline left to produce any more E10.

Table 8 - Maximum E10 and Minimum E85 Production vs. Year (Billions of Gallons)

Year	BTU Equiv Total Gas Consumed	U.S Ethanol Production	**Pure Gasoline Consumed**	**Maximum E10 Consumed**	**Minimum E85 Consumed**	Pure Gas Used for Max E10	Pure Gas Used for Min E85	Total Pure Gasoline Consumed
2006	140.6	4.00	102.0	40.0	0	36.0	0.0	138.0
2007	142.6	6.50	79.8	65.0	0	58.5	0.0	138.3
2008	144.6	9.00	57.7	90.0	0	81.0	0.0	138.7
2009	146.6	11.10	39.4	111.0	0	99.9	0.0	139.3
2010	148.6	12.95	23.5	129.5	0	116.6	0.0	140.1
2011	150.6	13.95	15.9	139.5	0	125.6	0.0	141.4
2012	152.6	15.20	5.8	152.0	0	136.8	0.0	142.6
2013	154.6	16.55	0	159.6	0.7	143.7	0.1	143.8
2014	156.6	18.15	0	160.4	2.5	144.4	0.4	144.7
2015	158.6	20.50	0	160.4	5.2	144.4	0.8	145.2
2016	160.6	22.25	0	161.1	7.2	145.0	1.1	146.0
2017	162.6	24.00	0	161.7	9.2	145.5	1.4	146.9
2018	164.6	26.00	0	162.1	11.5	145.9	1.7	147.6
2019	166.6	28.00	0	162.4	13.8	146.2	2.1	148.3
2020	168.6	30.00	0	162.8	16.1	146.5	2.4	149.0
2021	170.6	33.00	0	162.3	19.7	146.0	3.0	149.0
2022	172.6	36.00	0	161.7	23.3	145.5	3.5	149.0

Table 8 shows that a significant amount of E85 must be consumed starting in 2013 and that over 23 billion gallons of E85 must be consumed per year by 2022. There were approximately 250 million cars and light trucks on the road in the US in 2006. These vehicles consumed approximately 140 billion gallons of pure gasoline. That works out to approximately 560 gallons of pure gasoline consumed per vehicle per year. 560 gallons of pure gas is energy equivalent to 580 gallons of E10 and 793 gallons of E85. In 2022 there must then be at least 29 million FFVs with owners who will always choose to use E85 instead of E10 to achieve the mandated ethanol consumption in the 2007 Energy Act.

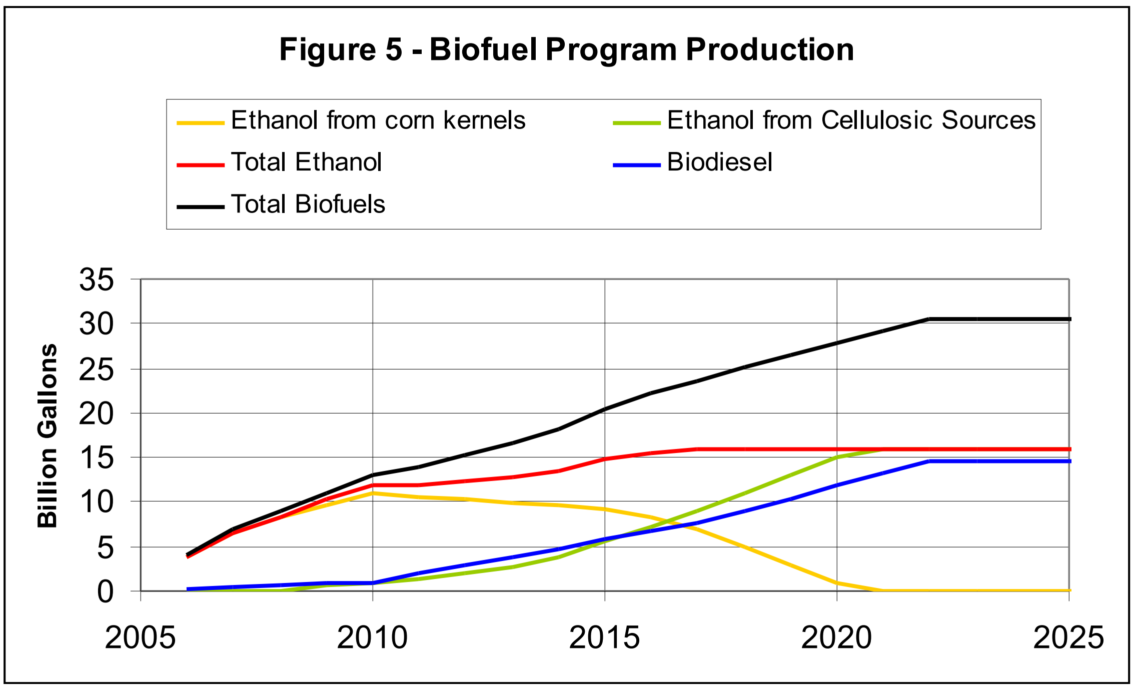
It is unlikely that all gasoline will be used to produce E10 and E85. There is no infrastructure to distribute ethanol to all parts of the country. If not all gas is used to produce E10 and E85, then the amounts of E85 that must be produced and consumed will need to be larger than shown in table 8 after 2012.

It is unlikely that there will be at least 29 million FFVs on the road by 2022. FFVs cost about $100 more than cars and trucks without this capability. It is unlikely that over 20 million vehicle purchasers will opt to select this option between now and 2022 since there is really no apparent advantage to having this capability.

It is unlikely that E85 will ever be the fuel of choice for most FFV owners. Even if the cost per gallon of E85 relative to gasoline and E10 is based on energy content (71.2 % of the cost of pure gasoline and 73.7 % the cost of E10) consumers will have to refuel their vehicles much more frequently. If a vehicle using gasoline or E10 needs to be refueled every 7 days that same vehicle will need to be refueled every 4 or 5 days if it uses E85. Given a choice, the FFV owner will pull up to the E10 pump before going to the E85 pump. If gas stations attempt to charge more for E85 than 73.7 % of the price of E10, this will further reduce the incentive to select E85 since the effective cost per mile will be better for E10. There is no incentive for gas stations to charge less than 73.7 % for E85 than E10, since that is what they need to charge to maintain an equal profit margin. Only ultra-altruistic consumers will deliberately purchase FFVs and E85, and then only when they do not mind refueling more frequently.

6.0 Biofuel Program Net Oil Displacement

Figure 5 shows US biofuel production by year assuming that E85 is eliminated and that ethanol production is limited to 16 billion gallons per year, as discussed in Chapter 5. Biodiesel production is limited to 14.6 billion gallons assuming that B20 is used to replace all petroleum distillate consumed in the US by 2022.



Approximately 8 billion gallons of ethanol can be produced using corn stover that remains after harvesting the corn kernels in US crops. The net Energy-out/Energy-in ratio for ethanol produced from corn stover is estimated to be 10:1. The net ethanol production from corn stover could be 7.2 billion gallons per year by 2022. This is equivalent to 103.8 million barrels of oil per year assuming that the energy-in is from oil.

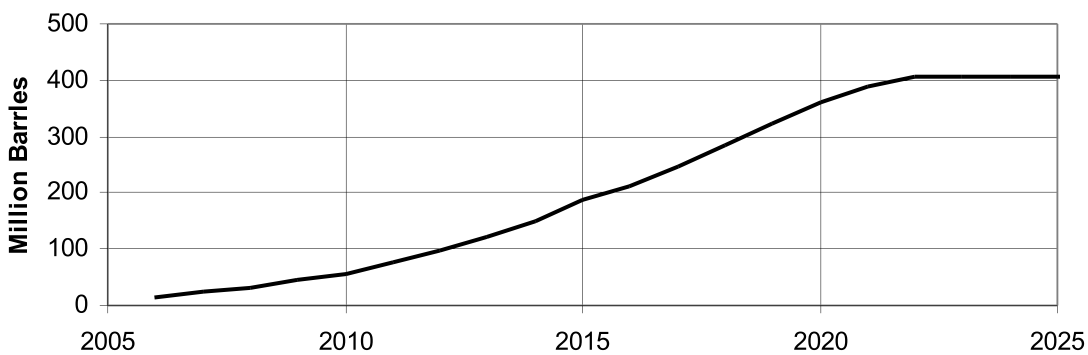
Another approximately 8 billion gallons of ethanol can be produced using switchgrass. The net Energy-out/Energy-in ratio for ethanol produced from switchgrass is estimated to be 5:1. The net ethanol from switchgrass could be 6.4 billion gallons per year by 2022. This is the equivalent to 93.3 million barrels of oil per year assuming that the energy-in is from oil.

Approximately 13.2 billion gallons of biodiesel can be produced using soybeans or canola. The net Energy-out/Energy-in ratio for ethanol produced from switchgrass is estimated to be 3.5:1. The net biodiesel production from this would be 9.43 billion gallons. This is the equivalent to 211.6 million barrels of oil per year. Technology improvements may allow this much biodiesel to be produced from algae with a higher net Energy-out/Energy-in ratio. If the Energy-out/Energy-in ratio turns out to be 7:1 the net biodiesel production would be 11.44 billion gallons per year by 2022. This is the equivalent to 256.8 million barrels of oil per year assuming that the energy-in is from oil.

The Biofuel program can result in the gross production of 30.6 billion gallons or 729 million barrels of biofuel per year by 2022.

Given that ethanol has an energy equivalence of 75,000 BTUs per gallon and biodiesel has an energy equivalence of 118,296 BTUs per gallon, the net amount of oil displaced by the Biofuels program would be 408 million barrels per year with a biodiesel Energy-out/Energy-in = 3.5. It would be 453 million barrels per year if the biodiesel Energy-out/Energy-in turns out to equal 7.5 using algae. The profile of oil displacement per year for Energy-out/Energy-in = 3.5 is shown in Figure 6.

Figure 6 - Potential US Oil Consumption Displaced by Biofuels



7.0 How to Significantly Improve the 2007 Energy Act

The 2007 Energy Act can be significantly improved through the following actions.

Change the mandate in the 2007 Energy Act that US agencies replace old worn-out vehicles with FFVs if they are available to a requirement that they replace old worn out vehicles with FFVs only if the FFV has the same or fewer cylinders than the old vehicle and then only if the FFV will be garaged within 5 miles of an existing E85 pump.

Better yet, stop producing E85 and FFVs, which are unlikely to be used very much anyway. FFV owners are more likely to purchase E10 than E85 because it would require them to refuel more often.

Limit the amount of ethanol produced to the amount needed for E10 only. This is about 16 billion gallons per year in 2013 and slightly more in the following years.

Require ethanol producers using corn as a feedstock to use DDSG instead of natural gas or coal to generate heat and electricity for ethanol production. This has the potential to significantly reduce the amount of natural gas that needs to be imported for ethanol production. It also substantially reduces the amount of greenhouse gas released into the atmosphere.

A primary goal of the ethanol program should be to produce all ethanol from corn stover, switchgrass or other cellulosic feedstocks, thus allowing corn to be phased out entirely from ethanol production. This provides a win-win situation for everyone: farmers, ethanol producers, food consumers, ethanol consumers and, last but not least, the environment.

Encourage ethanol producers to transition from corn kernels to corn stover, switchgrass or other cellulosic biomass as the production feedstock. (Note: this was accomplished in the 2008 Farm Bill via increased subsidies for cellulosic ethanol production and decreased subsidies for corn kernel ethanol production. Now it is up to the producers and farmers to make it happen.) This will substantially increase the amount of corn available for food instead of ethanol production while at the same time reducing the overall need for corn production. This will also reduce the energy needed, including natural gas, to produce ethanol. It will also substantially reduce fertilizer use and greenhouse gas emissions. Reduced fertilizer use, due to decreased corn production, will help to reduce the size of the Gulf of Mexico Dead Zone off the coast of Louisiana and Texas. Reduced greenhouse gas emissions will contribute to the reduction of global warming.

Encourage the development of switchgrass and other cellulosic feedstocks on general Conservation Reserve Program (CRP) Lands, which encompass 32,449,279 acres.

Minimize the use of soybeans, canola and other food crops for biodiesel production. Encourage biodiesel production from algae and other non-food crops. This will reduce pollution and greenhouse gas and decrease impact on food prices and availability.

Maintain and analyze detailed data on energy used to generate biofuel feedstocks and the energy-effectiveness of feedstock suppliers. This is needed to allow detailed understanding of the good and bad aspects of the biofuels program. Results can be used to identify farmers using more energy than the resultant energy of the ethanol produced and allow them to be deterred from supplying feedstocks to the program.

References (All but one is available on the Internet)

1 DOE Energy Information Agency, "Annual Energy Review 2007," June 2008 http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf

2 US Congress, “2007 Energy Act” or “Energy Independence and Security Act of 2007,” December 2007 http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

3 Kimberly Kindy and Dan Keating, “US ‘flex fuel’ mandate backfires as problems persist,” The Washington Post, November 1, 2008 http://www.bma.org.uk/ap.nsf/content/LIBReferenceStyles

4 US Congress, “The 2008 Farm Bill” or ‘‘Food, Conservation, and Energy Act of 2008 http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6124enr.txt.pdf

5 “Fueling Growth in Renewable Energy,” Legislative News, April 2008 http://www.globalethanolservices.com/Legislative_News.html

6 Anna Austin, “The Road Ahead for FFVs,” Ethanol Producer Magazine, December 2008 http://www.ethanolproducer.com/article.jsp?article_id=5010

7 BoatUS Magazine, “Ethanol Exemption Becomes Law in Oregon,” May 2008, Volume XIII (not on the internet)

8 Tiffany Groode and J. B. Heywood, “Biomass to Ethanol: Potential Production and Environmental Impacts,” Massachusetts Institute of Technology Laboratory for Energy and the Environment Report No. LFEE 2008-02 RP, February 2008 http://lfee.mit.edu/public/LFEE%202008-02%20RP.pdf

9 Hosein Shapouri, “The 2001 Net Energy Balance of Corn-ethanol,” US Department of Agriculture (USDA), Office of the Chief Economist (OCE) http://www.usda.gov/oce/reports/energy/net_energy_balance.pdf

10 Robert Bryce, “The ethanol subsidy is worse than you can imagine,” Slate, 2005 http://slate.com/id/2122961/

11 M. Wang, “Key Differences between Pimentel/Patzek Study and Other Studies,” Center for Transportation Research, Argonne National Laboratory, July 19, 2005

12 ”BP Statistical Review of World Energy,” June 2008, MS Excel Workbook http://www.bp.com/statisticalreview

13 USDA, “Long-Term Agricultural Projection Tables, Table 8 - US Corn,” Released February, 2008 http://usda.mannlib.cornell.edu/usda/ers/94005/2008/Table08.xls

14 Food and Agriculture Organization of the UN, Natural Resources Management and Environment Dept, “Bioenergy,” 2007 http://www.fao.org/nr/ben/ben_en.htm

15 DOE's National Renewable Energy Laboratory (NREL), "Enzyme Subcontract Liaison," http://www.eere.energy.gov/biomass/progs/biogeneral/obp_gate/esl.doc

16 Dan Morgan, "Brazil's Biofuel Strategy Pays Off as Gas Prices Soar," Washington Post, June 18, 2005 http://www.washingtonpost.com/wp-dyn/content/article/2005/06/17/AR2005061701440.html

17 Larry Rohter, "With Big Boost From Sugar Cane, Brazil Is Satisfying Its Fuel Needs," N.Y. Times, April 10, 2006 http://www.nytimes.com/2006/04/10/world/americas/10brazil.html?pagewanted=1&_r=1

18 "Gulf of Mexico paying price for ethanol boom," Earthnews, December 2007 http://www.earthportal.org/news/?p=748

19 A. Zarembo, "Biofuel crops increase carbon emissions," Los Angeles Times, February 8, 2008 http://www.latimes.com/news/science/la-sci-biofuel8feb08,1,7603480.story?ctrack=1&cset=true

20 DOE, Environmental Protection Agency, "Model year 2008 Fuel Economy Guide," 2008 http://www.fueleconomy.gov/feg/FEG2008.pdf

21 "Uniform Engine Fuels, Petroleum Products, and Automotive Lubricants Regulation" as adopted by The National Conference on Weights and Measures http://ts.nist.gov/WeightsAndMeasures/Publications/upload/h130-02_engreg.pdf

22 BioWillie Premium Biodiesel FAQs http://www.biowillieusa.com/faq.php#17

23 Randall von Wedel, "Technical Handbook for Marine Biodiesel," CytoCulture International, Inc., April 1999 http://www.cytoculture.com/Biodiesel%20Handbook.htm#BIODIESEL:%20Fuel%20Additive%20made%20from%20Vegetable%20Oil

24 Biodiesel Standards and Warranties, "The Biodiesel Standard (ASTM D 6751)" http://www.biodiesel.org/resources/fuelfactsheets/standards_and_warranties.shtm

25 "Biodiesel" http://www.green-trust.org/biodiesel2.htm

26 Official Site of the National Biodiesel Board, Biodiesel Fact Sheets, "Biodiesel Production and Quality," April 26, 2007 http://www.biodiesel.org/resources/fuelfactsheets/

27 Katie Fehrenbacher, earth2tech, "15 Algae Startups Bringing Pond Scum to Fuel Tanks," Earth2Tech, March 2008 http://earth2tech.com/2008/03/27/15-algae-startups-bringing-pond-scum-to-fuel-tanks/

28 Biodiesel Now, "Biodiesel Yields Even Higher Energy Balance," Feb. 6, 2008

http://www.biodieselnow.com/blogs/general_biodiesel/archive/2008/02/07/biodiesel-proven-to-have-a-significant-positive-net-energy-ratio.aspx

About the Author

The author is a retired aerospace engineer with 44 years of professional technical and management experience. He has worked for TRW Systems Group, Central Intelligence Agency/Office of Development and Engineering, and General Dynamics/Advanced Information Systems Group. He has conducted many technical analyses and studies throughout his career to support the development and operation of complex aerospace systems.

He was motivated to pursue analysis of the transportation fuel problem by reading several internet articles about the world running out of oil. It was soon discovered that many articles and reports on the internet are focused on one small aspect of the problem or are biased and present data that supports only one side of the related issues. The author has attempted to seek the truth. The above report attempts to present the important parts of the entire biofuel story in an unbiased manner with references to supporting data on the internet.

This report is an update of section 3.3 of the report "An Oil Crisis is Probably Imminent," February 13, 2008 also written by the author. This report may be found at the following website address: http://www.peakoil.net/publications/an-oil-crisis-is-probably-imminent

The author intends to continue studying this issue and publish updated versions of this report as the story unfolds and as additional information becomes available. Any <u>constructive</u> critique of the report and additional applicable information is welcomed. Please send to krberge@earthlink.net Please indicate a relationship to this report in the email subject line since the author deletes email from senders not in his address book.