ternatives to petroleum and to preserve energy, the U.S. Congress passed the Energy Policy Act of 2005. The Act gives high priority for continued growth of ethanol fuel. Subsidies and mandated targets are provided. For various reasons, the Act emphasizes derivation of ethanol from lignocellulosic sources to reinforce that made from corn grain. There was no ethanol made commercially from lignocellulose in June 2007, but plants were planned.

Making ethanol from corn reduces petroleum use usually at the expense of more natural gas and coal use and. as indicated previously, there is a slight positive energy balance in making ethanol from corn. Usually, there is also a slight saving in fossil fuel us age. This saving is greater when renewable fuel such as wood chips is used for process energy.

Cost differentials. Despite the advantages in making ethanol from cellulosics, there is a major problem in trying to do this economically. Because supplies of wood for making ethanol are dispersed over wide areas and stocks of corn are more concentrated, transportation costs for getting wood feedstock to the plant are higher. Higher concentrations of feedstock around plant sites facilitate construction of larger plants with economies of scale in lower plant costs per unit capacity. Capital costs of wood plants are also higher because of lower yields per ton of feedstock with currently available technology, and the fact that simpler processing of corn results in the need for less expensive equipment and lower costs for manufacturing enzymes and chemicals needed in processing plants in the case of corn. Current fermentation processes produce ethanol of 14-20% concentration with corn, but a concentration of only 4% with cellulosic starting materials. This means that expenditures of costly distillation energy are significantly higher with cellulosic ethanol.

Capital costs can be recovered; however, payoff would be over a significantly longer term for cellulosics. Ethanol yields from cellulosics today are based on yields estimated from technologies proven in use. These are acid and enzyme hydrolysis technologies and glucose and xylose sugar fermentation technologies. There are technologies under research that would gasify cellulosic materials and make ethanol through Fischer-Tropsch synthesis (a catalytic process to synthesize hydrocarbons and their oxygen derivatives by the controlled reaction of hydrogen and carbon monoxide). Fischer-Tropsch and other synthetic procedures take synthesis gas from wood and through the use of catalysts could get yields that are largely ethanol. Although this gasification technology is also being investigated for other fuels such as diesel, gasoline, and mixtures of ethanol and higher alcohols, ethanol yield in itself could be increased to over 100 gal (378.5 L) per dry ton and potentially much more. This would be a higher yield than ethanol from corn grain, which is about 98 gal (371 L) per ton.

Overcoming high costs. Because of the high product costs for making ethanol from wood, commercial plants in the past were more concerned with getting the product at any cost and providing employment than in making a profit. This was the case

Ethanol from wood

With greatly increased gasoline and diesel prices in the United States, worldwide crude oil prices at record levels, dependence on imports from insecure sources, and environmental concern over accumulation of greenhouse gases from burning fossil fuels, residents and legislators recognize the increasing need for alternative supplies of transportation fuels. Production of ethanol from wood is not yet economically viable, but new legislation supports research to solve problems and provides subsidies that can make manufacturing profitable.

Advantages of wood as a feedstock. In June 2007, the main source for alternatives to gasoline and diesel from petroleum was ethanol from corn grain. However, it is generally agreed that cellulosic ethanol (ethanol from lignocellulosic sources such as wood) has environmental and nonmonetary economic advantages over ethanol made from starch from corn. Cellulosic raw material could come from unused surplus materials such as sawdust and bark residues at manufacturing plants; from tops and limbs of trees left over after harvesting trees for lumber, plywood, and pulp and paper; or from crops such as hybrid poplar trees grown specifically for feedstocks for manufacturing ethanol. Corn ethanol on the other hand uses a raw material that could otherwise be used for food. Before June 2007, because of the high demand for corn to make ethanol, the price of corn doubled in a short time from $2.00 per bushel to $4.00 per bushel. This had a significant increase on food prices. As an example, steaks from grazing animals raised on corn became higher in price. Also, there is much controversy concerning the true benefit of corn in conserving fossil fuel use, using less petroleum specifically, and whether there is overall conservation of energy in comparing energy value of ethanol to energy consumption in making ethanol. It is generally agreed that making ethanol from corn shows a positive balance in end-product energy compared to fossil fuel use in production. However, this ratio would be better for ethanol from cellulosic raw materials.

There has been significant growth in fuel ethanol production since 1980. In 2006, U.S. production was about 6 billion gallons (22.7 billion liters) per year, and in 2007 the estimated production capacity was about 7 billion gallons (26.5 billion liters) per year. In order to boost energy production from al-in the United States during World War I, in Germany during World War II, and in the centrally planned economies of Russia and Bulgaria after World War II. The Energy Policy Act of 2005 (EPACT) provides for supporting research on ethanol, particularly cellulosic ethanol, so that it may become more profitable. Approaches to problem solving for improving economy of production include improving harvesting of woody forest residues to reduce feedstock costs; reducing high capital costs for plants per unit of production through integration of process energy requirements and energy surpluses as through use of lignin for fuel in fermentation ethanol processes, that would otherwise only use cellulose and hemicelluloses effectively, and using outside sources of hydrogen to obtain higher yields in thermochemical processes; gaining higher yields per unit of feedstock through thermochemical processing; and improving enzyme productivity per unit cost in fermentation processing; reducing consumption of energy for distilling ethanol from water through thermochemical production; or developing membrane filter technology to separate water from ethanol.

In February 2007, to follow through on provisions in EPACT, the U.S. Department of Energy announced investment of up to $385 million for six biorefinery projects over the next four years. When fully operational, the biorefineries are expected to produce more than 130 million gallons (492 million liters) of cellulosic ethanol per year. This production will help further the goal of making cellulosic ethanol cost-competitive with gasoline by 2012 and, along with increased automobile fuel efficiency, reduce America's gasoline consumption by 20% in 10 years. Combined with the industry cost share, more than $41.2 billion will be invested in these six biorefineries.

One of the plants in LaBelle, Florida, with a grant of up to $33 million, will produce 13.9 million gallons (52.6 million liters) of ethanol and 6255 kilowatt-hours of electric power per year, as well as 8.8 tons of hydrogen and 50 tons of ammonia per day. For feedstock, the plant will use 770 tons per day of yard, wood, and vegetative wastes, and eventually energy cane (sugarcane of high fiber content).

In Irvine, California, a plant is to receive up to $40 million to use 700 tons per day of sorted green waste and wood to produce about 19 million gallons (72 million liters) of ethanol per year.

In Shelley, Idaho, a Canadian company that has been working on ethanol from biomass for more than 20 years has an allocation of up to $80 million to produce 18 million gallons (68 million liters) of ethanol per year. Wood will not be a feedstock initially, but could become one later.

Near Soperton, Georgia, a plant will use up to $76 million to produce about 40 million gallons (151 million liters) of ethanol per year and 9 million gallons (34 million liters) of methanol per year from wood chips and unmerchantable Georgia pine trees and forest residues. This company will not use a fermentation technology that limits conversion of only cellulose and hemicellulose in wood, but a thermochemical process that converts all of the constituents in wood including lignin and bark. In a two-step process, wood is first gasified and synthesis gas is then converted to products.

However, fermentation technology development also gained a significant boost when, in March 2007, the U.S. Department of Energy announced an additional follow-on grant award package to provide $23 million in federal funding for five projects focused on developing highly efficient fermentative organisms to convert biomass material to ethanol.

More money to further the ethanol from wood cause became available in June 2007 when the Department of Energy announced that it would allocate $125 million to each of three new research centers (in Oak Ridge, Tennessee; Madison, Wisconsin; and near Berkeley, California) for investigation into new ways of turning wood and plants such as switchgrass into fuel. Research projects at these new centers will bring together scientists from 18 universities, seven Department of Energy national laboratories, one nonprofit organization, and several private companies. The collaborations are aimed at improving cellulose to fuel processes and making these processes more cost-effective.

With investment in projects such as these, there is hope for research breakthroughs that could make ethanol from wood economically competitive with ethanol from corn grain. The U.S. Department of Energy-has a goal for reducing the cost of cellulosic ethanol to $1.07 per gallon by 2012, which probably would be less than the cost of making it from corn grain. At long last, the possibilities for using excess wood to manufacture transportation fuel profitably appear promising.

For background information *see* ALCOHOL FUEL; ALTERNATIVE FUELS FOR VEHICLES; BIOMASS: CELLULOSE; CORN; ETHYL ALCOHOL; FISCHER-TROPSCH PROCESS; LIGNIN; RENEWABLE RESOURCES; WOOD ANATOMY; WOOD CHEMICALS in the McGraw-Hill Encyclopedia of Science & Technology.

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Bibliography. A. E. Farrell et al., Ethanol can contribute to energy and environmental goals, Science, 311:506-508, 2006; R. D. Perlack et al., Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply, Oak Ridge National Laboratory, U.S. Department of Energy contract DOE/GO-102005-2135, April 2005; N. Schmitz and meó Consulting Team, Renewable raw materials, in *Bioethanol in Deutschlund,* Series No. 21, Federal Ministry for Consumer Protection, Nutrition, and Agriculture (BMVEL), BMVEL no. 22009200, 2003; J. I. Zerbe, Thermal energy, electricity, and transportation fuels from wood, *Forest Prod. J.,* 56:4-12, 2006.

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