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Biofuels '101' SP700-A

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Introduction

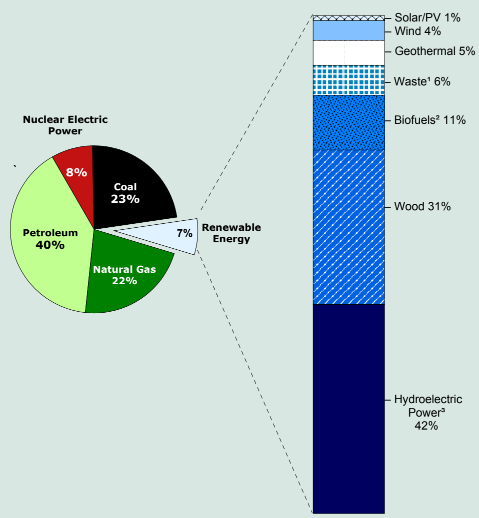
The United States is the world's largest consumer of energy. Our energy needs are as diverse as they are vast. Meeting these needs in a manner that ensures a sufficient and stable supply, reduces environmental effects and fosters future economic prosperity is critical. Achieving these goals has implications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

Energy consumption is generally classified by end users. The four primary consumers in the United States are the industrial (32 percent), transportation (28 percent), residential (22 percent) and commercial (18 percent) sectors. These sectors use a variety of energy resources (Figure 1). 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.[1] In contrast, renewable energy sources are inexhaustible by definition, as natural processes replenish them in a relatively short time period.

Energy resources are primarily dedicated to power generation, temperature regulation (heating and cooling) and industrial processes. Transportation also plays a significant role. Petroleum products are by far the most important source of transportation fuels, accounting for 97 percent of the market. However, decreasing our 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 United States is imported. As Table 1 shows, our top 15 foreign petroleum sources – representing 85 percent of all oil imports in 2006 – originate from several countries that are unstable, according to the Failed State Index. Secondly, almost half (41 percent) of our imports originate from OPEC countries, some of which have a tenuous relationship with the United States. Lastly, petroleum is a non-renewable 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.

Figure 1. U.S. Renewable Energy as Share of Total Energy, 2006



Source: Energy Information Administration. Annual Energy Review, 2006.
http://www.eia.doe.gov/emeu/aer/pdf/pages/sec10_2.pdf
[1] Municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural byproducts and other biomass.
[2] Fuel ethanol and biodiesel consumption, plus losses and co-products from the production of fuel ethanol and biodiesel.
[3] Conventional hydroelectric power.

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.

Table 2 compares the major petroleum-based transportation fuels (gasoline and diesel), compressed natural gas and the two most common biofuels: 85 percent ethanol blended with 15 percent gasoline

Table 1: Top 15 Origins of U.S. Petroleum Products and Indication of Country Stability

Country	Percent of US Petroleum Imports (2006)	Stability Index[a] (1 = Most, 177 = Least)
Canada	16.9	10
Mexico	12.5	76
Saudi Arabia	10.7	95
Venezuela	10.3	104
Nigeria	8.2	161
Algeria	4.8	89
Iraq	4.1	176
Angola	3.9	125
Russia	2.7	113
U.S. Virgin Islands	2.4	18[b]
Ecuador	2.0	105
United Kingdom	2.0	20
Norway	1.4	1
Brazil	1.4	61
Kuwait	1.3	54

Sources: Energy Information Administration. Petroleum Navigator. 20 June 2007
http://tonto.eia.doe.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_m.htm
and Foreign Policy. The Failed States Index 2007. 20 June 2007
http://www.foreignpolicy.com/story/cms.php?story_id=3865&page=0
[a]This index is comprised of 12 social, economic and political indicators.
[b]Rank for the United States

(E85) and 20 percent biodiesel blended with 80 percent petroleum-based diesel (B20). Table 3 provides a basic comparison of the vehicles that use these fuels.

Ethanol

Ethanol is commonly known as grain alcohol or ethyl alcohol. Ethanol is a component of alcoholic beverages and is used in many industrial applications. Its use as a fuel began with the invention of the automobile. More recently, ethanol is the subject of intense interest because of its potential to supplement or replace petroleum-based transportation fuels.

Ethanol Production – The Basics

Ethanol is produced by the fermentation and subsequent distillation of sugars obtained from plants (*feedstock*).[2] 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. A promising feedstock is lignocellulose, obtained from the biomass of trees, grasses and forest or food crop residues. Lignocellulosic feedstocks are relatively cheap to produce and use less production inputs.

The primary difference between feedstocks, when used in ethanol production, is the method through which the desired sugars are obtained. The simplest process is associated with sugar crops. These crops produce simple sugars that can be directly extracted by milling. Sugar cane is approximately one-third simple sugar (sucrose) and two-third biomass (*bagasse*).[3] Starchy crops (e.g., corn) require additional steps before fermentation, as the starches must first be converted into their constituent simple sugars. This occurs through wet or dry milling.

Approximately 75 percent of grain-based ethanol is produced through dry milling and 25 percent through wet. Dry milling is less capital-intensive and results in the production of a single co-product, distiller's dried grain with solubles (DDGS) used as animal feed. Wet milling is more capital-intensive but results in more co-products. Dry milling requires grinding of the corn kernel to extract the starch, while wet milling uses a chemical solution to break down the corn kernel into its useful components (germ, fiber, gluten and starch). Heat, water and enzymes are used to transform starch into simple sugars (dextrose).

At this time, the most complex feedstock is lignocellulosic biomass. Its anticipated advantages over grain-based feedstock have made it the subject of intense research and development. Current research focuses on how to obtain the simple sugars in the most efficient and cost-effective manner. Lignocellulosic biomass derives its name from its cellulose, lignin and hemicellulose components, which are found in virtually all plant cells as the main constituents of the cell wall. These components are more complex than simple sugars and starch and require relatively more intensive pre-fermentation (pretreatment and hydrolysis) steps to obtain the desired simple sugars. The properties of the lignocellulosic

Table 2. Comparison of Transportation Fuels

Item	Gasoline	Ethanol (E85, grain-based)	Ethanol (E85, cellulose-based)	No.2 Diesel	Biodiesel (B20)	Compressed Natural Gas (CNG)
Source	Crude oil	Grains (corn, wheat, sorghum, etc.)	Energy crops (trees, shrubs and grass), agricultural residues, forest residue and municipal solid waste	Crude oil	Oilseeds (soybean, rapeseed (canola), etc.), animal fats, waste cooking oil	Underground reserves
Physical State	Liquid	Liquid	Liquid	Liquid	Liquid	Compressed gas
Fuel Availability	All fueling stations	41 states have at least one station; only 7 have more than 50 – all Midwest	Cellulose-based ethanol is not commercially available but is the same as grain-based.	Select fueling stations	45 states have at least one station; only North and South Carolina have more than 50 stations.	More than 700 stations in US; 25 percent located in CA
	For local information: http://www.eere.energy.gov/afdc/infrastructure/locator.html					
National Average Cost in Energy Equivalent Prices[a] ***(as of October 2007)***	$2.76/gal	$3.39/gal (gasoline)	Not commercially available	$3.11/gal	$3.14/gal (diesel)	$1.77/gal (gasoline) / $1.98/gal (diesel)
	For more information: http://www.eere.energy.gov/afdc/resources/pricereport/price_report.html					
Environmental Impacts of Burning Fuel[b]	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.	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.	Reduces gas emissions and particulate matter in comparison to vehicles using gasoline.
Energy Security Impacts	Majority of current and future production based on imported oil.	Produced domestically	Produced domestically	Majority of current and future production based on imported oil.	Produced domestically	Produced domestically

Source: Adapted from Energy Efficiency and Renewable Energy Alternative Fuels Data Center Home Page. Fuel Comparison Chart. 9 June 2003. Accessed 20 June 2007 http://www.eere.energy.gov/afdc/fuels/properties.html

[a] Data from Energy Efficiency and Renewable Energy Alternative Fuels Data Center Home Page. October 2007 Alternative Fuel Price Report. October 2007. Accessed 11 January 2008. http://www.eere.energy.gov/afdc/pdfs/afpr_oct_07.pdf and prices are listed in energy equivalents for comparison across substitute fuels.

[b] This refers to tank-to-wheel emissions, which include evaporative and direct-use emissions.

Table 3. Comparison of Alternative Fuel Vehicles

Item	Gasoline	Ethanol (E85, grain-based)	Ethanol (E85, cellulose-based)	No.2 Diesel	Biodiesel (B20)	Compressed Natural Gas (CNG)
Types of Vehicles Available	For more information about currently available vehicle types and brands, see your local car/truck dealer or visit http://www.eere.energy.gov/afdc/afv/afdc_vehicle_search.php or http://www.fueleconomy.gov/feg/byfueltype.htm					
Vehicle Conversion Information[a]	N/A	Only flex-fuel vehicles can operate using E85.[b] No legal conversion options are available. All gasoline-powered vehicles can operate using blends of up to 10 percent ethanol (E10).	Only flex-fuel vehicles can operate using E85.[b] No legal conversion options are available. All gasoline-powered vehicles can operate using blends of up to 10 percent ethanol (E10).	N/A	Contact original equipment manufacturer and consult engine warranty statement before use. In general, all diesel vehicles can run on a blend of up to 5 percent biodiesel (B5) and more recent vehicles on 20 percent blend (B20) without modifications. Higher biodiesel blends (>20 percent) will likely require some modifications.	Vehicles converted from gasoline to CNG need to follow EPA regulations.
Additional Maintenance Issues	N/A	Special lubricants may be required. Replacement parts often specific to flex-fuel vehicles.	Special lubricants may be required. Replacement parts often specific to flex-fuel vehicles.	N/A	Filters, hoses and seals should be inspected and changed per original equipment manufacturer and consult engine warranty statement.	High-pressure tanks that hold CNG require periodic inspection and certification by a licensed inspector.[c]

Source: Adapted from Energy Efficiency and Renewable Energy Alternative Fuels Data Center Home Page. Fuel Comparison Chart. 9 June 2003. Accessed 20 June 2007 http://www.eere.energy.gov/afdc/fuels/properties.html

[a] *For more information on the regulations for conversion from gasoline to alternative fuels,see: http://www.eere.energy.gov/afdc/vehicles/conversions.html*

[b] *For more information about flex-fuel vehicles, see: http://www.eere.energy.gov/afdc/vehicles/flexible_fuel.html*

[c] *For more information about certified cylinder inspectors, see: http://webext.csa.ca/cng/*

biomass are dependent on its feedstock source and the pretreatments, both chemical and mechanical. The enzyme-driven hydrolysis (a process to break down cellulose) must be paired appropriately to efficiently obtain the simple sugars. As with other feedstocks, lignocellulosic biomass results in a co-product, lignin, which can be used to generate power. Once the simple sugars are obtained from the plant material, the fermentation and distillation process used to make ethanol is identical to grain-based feedstocks.

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. Over the past few years, flex-fuel vehicles have been introduced into the American automobile market at affordable prices. Flex-fuel vehicles are designed to use blends of gasoline:ethanol between 100:0 (pure gasoline) and 15:85 (E85, or 85 percent ethanol). While the number of flex-fuel vehicles on the road increases each year, a limiting factor to their wholesale adoption nationwide has been the limited availability of E85 fuel. For example, as of July 2007, fewer than 10 stations had E85 publicly available in Tennessee. However, the number of stations should increase as the industry develops.

Ethanol Benefits

Ethanol as a transportation fuel has many benefits. Energy-balance benefits (how much energy is required to produce one unit of ethanol energy) vary depending on the feedstock. Lignocellulosic ethanol likely has a much better energy-balance profile than its grain-based counterpart. In addition, ethanol is produced from domestic feedstock sources and has been shown to have environmental benefits by lowering tailpipe emissions.

Biodiesel

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.[4] 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 composed of fatty acid methyl ester molecules. These molecules are obtained by combining oils or fats with methanol (an alcohol like ethanol) and a catalyst that promotes the chemical reaction. The reaction, called transesterfication, results in biodiesel and glycerol. Glycerol can be sold as a co-product. Biodiesel can be produced on a small or large scale, but fuel-quality issues provide a reason to be sure that purchases are made from reputable retailers. Soybean oil's relatively low price has made it the mainstay of commercial biodiesel production in the United States.

Biodiesel Uses

Biodiesel is commonly sold in a B20 blend form as a transportation fuel. Any biodiesel blend containing 20 percent or less of biodiesel can be used without harm in conventional diesel engines. Blends that are more than 20 percent biodiesel typically require slight vehicle modifications, such as changing the fuel filter more often than usual at the onset of use and the replacement of fuel hoses and fuel pump seals to those that are designed for use with high levels of biodiesel fuel. Consulting the vehicle owner's manual, warranty and the dealership where the vehicle was purchased is highly recommended prior to using blends higher than B20.

Temperature may also effect the performance of vehicles using biodiesel. Some recommend using higher-level biodiesel blends during the warmer months and increasing the No. 2 diesel content during the colder months to avoid clouding (a gelling of the fuel that can also occur with conventional diesel at very cold temperatures).

Biodiesel Benefits

Benefits derived from the production and use of biodiesel are well known and less controversial than grain-based ethanol. Feedstock for biodiesel is produced domestically and has a net positive estimated energy balance, which means that for every unit of energy used to produce biodiesel, more than one unit (actually 3.24) of energy results. Also, 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. There is some evidence that nitrogen oxide levels may increase with the use of biodiesel, but this may be mediated though the use of additives and depends on the type of engine in use. In any case, 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.

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. But when grain production has reached full capacity, alternative feedstocks will be needed to meet demand. The potential economic implications of biofuel production are wide-ranging and warrant further attention, especially in rural areas where the feedstocks originate.

Footnotes

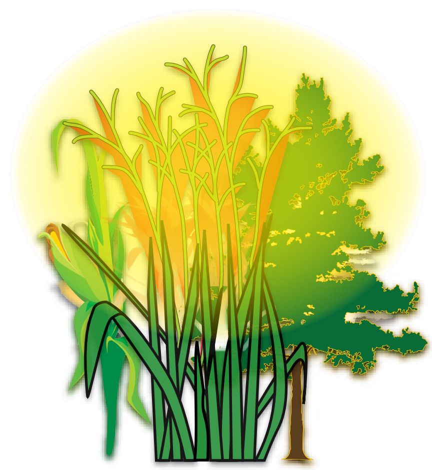
1 A small fraction of the natural gas consumed in the United States is derived from renewable sources such as animal offal, but this is accounted for in "Waste" under Renewable Energy.

2 For more detailed information about ethanol production, please see:

(Basic)-(Grain based)
http://www.eere.energy.gov/afdc/fuels/ethanol_production.html
(Basic)-(Cellulose based)
http://www.eere.energy.gov/afdc/fuels/ethanol_research.html
(Intermediate)
http://www.ethanolrfa.org/resource/made/
and
(Intermediate)
http://www.ces.purdue.edu/extmedia/ID/ID-328.pdf.

3 Bagasse can be used to power the ethanol production facility and may be fermented into bioethanol (cellulosic) as technologies improve.

4 While strictly speaking not biodiesel, vegetable oils are the feedstock for the majority of biodiesel produced today.



The University of Tennessee Biofuels Initiative

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