ENERGY

Driving on Biomass

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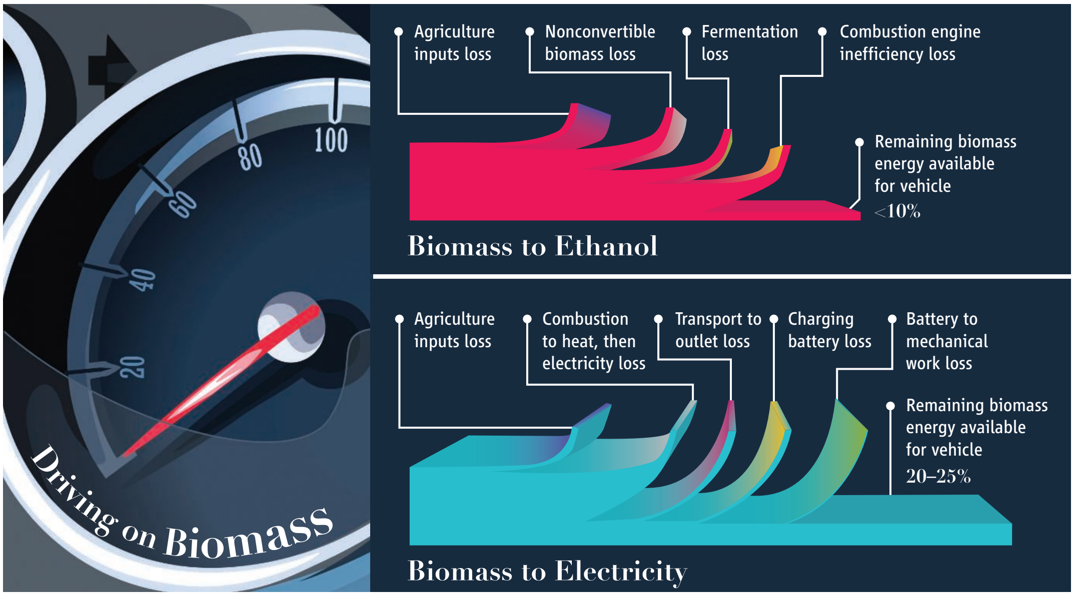
Burning biomass to produce electricity for battery-driven vehicles can power more travel and displace more petroleum than converting it to ethanol or other fermentation products.

The development of the internal combustion engine (ICE) vehicle dramatically influenced American society during the 20th century by providing affordable, reliable transportation. However, the ICE vehicle is an inherently inefficient converter of chemical energy to mechanical power; less than 20% of the energy in gasoline is transformed into mechanical work, and the remainder is lost as heat. With seemingly unlimited supplies of low-cost petroleum in the last century, the poor efficiency of the ICE was initially less important than the power, convenience, and reliability it provided. However, two major factors make it likely that electric vehicles, rather than the ICE, will be the power source of choice for passenger vehicles in the 21st century. First, heightened world petroleum demand coupled with more expensive oil recovery will continue to increase gasoline costs. Second, concerns over the environmental impact of CO_2 production are leading toward carbon taxes, cap-and-trade limits, and other strategies that will impact the ICE.



Driving on biomass. Energy losses in conversion of biomass to electricity or to ethanol for automobile propulsion.

In response to escalating monetary and political costs of imported petroleum and the existence of surplus U.S. agricultural capacity in the 20th century, the U.S. government instituted policies to support the conversion of the chemical energy stored in plant-derived starch to ethanol. This conversion now consumes almost 30% of U.S. corn production. Starch is a simple polymer of glucose that is easily converted to ethanol with existing technology, yet almost one-third of the chemical energy of starch is lost in producing ethanol (*1*). Concerns about fuel competing with food, fertilizer runoff, and potent greenhouse gases such as NO_2 released from microbial conversion of fertilizer in agricultural fields have brought into question the sustainability of corn-based ethanol production (*2*). Therefore, a major effort has begun to develop alternative feedstocks for ethanol (or other liquid fuels) by using crop residues, forest by-products, perennial grasses, and other forms of plant biomass that are collectively termed “lignocellulosics.” The 2005 “billion-ton vision” (*3*) proposed by the U.S. Departments of Energy (DOE) and Agriculture (USDA) has set a goal of replacing 30% of U.S. petroleum consumption with lignocellulosic-derived liquid fuels—a goal that would require the production of ~60 billion gallons of ethanol annually by 2030. Several billion dollars have been invested for research and development toward this goal, and tax advantages and other subsidies for ethanol and biodiesel production have been estimated at $9 billion for 2008 and could increase to over $30 billion annually under current legislation (*4*).

Unlike starch, lignocellulose is one of the most complex natural heteropolymers, and its conversion to liquid fuels is not yet economically sustainable. Currently, the recovery of fermentable sugars from most lignocellulosics represents <70% of the chemical energy content. About 27% of this chemical energy is then lost during fermentation. Loss of energy as heat in an ICE results in less than 10% of the original energy of lignocellulose available for vehicle propulsion (see figure above). In addition, development of the capacity to produce 60 billion gallons of liquid fuel annually from lignocellulosics will require new and large infrastructures, including facilities for storage and processing of enormous volumes of biomass, as well as for the distribution of ethanol.

Since the introduction of the DOE billion-ton biomass vision, many alternatives have emerged. Among these, improved technologies for electric motor vehicles and diesel engines should provide some of the best strategies to offset petroleum consumption. Burning biomass in power plants to produce electricity for battery-driven vehicles captures more biomass energy and provides more vehicle miles than converting it to ethanol or other fermentation products for ICE vehicles [see report by Campbell *et al.*, (*5*)] (see figure, above).

Although producing electric power directly by burning carbon-based fuels is only 30 to 40% efficient in conventional power plants, comparatively small losses occur between electric generation and vehicle propulsion,

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resulting in conversion of 20 to 25% of the chemical energy of a biofuel stock to vehicle power. Therefore, roughly twice as much petroleum can be displaced by lignocellulosic biomass via electric vehicles as compared with ICE. Furthermore, rather than being lost to the environment as in an ICE, excess heat generated in burning biomass for electricity can be used for heating water and buildings. This allows the overall efficiency of chemical energy conversion to rise to 60% or higher (*6*). Such cogeneration (or combined heat and power plants) generate almost 50% of electric power in Denmark, but less than 10% in the United States.

If biomass is burned for electricity generation rather than conversion to liquid fuels, the "billion-ton vision" of replacing 30% of U.S. petroleum consumption by biomass could be met with a half or less of the land and less infrastructure. In fact, if the ~12 million hectares of farm land now devoted to biofuels are used to produce miscanthus biomass at 20 to 30 tons per hectare (*7*) for electricity generation, the mileage from electric cars would be roughly equivalent to the mileage obtained from a target of 60 billion gallons of renewable fuel by 2030. Thus, in principle, little additional farmland would be needed to meet the petroleum displacement targets of the billion-ton vision.

The widespread use of plug-in electric vehicles will increase electricity consumption. This increased demand can be met from a wide range of carbon-neutral sources, including solar, nuclear, wind, and hydroelectric, as well as biomass, or from coal and natural gas. In the near to midterm, electric vehicles will not require large changes in electrical infrastructure because up to 70 million vehicles can be charged overnight by the existing electrical grid (*8*). By contrast, the infrastructure for fueling this number of cars with 60 billion gallons of ethanol will be much greater.

The large subsidies and tax advantages now and projected for future liquid biofuels might be better directed to support electric vehicle production and to offset the initial high purchase price. In this regard, the Emergency Economic Stabilization Act of 2008 (H.R. 1424) includes up to a $7500 (€5600) tax offset for the purchase of plug-in electric vehicles (*9*).

A primary consumer advantage of electric power for vehicles is the greatly reduced cost of 1 to 3 cents per mile for fuel compared with gasoline cars at 8 to 12 cents per mile (*10*). This leads to savings of up to $10,000 (€7500) per 100,000 miles. Electric vehicles in the past have been substantially limited in range, but recent advances in battery technology and designs with range-extending small gas engines have overcome these limitations, and this technology will continue to improve. In fact, the consensus of the car industry is that electric vehicles will gain substantial market share in the coming years. Most major automotive manufacturers and a number of smaller companies plan to sell plug-in hybrid or all-electric vehicles beginning in 2010 or soon after (*11*). The success of hybrids (>50% average growth per year, 2001–07) (*12*) may be matched or exceeded by electric vehicles and/or plug-in hybrids. By 2030, it is forecast that about one-third of vehicle miles in the United States may be powered by electricity (*8*).

The Future for Diesel

Because of battery weight, electric motors offer the greatest advantage for smaller vehicles. For vans, large sport utility vehicles (SUVs), and light trucks (~50% of U.S. vehicle sales) a transition from gasoline to diesel engines can be expected. Diesel is a better fuel than ethanol or gasoline because of higher energy density and at least 30% higher mileage (*13*). Large trucks, buses, most trains, and other heavy vehicles will continue to use diesel (now 30% of U.S. transportation fuel use). Diesel cars are the major passenger vehicle in much of Europe, and new diesel engines are quiet, have very low emissions, and are nearly indistinguishable from gasoline engines in performance (*13*). The increased fuel efficiency of diesel engines could yield a further 10 to 20% reduction in U.S. petroleum consumption if much of the passenger car, light-truck, and SUV fleet switches from gas to diesel. The higher initial cost of a diesel engine can be offset with tax incentives and fuel cost recoveries.

Future Research

Increasing supplies of biodiesel is one priority for future biofuel research. However, production of biodiesel from temperate oilseed crops can provide only a small part of U.S. transportation needs (*14*). Therefore, non–seed-based production systems, perhaps including algae or thermochemical conversion of biomass, should be developed.

Public funding should support research alternatives that look beyond "lignocellulose fermentation" technology and focus both on increasing biomass yields and the energy density of biomass. Perennial grasses and trees are the most sustainable future sources of biomass. Additional resources devoted to breeding and agronomy for higher biomass per hectare are likely to pay the greatest immediate dividends. Other promising research targets include the following:

Reducing the loss of 20 to 50% of biomass that occurs during senescence or late-season storage in the field. Targets might include engineering crops to retain starch and other carbohydrates that usually break down for translocation to roots and seeds. Increasing the cellulose and/or hemicellulose content will capture carbon in forms that are not remobilized for seed or rhizome storage.

Increasing energy density of biomass. Lignin has 1.7-fold, and oils and isoprenoids have twofold, the energy of a kilogram of cellulose. Increasing these components would increase the energy density of biomass either for burning or for biodiesel production. Reducing leaf loss during senescence could contribute 10% or more to biomass yields and might be achieved by engineering reduced abscission. Reducing water content at harvest by accelerated drying in the field may be achievable owing to recent advances in understanding the control of stoma apertures.

In summary, although there are uncertainties in the pace of electric car development and market penetration, replacement of gasoline by bioelectricity in cars and with diesel engines in heavier vehicles may be the best route to the goal of reducing petroleum consumption and CO_2 emissions.

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