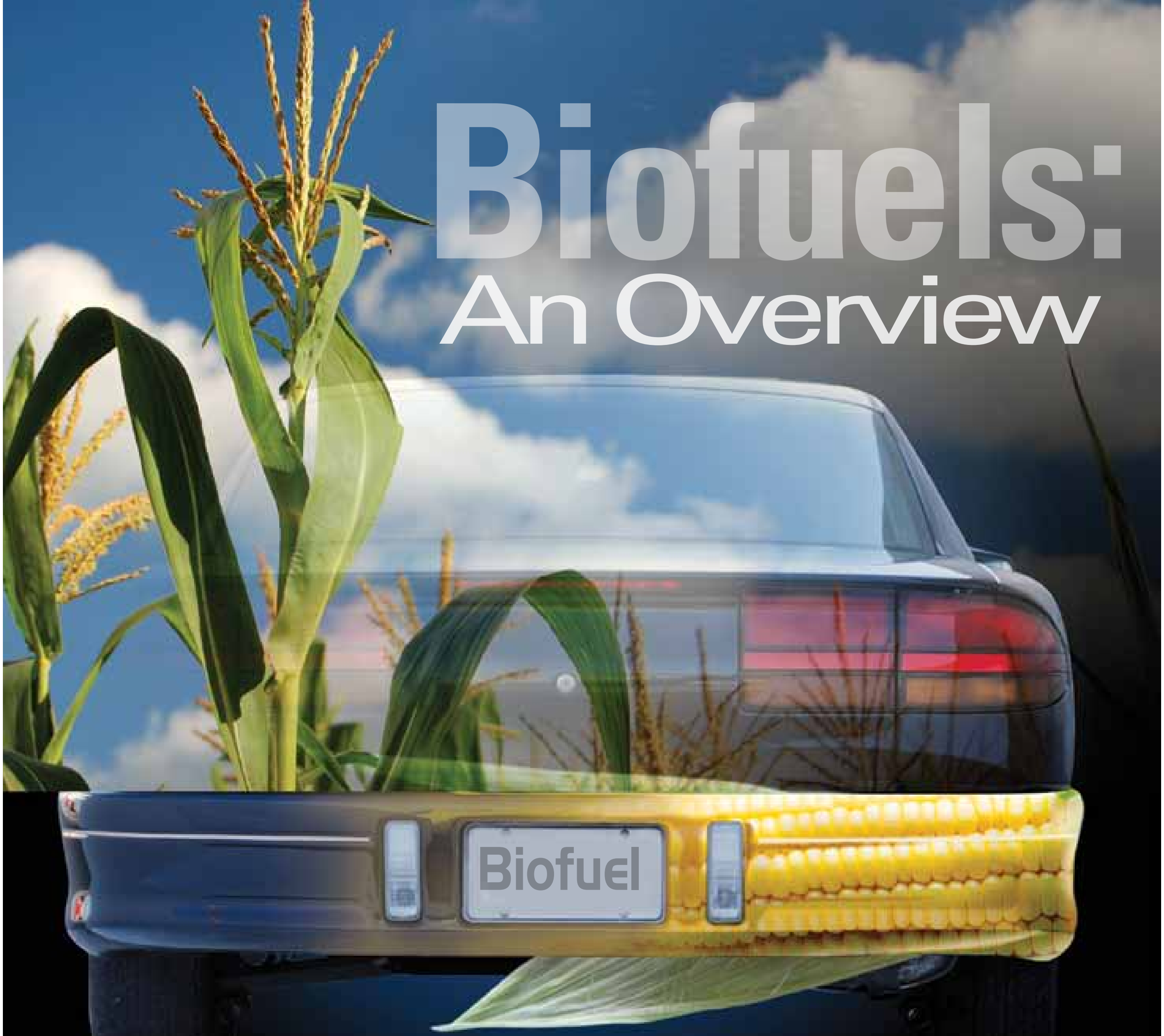
Biofuels: An Overview



The United States is the world's largest consumer of energy. Our energy needs are as diverse as they are vast. Meeting these needs in a manner that ensures a sufficient and stable supply, reduces environmental effects and fosters future economic prosperity is critical.

Energy resources are primarily dedicated to power generation, temperature regulation (heating and cooling), industrial processes and transportation. The majority of these resources are non-renewable (93 percent), which means that these resources, once extracted from the earth and consumed, are not replaced. In contrast, renewable energy sources are inexhaustible by definition, as natural processes replenish them in a relatively short time period. Petroleum products are by far the most important source of transportation fuels, accounting for 97 percent of the market. However, decreasing the US dependency on petroleum, especially from foreign sources, has generated a significant amount of interest for three reasons. First, 60 percent of the petroleum consumed in the US is imported. Secondly, almost half (41 percent) of the US imports originate from OPEC countries, some of which have a tenuous relationship with the United States. Lastly, petroleum is a nonrenewable resource that has raised serious environmental concerns due to the accumulation of atmospheric carbon dioxide, carbon monoxide, nitrogen oxides, particulate matter and unburned hydrocarbons from vehicle emissions.

Table 1 compares the major petroleum-based transportation fuels (gasoline and diesel) and the two most common biofuels: 85 percent ethanol blended with 15 percent gasoline (E85) and 20 percent biodiesel blended with 80 percent petroleum-based diesel (B20).

Comparison of Transportation Fuels

Item	Gasoline	Ethanol (E85, grain-based)	No. 2 Diesel	Biodiesel (B20)
Source	Crude Oil	Grains (corn, wheat, sorghum, etc.)	Crude Oil	Oilseeds [soybean, rapeseed (canola), etc.], animal fats, waste cooking oil
Physical State	Liquid	Liquid	Liquid	Liquid
Fossil Energy Ratio *(amount of energy it takes to produce the fuel vs. the amount of energy provided by the fuel - over 1.0 means we get more energy than it takes to produce)*	0.8	1.8	0.833	3.2
Environmental Impacts of Burning Fuel	Produces harmful emissions; changes can be made to fuel and vehicles to lower emissions	May reduce some harmful gas emissions in comparison to vehicles using gasoline	Produces harmful emissions; changes can be made to fuel and vehicles to lower emissions	Lowers most harmful gas emissions and particulate matter when compared to No. 2 Diesel

Biofuels

Non-petroleum sources of transportation fuels include natural gas (2.2 percent) and biofuels (1.1 percent). While used in small amounts now, demand for biofuels (**ethanol** and **biodiesel**) is expected to increase as United States energy policy aims to: 1. increase reliance on domestic fuel sources, 2. identify and expand the use of more cost-effective and efficient renewable fuel alternatives, and 3. decrease the amount of carbon released by transportation fuel usage. Biofuels differ from other renewable energy sources (such as wind, hydroelectric, geothermal and solar), as they are primarily used in the transportation sector and are derived from recently living matter, both plant and animal (as opposed to fossil fuels which are derived from long dead "fossil" plant and animal remains).

Ethanol

Ethanol has become a major player in alternative fuels over the last few years. Our nation uses approximately 384 million gallons of gasoline each day. That amounts to more than 140 billion gallons each year. Ethanol is one of these renewable fuels that can be produced within our nation's borders. The feedstocks, conversion and distribution all take place within the country. With recent federal legislation, national goals are to replace 30 percent of our petroleum consumption with biofuels, such as ethanol.

Ethanol (commonly known as grain alcohol or ethyl alcohol) is a component of alcoholic beverages, is used in many industrial applications, and can be used as a liquid fuel. It is made up of oxygen, hydrogen and carbon (CH_3CH_2OH) and is made by fermenting sugars or converted starch into alcohol. The chemical makeup of ethanol is the same, whether it is made from grains or plant materials.

Ethanol Production —The Basics

Ethanol is produced by the fermentation and subsequent distillation of sugars obtained from plants (feedstock). In the United States, ethanol is produced using the grains from edible starch crops such as corn (90 percent), wheat, barley and sorghum. Edible sugar crops, primarily sugar cane, are used outside the U.S. Another promising feedstock is lignocellulose, obtained from the biomass of trees and grasses. Regardless of the crop, the goal is ethanol. The difference comes from how the feedstock is processed to maximize sugars.

Producing Ethanol from Grain

Traditionally, alcohols, including ethanol, have been produced from corn and other grains. Field corn is the primary choice, because a kernel of corn is approximately two-thirds starch, the component that ethanol manufacturers depend upon. In early 2008, production levels of corn ethanol reached 8.1 billion gallons per year at 143 plants in the United States. The type of corn used for ethanol production is field corn—not the "sweet" corn used for human consumption. A general expectation of corn ethanol is that one bushel of corn produces 2.8 gallons of fuel through one of two primary methods: wet milling and dry milling.

In the wet milling process, the grain is soaked in a dilute water and acid mixture–which begins to break down the celluloses and starches into sugars. The resulting mixture, or slurry, is then passed through a variety of separation procedures to separate out four main parts: corn oil, gluten, fiber and starch. These three components are often dried and sold as animal feeds as it is high in protein content and is in demand by animal producers. The remaining starch is put into a fermentation process with yeast, which metabolizes the starch in the absence of oxygen, and produces ethanol and carbon dioxide. The resulting liquid is transferred to distillation columns where the ethanol is separated from the residual mash. The ethanol is then processed to remove any residual water, and once that is complete, the result is pure ethanol.

In the dry milling process, the corn grain is ground into flour called "meal" and mixed with water to form the mash. Enzymes, proteins that accelerate chemical reactions, are added to the mixture and convert the starch to dextrose, a simple sugar. The mash is then heated to a high temperature to kill any bacteria prior to fermentation. After heating, the mash is fermented in a similar method to wet milling. In dry milling, the mash left after fermentation is dried and sold as dried distillers grains with solubles (DDGS) as an animal feed. The carbon dioxide from the process can be captured and often used for other purposes, such as carbonating soft drinks.

Producing Ethanol from Cellulosic Materials

Another source of sugars to manufacture ethanol comes from cellulose, which is found in the walls of plant cells and is one of the most common organic compounds on earth. By using cellulose to create ethanol, a wide variety of new sources of sugar are available for ethanol production, and producers do not have to rely on a specific grain commodity. Materials commonly used for cellulosic ethanol include corn stalks, wood residues and chips, wheat straw, fast-growing trees, native grasses and sugarcane.

Cellulosic ethanol technologies, however, are not as well developed as the grain technologies. The primary difference between the two is that it is difficult to access and free the cellulose in plant cells. Another challenge lies in converting cellulose to simple sugars for fermenting. Two different processes, biochemical conversion and thermochemical conversion, can be used to access cellulose and convert it into simple sugars. Once these processes are complete, the fermentation process is identical to ethanol made from grain.

Common Concerns about Ethanol Production

Water usage in producing ethanol is an issue. Making one gallon of gasoline from petroleum takes about 1.5 gallons of water. Ethanol from corn takes about 4 gallons of water for every gallon produced. Current cellulosic ethanol production technology requires 5-9 gallons of water per gallon of ethanol made. However, demand for fresh water can be significantly reduced by recycling it through wastewater treatment prior to reuse in the production process.

Producing ethanol from corn may have an impact on food and feed prices and availability. As the ethanol industry has developed, more corn has been diverted from traditional markets to ethanol production. While demand may have some impact on corn prices and availability, it is important to look at the bigger picture to assess the situation. As petroleum prices increase, so do costs of things depending upon petroleum. Fertilizer, herbicides and pesticides that crop producers depend upon are derived in some way from petroleum. Input costs have gone up dramatically since 2007, with some pesticide costs doubling. Fuel costs for planting, harvesting and transporting corn have also increased. Concern has also been raised about the amount of corn exported from the US to other countries. Many nations depend upon our corn for their food supplies. In reality, though, US corn exports have increased, up 6 percent between 2006 and 2007, to their highest levels since 1990.

All of these factors, including demand, have affected corn prices. Higher corn prices may impact food markets, as it will cost more to feed animals and more to buy products derived from field corn. There is a limit to the amount of ethanol that can be produced from corn without significantly impacting food and related markets. This is one reason why cellulosic ethanol, produced from crops with less effect on food commodities, is continuing to be developed.

Ethanol Uses

Ethanol is most commonly used in the transportation sector as a fuel additive that enhances fuel combustion and reduces tank-to-wheel emissions. A blended fuel with up to 10 percent ethanol and 90 percent gasoline (E10) can be used in any gasoline-powered vehicle. Flex-fuel vehicles are designed to use blends of gasoline/ethanol between 100:0 (pure gasoline) and 15:85 (E85, or 85 percent ethanol). In the US, no road vehicles can use 100 percent ethanol due to the design of current engines.

Biodiesel

Biodiesel fuel is widely used throughout the transportation, construction and agricultural industries of the United States. Biodiesel debuted with the invention of the first diesel engine in the late nineteenth century. Rudolph Diesel's first diesel engines used peanut oil, and eventually other vegetable oils, as fuel. Biodiesel is now making a comeback more than 80 years after the introduction of the petroleum-derived No. 2 diesel. Presently, commercial production of biodiesel is soybean- (U.S.) or canola- (rapeseed in Europe) oil-based, but some producers also recycle greases and oils or use animal fat. Biodiesel is typically blended with petroleum-based diesel (B20 is 20 percent biodiesel).

Biodiesel Production —The Basics

Biodiesel is not raw vegetable oil! Although using raw vegetable oils in a diesel engine will work, the oils are thicker than biodiesel and can clog fuel filters and leave significant deposits in the engine. Biodiesel is a refined fuel, meaning that these impurities have been removed.

Biodiesel is produced by combining fatty oils with alcohol. Sources of these oils include agricultural crops, such as soybeans, canola and peanuts, recycled restaurant "fry" greases and oils, algal oils and animal fats often obtained from a meat processing facility. Regardless of the oil source, all oils must be purified to remove water and other impurities prior to the biodiesel conversion process. (Note: Producing biodiesel from algae is a relatively new technology and has not yet been commercialized.)

To produce biodiesel, these oils go through a transesterification process. The clean oils are mixed with an alcohol, most often methanol, and a catalyst like sodium hydroxide. The catalyst enables the transesterification reaction to proceed in a highly efficient manner, yielding fatty acid methyl esters and glycerin as products. When the reaction is complete, a layer of glycerin mixed with unreacted alcohol and catalyst is removed from the methyl ester-rich layer. The alcohol is recovered and reused. The glycerin by-product is recovered, refined and used in cosmetics and other industries. The methyl esters are, in reality, biodiesel. The biodiesel is "washed" several times through a filtering process to remove residual amounts of catalyst materials and glycerin.

Biodiesel Uses

Biodiesel is sold in a variety of ways. Most often, it is sold as a blend with regular diesel. These blends can be B-10 (10 percent biodiesel, 90 percent diesel), B-20 (20 percent biodiesel, 80 percent diesel), and so on up to B-100 or 100 percent biodiesel. As opposed to a fuel like ethanol, using biodiesel does not require significant engine modifications. Current diesel engines can burn biodiesel at low blend rates without mechanical problems.

Materials commonly used for biofuels include soybeans, sugarcane, switchgrass and corn.

Many farm machines at the ARS' Beltsville, MD Agricultural Research Center are running on a mixture of diesel fuel and biodiesel.

Biodiesel Benefits

Benefits derived from the production and uses of biodiesel are less controversial than grain-based ethanol. Biodiesel feedstocks involve recycling fats and oils or the use of readily available vegetable oils. Environmental benefits are rooted mainly in the almost across-the-board lower emission levels compared to burning petroleum-based No. 2 diesel. Sulfur-based emissions are reduced or eliminated and emissions of particulate matter, carbon monoxide and hydrocarbons (total and aromatic) are also reduced, even with blends that contain up to 80 percent No. 2 diesel. In 2007, petroleum-based diesel consumption in the United States was 64.6 billion gallons. In early 2008, the U.S. had the capacity to produce more than 2.2 billion gallons of biodiesel per year or the equivalent of just over 3 percent of total petroleum diesel consumption.

Connection of Biofuels to Soils and Agronomy

Biofuels can be a part of national and international strategies to move towards a sustainable energy infrastructure. Because these fuels rely on renewable resources they are by definition renewable. One major consideration that must be taken into effect is that the production of these fuels relies on our soil resources and proper crop and agronomic practices.

The production of crops for biofuels presents many new agronomic challenges. Whether using a traditional cropping system (such as corn or soybeans) for a "new" purpose or developing a new cropping system (like switchgrass) for cellulosic biofuel, understanding the effects these alternative systems have on our soil resources is of utmost importance. Initial research suggests that some potential biofuel crops, particularly perennial grasses, have relatively low soil nutrient input requirements, yet removal of large quantities of biomass from these systems are likely to have long-term effects on soil productivity.

The affect of biofuel cropping systems on soil chemical and physical properties will ultimately impact the sustainability and viability of using crops as alternative energy resources, since many of these crops will often be grown on marginal lands of limited use for traditional row cropping systems or as an alternative to row crops in some locations.

Over the years agronomists, crop scientists and soil scientists have worked to develop management practices that can protect the soil resources while improving crop production. For example, the effects of fertilizer and crop rotation treatments on corn yield have been studied at the Morrow Plots. Yields were lowest in continuous corn and the highest in a three-year rotation, whether or not the soil was fertilized. These practices must be followed when crops are grown for biofuels as well. Only through this approach can the renewable and sustainable promise of biofuels be attained.

Conclusions

Biofuels continue to contribute to the attainment of the energy-related goals of the United States, including increasing energy security and reducing the environmental degradation linked to transportation fuels. Demand for biofuel production will increase as new technologies are deployed and adopted by producers and consumers. The composition of feedstock for biofuel production, such as grain, will continue to grow. Ongoing research and management practices will be crucial in ensuring the availability of our soil resources.

Adapted with permission from the following:

Jackson S. Ethanol: A Primer. Available on www.utbioenergy.org/TNBiofuelsInitiative/ (accessed 06/11/2010). The University of Tennessee, Knoxville, TN.

Jackson S. Biofuels: A Primer. Available on www.utbioenergy.org/TNBiofuelsInitiative/ (accessed 06/11/2010). The University of Tennessee, Knoxville, TN.

Wilcox M., Lambert D., Tiller K. Biofuels "101." Available on www.utbioenergy.org/TNBiofuelsInitiative/ (accessed 06/11/2010). The University of Tennessee, Knoxville, TN.

Ron Gehl, personal communication, 06/10/2010.

Reference:

The Morrow Plots: A Landmark for Agriculture http://agronomyday.cropsci.illinois.edu/2001/morrow-plots/

Photos: USDA-ARS

Visit www.soils.org/lessons
for more soil resources and a classroom exercise on soil, plants, and the energy cycle.

Soil Science Society of America
www.soils.org