BIOFUELS FOR TRANSPORTATION: A CLIMATE PERSPECTIVE

SOLUTIONS WHITE PAPER SERIES

by

Naomi Peña

PEW CENTER ON Global CLIMATE CHANGE

BIOFUELS FOR TRANSPORTATION: A CLIMATE PERSPECTIVE

Prepared for the Pew Center on Global Climate Change

by

Naomi Peña
June 2008

The author and the Pew Center would like to thank John Sheehan of LiveFuels and all others who reviewed and provided advice on previous drafts of this report. We would also like to acknowledge the late Alex Farrell, who provided a very helpful review of this paper and who made a major contribution to the biofuels field.

Contents

Executive Summary

As the United States seeks to reduce greenhouse gas (GHG) emissions from motor vehicles and to lessen its dependence on imported oil, biofuels are gaining increasing attention as one possible solution. This paper offers an introduction to the current state of play for biofuels: the technologies used in their production, their GHG emissions, and associated policy issues.

The amount of emission reductions that can be achieved through the use of biofuels varies widely, depending on choices made at each step from feedstock selection and production through final fuel use. Technologies exist today to produce a wide variety of biofuels from a wide range of feedstocks. However, currently commercial options are limited to ethanol made from cornstarch or sugarcane, and biodiesel made from soybean or palm oil seeds. Current research and development focuses on lowering biofuel costs, GHG emissions, and land and water resource needs, and on improving compatibility with fuel distribution systems and vehicle engines. Policy priorities should be aligned with these R&D objectives as well as with other policies addressing climate, agriculture, forestlands and international trade.

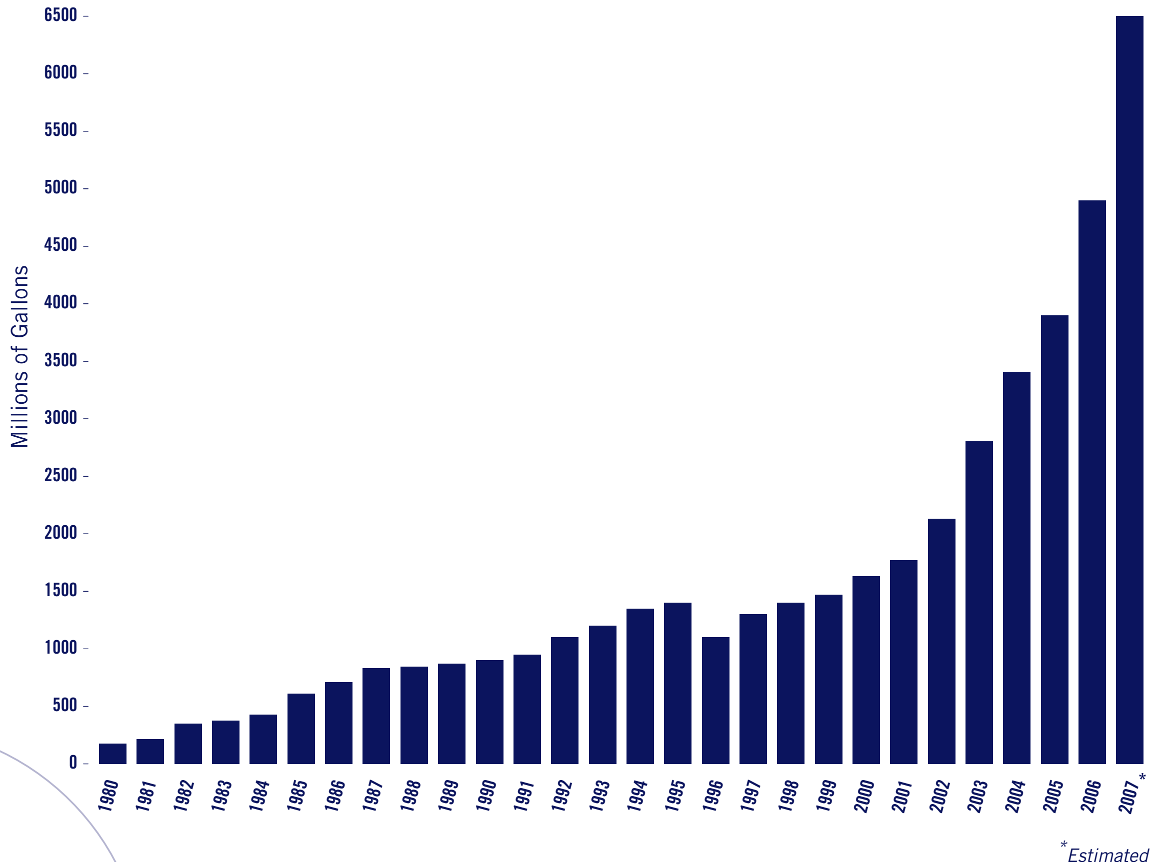
The critical issue when considering the climate benefits of biofuels is each fuel's GHG profile—not whether it is "renewable" or "fossil-fuel"-based. Also, vehicle efficiency is especially important for biofuels because less overall fuel demand means less competition with other uses for land and biomass. Therefore, policies to encourage further development and use of biofuels for climate-related purposes should focus on their GHG profiles and on increased vehicle efficiency. In addition to climate change and energy security, the opportunity to support the agricultural sector is an extremely important and powerful motivation for pursuing biofuels worldwide. However, any benefits to the agricultural sector must be weighed against impacts on food prices and land use, both of which are also major international concerns.

State of Play: Current and Emerging Biofuel Pathways

Biofuel use on the rise. Interest in biofuels is escalating not only in the United States, as shown in Figure 1, but also worldwide.

The dramatic rise in U.S. ethanol production is due to four factors: (1) the substitution of ethanol for MTBE, a gasoline additive that had been used to reduce emissions of carbon monoxide[1] from vehicles but has been banned in a number of states; (2) increases in renewable fuel mandates at the state and federal levels; (3) subsidies and tariffs that create hurdles to entry of Brazilian ethanol into the U.S. market; and (4) the lack of GHG performance requirements. Interest in biofuels is escalating worldwide for a variety of reasons, including concerns about energy security, rising petroleum prices, and climate change, and the opportunity to increase and diversify agricultural and export income.

Figure 1: U.S. ethanol production 1980–2007



Source: Renewable Fuels Association, January 2008

At the same time that biofuels are attracting new interest and investment, concerns are growing about competing objectives for water and land resources. These competing objectives include: producing adequate food at reasonable prices; producing feed and timber products; removing carbon dioxide from the atmosphere and storing it as carbon; mitigating climate impacts; providing habitat for threatened species; and providing plant material for heat and power. In addition, governments, scientists, environmental groups, and others are recognizing the need for improved methods to account for the GHG emissions caused by using plants to produce transportation fuels. In particular, better estimates of emissions due to land-use changes are needed.

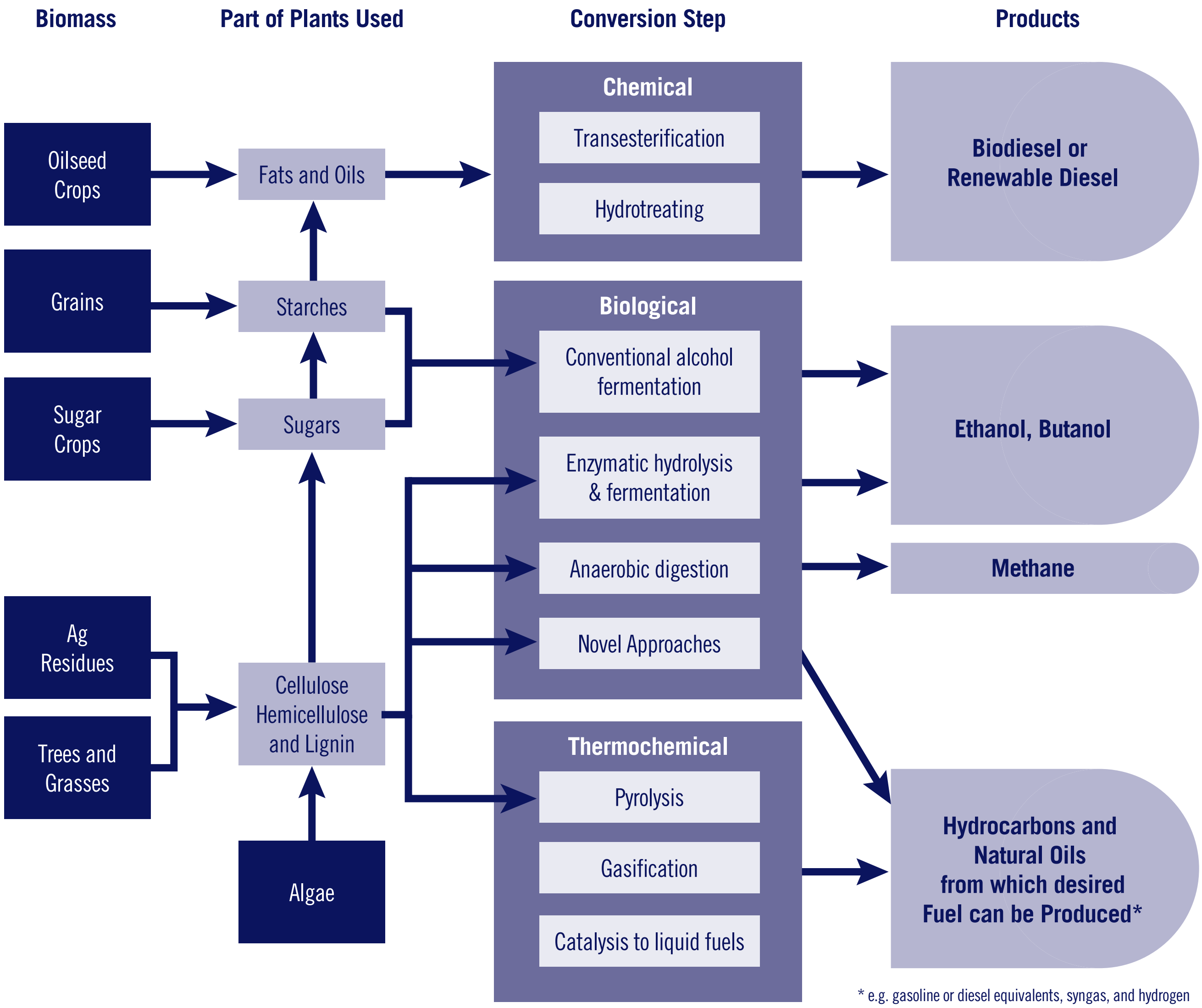
Biofuels in various stages of pre-commercial research and development promise a number of important advances, including the potential to: significantly lower GHG profiles; reduce conflicts with food, animal feed, land, and water; and improve compatibility with existing infrastructure and vehicles. Corporate, federal, and nonprofit research is rapidly enhancing prospects for commercial use of a wider range of feedstocks, conversion processes, and end products. Due to expectations of market growth, new companies are forming to focus on specific steps in the production and distribution process—i.e., feedstock production, conversion technology, or marketing. In addition, existing companies with expertise in specific steps are exploring partnerships.

As indicated by Figure 2, known processes can convert almost any plant material into a transportation fuel. Processes currently considered commercial include fermentation[2] of cornstarch and sugarcane to produce ethanol, and transesterification[3] of oils to produce biodiesel. Corn-to-ethanol is the predominant commercial biomass-based transportation-fuel pathway in the United States today. This pathway involves fermenting starch-derived sugars from corn kernels, using natural gas for the energy needed in the conversion process, producing ethanol, and transporting the ethanol to retailers using infrastructure separate from gasoline pipelines. The separate infrastructure is needed because current pipelines are not designed to carry gasoline-ethanol mixes due to the propensity of ethanol to absorb contaminants and water.[4]

In Brazil, the primary feedstock for producing ethanol is sugarcane, with crop wastes (called bagasse) used for the conversion process energy. The United States, Brazil and China are the world's largest ethanol producers, producing 4.8, 4.5, and 1 billion gallons respectively in 2006 (http://www.ethanolrfa.org/industry/statistics). In Europe, more biodiesel is produced than ethanol, with rapeseed used as the primary feedstock.

While only a few of the pathways shown in Figure 2 are currently commercial, each is the subject of ongoing research and development. Among the most promising of these pathways are the following: production of ethanol, butanol or related products using enzymes to break down cellulose[5] (enzymatic hydrolysis); production of gasoline or diesel equivalents through gasification or pyrolysis[6] of plant material; production of any of the end products shown in Figure 2, via any of the conversion processes, using algae as the feedstock; and use of algae as a mechanism to produce oils or sugars easily convertible into fuels. As new products come online, it will be critical that standard-setting for fuels keeps pace.[7]

Figure 2: Current and Emerging Biofuel Pathways

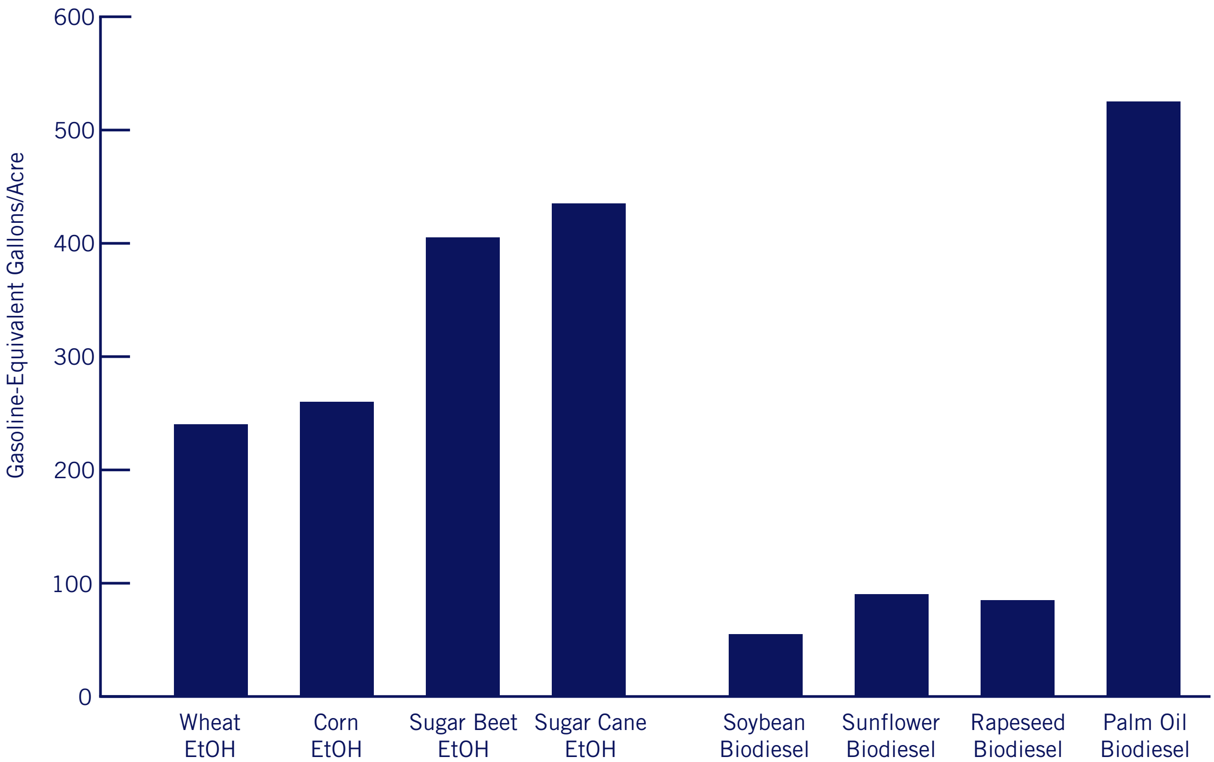


Source: Peña and Sheehan, 2007.

As shown in Figure 2, a very wide variety of feedstocks are in current use or under development to produce biofuels.[8] These feedstocks differ significantly in per-acre yields, types of lands on which they can be grown, and fuels into which they are processed. Of feedstocks that are in use right now, sugar beets, sugarcane, and palm oil yield the highest amounts of fuel per acre on a gasoline-equivalent basis (Figure 3). It is necessary to convert biofuels to their gasoline-equivalents because, for example, ethanol contains only 66 percent as much energy per gallon as a gallon of gasoline.[9]

Emerging feedstocks drawing the attention of companies with a U.S. presence include algae, crop wastes, jatropha, perennial grasses, short rotation woody crops, and forest-industry wastes. Key features sought in new feedstocks for biofuels include: low costs; high per-acre productivity; limited competition with food and feed for land and fresh water; low fertilizer inputs; reduced tillage; and ease of producing fuels compatible with existing vehicle engines and delivery infrastructure. Among emerging feedstocks, jatropha currently can be converted to biodiesel with commercial processes, while processes capable of converting algae, crop wastes, perennial grasses, wood and wood wastes are still at pre-commercial stages.

Figure 3. Fuel Yield, Selected



Sources: Edwards et al., 2007; Kaltner et al., 2005; Wang, 2008.

Note: The chart only shows fuel yield per acre for a given biofuel production pathway. In addition to fuel yields, many of the pathways produce large amounts of by-products such as animal feeds.

Today's commercial processes convert only simple sugars, starches, or oils to biofuels. However, the vast majority of plant material is in the form of cellulose, hemicellulose, and lignin.[10] Processes capable of converting the energy in cellulose to fuels represent one pathway to significantly limiting competition for land and water resources. Further, once the cellulose is extracted, the lignin can be used as the source of energy needed to convert plant materials to transportation fuels. The use of plant wastes for conversion energy in the Brazilian sugarcane-to-ethanol process results in ethanol with a very low GHG profile, and cellulosic-based ethanol where lignin is used for the conversion energy is expected to have a similarly attractive GHG footprint.

Efforts to commercialize cellulosic conversion processes have focused on three paths: (1) developing enzymes capable of breaking cellulose down (enzymatic hydrolysis); (2) heating plant materials in oxygen-depleted environments to create syngas that can be converted to liquid fuels (pyrolysis and gasification); and (3) hydrocracking (use of high-pressure, high-temperature catalysts and hydrogen) to produce hydrocarbons. Pyrolysis, gasification, and hydrocracking hold promise for creating biomass-based petroleum equivalents, i.e., biocrude, biogasoline, and biodiesel fuels that would be virtually indistinguishable from, and even have advantages over, their petroleum-based counterparts.

The advantages that could accrue from development of biofuels with small GHG, land and fresh water footprints at competitive prices have led the U.S. Departments of Agriculture and Energy (USDA and DOE) to offer over $18 million for research, development and demonstration of advanced biofuel technologies. Near-commercial projects funded or in negotiation for funding by DOE are shown in the Appendix. The expected financial and market rewards have resulted in a number of corporate collaborations. Perhaps best known is the collaboration uniting DuPont's expertise in biochemicals with BP's expertise in fuel characteristics and marketing. Other collaborations include: Shell and HR Biopetroleum, a firm with algae production experience; and Chevron and Weyerhaeuser, which have undertaken a joint venture to develop low-cost, low-GHG-profile transportation fuels from cellulose feedstocks.

State of Play: Biofuel Production Costs and Biomass Availability

Biofuels usually are more expensive to produce than petroleum-based fuels. The exceptions are Brazilian sugarcane-based ethanol and biodiesel produced from waste greases and oils. In fact, most biofuel produced in both Europe and the United States has only been competitive in the market due to subsidies, with biodiesel needing larger per-gallon subsidies than ethanol.[11] Current petroleum prices are, however, altering this dynamic. The costs of biofuels relative to petroleum products change not only as petroleum prices change but also as feedstock, natural gas, and by-product prices change. For biodiesel, the most important factor is feedstock cost, which accounts for 80 percent of production costs, whereas in the case of ethanol each of these factors can play a significant role.

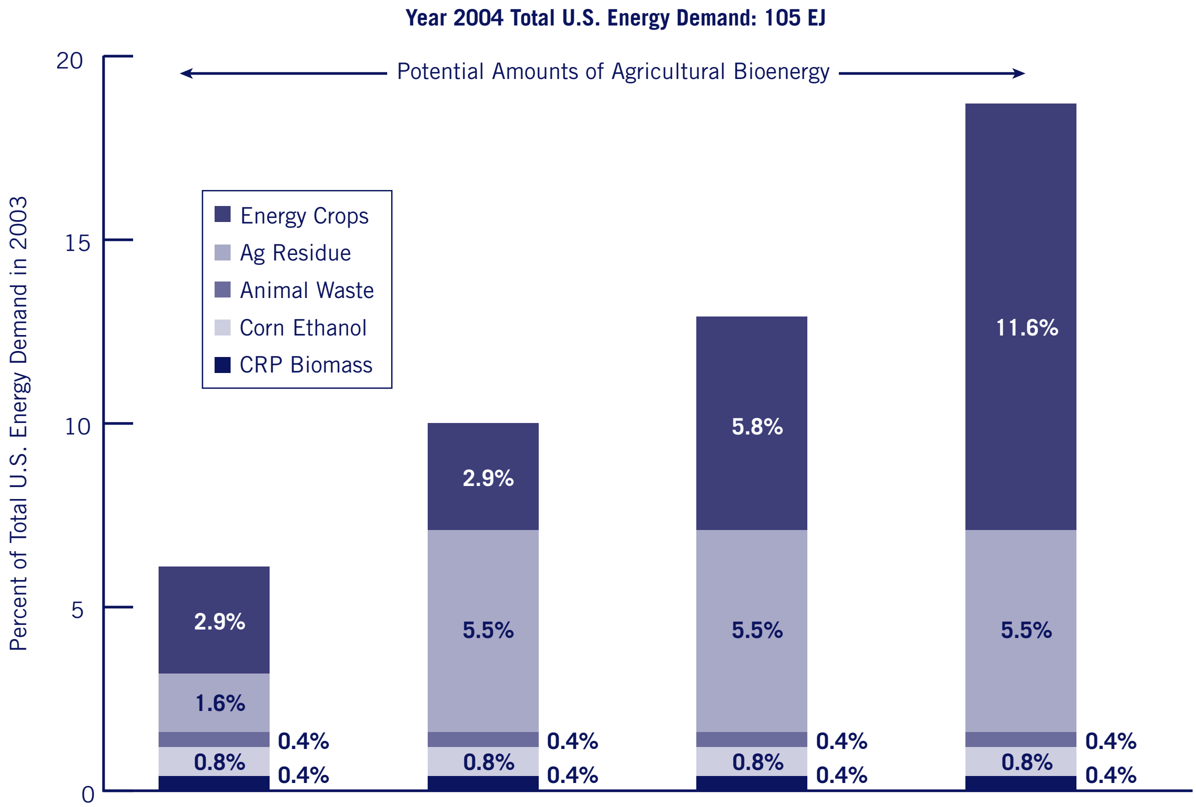
Corn and sugarcane ethanol costs. When corn is available at $2.60 per bushel and natural gas at $5.70 per gigajoule, U.S. ethanol production costs are about $1.20 per gallon of ethanol, or $1.82 per gallon on a gasoline-equivalent basis (gge), a cost that includes a $0.40 per gallon credit from sale of co-products (Paustian et al., 2006).[12] Adding a 12-percent return on investment raises the cost to $1.33 per gallon of ethanol ($2.20 per gge). Every $1.00 per bushel rise in the price of corn increases the production cost of ethanol by $0.35 per gallon. Since 2006, the spot market price for corn has regularly exceeded $4.00 per bushel (Caesar et al., 2007). At that price, ethanol production cost, including a return on investment, is about $2.77 per gge (Rotman, 2008; Eidman, 2008). Given these costs, U.S. cornstarch ethanol is competitive with gasoline (i.e., would not need a subsidy to compete in the market) when refiner acquisition cost[13] is in the $66 per barrel to $91 per barrel range for corn prices in the $2.60 to $4.00 range.

Brazil produces sugarcane-based ethanol at costs significantly below those of cornstarch-based ethanol—and, indeed, at lower costs than any other biofuel worldwide. The estimated cost of the Brazilian biofuel is $0.85 to $1.40 per gge (IEA, 2004; Fagundes de Almeida, et al., 2007). This makes Brazil's product at least 30 percent less expensive than U.S. ethanol from cornstarch (Davis and Etter, 2007). Indonesia and Malaysia also can produce biofuels at costs substantially below U.S. costs (Kaltner et al., 2005). However, the United States—along with Australia and countries in the European Union—imposes tariffs or import duties that reduce the competitiveness of imported biofuels. Where low-cost imported biofuels have lower GHG footprints than domestic biofuels, these import fees both increase consumer costs and reduce biofuels' potential to contribute to emission reduction goals (Doornbosch and Steenblik, 2007; GTZ, 2006; Paustian et al., 2006).

Biomass supply and costs. There are large uncertainties in estimates of the amount of energy that could be supplied by biomass both domestically and globally. Estimates of the amount of global energy that could be supplied by biomass in 2050 range from 40 to more than 1,000 exajoules (EJ).[14] To put these numbers in perspective, 40 EJ is close to current global biomass-derived energy (10 percent of global energy demand). On the other hand, 1,000 EJ conceivably could be enough to meet total 2050 energy demand (UNDP, 2000; GTZ, 2006). Factors that contribute to this wide range of estimates include uncertainty about future crop yields and prices, water availability, and competition for land.

Estimates for the United States show a similarly wide range. Figure 4 shows estimates of the amount of energy that could be produced if a maximum of 15 percent of current U.S. agricultural lands were dedicated to supplying biomass for energy.[15] These estimates range from a low of 6.5 EJ to almost 20 EJ. Estimates of biomass from all sources by 2050, including trees and forest wastes, range up to 1.3 billion tons (Perlack et. al., 2005). These 1.3 billion tons would be useful for biofuels only if processes to convert cellulosic materials become commercial. How much of this biomass might realistically be converted into transportation fuels depends on the costs of these cellulosic feedstocks, as well as on: efficiencies of the conversion processes; other production costs; and prices of competing transportation fuel options, including electric- and hydrogen-powered vehicles and biofuels from algae should they be commercially available by 2050.

Figure 4. Potential Energy Supply from Biomass: Four Scenarios



Scenario 1: Current yield for energy crops. Moderate conventional crop yield and practice improvements. 6.5 EJ per year. 27% of on-road petroleum demand.

Scenario 2: Current yield for energy crops. High conventional crop yield and practice improvements. 10.6 EJ per year. 44% of on-road petroleum demand.

Scenario 3: 3x yield for energy crops. High conventional crop yield and practice improvements. 13.7 EJ per year. 57% of on-road petroleum demand.

Scenario 4: 4x yield for energy crops. High conventional crop yield and practice improvements. 19.8 EJ per year. 82% of on-road petroleum demand.

Source: Paustian, et al., 2006.

Just as the cost of feedstocks plays a large role in costs of current ethanol and biodiesel products, feedstock costs are expected to play a similarly significant role in cellulose-based fuel costs, and therefore in amounts that can be economically produced. It has been estimated, for example, that if cellulosic conversion costs decrease by half and their efficiencies improve considerably, cellulose-based biofuels could be economically competitive at a farm-gate feedstock price of $30 per dry ton or less (again, this depends on petroleum prices and other factors). At this price, however, it is estimated that only 500 million dry tons of biomass would be available by 2025 from a combination of woody crops, wood and agricultural wastes, and perennial grasses grown as energy crops (http://www.bioweb.sungrant.org). The fact that cellulosic conversion costs likely need to decrease by half to be competitive is illustrative of the cost challenges facing emerging biofuel options. It will take significant, consistent expenditures in biofuel R&D for the emerging pathways shown in Figure 2 to become cost-competitive with petroleum fuels.

State of Play: Biofuel GHG Footprints

For biofuels to assist in meeting transportation demand, biomass must be grown and converted into a fuel, and the fuel delivered to market and used in vehicles. A fuel's GHG profile or footprint is the sum of GHG emissions caused by its production, distribution, and use. This type of analysis is sometimes called cradle-to-grave, well-to-wheels, or life-cycle analysis. The GHG profile is the appropriate measure to use—in conjunction with total amounts of fuels produced, vehicle mileage efficiency, and total miles driven—to determine the overall impact of fuels on a nation's GHG emissions. In the case of both biofuels and petroleum-based fuels, choices made along the production-distribution-use pathway can have significant impacts on the fuel's overall GHG profile.

The stage at which most emissions occur is different for petroleum- and biomass-based fuels. In the case of biofuels, most emissions result from crop (feedstock) production and conversion of feedstocks to transportation fuels. However, different production and conversion pathways result in significantly different GHG footprints for different biofuels. For example, Brazilian sugarcane-based ethanol, which uses plant wastes for the conversion energy, reduces GHG emissions by 80 to almost 100 percent relative to the use of petroleum (Wang et al., 2008). On average, U.S. cornstarch-based ethanol facilities, where natural gas is the most commonly used conversion energy, reduce GHG emissions by about 20 percent (Wang, et al. 2007).

In the case of petroleum-based fuels, most emissions occur during combustion, with fewer emissions due to production and conversion processes (i.e., oil extraction and petroleum refining). No CO_2 emissions are attributed to combustion of biofuels because it is assumed that new plant growth during a subsequent growing cycle will remove as much CO_2 from the atmosphere as is released during combustion. In the case of combustion of petroleum in vehicles, the CO_2 released into the atmosphere is included in the GHG footprint because this CO_2 results from combustion of carbon that had been stored in geologic reservoirs for eons and currently no available technology is capable of capturing and returning this CO_2 to the reservoirs.[16]

From a climate perspective, the critical issue is neither the stage at which emissions occur nor whether the fuel is derived from plants or fossil fuels. The critical issue is the fuel's overall (total) GHG profile. For example, if the United States or California adopts a low-carbon fuel mandate, as has been proposed in California,[17] each fuel's GHG profile would need to be known to determine whether firms are in compliance with the standard.

Developing GHG profiles, however, is not an easy task. It is challenging to design scientifically based, equitable methodologies for estimating GHG profiles for both petroleum and bio-based fuels, as well as for use of electricity or other potential energy-source options. Uncertainties about the emissions resulting from land-use changes make the job especially hard for biofuels. Estimation methods must: ensure a level playing field among all transportation fuel options; include emission sources along the entire production-distribution-use pathway; gain acceptance by a wide range of stakeholders; and be sufficiently, accurate, transparent and practical for widespread use.

In practice, not all GHG emissions can be included in a fuel's GHG footprint; choices must be made as to which emissions to include. In the case of biofuels, for example, emissions from the manufacture and use of fertilizer to produce a feedstock are usually included, but emissions related to the building of the fertilizer plant itself generally are not.

GHG Emissions from Feedstock Production

Current and prior land-uses, management practices, crop choices, and per-acre yields determine the GHG emissions due to feedstock production for biofuels.

Land-use changes. It is doubtful that current models provide reliable estimates of emissions resulting from biofuel-related land-use changes (Kammen et al. 2007). Many available model results have been obtained assuming only modest land-use changes, or even no land-use changes. Recent literature suggests that these assumptions may have resulted in a significant underestimation of CO_2 emissions due to land-use change. However, this more recent literature also relies on estimates and assumptions, many of which merit further investigation.

Obtaining reliable estimates of emissions due to land-use changes is extremely difficult because these emissions result from both "direct" and "indirect" land-use changes. Conversion of grasslands to corn to make ethanol, or of tropical forests to palm plantations to make diesel fuels, are examples of direct land-use changes. In the United States, it is expected that millions of acres currently enrolled in the U.S. Conservation Reserve Program, most of which is now grassland, will convert to cropland in response to increased ethanol demand and higher corn prices as contracts expire (Greenwire, 2008).

Indirect land-use changes occur when land is converted to food and fiber production to take advantage of rising prices or unmet demand related to the production of biomass for energy. Indirect land conversion can take place in nations far removed from biofuel demand. Of particular concern is the conversion of forests, peats, grasslands, or wetlands in developing countries as a result of biofuel mandates in developed countries.

Land-use changes occur for a variety of reasons, including the need to meet rising demand for food due to rising populations and incomes. Thus, separating out land-use change emissions induced by biofuel demand is challenging and requires making a number of estimates and assumptions. Assumptions must be made regarding the impacts on land-use of: population and income growth; land-use policies; and changes in yields and management practices resulting from higher agricultural prices, better information, and higher incomes. In addition to estimates of how much land converts due to biofuel demand, critical assumptions include which lands convert for this purpose and the ultimate fate of the carbon on those lands (Searchinger, 2008).

Recent experience in the United States shows the difficulties inherent in making relevant estimates of land-use change due to increased biofuel demand. Due largely to demand for corn for ethanol, 2007-08 U.S. corn prices reached $5.12 per bushel in January 2008 (E&E News, 2008),[18] and U.S. farmers devoted more land to corn production, as would be expected (http://www.ers.usda.gov/AmberWaves/February08/Features/CornPrices.htm.). However, U.S. corn exports in 2007 were also higher than at any time in the preceding decade (National Corn Growers Association, 2008). Therefore, if land conversion took place internationally, it would not be attributable to a lowered supply of corn on the market. Rather it would it would have been due to commodity price increases, for instance the higher soy prices induced by U.S. farmers devoting less cropland to soy production.

CO_2 emissions from land-use conversion can be counter-balanced by the substitution of biofuels for fossil fuels over a number of production-and-use cycles.[19] However, the fact that feedstocks grown in one country can be used to produce biofuels that will be used in another country creates challenges. Under current international climate change agreements, each nation is responsible for the GHG emissions—and gets credit for emission reductions—that occur within its national boundaries. Under this paradigm, a developing country might be held responsible for emissions due to land-use changes while a developed country might benefit from the reductions achieved by using the fuels.

Further complicating the effort to create equitable agreements is the fact that developing countries are currently converting native ecosystems to agriculture whereas developed countries underwent this process some time ago. For example, in the northern hemisphere, only about 20 percent of land remains in forests, whereas almost 40 percent of land in the southern hemisphere is still forested (Blaser, 2006). As a consequence, the United States and Europe are significantly more likely than developing countries to produce biomass for energy on land that has already converted—i.e., its conversion-related emissions occurred in the past. One approach that might resolve some of these difficulties would be for each country to be held responsible for the life-cycle GHG emissions of the biofuels it uses.[20]

Other land-use changes—for instance, growing grasses or trees on degraded lands—will *remove* CO_2 from the atmosphere. The carbon from this process that ends up stored in the plants or soils reduces any emissions attributable to biofuels from such lands. Finally, some land-use changes—for example switching from one row crop to a different one—may have little or no CO_2 impact. In the United States, for example, cropland devoted to corn increased by nearly 20% between 2006 and 2007 (USDA, 2008). To the extent that the corn acreage increase resulted from planting corn rather than, for example, soy, any emission changes would be modest in comparison with emissions due, for example, to conversion of old growth forest, and would be due to differences in management practices.

Management practices and crop choices. Management practices and crop choices also affect GHG emissions. For example, no-till practices, which are suitable to some crops and locations, can remove CO_2 from the atmosphere, while switching from no-till to conventional tillage can result in GHG emissions until soils reach a new equilibrium. Similarly, the amount and timing of fertilizer use as well as application methods determine nitrous oxide (N_2O) emissions, which can be a very significant part of a biofuel's GHG profile.[21] In the case of U.S. ethanol produced from corn, for example, emissions from fertilizer use are estimated to represent 25 to 30 percent of the total GHG profile. Per-acre crop yields also influence GHG emissions, with higher per-acre yields associated with lower emissions per gallon of biofuel. Soybeans, for example, typically yield 440 liters of oil per hectare per year while palm can yield 4,000 liters or more (Fagundes de Almeida et al., 2007; http://journeytoforever.org/biodiesel_yield.html). For each unit of fossil fuel used in the production process nine units of energy are obtained when palm oil is used, whereas only three units are obtained if soybeans are used (GTZ, 2006).

GHG emissions due to conversion processes. Emissions due to the conversion process are determined by two key factors: (1) the energy efficiency of the process (i.e., the amount of energy in the final product per unit of energy used in the conversion process); and (2) the type of energy used. In the case of ethanol from cornstarch, an animal feed (DSG) can be produced from unfermentable portions of the corn kernel, and some portion of emissions due to conversion energy can be attributed to the co-products rather than to the ethanol. If markets for co-products saturate, the unfermentable material could supply the process energy, significantly reducing GHG emissions and fuel costs, but also reducing income. Co-products can have very significant implications for determining the GHG profile of a fuel, and how large—or even whether—any portion of emissions should be attributed to such co-products is an area of controversy.

As can be seen in Figure 2, conversion processes fall into three major categories: chemical, biological, and thermochemical.[22] The most efficient processes may be those that combine two or more processes and use the entire plant. Transesterification to produce biodiesel is more energy-efficient than fermentation to produce ethanol. The ratio of the energy in corn-based ethanol to energy used in conversion is 1.5-to-1 compared to the 9-to-1 and 3-to-1 ratios for palm and soybean-based biodiesel. To the extent that fossil fuels are used for the energy needed in the conversion process, fermentation results in more GHG emissions per unit of energy in the biofuel than transesterification. In the case of sugarcane-based ethanol, biomass is used instead of fossil fuels for the conversion energy, with the result that conversion-related emissions for sugarcane-based ethanol are in the same range as those for palm-oil-based biodiesel. For both of these pathways, the ratio of energy in the fuel to fossil energy used to produce the fuel ranges from about 4-to-1 under "worst-case" assumptions to 10-to-1 under "best-case" assumptions (Fagundes et al., 2007).[23]

Of the multiple biofuel pathways suggested by Figure 2, only a few have been studied sufficiently to be able to provide quantitative estimates of their GHG emissions. Figure 5 shows GHG emissions per gallon of gasoline equivalent for a number of ethanol pathways and one biodiesel pathway. As shown, ethanol produced using current, average production and conversion technologies (the bar labeled "ethanol-corn average") provides a modest emissions improvement—about 20 percent—compared to gasoline use, with biodiesel doing significantly better.

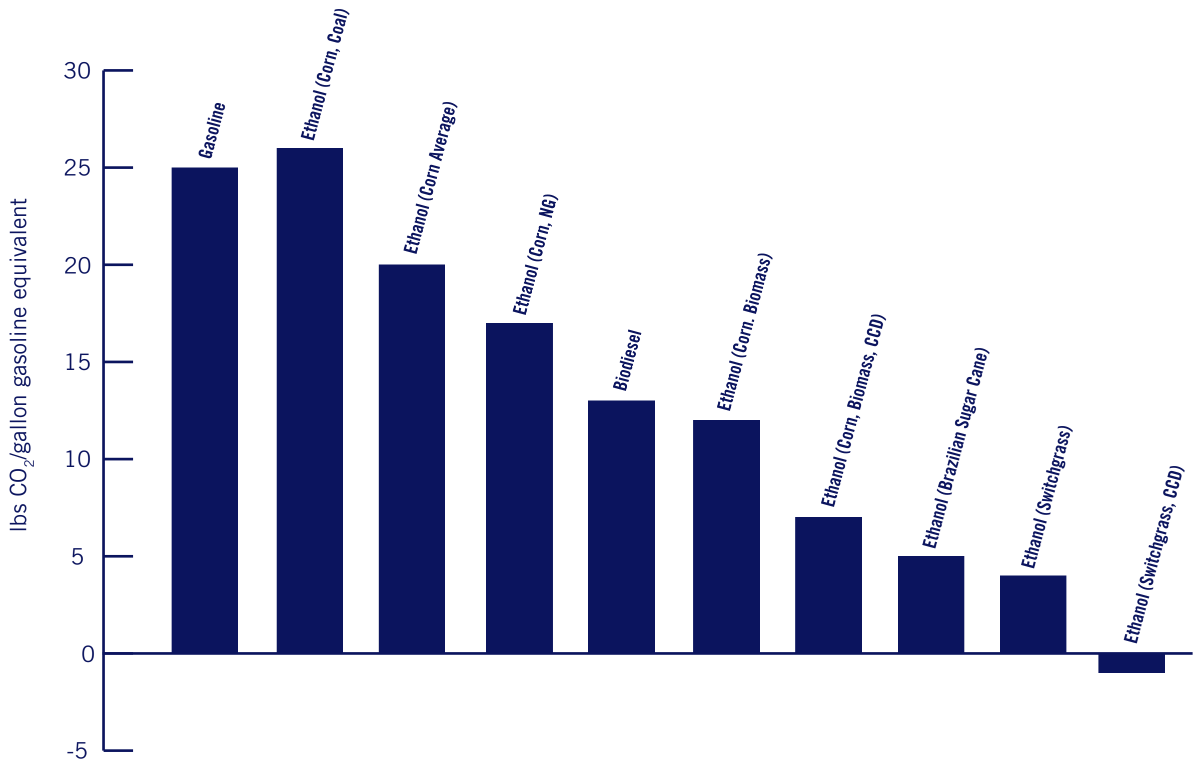


Figure 5. "Well to Wheels" CO_2 Emissions from Alternative Fuels

Sources: Adapted from NRDC: "Getting Biofuels Right"; http://www.nrdc.org/air/transportation/biofuels/right.pdf. Wang et al., 2008.

Notes:

1. "Well to Wheels" is another term for "life-cycle."

2. These estimates include emissions due to U.S. land-use changes estimated to occur at the 4 billion gallon production level. Current U.S. production is already over 6 billion gallons, so the estimates of emissions due to land-use change are already out of date. No emissions due to land-use change are included for Brazilian ethanol because available studies to date indicate that ethanol production does not induce land-use change in Brazil (Fagundes, et. al. 2007).

3. NG = natural gas

4. CCD = carbon capture and disposal. In effect, some of the CO_2 removed from the atmosphere during photosynthesis is not returned to the atmosphere but rather is permanently (or for very long time periods) kept out of the atmosphere. Storage of CO_2 in geologic formations is one way to do this.

5. The negative emissions shown in the case of ethanol produced from switchgrass with the use of CCD mean that this pathway would remove more CO_2 from the atmosphere than is emitted.

Figure 5 also shows that if coal is used for the conversion energy, ethanol fails to reduce GHG emissions compared to gasoline use. On the other hand, if biomass is used for the conversion energy, emissions are reduced by about half. Furthermore, if an ethanol plant captures and stores its CO_2 emissions in geologic formations, emissions could be about one-third of those from gasoline use. Storing CO_2 emissions from ethanol plants is considerably easier and less expensive than storing CO_2 emissions from the current fleet of coal-fueled plants. The ethanol production process results in a relatively pure CO_2 exhaust stream, whereas the exhaust stream from power plants includes some CO_2 but is largely composed of nitrogen. Thus, to enable storage, the CO_2 in coal-plant emissions has to be separated from other gases, a costly and energy-intensive process.

Non-GHG Biofuel Impacts

In addition to impacts on GHG emissions and food, feed and timber prices, biofuel production can affect water supply; habitat and ecosystems; soil, air, and water quality; and recreational opportunities. Conversion of forest, peat, or grasslands to row crops is particularly controversial because it can cause loss of, or damage to, pre-existing ecosystems. Such conversion can also have negative impacts on soil, air, and water quality and on water availability. On the other hand, if carried out on degraded lands, including degraded forests, production of feedstocks for biofuels can have a positive impact on the same parameters—for example, building soil fertility and water retention capacity, and improving habitat and biodiversity.

In this context, it is important to bear in mind that conversion of forests, peats, and grasslands—including for food, feed, or fiber production; domestic provision of transportation fuels; or residential or industrial use—is likely to occur in many southern hemisphere countries as part of their economic development. Differences in stage of development create differences between developed and developing countries' perspectives and ranking of priorities. Discussions are underway in a number of fora both within and outside of the United Nations Convention on Climate Change (UNFCCC) process to find suitable mechanisms to address these differences and the resulting controversies. One possibility is to use policies that differentiate between developed and developing countries as has been done in the UNFCCC (http://unfccc.int/resource/docs/convkp/conveng.pdf) and Kyoto Protocol.

State of Play: Policy and Legislative Issues

Federal, state, county, and local governments currently support biofuels in a variety of ways. This support falls into two general categories: (1) policies that mandate levels of use for biofuels; and (2) policies that subsidize biofuels. Subsidies have been offered at every step of the value chain—from feedstock production and conversion to distribution, retailing and consumption. These subsidies have been provided through a wide variety of mechanisms, including tariffs, crop price supports, grants, tax incentives, preferential loan and credit treatment, below-market provision of land and infrastructure, and R&D funding (Koplow, 2006).

Under the Energy Policy Act of 2005, U.S. renewable transportation fuels are scheduled to reach 7.5 billion gallons by 2012. The 2007 Energy Independence and Security Act requires 36 billion gallons of ethanol by 2020, with 21 billion gallons coming from "advanced" biofuels such as cellulose-based ethanol. In order to reach this target, federal support for R&D will most likely need to escalate significantly. Without significant R&D successes, consumer costs for advanced biofuels will be quite high. Engineering studies suggest that with today's technologies, the cost of advanced biofuels would exceed gasoline costs by a factor of two (though as noted previously these relative costs change based on changes in petroleum, feedstock, natural gas, and by-product prices).[24] Moreover, if subsidies for cornstarch ethanol remain at current per gallon payment levels, total costs, and therefore total taxpayer liability, will increase in concert with production increases.

Subsidies for U.S. ethanol. The need for subsidies for cornstarch-based ethanol has come into question recently, particularly as petroleum prices have reached levels that can render even U.S. ethanol cost-competitive. Further, price supports for corn and subsidies for biofuel producers do not qualify as allowable "green box" payments[25] under World Trade Organization (WTO) rules (Dana, 2004; USDA, 2006). In fact, both the United States and European Union nations may be in violation of pledged reductions in trade-distorting "amber box" payments, in part because of non-reporting of biofuel supports to the WTO. As an example, the United States has not reported Commodity Credit Corporation Bioenergy Program payments that go to fuel processors (Howse, et al. 2006; USDA, 2006). As elected officials weigh the policy issues related to biofuels, an examination of subsidies for corn-based ethanol is advisable.

Reducing tariffs and duties. One way to reduce the cost to the nation and consumers of meeting biofuel targets would be to lower or remove current tariffs and import duties on Brazilian ethanol. As discussed above, ethanol from sugarcane produced in Brazil enjoys the advantages of both low costs and a low GHG profile. Consequently, current U.S. policies designed to support domestic production of biofuels need to be weighed against the costs to fuel consumers and taxpayers. As increasing numbers of countries seek to produce and export biofuels, a number of developing countries may be able to produce biofuels less expensively than the

United States. As this occurs, rules governing international trade of biofuels are likely to emerge. Such rules may be adopted as a means to address tensions between interest in preserving native ecosystems and using land to produce biofuels.

Low-carbon mandates. As discussed earlier, the critical determinant of a specific fuel's climate impact is its GHG profile—not whether it is derived from biomass. Consequently, mandates specified in terms of the GHG footprint of fuels are more appropriate from a climate change perspective than ones that specify the source of the fuel's energy (i.e., biomass or fossil). Low-carbon mandates would have benefits beyond biofuels by providing an incentive to reduce the carbon profile of gasoline; use electric cars in conjunction with low-GHG-emitting electricity; and, ultimately, deploy technologies still in early development stages such as compressed air or hydrogen-driven vehicles. While lowering the GHG profile of gasoline will not assist in meeting energy-security goals, the other low-GHG vehicle options would.

Due to the relative price insensitivity of demand for transportation fuels, it may be difficult to achieve significant GHG reductions from vehicles through an economy-wide GHG cap-and-trade program[26] alone, particularly in early years when the price signal for GHG emissions is likely to be relatively modest. A low-carbon fuel mandate therefore may be an appropriate complementary policy to assist in achieving any specified national cap on GHG emissions. However, implementing a low-carbon fuel mandate will require the development of environmentally sound, transparent, equitable methods of establishing GHG profiles for a full range of fuel options. Development of methodologies acceptable to the broad range of stakeholders involved and yet sufficiently simple for fuel producers, both small and large, is expected to be challenging. One option for a hybrid approach is to use emission caps for large stationary emission sources and low-carbon fuel mandates and vehicle standards for mobile sources (Ellerman, et al., 2006; Gallagher, et al., 2007).

Vehicle efficiency policies. Increased vehicle efficiency is another critical component of any strategy to increase use of biofuels. As the vehicle efficiency of the U.S. fleet improves, demand for all fuels is reduced and biofuels can constitute a larger proportion of total demand. In addition, the pressure to import biofuels could be alleviated and less land and water would be needed.

Existing technologies or improvements to existing technologies can yield substantial increases in vehicle efficiency. For example, if efficiency improvements to conventional internal combustion engines were focused on fuel economy rather than enhanced performance, fuel economy improvements of 40 to 50 percent could be achieved in passenger vehicles without sacrificing safety. The costs of these improvements (about a 5-percent increase in vehicle price) would be recovered by consumers through fuel savings (DeCicco, et al., 2001; Gordon et al., 2007; Green and Schafer, 2003; Meszler, 2007). However, these efficiency gains are not likely to occur without policies to drive them (Greene and Schafer, 2003). The recent increase in corporate average fuel economy (CAFE) standards in the Energy Independence and Security Act is an important step in the right direction. However, as new vehicle options reach the market, fuel economy standards can continue to be raised accordingly.

Conclusion

Biofuels have the potential to satisfy a portion of U.S. on-road fuel needs, assist in addressing climate change, augment and diversify rural income, and enhance energy security. However, reaching this potential at a meaningful scale will require significant investment both in biofuels and passenger vehicles. A new generation of biofuels is needed—with significantly lower GHG profiles and costs, made from feedstocks that put less pressure on agricultural and recreational lands, potable water supplies, and habitat. Wide deployment of passenger vehicles able to go substantially further for each unit of energy in the fuel is also essential. Policy makers will need to balance competing interests, including:

- Users of transportation fuels versus producers of feedstocks and biofuel manufacturers;
- Agricultural producers versus consumers of agricultural products;
- Biofuels versus other transportation fuel options; and
- Use of lands for biofuels versus use of land for other purposes.

Policymakers will also need to assess interactions between biofuel policies, the wide array of existing policies that affect land use—particularly crop supports and trade policies—and land-use components of climate agreements. To the extent that biofuel policies are intended to contribute to the achievement of climate change goals, support for biofuels should be linked to their GHG profiles. Development of methodologies acceptable to a large range of stakeholders will be a critical step in enabling and implementing any such policies.

Appendix

CURRENT DOE CO-FUNDED PROJECTS: PRE-COMMERCIAL ADVANCED BIOFUEL PRODUCTION				
Project Participants	**Status**	**Technology**	**Biomass Source**	**Biofuel Produced & Scale**
Range Fuels	Under construction	Gasification	Wood and wood wastes	Ethanol 20-30 Mg/yr
Abengoa Bioenergy Biomass	Approved	Enzymatic hydrolysis	Corn stover, wheat straw, switchgrass	Ethanol 11.4 Mg/yr
Poet (formerly Brion)	Approved	Enzymatic hydrolysis	Corn fiber, cobs, and stalks	Ethanol 30 Mg/yr cellulosic-based
BlueFire Ethanol	Approved	Acid Hydrolysis	Landfill waste	19 Mg/yr
ALICO	In negotiation	Gasification/ fermentation	Yard, wood and vegetative waste	Ethanol 14 Mg/yr
Iogen	In negotiation	Enzymatic hydrolysis	Agricultural residues	Ethanol 18 Mg/yr
ICM, Inc.	In negotiation	Combined biochemical & Thermochemical	Agricultural residues, switchgrass, sorghum	Ethanol
Lignol Innovations	In negotiation	Biochem-organisolve	Wood residues	Ethanol
Pacific Ethanol Inc.	In negotiation		Agricultural and forest residues	Ethanol

Sources: www.energy.gov/news/5903.htm.

www.energy.gov/news/4827.htm.

www.eere.energy.gov/biomass/news_detail.html?news_id=11409

http://www.abengoabioenergy.com/NewTechnologies/index.cfm?page=16

http://www.poetenergy.com/news/showRelease.asp?id=13

http://bluefireethanol.com/pr/40/

http://alicoinc.com/news_releases/2007/03-01-07A.html

http://www.iogen.ca/company/technology/cellulose_ethanol.html.

Bibliography

Blaser, J. 2006. Lessons learned from other national and international efforts to reduce deforestation. Presented at the Reducing Emissions from Deforestation in Developing Countries (REDD) workshop. Bad Blumau, Austria. May 10-12.

Caesar, William, J. Riese, and T. Seitz. 2007. Betting on Biofuels. The McKinsey Quarterly, May 2007.

Davis, B. and L. Etter. Brazil's Sugar-Cane Ethanol Gets a Boost from IMF Report. *The Wall Street Journal*. October 18, 2007.

DeCicco, J., F. An, and M. Ross. 2001 Technical Options for improving the Fuel Economy of U.S. Cars and Light Trucks by 2010-2015.

Doornbosch, R. and R. Steenblik. 2007. Biofuels: is the cure worse than the disease? OECD. Paris. September 11-12.

E&E News (Energy and Environment News). 2008. Agriculture: Corn prices soar to new record. January 14, 2008.

Edwards, R., J-F. Larive, V. Mahieu, and P. Rouveirolles. 2007. Well-to-wheels analysis of future automotive fuels and powertrains in the European context. Version 2c, March 2007. http://ies.jrc.ec.europa.eu/WTW.

Eidman, Vernon. 2008. Personal communication.

Ellerman, D.A.; H.D. Jacoby; and M.B. Zimmerman. 2006. Bringing Transportation into a Cap-and-Trade Regime. MIT Joint Program on the Science and Policy of Global Change. Report No. 136. http://mit.edu/globalchange.

Faguendes de Almeida, E., Bomtempo, J.V., and Souze e Silva. 2007. The Performance of Brazilian Biofuels: An Economic, Environmental and Social Analysis. Energy Economics Group, Institute of Economics, Federal University of Rio de Janeiro. To be published by OECD.

Farrell A., R. Plevin, B. Turner, A. Jones, M. O'Hare, and D. Kammen. Ethanol can contribute to Energy and environmental goals. *Science.* Vol. 311. January 27.

Gallagher, K., G. Collantes, J. Holdren, H. Lee, and R. Frosch. Policy Options for Reducing Oil Consumption and Greenhouse-Gas Emissions from the U.S. Transportation Sector. 2007. www.energytechnologypolicy.org.

Gordon, D., D. Greene, M.H. Ross, and T. Wenzel. 2007. Sipping Fuel and Saving Lives: Increasing Fuel Economy Without Sacrificing Safety. http://www.hewlett.org/Programs/Environment/Energy/Publications/Sipping+Fuel+and+Saving+Lives.htm.

Greene, N. 2006. Biofuels and the Environment: Promises and Challenges. September 14.

Green, D. and A. Schafer. 2003. Reducing Greenhouse Gas Emissions from U.S. Transportation. Pew Center on Global Climate Change. www.pewclimate.org.

Greenwire. 2008. Agriculture: Millions of conservation acres going to row crops – USDA. http://www.eenews.net/Greenwire/2008/02/05/archive.

GTZ (Deutsche Gesellschaft fur Technische Zusammenarbeit). 2006. Conference Handout. Biofuels for Transportation: Global potential and implications for sustainable agriculture and energy in the 21st century. Bonn, May 16-17. www.gtz.de/biofuels-conference.

Gustavsson, L., J. Holmberg, V. Dornburg, R. Sathre, T. Eggers, K. Mahapatra, and G. Marland. Using biomass for climate change mitigation and oil use reduction. Energy Policy. Vol. 35. August 2, 2007)

Howse, R., P. van Bork, and C. Hebebrand. 2006. WTO Disciplines and Biofuels: Opportunities and Constrains in the Creation of a Global Marketplace. International Food & Agricultural Trade Policy Council, IPC Discussion Paper. International Policy Council (IPC) and Renewable Energy and International Law (REIL). Washington. DC. October 2006.

IEA (International Energy Agency. Biofuels for Transport: An International Perspective. 2004. http://www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf.

Jefferies CleanTech Review. 2007. Biofuels in 2007: A U.S. Perspective. Vol. 2, No. 1.

Johansson, D.J.A. and C. Azar. 2007. A scenario based analysis of land competition between food and bioenergy production in the US. Climatic Change. 82:267-291.

Kaltner, F.J., G.F.P. Azevedo, I.A. Campos, and A.O.F. Mundim. 2005. Liquid Biofuels for Transportation in Brazil. http://www.fbds.org.br/IMG/pdf/doc-116.pdf.

Kammen D.M., A.E. Farrell, R.J. Pleven, A.D. Jones, G.F. Nemet, and M.A. Delucchi. 2007. OECD Research Round Table: Biofuels: Linking Support to Performance. September 2007 version.

Koplow, D. 2006. Biofuels—At What Cost? Global Subsidies Initiative, International Institute for Sustainable Development. Geneva.

Melzer, D. 2007. Cost-Effective Passenger Vehicle fuel Economy Levels Updated to Current Fuel Prices. www.theicct.org/documents/Meszler.

National Corn Growers Association. 2008. 2008 World of Corn. http://www.ncga.com/WorldOfCorn/main.

Paustian, K., J. Antle, J. Sheehan, and E. Paul. 2006. Agriculture's Role in Greenhouse Gas Mitigation. Pew Center on Global Climate Change. Arlington, VA.

Peña, N. and J. Sheehan. 2007. Biofuels for Transportation. CDM Investment Newsletter. Number 3/2007.

Perlack, R., L. Wright, A. Turhollow, R. Graham, B. Stokes, and D. Erbach. 2005. Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. www.osti.gov/bridge.

Rotman, D. 2008. The Price of Biofuels. MIT Technology Review. https://www.technologyreview.com/Energy/19842.

Reynolds, R. 2000. The Current Fuel Ethanol Industry Transportation, marketing, Distribution, and Technical Considerations. Oak Ridge National Laboratory Ethanol Project. Subcontract No. 4500010570. http://www.ethanolrfa.org/objects/documents/111/4788.pdf.

RFA (Renewable Fuel Association). 2007. Ethanol Industry Outlook 2008: Changing the Climate. http://www.ethanolrfa/objects/pdf/outlook/RFA_Outlook_2008.pdf./

Schlamadinger, B. 2001. Greenhouse Bas Balances of Biomass and Bioenergy Systems. www.joanneum.at/iea-bioenergy-task38.

Schnepf, R. 2005. Agriculture-Based Renewable Energy Production. CRS Report for Congress. RL32712. May 18.

Sheehan, J. 2007. Biofuels and climate change... a sustainable opportunity? Presented at the Colorado Agricultural Outlook Forum, Denver, CO, February 21.

UNDP (United Nations Development Program), United Nations Department of Economic and Social Affairs, and World Energy Council. 2000. World Energy Assessment: energy and the challenge of sustainability. UNDP. New York, New York.

USDA (United States Department of Agriculture). 2006. Energy and Agriculture – 2007 Farm Bill Theme Paper. Release No. 0283.06. August, 2006. www.usda.gov/documents/Farmbill07energy.pdf.

USDA (United States Department of Agriculture). 2008. National Agricultural Statistics Service. News Release. January 11, 2008. http://www.nass.usda.gov/Newsroom/2008/01_11_2008.asp.

Wang, M., M. Wu, and H. Huo. 2007. Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types. Environmental Research Letters 2 (2007) 024001. http://www.iop.org/EJ.

Wang, M., M. Wu, H. Huo, and J. Liu. 2008. Life-Cycle Energy Use and Greenhouse Gas Emission Implications of Brazilian sugarcane Ethanol Simulated with the GREET Model. International Sugar Journal. In press.

Wegner, S. 2007. Realities in Cellulose Ethanol from Wood. Presented at: Biomass Energy: Biorefineries Seminar. Resources for the Future, April 4.

Worldwatch Institute. 2006. Biofuels for Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century.

Endnotes

1. Carbon monoxide is a conventional air pollutant, distinct from carbon dioxide, the major greenhouse gas.

2. Fermentation is the conversion of a carbohydrate such as sugar into an acid or an alcohol.

3. Transesterification is a process that modifies the oils in the feedstocks by replacing glycerin in fatty acid chains of vegetable oils with methanol.

4. If over ~ 0.5% of the total volume is water, separation occurs and reblending becomes difficult or impossible (Reynolds, 2000).

5. Cellulose, which is a polysaccharide, is the most abundant source of organic carbon in the biosphere. Perennial grasses, crop residues, and short-rotation trees are all under consideration as sources of cellulose for biofuel production.

6. Pyrolysis is a process in which heat is used to decompose and liquefy solid biomass, usually in the absence of oxygen.

7. Because the American Society for Testing and Materials (ASTM), which is currently responsible for setting fuel standards, operates by consensus, new standards can take years to develop. The current specification for biodiesel, for example, took seven years to establish (http://www.biodiesel.org/resources/fuelfactsheets/standards_and_warranties.shtm).

8. This discussion focuses on factors that determine GHG emissions from biofuels derived from plant materials. Animal and municipal wastes, another potential source of transportation fuels, are most often used for generation of heat and power and currently represent a very small fraction of transport fuel except in Sweden. Furthermore, both of these sources are, ultimately, derived from plant materials.

9. Ethanol, gasoline, and diesel fuel have differing amounts of energy per gallon. Gasoline has 115,000 Btu per gallon while ethanol contains only 76,300 Btu per gallon and diesel contains 133,000 Btus per gallon.

10. Both cellulose and hemicellulose are long-chain (i.e., polymer) sugar molecules (Paustian, et al. 2006). Lignin is a non-carbohydrate substance found in woody materials and can be used as a source of energy in conversion processes.

11. Refinery gate prices for ethanol typically have been twice the refinery price of gasoline. Gate prices for biodiesel have typically been three times diesel refinery prices (IEA, 2004).

12. If co-product prices fall, ethanol's costs would rise.

13. Refiner acquisition cost is typically $6 to $8 lower than the price of West Texas intermediate crude, the price commonly quoted in the news (http://tonto.eia.doe.gov/ask/crude_types1.html).

14. 1 exajoule = 10^{18} joules

15. Using more than 15 percent of agricultural land for energy is expected to result in unacceptable increases in costs of food and fiber.

16. CO_2 released from large point sources such as electric power plants can be captured and returned to geologic reservoirs, but no technologies are currently available that can capture CO_2 released from small, mobile sources.

17. Executive Order S-01-07. http://gov.ca.gov/index.php?/executive-order/5172/

18. Corn prices were in the $2.00 to $3.25 per bushel range prior to 2007.

19. The number of years to balance initial releases will vary widely depending on the amount of carbon on the land prior to conversion, the productivity of the land, the conversion process, and the fuels produced.

20. Under current international climate change agreements, each nation is responsible for the GHG emissions that occur within it. However, where, as in the case of biofuels, emissions occur in one country (e.g., the country where feedstocks are grown) but the emission reduction benefits accrue to another (i.e., the country that uses the biofuels), an approach based on GHG profiles of product use may have some advantages.

21. N_2O has a much higher global warming potential than CO_2. Each ton of N_2O emitted into the atmosphere causes approximately 310 times as much warming as a ton of CO_2.

22. Thermochemical processes use a combination of heat and chemicals.

23. This means that there are four to ten Btus of energy in the sugarcane ethanol or biodiesel products for each Btu of fossil fuel used to produce the fuel.

24. Biofuels from cellulosic materials are not yet produced commercially so there is no “real world” cost information.

25. There are no limits to the number or amount of payments or subsidies a nation may provide to agricultural producers or manufacturers if such subsidies qualify as “green box” payments.

26. Under a GHG cap-and-trade program, U.S. GHG emissions are limited to a specified amount but a market in emission allowances enables sources (e.g., electric power plants and petroleum producers) to buy and sell rights to emit. For a further explanation of cap-and-trade see Climate Change 101: Cap-and-trade at http://www.pewclimate.org/global-warming-basics/climate_change_101

This paper offers an introduction to the current state of play for biofuels: the technologies, their greenhouse gas emissions, and associated policy issues. The Pew Center on Global Climate Change was established in 1998 in order to bring a cooperative approach to the debate on global climate change. The Pew Center continues to inform the debate by publishing reports in the areas of policy (domestic and international), economics, environment, and solutions.

Pew Center on Global Climate Change
2101 Wilson Boulevard
Suite 550
Arlington, VA 22201 USA
Phone: 703.516.4146
www.pewclimate.org